Advanced Warning Operations Course

Winter Weather Track

Presented by the

Warning Decision Training Branch

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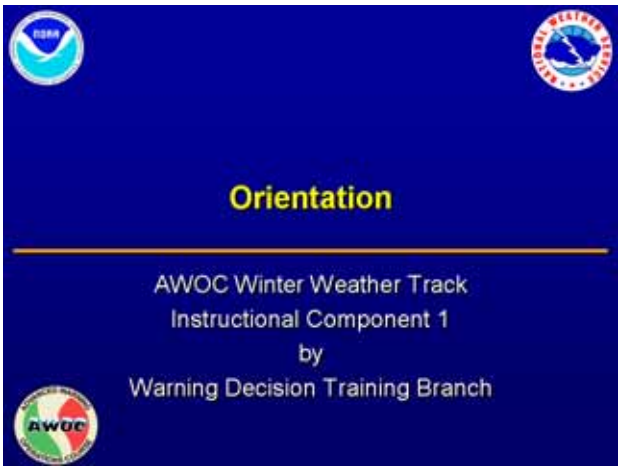
IC Winter 1: Orientation

1. IC1.1: Orientation

Instructor Notes: This instructional component is designed to introduce you to the AWOC Winter Weather Track. For the next 20-25 minutes, we're going to be showing you a brand new training course on winter weather developed by partners in the NWS in collaboration with the Warning Decision Training Branch. This is the first comprehensive winter weather warning decision making course for NOAA's NWS.

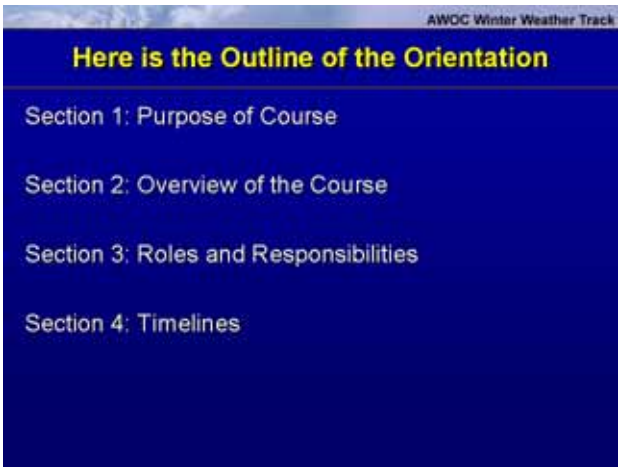
Student Notes:



2. Here is the Outline of the Orientation

Instructor Notes: Section 1 describes the goals of the course such as GPRA goals. Section 2 details the structure of the course, such as ICs and objectives. Section 3 describes the roles of the training management team and Section 4 briefly describes the course delivery schedule.

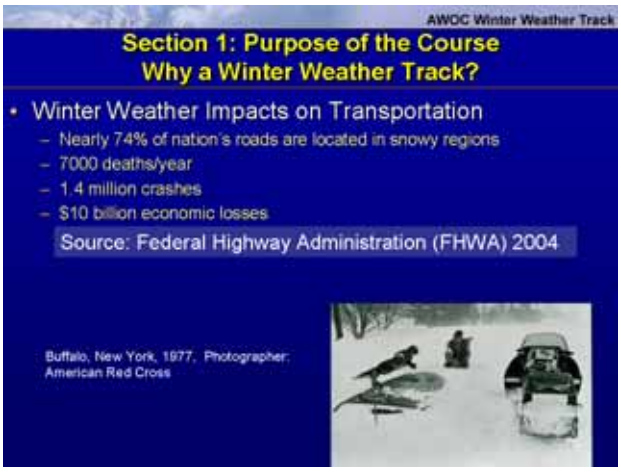
Student Notes:



3. Section 1: Purpose of the Course Why a Winter Weather Track?

Instructor Notes: Recent statistics in 2004 on adverse weather impacts on transportation by the Federal Highway Administration (FHWA) indicate that winter weather dramatically impacts roadway safety. Each year 18% of fatal crashes and 22% of injury crashes occur due to combination of adverse weather (rain, snow, sleet, hail, or fog) and poor pavement conditions. 74% of nation's roads are located in snowy locations (and 70% of the population). Reported economic losses of $42 billion are from adverse weather from travel delays: 23% ($10 B) due to fog, snow, and ice, additional road operating costs, and maintenance costs. Nearly 39% of road operating costs can be attributed to winter maintenance annually. Each year, state and local agencies spend over 2.3 billion dollars on snow and ice control operations and an est. $5 billion to repair roadway infrastructure (Paul Pisano, Lynette Goodwin, and Andrew Stern, 2004: Surface Transportation Safety and Operations: The Impact of Winter within the Context of Climate Change). The image at the right is of Red Cross workers searching for victims buried in cars following heavy snowfall. The picture shows the roof of a car. Location: Buffalo, New York; Photo Date: February, 1977; Photographer: American Red Cross.

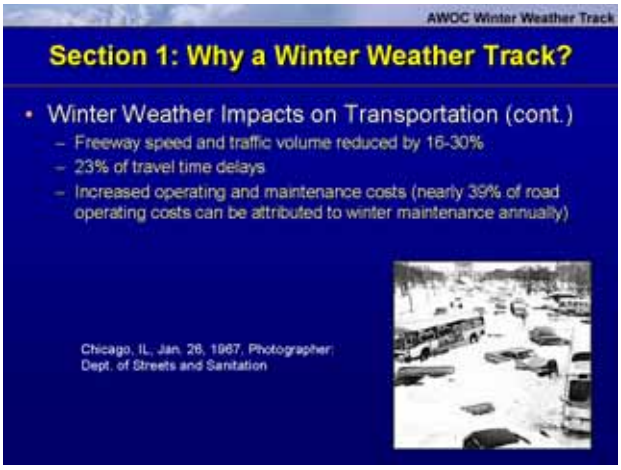
Student Notes:



4. Section 1: Why a Winter Weather Track?

Instructor Notes: The impacts on the transportation sector of our nation's commerce are well-known and significant. There have been several recent studies on the impacts of snow on roadway traffic (you will want to see the lesson on societal impacts). The picture shown was taken from the Jan. 26, 1967 snowstorm in Chicago, IL. Picture taken from the Dept. of Streets and Sanitation.

Student Notes:



5. Section 1: Why a Winter Weather Track?

Instructor Notes: Adverse winter weather impacts sectors of the economy in many ways, most notably with increased gas and electric consumption and inflated costs to heat businesses and homes. Over $3 trillion of the nation's annual economy is now directly affected by weather events (Freedman, 2003). With the change of the energy industry to a "no storage" model, energy availability is always "on the edge" and flirting with crisis in consumption and availability. Costs associated with snow removal industry are tied mostly to amounts and duration, which are linked to people hours. Also, property losses from winter storms can be significant, esp. with big snowstorms (March 2003, Denver Colorado $93 M) or ice storms (98 NE/Canada Ice Storm, $1.4 B USD, $3 B in Canada). When businesses close due to adverse weather, the local economies are affected. Insurance losses associated with one major winter storm can cost up to $6 billion (Kunkel et al, 99).

Student Notes:

6. Rapidly Escalating Societal Demands

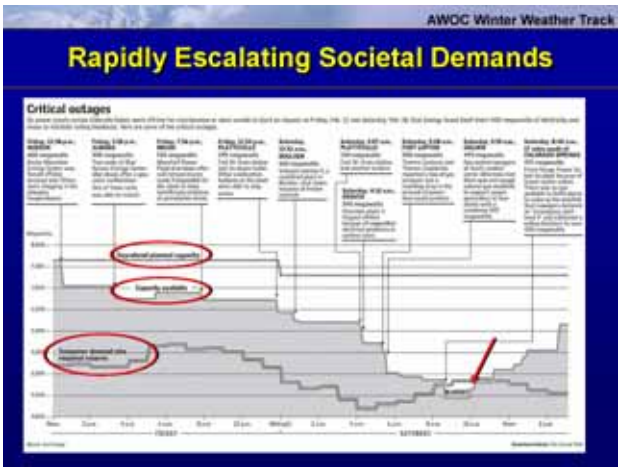
Instructor Notes: More impacts on society from winter weather include the change in the energy industry to a no storage model. Missed forecasts can lead to rolling blackouts due to consumer demand plus required reserves exceeding capacity available. This example from February 2006 in Colorado was taken from the Denver Post.

Student Notes:

7. Rapidly Escalating Societal Demands

Instructor Notes: Note the critical outages occurred on Saturday morning around 9-10 am.

Student Notes:



8. Section 1: Why a Winter Weather Track?

Instructor Notes: Winter weather affects our children, and slick roads can cause devastating accidents. All schools have a specific plan of action to mitigate winter weather impacts. Most schools do not close during the day because there is no one home to pick

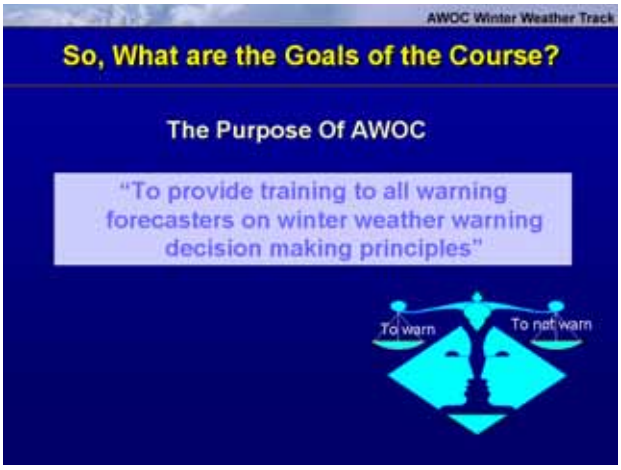
them up. Schools make their decisions on when to close usually 1-2 hours before buses are scheduled to leave which, in many districts is around 6 A.M. local time. School superintendents meet with local transportation officials and make a decision using direct observations, the current weather forecasts (from TV and internet), and what other districts are doing. There are other variables to the decision making process when events occur that are “unexpected” (such as a “rush-hour” storm).

Student Notes:

9. So, What are the Goals of the Course?

Instructor Notes: With all of these societal impacts it is clear that winter weather is an important priority for training. The course that WDTB has helped develop is composed of the latest science, technology, and human factors associated with winter weather warning decision making.

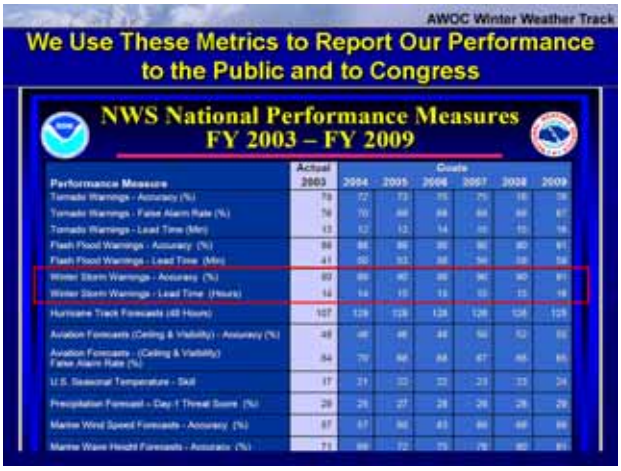
Student Notes:



10. We Use These Metrics to Report Our Performance to the Public and to Congress

Instructor Notes: 7 of the 14 GPRA goals which are reported to Congress and the White House are warning related. The 2006 GPRA goals for winter weather are POD= 90%, and Lead time = 15 hours. As a whole the NWS is very close to these goals. However, these goals are bulk measures and are conservative in nature, according to Dr. Uccellini. For example, they do not reflect our stretch goals, or what the public expects. User expectations are increasing with each event. In a memo from NWS director DL Johnson last year, he stated the reason for AWOC was very important because of the relationship to the warning GPRA goals. This memo sent an important message: “AWOC training is directly tied to skills necessary to perform our mission.”

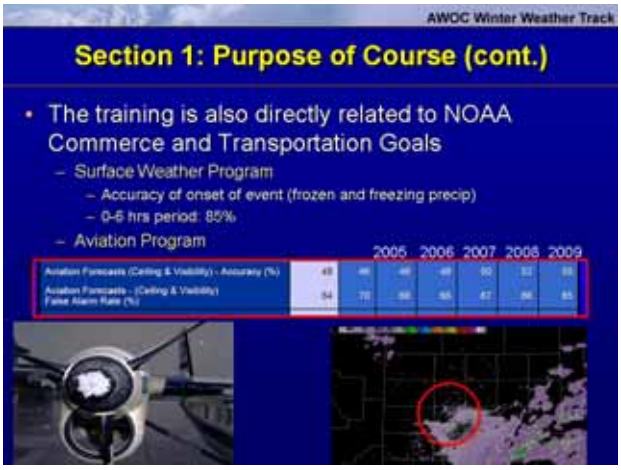
Student Notes:



11. Section 1: Purpose of Course (Cont.)

Instructor Notes: Since winter weather impacts transportation goals, we need to consider the components of surface weather such as the onset of precipitation (frozen and freezing) in the course goals.

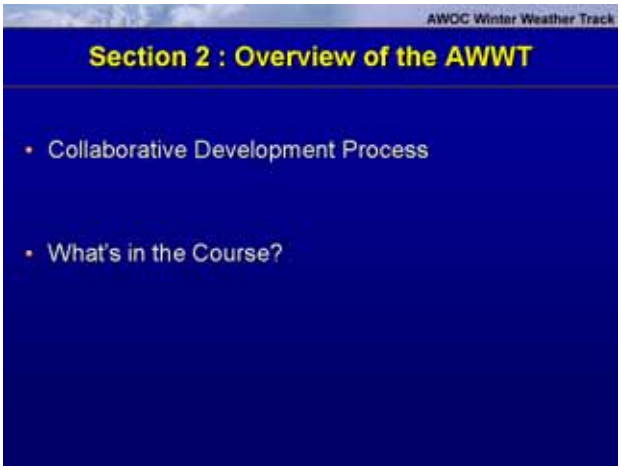
Student Notes:



12. Section 2: Overview of the AWWT

Instructor Notes: This is what we are going to talk about in section 2. But first, a bit about how we got here. The initial needs and training priorities were determined from the NSTEP Winter Program Team. WDTB then assessed priorities from the field to help determine what training topics should be addressed in the AWOC Winter Track.

Student Notes:



13. Partnerships

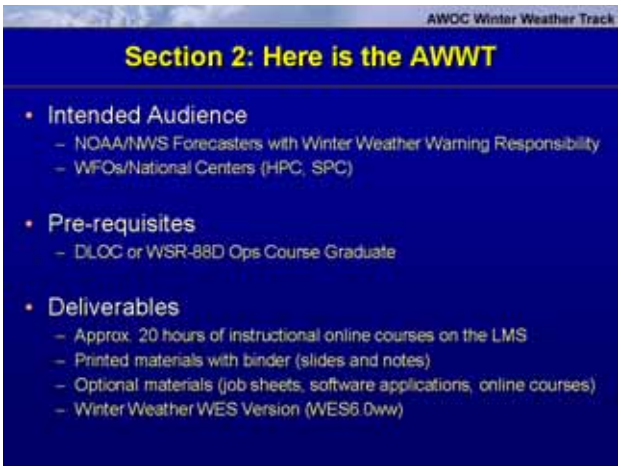
Instructor Notes: We enlisted a volunteer team of 25 Subject Matter Experts (SMEs) for direct content development and/or review. This collaboration was a new way of doing business but proved very exciting and productive.

Student Notes:

14. Section 2: Here is the AWWT

Instructor Notes: The intended audience is forecasters with winter weather warning responsibilities. The pre-requisites are DLOC. The deliverables are 21 hours of on-line content, printed materials, and a WES case.

Student Notes:



15. So, What Will the AWOC Winter Weather Track Look Like?

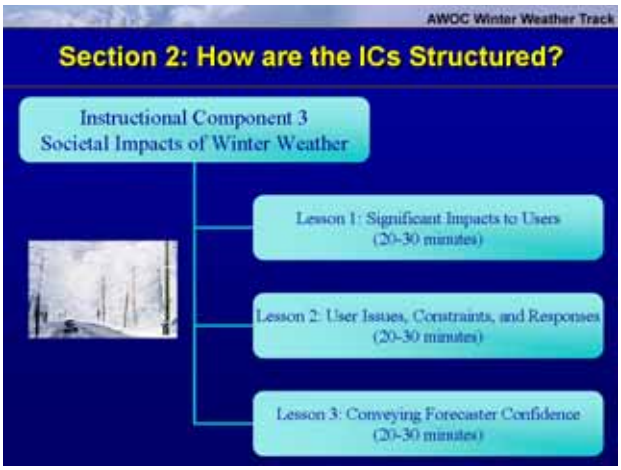
Instructor Notes: This begins Section 2 of the Orientation. This is how the course breaks down into individual instructional components. 25 Subject Matter Experts in Winter Weather have collaborated with WDTB in developing these ICs. It amounts to about 21 hours of instruction. That includes all 31 lessons. There are 3 lessons that are optional (topographic forcing, using CPC products, and LES). That reduces the length of instruction to 19 hours.

Student Notes:

16. Section 2: How are the ICs Structured?

Instructor Notes: There are multiple lessons within each IC. After completing each lesson, the student will need to take an exam in the LMS that addresses the learning objectives of the course.

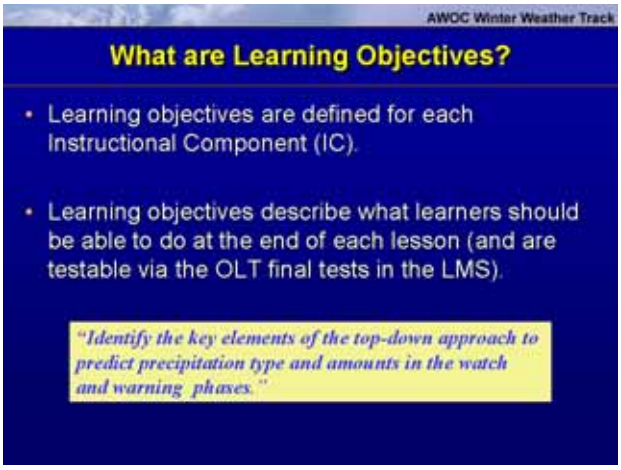
Student Notes:



17. What are Learning Objectives?

Instructor Notes: Learning objectives are defined and described in the ICs for each lesson.

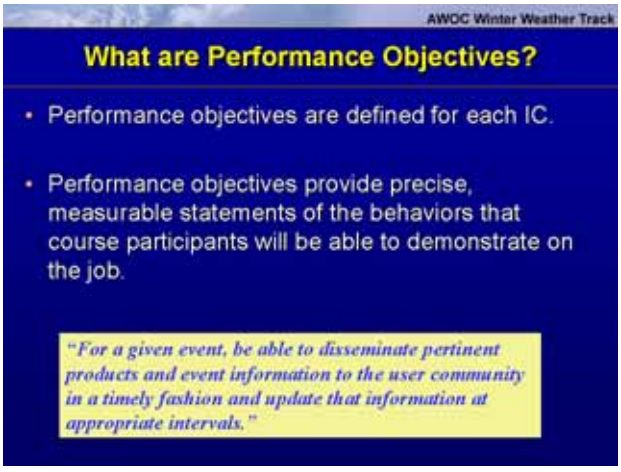
Student Notes:



18. What are Performance Objectives?

Instructor Notes: IC performance objectives are similar to the learning objectives and are defined for each lesson. Many of performance objectives will be included in IC 8, the Weather Event Simulator (WES) instructional case for the course. Facilitators should evaluate how well students can master specific performance objectives for each IC. After the entire course has been completed, students will be evaluated on the extent of training transfer of the performance objectives, to help determine behavioral changes. This is part of the level-3 training evaluation process.

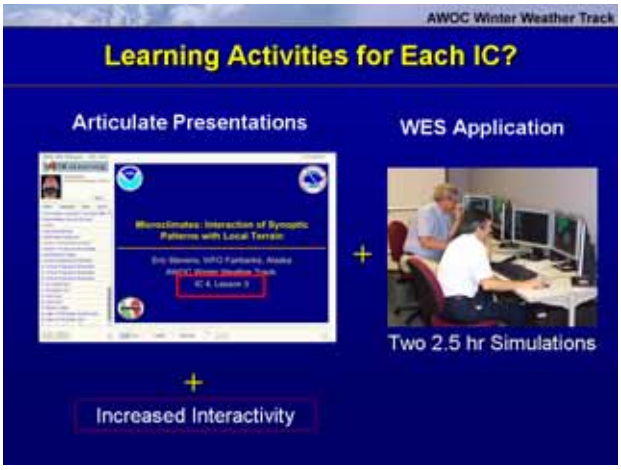
Student Notes:



19. Learning Activities for Each IC?

Instructor Notes: Articulates are a way you can play a PowerPoint presentation and hear the author deliver the speaker notes. Note, you can start and stop the Articulates (it remembers where you left off). In addition, we have lots of increased inter activity and of course, the WES simulations.

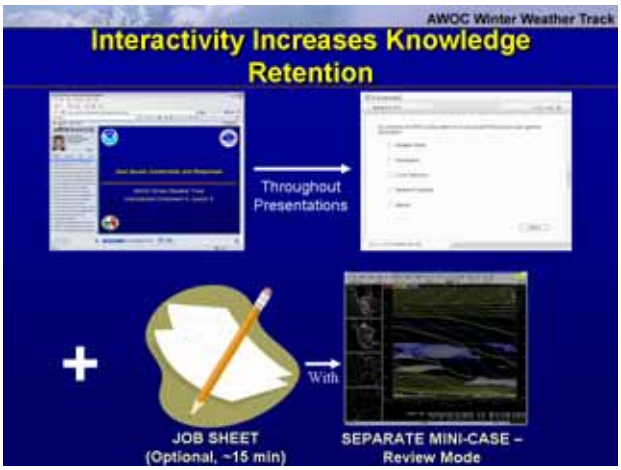
Student Notes:



20. Interactivity Increases Knowledge Retention

Instructor Notes: Most articulate presentations will contain increased interactivity with quiz questions, and some modules will have short 15 minute optional job sheets along with mini-case data that are separate from the primary Simulation case.

Student Notes:

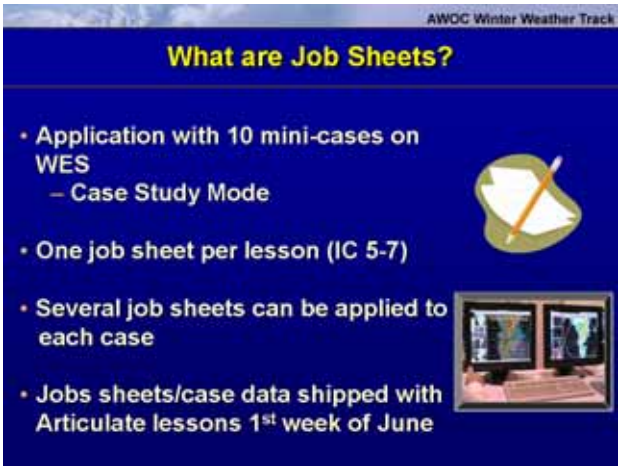


21. What are Job Sheets?

Instructor Notes: The job sheets will take 10-15 minutes to run through and we'll look at an example on the next slide. We are producing job sheets for those ICs that examine AWIPS case data in the warning process. You will not need to run the WES in simulator mode. Since these will be for case review mode, all that will be required is setting the clock to the desired event time. We plan on having just one model run, a few satellite images, surface observations, and radar imagery for one event. Thus, case size will be small, and even more importantly, many lesson job sheets can be applied to the same event. So the number of cases will be fewer than the number of job sheets. The goal is to have the job sheet case data loaded on your WES machines by the time the Winter

Weather AWOC training modules are released. We will have answer sheets available online.

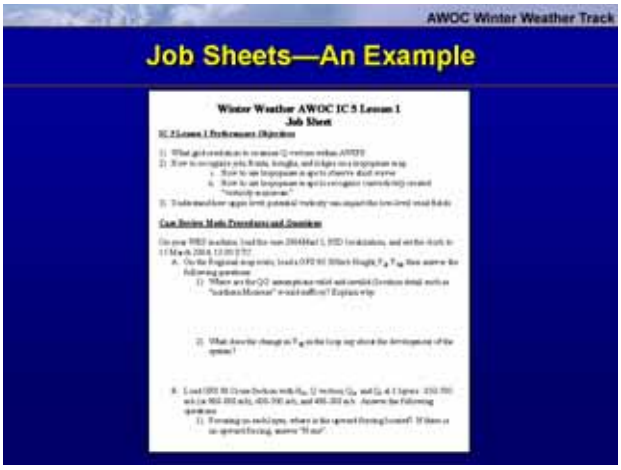
Student Notes:



22. Job Sheets—An Example

Instructor Notes: This is an example of one of the job sheets for AWOC Winter Weather Track.

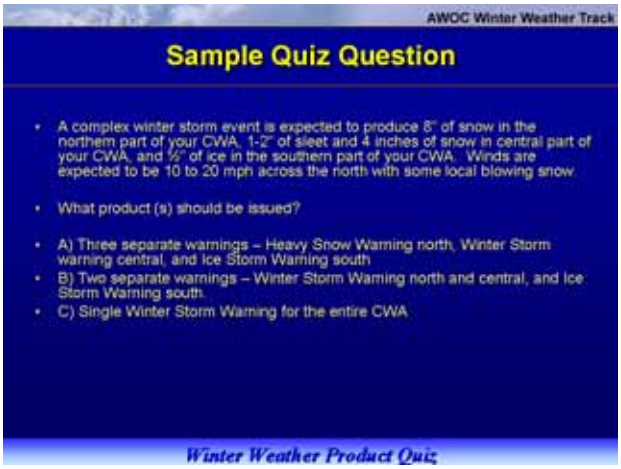
Student Notes:



23. Sample Quiz Question

Instructor Notes: Based on field input, several scenarios are presented in IC 2 lesson 1 to help you decide what winter weather products to issue. These scenarios are examples of increased interactivity in the lessons.

Student Notes:



24. Winter Simulation Case

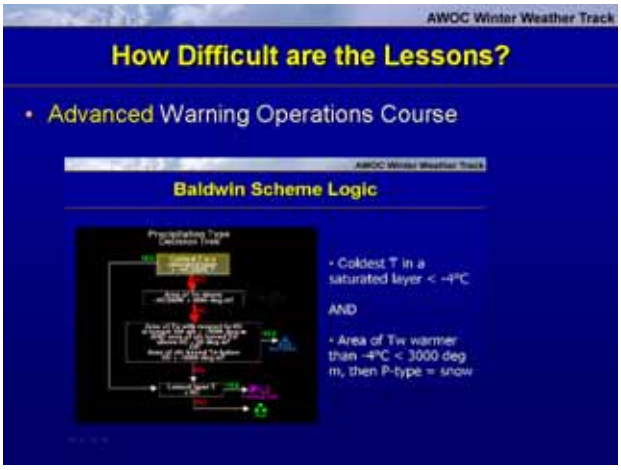
Instructor Notes: The WES case will be delivered with multiple DVDs by early July. The version will include support for GFE/GHG for issuing warnings. We will have multiple simulation examples complete with performance objectives and evaluation criteria for 2 CWAs. As with the previous AWOC Course, feel free to select your own local cases for a winter weather simulation. New with this simulation are GFE and SREF imagery. As always, WESSL will play a role in the simulation.

Student Notes:

25. How Difficult are the Lessons?

Instructor Notes: Some concepts may be review for some, but new for others.

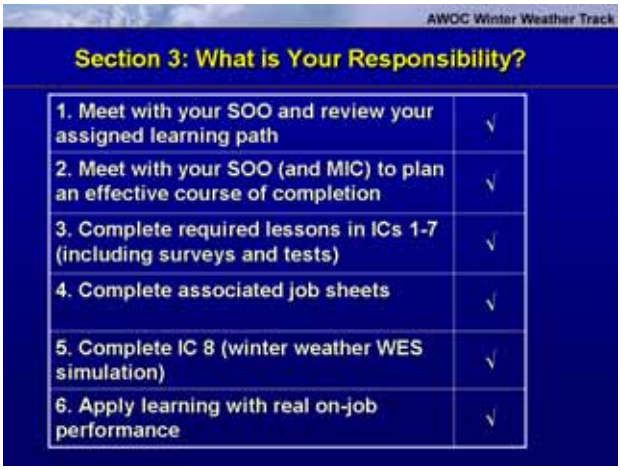
Student Notes:



26. Section 3: What is Your Responsibility?

Instructor Notes: This is the recommended course of action for students in AWOC.

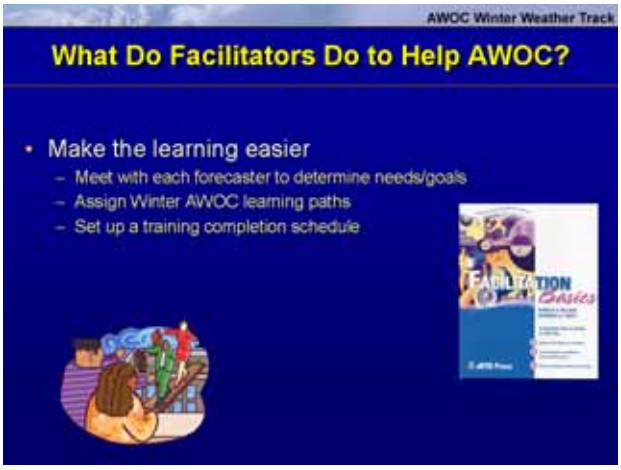
Student Notes:



27. What Do Facilitators Do to Help AWOC?

Instructor Notes: Facilitators are your helpers and they will help with the training – and make sure the training is performance based. Training can be a risky path unless we have some guidance.

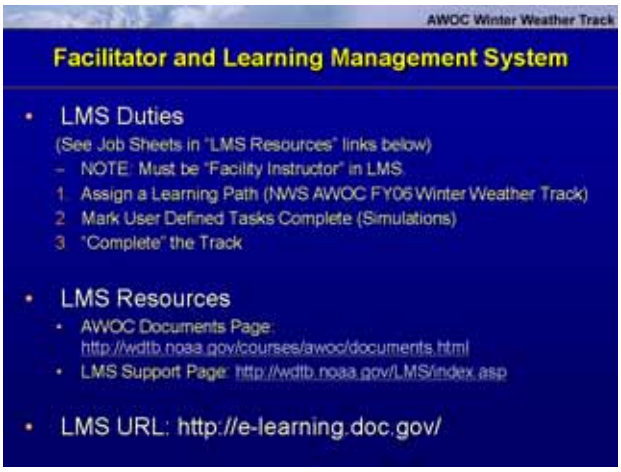
Student Notes:



28. Facilitator and Learning Management System

Instructor Notes: Facilitators must perform certain duties in the LMS including: Assigning a Learning Path, Marking User Defined Tasks Complete, and Completing the AWOC Track. There are Job Sheets on these tasks on the WDTB Web site. It is important to note that if you are facilitating the Winter Track, you need to be a Facility Instructor in the LMS. If you need help with this send a message to awochelp@wdtb.noaa.gov.

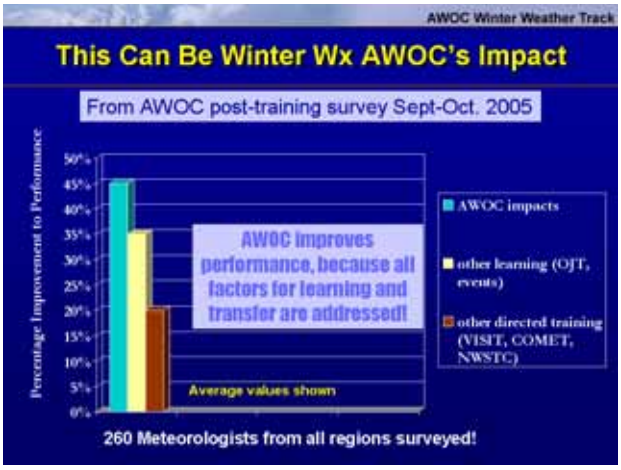
Student Notes:



29. This Can Be Winter Weather AWOC's Impact

Instructor Notes: This survey results were from 260 NOAA NWS employees, including 30 MICs and 30 SOOs. The post-training survey indicated that performance improvement was significant, but only because all factors for learning were addressed, including involving management in the process. We are aiming for even highest performance improvement in the winter AWOC course.

Student Notes:



30. Course Completion Requirements

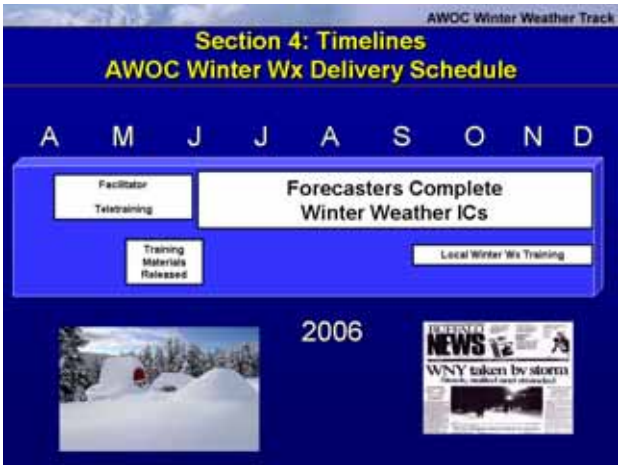
Instructor Notes: Every student registered in the AWWT is required to complete at least 28 lessons (note: 3 lessons are optional).

Student Notes:

31. Section 4: Timelines AWOC Winter Weather Delivery Schedule

Instructor Notes: Forecasters have from June 5 until the end of December 2006 to complete the course.

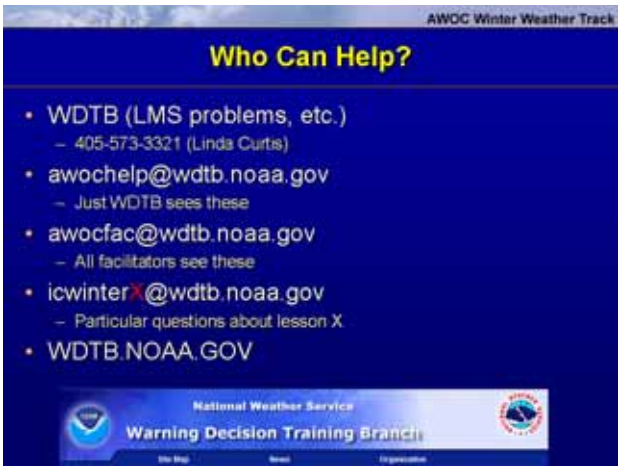
Student Notes:



32. Who Can Help?

Instructor Notes: We do provide a number of options to help alleviate potential problems in executing this course. Take advantage of these mechanisms to make the learning easier and the course more enjoyable.

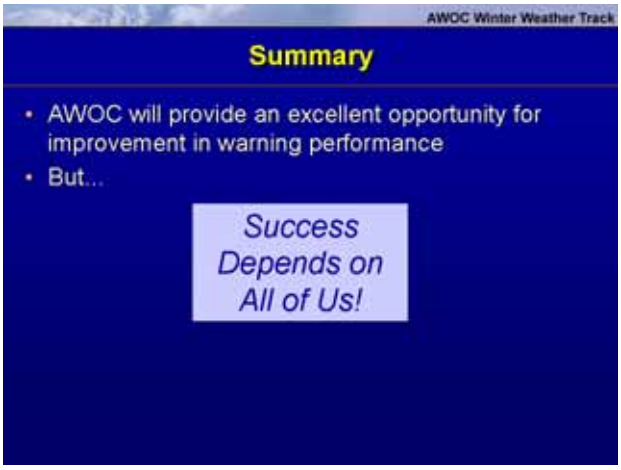
Student Notes:



33. Summary and Questions

Instructor Notes: We are committed to providing a rewarding learning experience for all participants in the AWOC Winter Weather Course. But, success in terms of how well it will be accepted and applied depends a lot on you. The developers of this course encourage all members of the entire training community to help provide support for learning and application of these very important learning concepts.

Student Notes:



IC1.1: References

Federal Highway Administration (FHWA), 2005: Road Weather Management Program (web site: http://ops.fhwa.dot.gov/weather/).

Paul Pisano, Lynette Goodwin, and Andrew Stern, 2004: Surface Transportation Safety and Operations: The Impact of Winter within the Context of Climate Change.

Kenneth Kunkel, Roger Pielke Jr., and Stanley Changnon, 1999: Temporal Fluctuations in Weather and Climate Extremes That Cause Economic and Human Health Impacts: A Review, Bulletin of the American Meteorological Society.

Freedman, D.H., 2003: Pinpoint Weather. Technology Review. Available online at http://www.technologyreview.com/articles/freedman0603.asp]

Denver Post Newspaper (http://www.denverpost.com/archives)

IC Winter 2: Products and Services

1. IC2.1: Why Certain Products Are Issued

Instructor Notes: Welcome to the AWOC Winter Track Instructional Component 2, Lesson 1. This presentation, Why Certain Products Are Issued, should last approximately 30 minutes.

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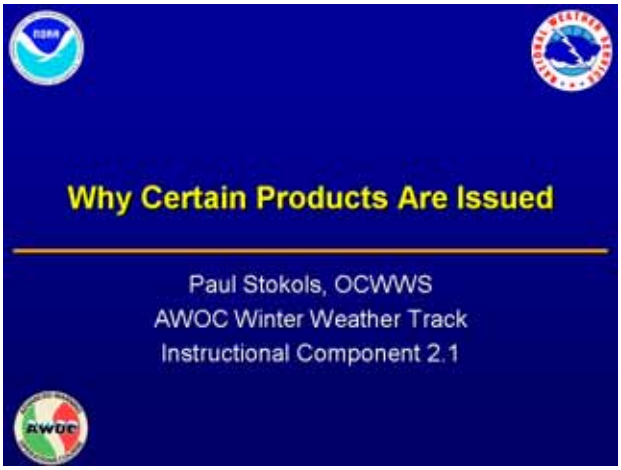
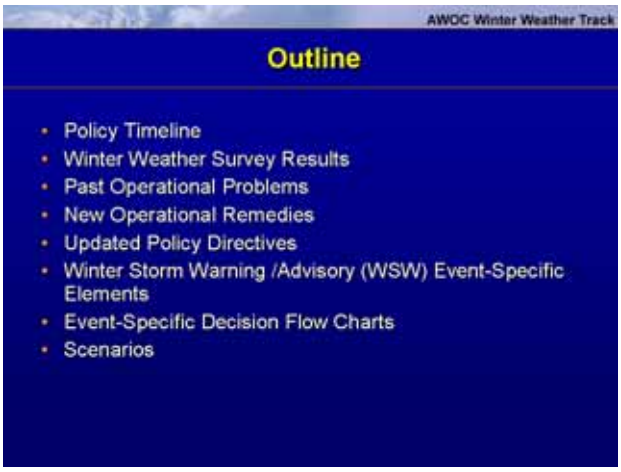


2. Outline

Instructor Notes: This lesson will focus on recent changes to NWS policy as a result of multiple surveys, regional coordination, forecaster input, and technological advances. We will look at past operational problems and their remedies; recently updated policy directives; the use of specific Winter Storm Warning and Advisory elements and event-specific decision flow charts; and finally, we provide numerous scenarios to aid in your decision-making skills.

Student Notes:



3. Winter Weather Policy Time Line

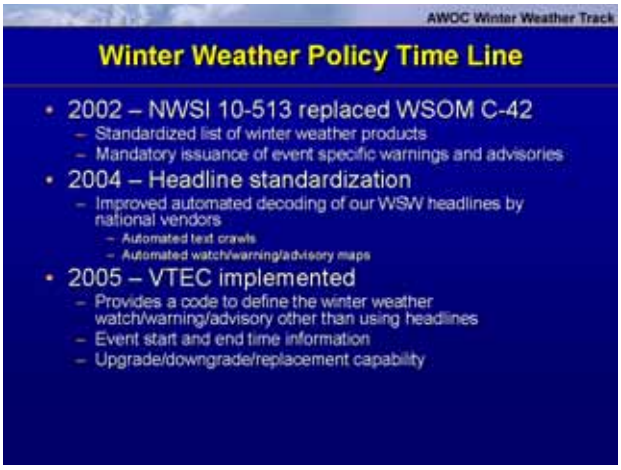
Instructor Notes: A little history…Event specific winter weather warnings and advisories are not new. They were used as far back as the 1970s in the zone forecast product and special weather statements. In 1992, winter storm warning products were implemented which allowed generic or event-specific headers and headlines in a non-segmented format. In 1998 segmented formatting allowed forecasters to issue separate headline hazards and follow up statements.

Student Notes:

4. Winter Weather Policy Time Line

Instructor Notes: NWSI 10-513 was updated in 2002 replacing the outdated WSOM C-42. The new policy directive had a standardized list of winter weather products and mandated the issuance of event specific warnings and advisories. As national vendors were able to decode automatically our WSW headlines into on screen text crawls and automated watch/warning/advisory maps, 2004 brought about headline standardization. After several years of development, VTEC arrived in 2005 which allowed specific event coding of Watch, Warnings, and Advisories and created automatic headlines.

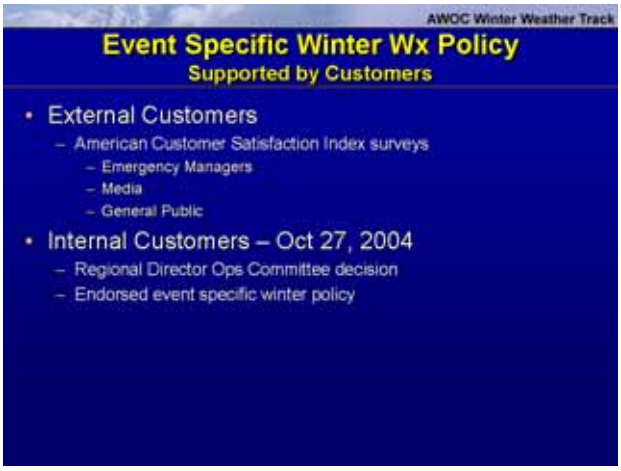
Student Notes:



5. Event Specific Winter Weather Policy Supported by Customers

Instructor Notes: Our customers support our event specific winter weather policy. NWS sponsored separate surveys of the emergency management, media, and general public communities during the 2003-2004 time frame. The survey was conducted by the American Customer Satisfaction Index (ACSI) group. ACSI and NWS developed a broad range of questions that were used to find the strengths and shortfalls in understanding of and need for NWS public forecast and warning products and services. Among the findings across all 3 surveys was that there is a need for more specific winter weather warning products. In Oct. 2004, the NWS internal Corporate Board Operations Committee was presented the results of the survey and they agreed to endorse event-specific winter weather policy.

Student Notes:



6. American Customer Satisfaction Index (ACSI)

Instructor Notes: What is the American Customer Satisfaction Index (ACSI)? ACSI was established in 1994 at the National Quality Research Center at University of Michigan using methodology licensed from CFI Group. ACSI is the #1 national economic indicator of customer satisfaction and is widely used in government agencies and the private sector. In fact, over 55 federal agencies and 200 companies representing 10 economic sectors and 41 industries and two thirds of the U.S. economy have participated in similar surveys. ACSI's advanced methodology uses a 0-100 scale to measure and link satisfaction levels to performance. Based on relative scoring, improvements can be prioritized which allows organizations to get the most bang for the buck. Results are published quarterly in the Wall Street Journal. See the web link for additional information.

Student Notes:

7. Background (cont.)ACSI in the News

Instructor Notes: These publications and media outlets have all run pieces on ACSI.

Student Notes:

8. Federal Government ACSI Clients

Instructor Notes: This is a listing of SOME of the federal government agencies that utilize ACSI.

Student Notes:

9. NWS Has Many "Customers"

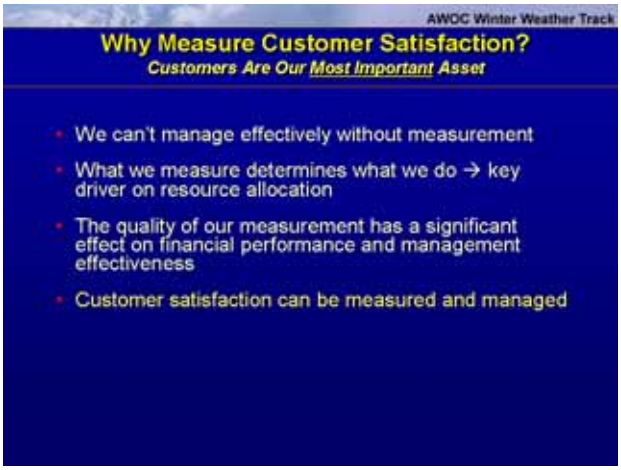
Instructor Notes: We have three "sets" of customers: 1) Partners – those that resell or rebroadcast our forecasts and warnings, 2) Customers – those that ultimately receive our forecasts and warnings and plan accordingly, and 3) Internal customers, or our employees

Student Notes:

10. Why Measure Customer Satisfaction? Customers Are Our Most Important Asset

Instructor Notes: Customers are our most important asset. Measurement and analysis of customer satisfaction allows us to manage resources and determine how we can improve our services to meet user's needs.

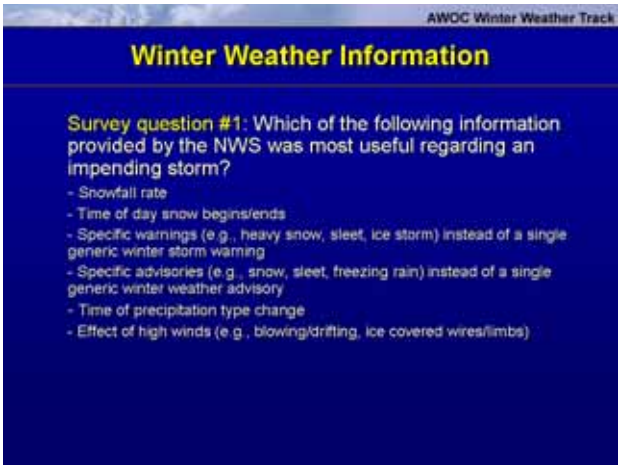
Student Notes:



11. Winter Weather Information

Instructor Notes: Our first winter weather question in the survey asked participants to rate the utility of critical winter weather information for an impending storm on a scale of 1 to 10 where 10 is the highest utility. There were 6 critical parameters: snowfall rate (intensity), start and end times, specific type advisory, specific type warning, time or precipitation type change, and effect of high winds.

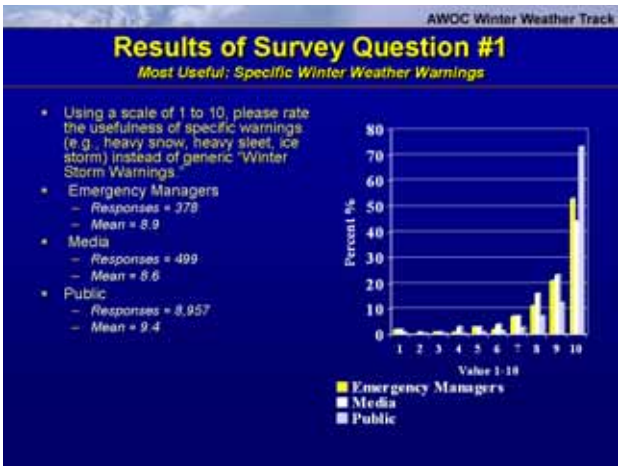
Student Notes:



12. Results of Survey Question #1 Most Useful: Specific Winter Weather Warnings

Instructor Notes: The clear winner for all 3 surveys was specific type winter weather warnings.

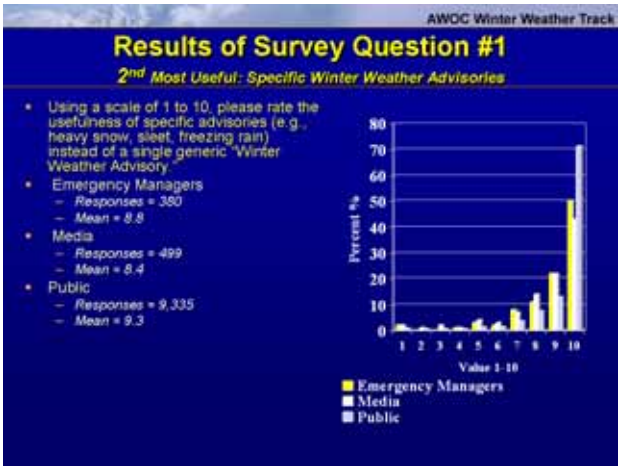
Student Notes:



13. Results of Survey Question #1 2nd Most Useful: Specific Winter Weather Advisories

Instructor Notes: Followed by specific type winter weather advisories.

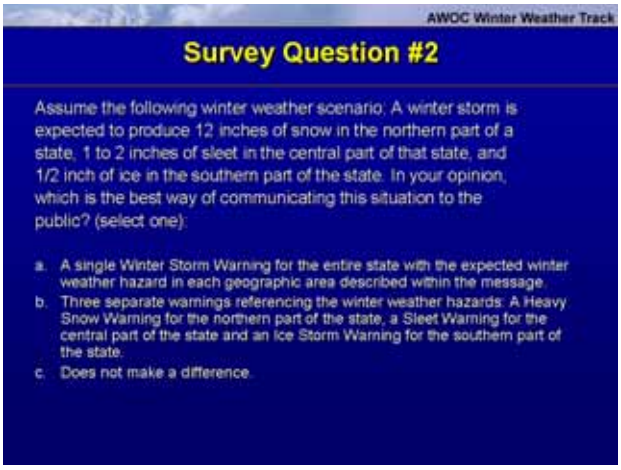
Student Notes:



14. Survey Question #2

Instructor Notes: Next, we wanted to gauge how much specificity respondents wanted to have in their warnings, given different forecast conditions expected across their region.

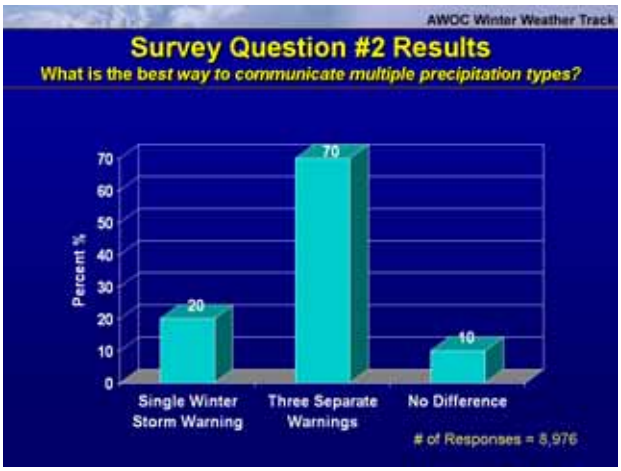
Student Notes:



15. Survey Question #2 Results: What is the best way to communicate multiple precipitation types?

Instructor Notes: By a 2 to 1 margin, a breakout of more detailed warnings was preferred.

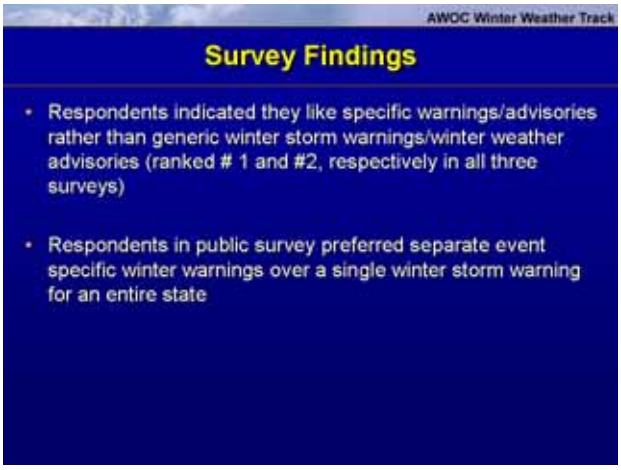
Student Notes:



16. Survey Findings

Instructor Notes: So the combined result of these two survey questions showed a preference for more specificity in winter event types and separate event warnings instead of a single catchall warning for an entire state or region.

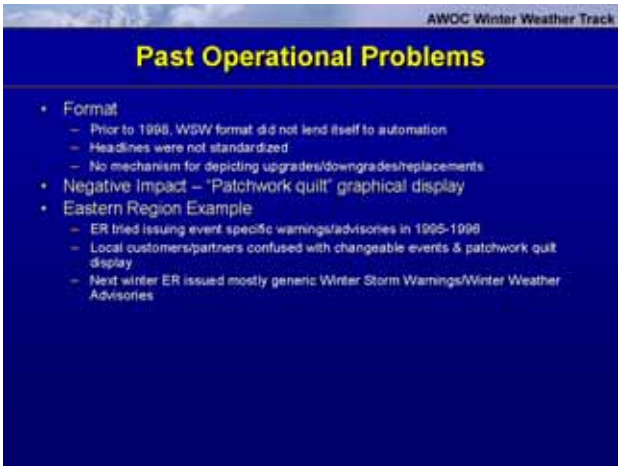
Student Notes:



17. Past Operational Problems

Instructor Notes: Historically, NWS was beholden to technology and software constraints. The Winter Storm Warning format did not lend itself to automation, headlines were not standardized, and there was no software mechanism for depicting upgrades/downgrades/replacements to existing products. As color graphical displays became the "norm" NWS products looked like a "patchwork quilt" that instantly had a negative confusing impact. For example, Eastern Region (no I am not picking on you) was ahead of its time as it tried issuing event specific warnings and advisories in the mid '90s. At that time local customers/partners were confused with changeable events and resultant patchwork quilt. After considerable negative feedback, the next winter ER WFOs went back to issuing mostly generic Winter Storm Warnings/Winter Weather Advisories.

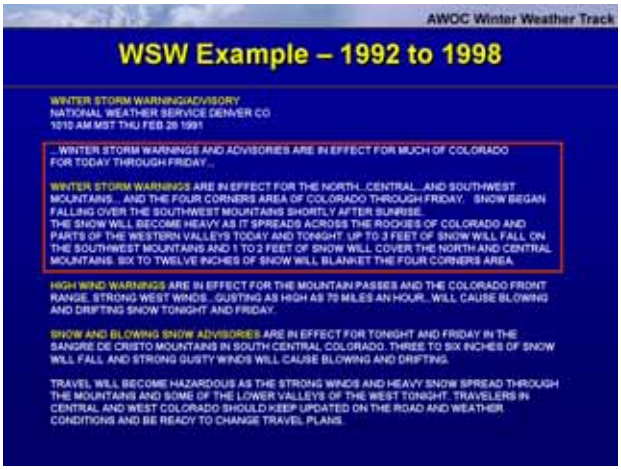
Student Notes:



18. WSW Example – 1992 to 1998

Instructor Notes: Another confusing example from the Denver WFO in 1991 shows multiple warnings and advisories for what essentially is a heavy snow storm with blizzard conditions forecast for the mountain passes and front range.

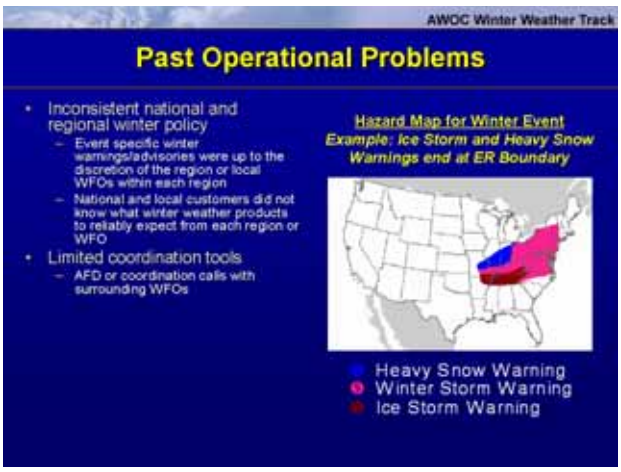
Student Notes:



19. Past Operational Problems

Instructor Notes: In the recent past, inconsistent and confusing national and regional policy, and limited coordination between surrounding WFOs and across regional lines led to a hodgepodge of warnings which is quite apparent in this colorized presentation of warnings for an event covering the Ohio Valley and Mid Atlantic regions. National and local customers were often confused and unhappy with the results.

Student Notes:



20. New Operational Remedies

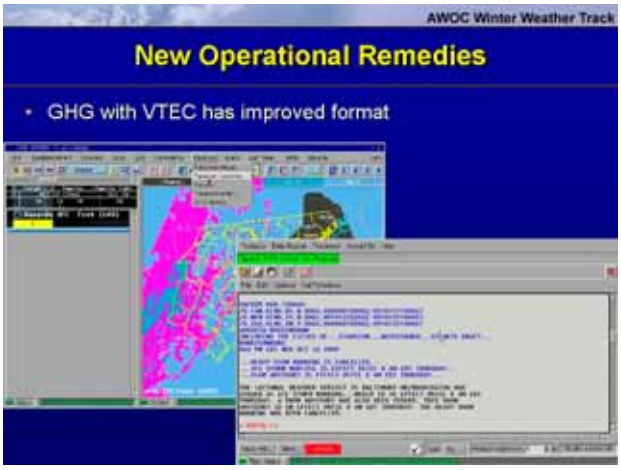
Instructor Notes: Today, a combination of consistent national and regional policy, and improved collaboration and coordination tools have clarified and enhanced the winter storm warning program. Forecasters have the knowledge and tools to produce warnings and advisories that meet customers needs, inform the public to take appropriate actions. Within the Weather Forecast Office, increased coordination and collaboration with HPC, other WFOs, and the external users via new gridded and graphical products, and inter-site coordination and communication tools, enable the entire forecast "team" to add value and consistency to the final products.

Student Notes:

21. New Operational Remedies

Instructor Notes: GHG provides a standardized segmented WSW format for vendor automation. It has helped to standardize headlines. VTEC provides an automated mechanism for depicting winter hazards. For example, upgrades/downgrades/replacements are automated in VTEC and Headlines. This provides a consistent, seamless graphical hazard display.

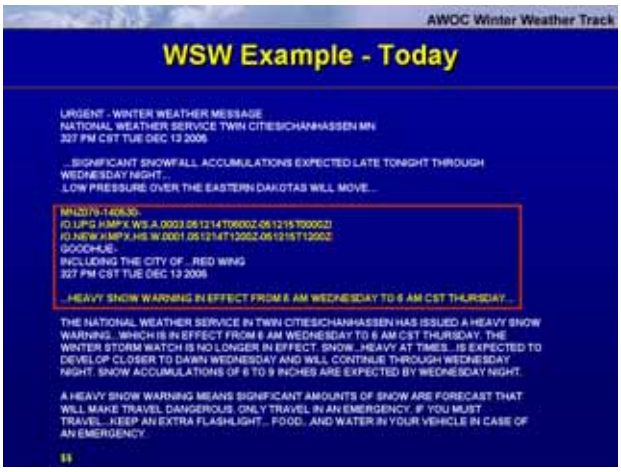
Student Notes:



22. WSW Example - Today

Instructor Notes: Unlike the earlier Denver example, today's warning shows specific event type, area and time of impact.

Student Notes:



23. Winter Weather Directives

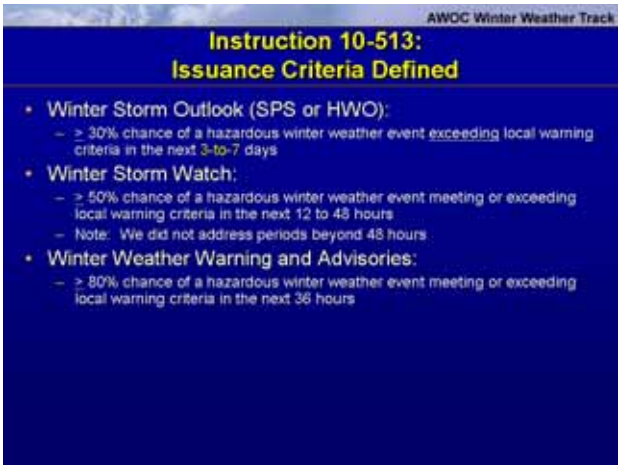
Instructor Notes: To reflect the results of the surveys and clarify confusing policy, new policy directives were agreed upon by NWS Headquarters and the Regions. Winter weather policy is contained within the broad scope of the Pubic Weather Services Policy Directive 10-5. which defines the mission critical, high level public weather warning policies. 2 Instructions, 10-513 and 10-514, specify requirements for Winter Weather Products issued by Weather Forecast Offices and NCEP Hydrometeorological Prediction Center, respectively. For the purposes of this training module, we will focus on the 10-513, WFO Winter Weather Products. 2 Instructions, 10-515 and 10-516, specify requirements for Non-Precipitation Products, such as high winds or freeze warnings, issued by WFOs and NCEP, respectively. All current directives and associated instructions are available on the Directives home page.

Student Notes:

24. Instruction 10-513: Issuance Criteria Defined

Instructor Notes: Instruction 10-513 defines 3 types of issuance criteria for products issued by WFOs based on probability of occurrence and when local warning criteria are likely to be met. A Winter Storm Outlook is issued using a Special Weather Statement (SPS) or Hazardous Weather Outlook (HWO) when there is a 30% or greater chance of a hazardous winter weather event exceeding local warning criteria in the next 3-7 days. This product is intended to provide information to those who need considerable lead time to prepare for the event. A Winter Storm Watch is issued using a WSW when there is a 50% or greater chance of a hazardous winter weather event meeting or exceeding local warning criteria in the next 12 to 48 hours. In some cases forecaster confidence may lead to a watch issuance for beyond 48 hours but this is not specifically addressed in the Instruction. Although a watch indicates the risk of a hazardous winter weather event has increased, the occurrence, location, and/or timing is still uncertain. A Winter Storm Warning or Advisory is issued when there is a 80% or greater likelihood of a hazardous winter weather event meeting or exceeding local warning criteria in the next 36 hours. A warning is used for conditions posing a threat to life or property. An advisory is for less serious conditions that cause significant inconvenience and, if caution is not exercised, could lead to situations that may threaten life and/or property. In some cases forecaster confidence may lead to a warning issuance for beyond 36 hours but this is not specifically addressed in the Instruction.

Student Notes:



25. Products quiz

Instructor Notes:

Student Notes:

26. Catalog of Event Specific Products

Instructor Notes: Based on user feedback and improvements in modeling accuracy and forecaster skill, winter weather warnings and advisories can be broken out into “event-specific” categories.

Student Notes:

27. Event Specific Winter Warnings

Instructor Notes: This table summarizes issuance criteria for event specific warning products. Policy clearly states these categories should be used when the precipitation type can be determined with a high level of confidence. When confidence is low for a predominant winter weather precipitation type or more than one type is expected, the WFO forecast team will issue a Winter Storm Warning.

Student Notes:

Event Specific Winter Warnings

Winter Weather Product	Issuance Criteria
Blizzard Warning	1) Sustained wind or frequent gusts ≥ 35 mph 2) Falling and/or blowing snow reducing visibility < ¼ mile for at least 3 hours
Heavy Snow Warning	Snow accumulation meeting or exceeding locally defined 12 and/or 24 hr warning criteria
Ice Storm Warning	Ice accumulation meeting or exceeding locally defined warning criteria (typical value ≥ ¼ inch)
Sleet Warning	Sleet accumulation meeting or exceeding locally defined warning criteria (typical value ≥ ½ inch)
Winter Storm Warning	Winter weather event having more than one predominant hazard: 1) Heavy snow and blowing snow* (near blizzard conditions) 2) snow and ice 3) sleet and ice 4) Snow, sleet and ice

28. Event Specific Winter Advisories

Instructor Notes: The “event-specific” Winter Weather Advisory categories are shown.

Student Notes:

29. Winter Weather Warning vs. Wind Speed Criteria: Three Tiered System

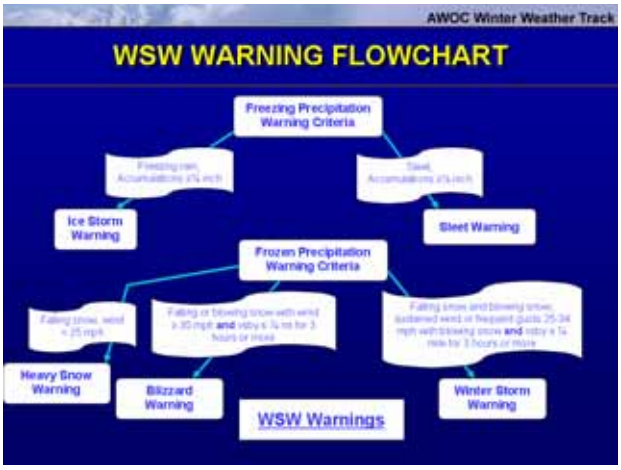
Instructor Notes: Another critical factor is the combined impact of wind and heavy snow. A Heavy Snow Warning becomes a Winter Storm Warning when sustained winds or frequent gusts exceed 24 m.p.h. but are less than the 35 m.p.h. threshold for a Blizzard Warning.

Student Notes:

30. WSW WARNING FLOWCHART

Instructor Notes: For those of you who think visually here's a decision flow chart to determine what Winter Storm Warning is appropriate.

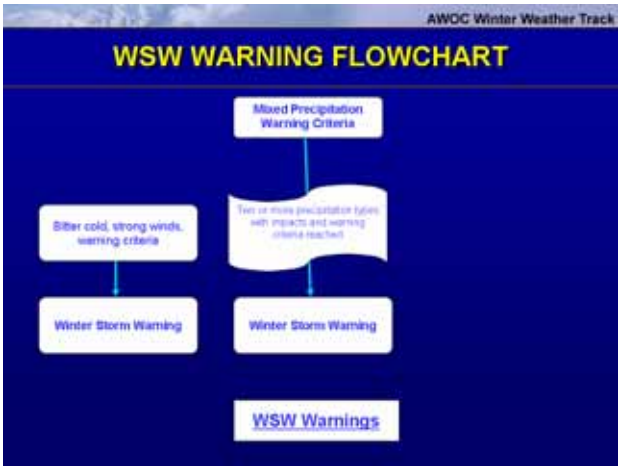
Student Notes:



31. WSW WARNING FLOWCHART

Instructor Notes: Part Two of the flow chart is for mixed precipitation scenarios.

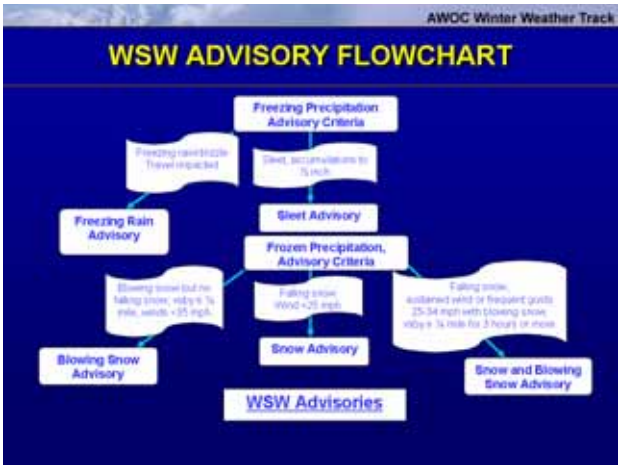
Student Notes:



32. WSW ADVISORY FLOWCHART

Instructor Notes: Similarly, an Advisory Flow chart is shown.

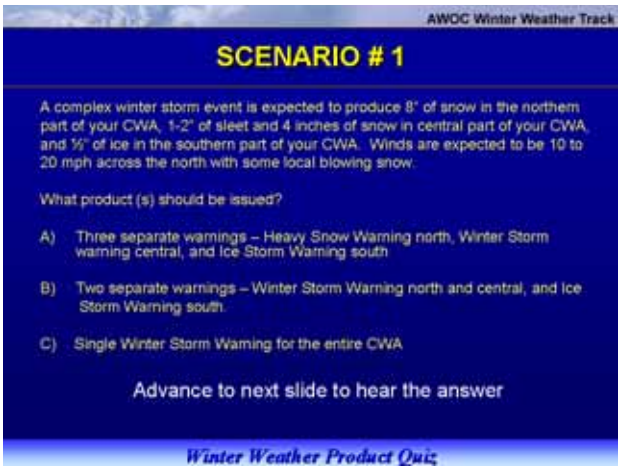
Student Notes:



33. SCENARIO # 1

Instructor Notes: Based on field input, several scenarios are presented to help you decide what product to issue. A complex winter storm event is expected to produce 8” of snow in the northern part of your CWA, 1-2” of sleet and 4 inches of snow in central part of your CWA, and 1/2” of ice in the southern part of your CWA. Winds are expected to be 10 to 20 m.p.h. across the north with some local blowing snow. What product (s) should be issued? A) Three separate warnings – Heavy Snow Warning north, Winter Storm warning central, and Ice Storm Warning south, B) Two separate warnings – Winter Storm Warning north and central, and Ice Storm Warning south, or C) Single Winter Storm Warning for the entire CWA .

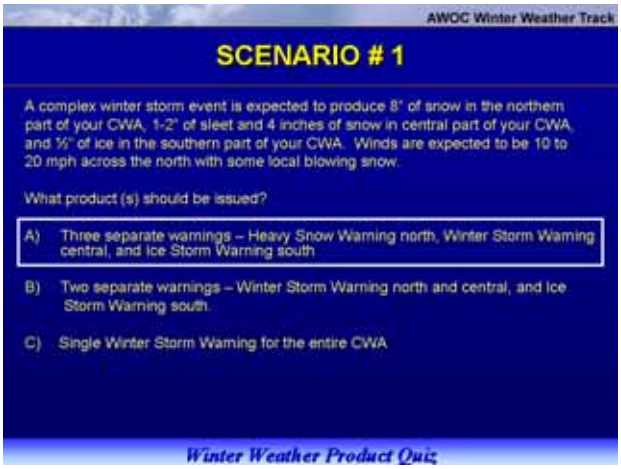
Student Notes:



34. SCENARIO # 1 (answer)

Instructor Notes: The answer is A, Three separate warnings – Heavy Snow Warning north, Winter Storm warning central, and Ice Storm Warning south, are needed. Wind speed and visibility criteria don’t meet WSW criteria across the north.

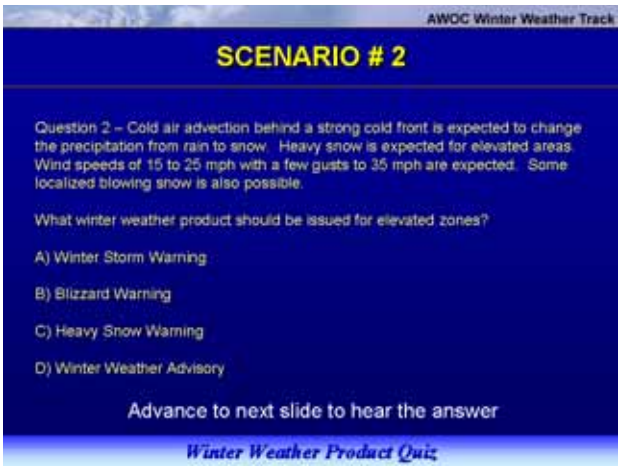
Student Notes:



35. SCENARIO # 2

Instructor Notes: Question 2 – Cold air advection behind a strong cold front is expected to change the precipitation from rain to snow. Heavy snow is expected for elevated areas. Wind speeds of 15 to 25 m.p.h. with a few gusts to 35 m.p.h. are expected. Some localized blowing snow is also possible. What winter weather product should be issued for elevated zones? A) Winter Storm Warning, B) Blizzard Warning, C) Heavy Snow Warning, or D) Winter Weather Advisory.

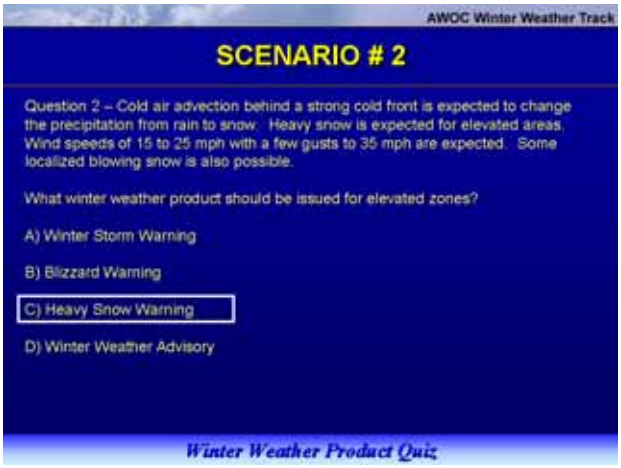
Student Notes:



36. SCENARIO # 2 (answer)

Instructor Notes: The answer is C, a heavy snow warning. Pay close attention to criteria. Winds are too low to meet Blizzard or WSW.

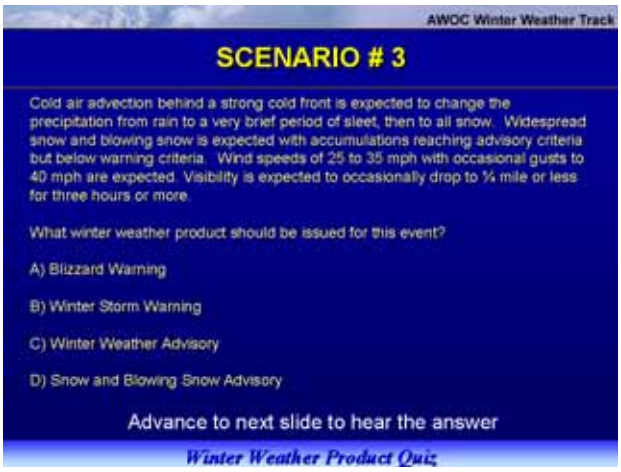
Student Notes:



37. SCENARIO # 3

Instructor Notes: Cold air advection behind a strong cold front is expected to change the precipitation from rain, to a very brief period of sleet, then to all snow. Widespread snow and blowing snow is expected with accumulations reaching advisory criteria but below warning criteria. Wind speeds of 25 to 35 m.p.h. with occasional gusts to 40 m.p.h. are expected. Visibility is expected to occasionally drop to 1/4 mile or less for three hours or more. What winter weather product should be issued for this event? A) Blizzard Warning, B) Winter Storm Warning, C) Winter Weather Advisory, or D) Snow and Blowing Snow Advisory. Hint: pay close attention to criteria.

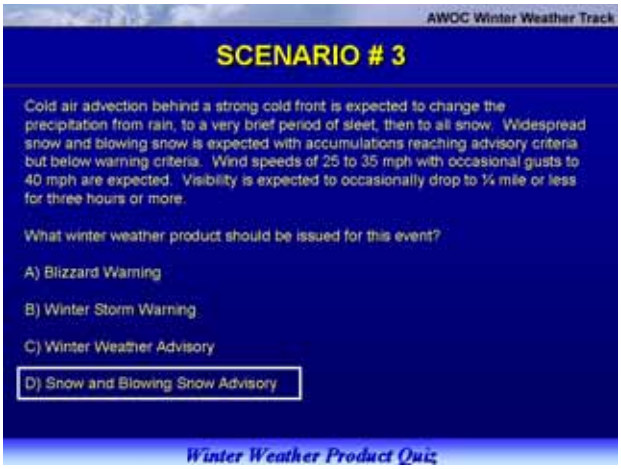
Student Notes:



38. SCENARIO # 3 (answer)

Instructor Notes: You have to pay close attention to criteria here. The answer is D, issue a Snow and Blowing Snow Advisory. The wind speed and snow criteria are not met.

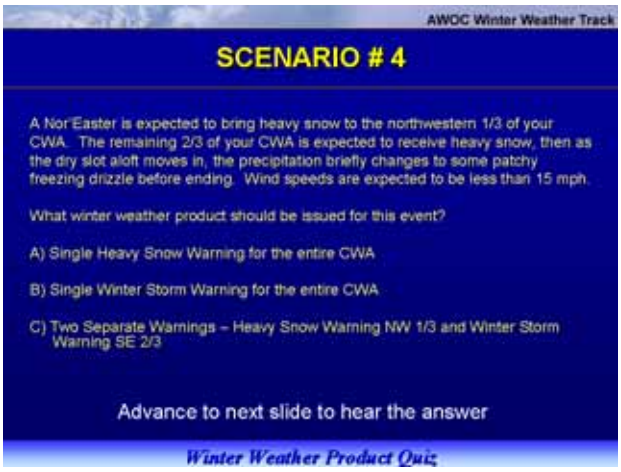
Student Notes:



39. SCENARIO # 4

Instructor Notes: A Nor'Easter is expected to bring heavy snow to the northwestern 1/3 of your CWA. The remaining 2/3 of your CWA is expected to receive heavy snow. Then, as the dry slot aloft moves in, the precipitation briefly changes to some patchy freezing drizzle before ending. Wind speeds are expected to be less than 15 m.p.h. What winter weather product should be issued for this event? A) Single Heavy Snow Warning for the entire CWA, B) Single Winter Storm Warning for the entire CWA, or C) Two Separate Warnings – Heavy Snow Warning NW 1/3 and Winter Storm Warning SE 2/3. Note: the key word is "predominant".

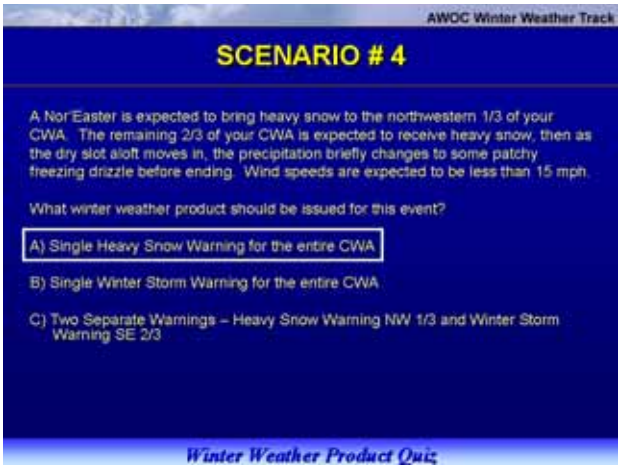
Student Notes:



40. SCENARIO # 4 (answer)

Instructor Notes: The answer is A, issue a single heavy snow warning for the entire CWA. The predominant precipitation is heavy snow.

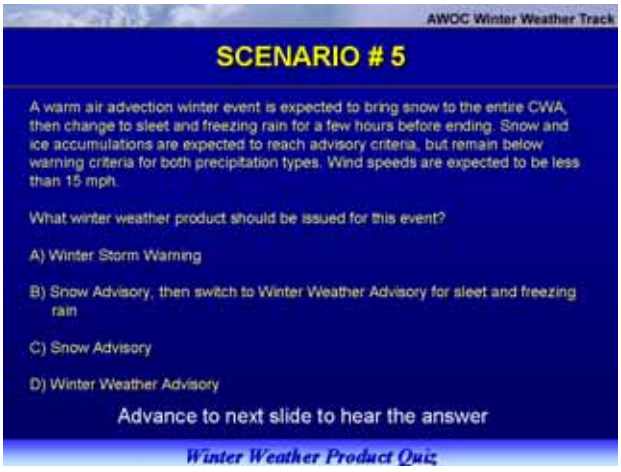
Student Notes:



41. SCENARIO # 5

Instructor Notes: Question 5 – A warm air advection winter event is expected to bring snow to the entire CWA, then change to sleet and freezing rain for a few hours before ending. Snow and ice accumulations are expected to reach advisory criteria, but remain below warning criteria for both precipitation types. Wind speeds are expected to be less than 15 m.p.h. What winter weather product should be issued for this event? A) Winter Storm Warning, B) Snow Advisory, then switch to Winter Weather Advisory for sleet and freezing rain, C) Snow Advisory, or D) Winter Weather Advisory.

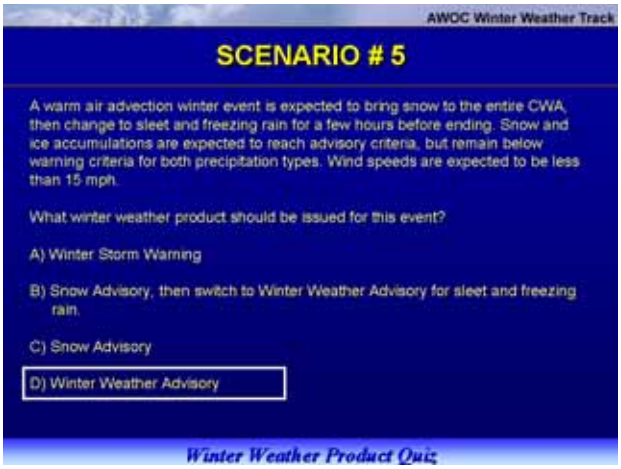
Student Notes:



42. SCENARIO # 5 (answer)

Instructor Notes: The correct answer is D, issue a winter weather advisory (WWA), since significant mixed precipitation events are expected to go with a generic WWA.

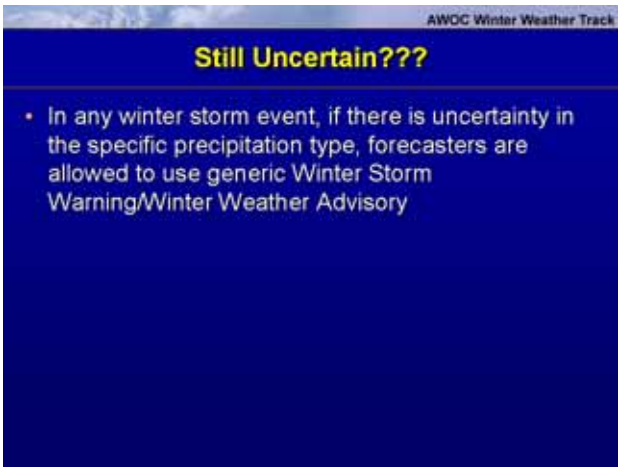
Student Notes:



43. Still Uncertain???

Instructor Notes: Although we as forecasters should try to provide the most accurate picture of what is to occur, there are situations that are rapidly changing, have tight gradients, or are just too close to call. If the forecaster feels there is too much uncertainty in the specific precipitation type, use the generic Winter Storm Warning or Winter Weather Advisory. In some parts of the country this will be the norm!

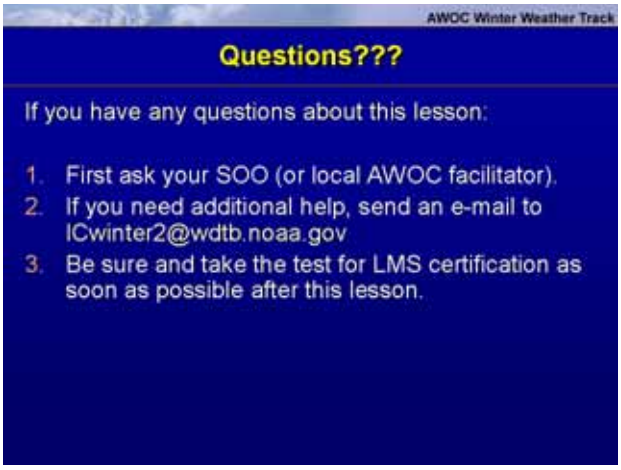
Student Notes:



44. Questions???

Instructor Notes: There are more scenarios on the LMS test. After going through this lesson if you have any questions, first ask your SOO (or your WCM about specific product formatting). Your SOO is your local facilitator and should be able to help answer many questions about AWOC. If you need additional info other than what your SOO provided, send an e-mail to the address on the slide. This address sends the message to all the instructors involved with this IC. Our answer will be CC'd to your SOO so that they can answer any similar questions that come up in the future. We may also consider the question and answer for our FAQ page. Thanks for your time and good luck on the exam!

Student Notes:



1. IC2.2: WFO/HPC Collaboration

Instructor Notes: Welcome to the AWOC Winter Track Instructional Component 2, Lesson 2. This presentation, Forecast and Product Collaboration, should last approximately 30 minutes. The two instructors for this lesson are Brian Motta, instructor for the Forecast Decision Training Branch in Boulder, and Peter Manousos, SOO of the HPC.

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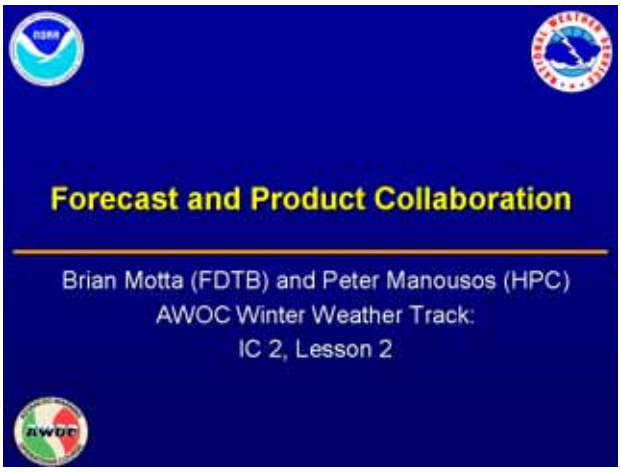

2. Learning Objectives

Instructor Notes: There are two objectives with this lesson. The first objective is to identify the key elements of an effective winter collaboration process. The second objective is to review effective techniques, which preserve and create consistency and accuracy in products and services.

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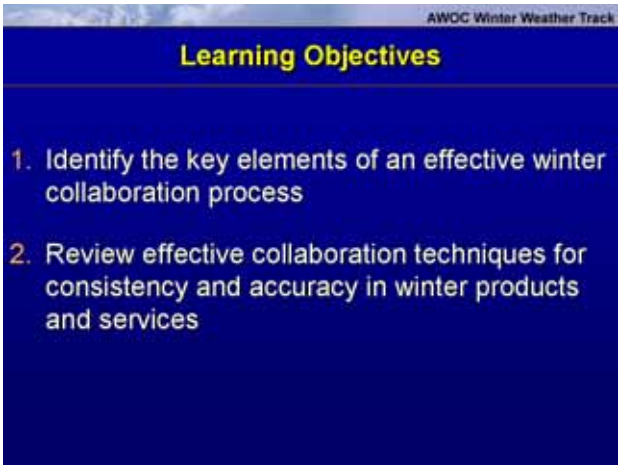

3. Performance Objectives

Instructor Notes: Execution of an effective collaboration process within the forecast process requires every forecast shift and those additional situationally-dependent expectations, including initiation of collaboration with other NWS forecasters at local, regional, and national levels. The identification, effective demonstration, and appropriate use of collaboration tools is important because each tool has advantages which assist other forecasters in key activities such as shift change briefings, intentions to modify grids, and effective/coordinated timing of publishing changes to the National Digital Forecast Database (NDFD). The importance of collaboration triggers can be realized up-front in high-impact weather situations. A key part of a successful collaboration process is anticipating your role in collaboration events and allocating the time necessary to participate before, during and after grid editing tasks. In-depth knowledge of schedules, guidance products, and available assistance from HPC and SPC in the winter weather forecast process is important. Local product users may also be using national center guidance and products too. Note that particular aspects and threats of winter weather may cover large areas and have significant timing and intensity uncertainties. Strategies for handling such events and providing a common base for collaboration are important outcomes of national center collaborations such as the Winter Weather Desk at HPC.

Student Notes:

4. Outline

Instructor Notes: The collaborative process is a necessary and ongoing part of the forecast process. Key aspects and best practices for WFOs will be presented along with the lessons learned. Of particular note are the high impact events which may demand modifying workload assignments and monitoring SPC and HPC products and guidance more intensively than usual.

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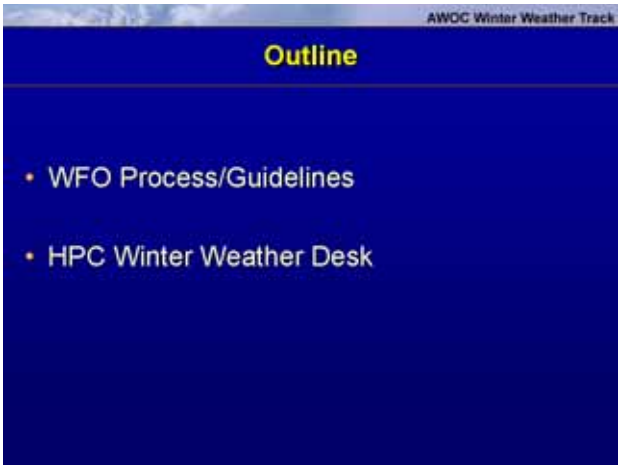

5. Collaboration Definition

Instructor Notes: An effective collaboration process is defined as an exchange of information at key decisional times which include the inheritance of the forecast grids from the previous shift, the consideration of new guidance, and proposed changes to the National Digital Forecast Database (NDFD). Often, the needed changes to the grids are greater than those which are required to be collaborated. See the speaker notes for details on the specific collaboration thresholds: Refer to NWSI 10-506 (Revised Winter 2006) for a New Threshold Memo.

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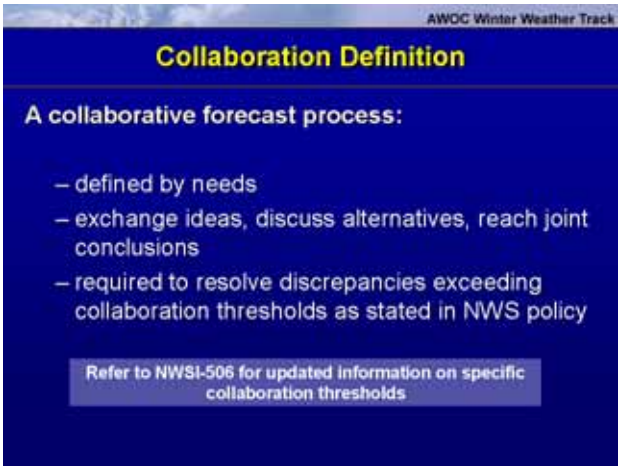

6. Collaborative Problem Solving Model

Instructor Notes: It is important to consider that several tools are in widespread use for collaboration. While office schedules and duty priorities can cause offices to become asynchronous in their communications, there are opportunities for different kinds of interactions. As an example, it is important to make initial and final contacts for collaboration. These are key points in the collaboration process and the previous and next shift's assessment and awareness. Recognizing the responsibilities of your neighboring offices

is a key to timing your exchanges whether they be by chat, phone, Intersite Coordination Grids, AFDs, etc. It's important to consider the "big picture" differences early and discuss the regional timing and placement of features exceeding collaboration thresholds. This early "heads up" can save significant time when including local effects later in the forecast process. Recall that the gridded forecasts are used to generate a number of forecast products both at the national and local levels. In addition, particularly for high-profile events, users may be referencing national products from the Storm Prediction Center (SPC) and the Hydro-meteorological Prediction Center (HPC). This presents an added level of collaboration above that needed for bordering CWAs. One common challenge is to avoid simple half-way compromises when time gets short as deadlines approach. In order to have the best result, collaborate significant changes early and confirm grid edit intentions with your neighboring office(s) as far in advance as possible or agree to make the changes by a later time.

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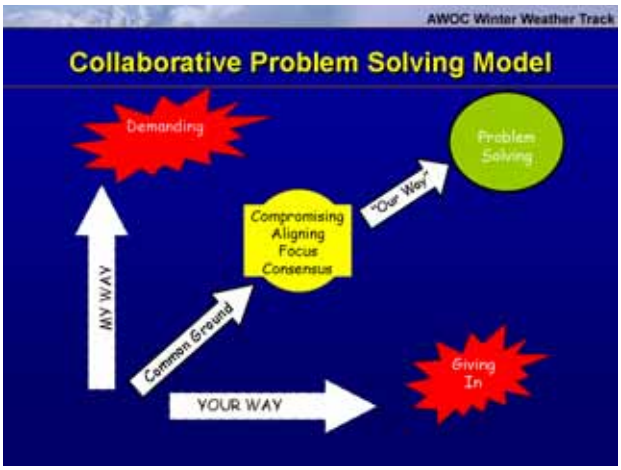

7. Collaboration Methodology

Instructor Notes: A key time saver and workload reducer is a good forecast process collaboration methodology. When possible, use the existing grid forecast as the basis for changes. Express your initial thoughts in chat so that others can be aware. Identify grids that will need little if any change and those needing major changes. Consider the following factors in deciding when and where event-based changes are needed: New model guidance (beware of model flip flops), dropping the first period, adding new Day 7, local customer needs/deadlines (e.g. DOT, media, etc.), or observed weather doesn't match the forecast. Be sure to address major points and significant changes as early as possible in the process. The best forecast collaborators do so in a focused and conservative way. For instance, you have an impending winter storm with several precipitation types. One decision to make is what aspects of the forecast you need to resolve first and which may cause you to collaborate. If there is agreement on the amount, timing and location of the heavy snow, then it makes sense to consider aspects related to possible ice accumulation and collaborate those in areas expected to be hard hit. You may be less concerned about the dewpoint or wind speed until the most important aspects of the storm are in-hand. Also consider that additional forecasters may be needed to complete the edits.

Synoptic scale changes to the current forecast database can help focus you early in the forecast process and will help to avoid potential problems and wasted time later. Typically, there are both early and late NCEP collaboration opportunities which you may trigger or participate in by collaborating with NCEP. Using the chat, ISC, and grid discrepancy tools, your ever-present goal as a forecaster should be to converge toward a solution based on sound reasoning from the most likely solution presented by the available guidance.

Student Notes:

8. NDFD Collaborative Forecast Process

Instructor Notes: This diagram attempts to highlight the overall collaboration process which can be cyclical in nature as forecasts become complex and high-impact. Note that the process starts with new information, typically new observations or model guidance but it may be triggered by a collaboration request from another office. Upon analysis and internal consideration of new information, WFOs collaborate with other WFOs or NCEP centers early in the process to assess what changes may be needed to the official NDFD database. The local forecast database can then be modified given the early sense of the changes to the forecast. While this initial collaboration may begin edits to the database, it's important to consider changes as collaboration continues. It has become practice for the WFOs which are expected to be most heavily impacted to take the lead in the collaboration and communicate changes or further adjustments as necessary. After working through the InterSite Coordination grids, further grid edits ensure that the weather elements are within the collaboration thresholds for the NDFD. An important aspect of collaboration is when the grids will be published to the central NDFD server. If the grid publishing times are not coordinated and executed as planned, the database will display the "popcorn" appearance as WFO grids get published at different hours. It's important to allow enough time for completed grid edits of high-impact weather elements so that the corporate appearance of the NWS products depicts the situation as neighboring offices intended. When CWA border values are within collaboration thresholds and publishing times are agreed upon, the grids should be sent to the NDFD. When grids are found to not be within collaboration thresholds, additional collaboration may be needed. There are three categories of changes. The first cause of values exceeding the collaboration

thresholds is that the actual meteorology places those gradients and border differences at that location. This can occur with sharp fronts or in areas where topography forms a natural discontinuity. In this circumstance, no editing or collaboration is needed, the grids are ready to publish when the time (hour) is agreed upon by your adjacent or affected CWAs. The second category of causes of values exceeding collaboration thresholds is subjective meteorological differences in interpretation and analysis. These can arise from different model preferences, forecasting techniques, smart tools, and differences in timing and track forecasts. These can be resolved if one understands the reasons for the differences and there is an exchange of preferences. NCEP centers can help with issues such as heavy snowfall gradients, precipitation type, and rain/snow lines. Perhaps the most difficult area to collaborate is local effects since they can vary over short distances. In such circumstances, it may be helpful to consider climatology, forecaster experience, and the impact of forecasting those local effects on customers and partners. 3) The third category of values exceeding the collaboration thresholds occurs when non-meteorological gradients exist along or near CWA borders. These grid differences tend to show up as marked discontinuities which would not actually occur along CWA boundaries. These circumstances require that the forecasters resolve the differences before publishing their grids officially to the NDFD server. In such cases, more collaboration is needed and possibly assistance from NCEP. When collaboration changes are agreed to and the edits can be completed, those grids can then be published to the official NDFD server. After publishing, the cycle begins again.

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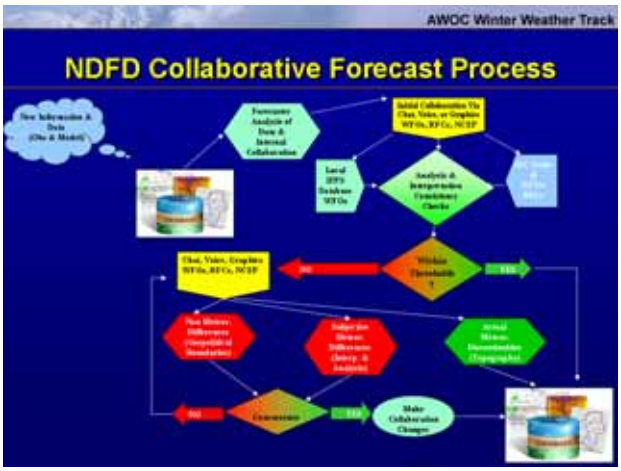

9. NCEP Winter Weather Support for WFOs

Instructor Notes: NCEP provides winter weather support to WFOs via two National Centers – HPC and SPC. SPC provides winter weather support in the nowcast time frame and HPC provides winter weather support out to day 3.

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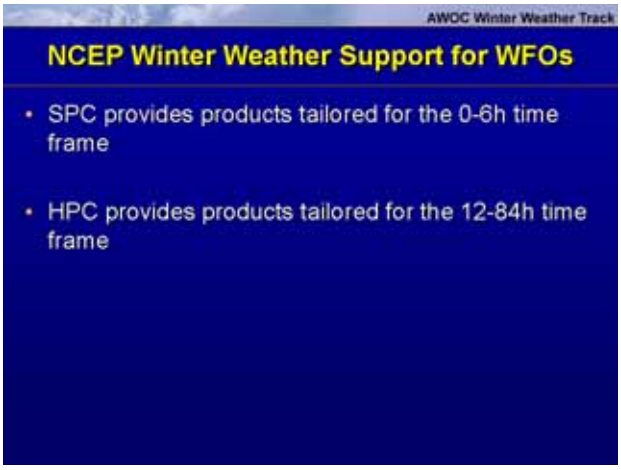

10. HPC Winter Weather Desk Strategy

Instructor Notes: Winter Weather Desk (WWD) strategy and process are based heavily off of WFO feedback (Winter Weather Experiments 2002 through 2004). WWD Internal guidance is based on GFS, NAM, SREF and other models available at HPC. Collaboration occurs routinely in 12 Planet or verbally by phone. Both parties (HPC and WFO) issue a public product suite. HPC's public suite are probability graphics tailored to compliment WFO grids. Collaboration is the key link to ensure the HPC probabilities are in sync with WFO grids. This process allows NWS users to obtain what's most likely to occur (via WFO grids), and a sense of the potential of the event (via HPC probabilistic products).

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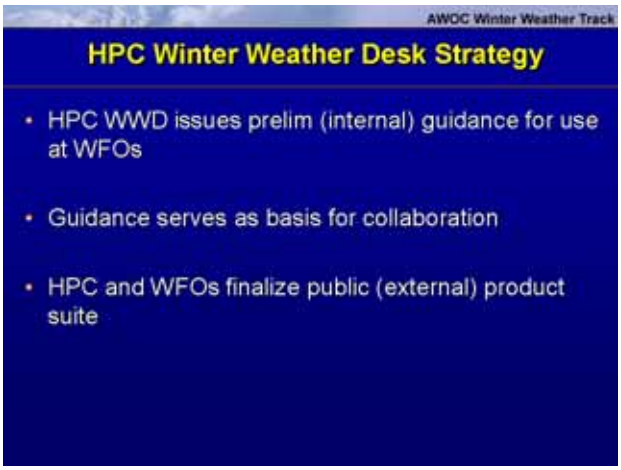

11. WWD Internal Graphics

Instructor Notes: Accumulations are drawn at HPC on a "storm scale", not quite mesoscale and not quite as coarse as synoptic scale. Details such as LES and terrain enhancement are included. HPC uses a technique called Parameter-elevation Regressions on Independent Slopes Mode (PRISM) to downscale the storm scale renditions of

accumulations to 5km for use in the intermountain region. Additionally, diagnostic fields routinely referred to by the WWD forecaster are available for the GFS, NAM and SREF at http://www.hpc.ncep.noaa.gov/mdd/mddoutput. This page houses diagnostic fields with a strong emphasis on QPF, F-gen, dendritic growth and banding.

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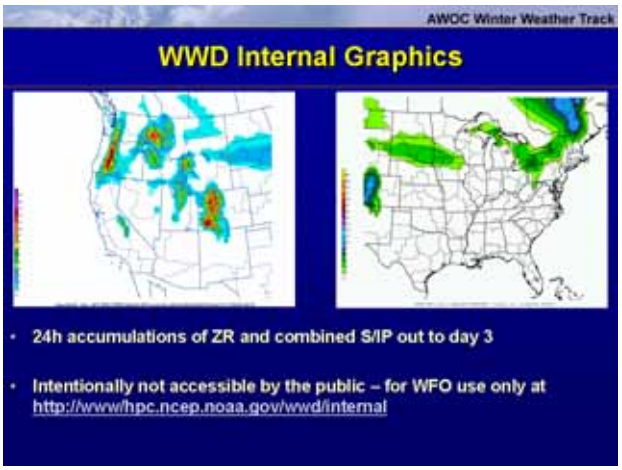

12. WWD External (Public) Graphics

Instructor Notes: The internal graphics, post collaboration, serve as the basis for the probability graphics. These CRITICAL differences in thinking on a storm scale between HPC and WFOs are collaborated.

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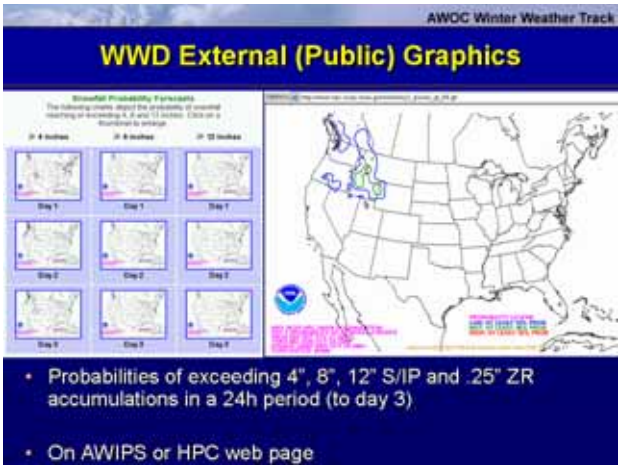

13. WWD External (Public) Graphics (Cont.)

Instructor Notes: A version of this graphic tailored for the public is also available on HPC's web page.

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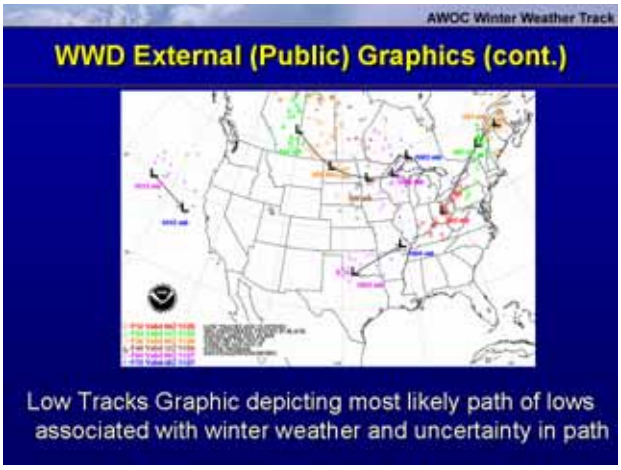

14. WWD Collaboration

Instructor Notes: Additionally, HPC can be used as a vehicle to convey model info not readily available in AWIPS to the forecaster at a WFO. Local expertise resides at WFO, not HPC, therefore storm scale accumulations are provided by HPC. And so HPC leaves decision for issuance of highlights (watches, warnings, advisories) to the WFOs.

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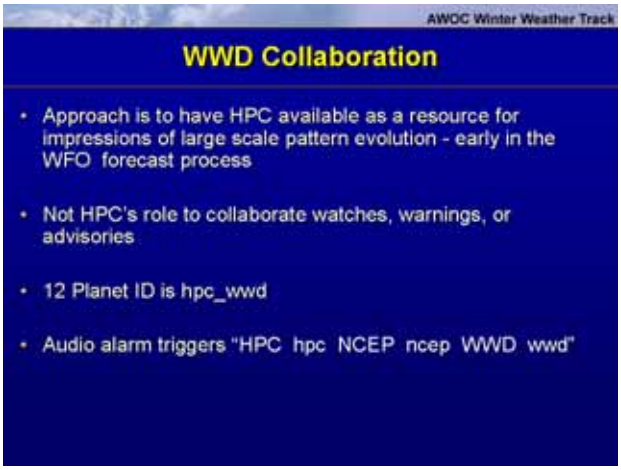

15. WWD Collaboration "Triggers"

Instructor Notes: 1-2" differences in regions where expected amounts straddle Watch/ Warning issuance should be collaborated. However, differences of 2" in a heavy snow event typically do not warrant collaboration. The bottom line is if you need to talk – you can call or chat.

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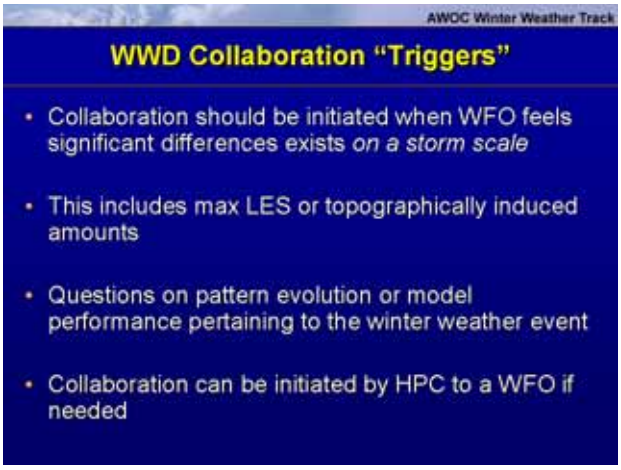

16. WWD Collaboration Call Criteria

Instructor Notes: Calls are not needed routinely, but can be quite helpful, especially when typing on 12 Planet becomes too cumbersome. It doesn't matter who initiates or facilitates a call, so long as communication is occurring.

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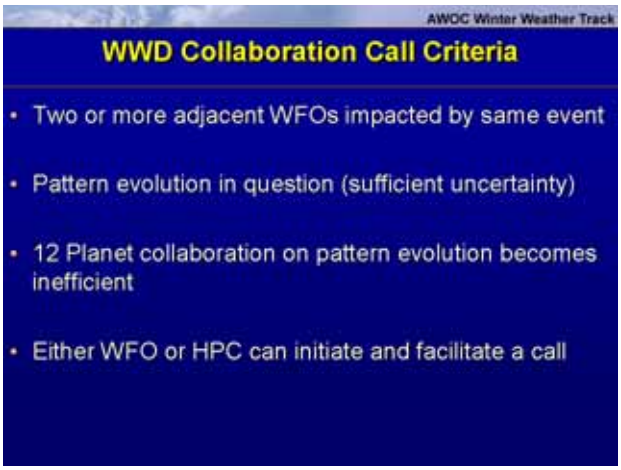

17. What to Expect from HPC During Call

Instructor Notes: HPC participation in WFO initiated calls will end when calls naturally gravitate towards highlight collaboration (watch/warning). Again, local expertise resides at WFOs. Therefore HPC feels WFOs should be making final call on issuance of watches/warnings.

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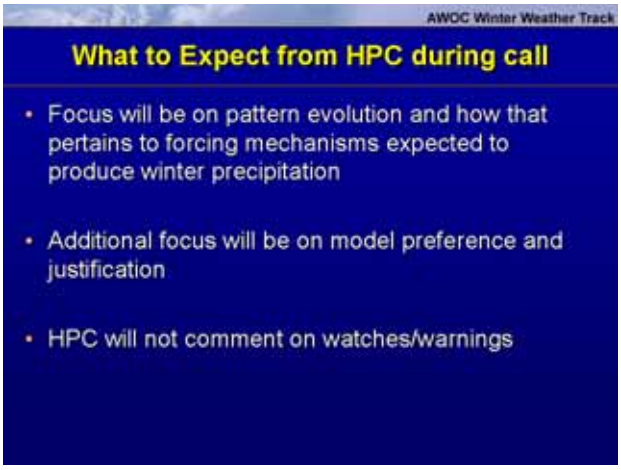

18. Function of WWD Collaboration

Instructor Notes: Goal is to ensure our NOAA's NWS WFO/HPC products are consistent so users get the same message from HPC and WFOs.

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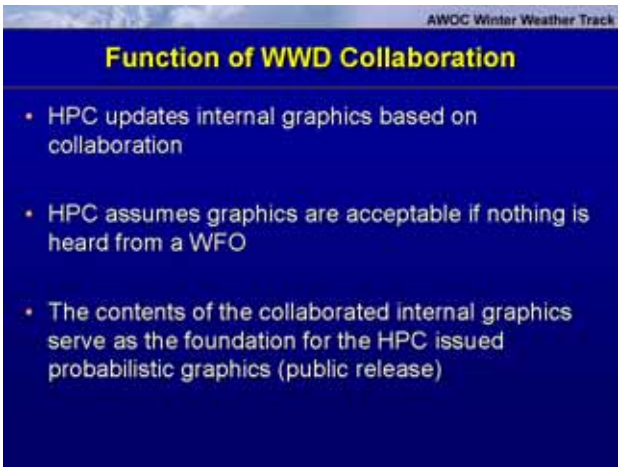

19. WWD Deadline Summary

Instructor Notes: Printable "under the glass" table.

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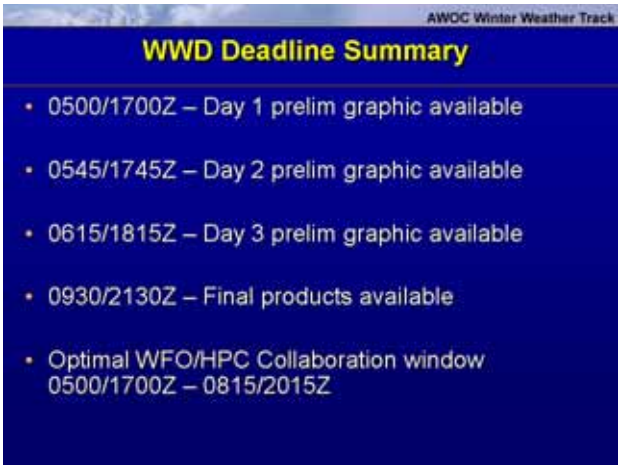

20. SPC Support

Instructor Notes: SPC focuses on nowcasting time frame. If you ask SPC about events in 12-84h time frame they will refer you to HPC and vice versa. If an event is ongoing, the Mesoscale Discussions (MDs) will be issued at least every 6 hours. Unscheduled MDs are issued as needed.

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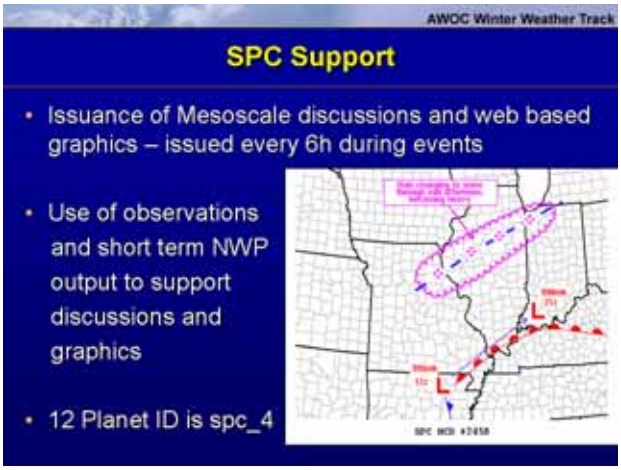

21. Concluding Comments

Instructor Notes: Good collaboration requires team work. It is the foundation of the current NDFD product generation. Collaboration works best when it is treated as a process integrated within the forecast process. Collaboration should begin early in the forecast process and be appropriate to the forecast challenges in the time and effort expended. While collaboration time can be minimized, at least a small amount of time should be devoted to it. Collaboration should continue throughout the forecast process until the grids are published as agreed upon. Finally, there can be valuable insights into model performance and guidance from NCEP (HPC and SPC) during winter weather situations.

Consider high-impact winter weather a collaboration trigger with HPC because customers and partners will likely get information from both sources.

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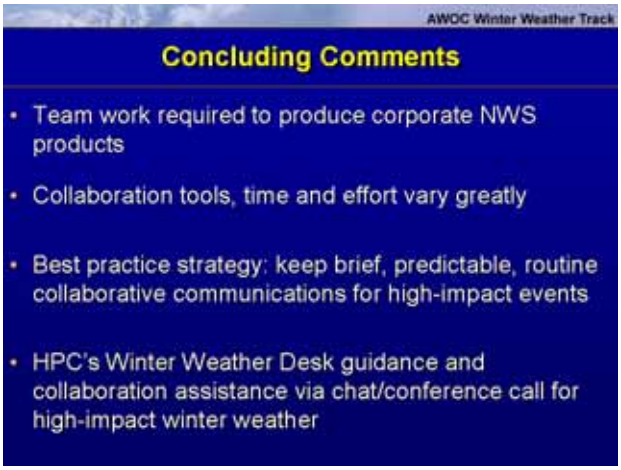

22. Collaboration

Instructor Notes: Take a few moments to complete the quiz questions on this slide.

Student Notes:

23. Have any Questions????

Instructor Notes: If you have any questions about this lesson, first ask your local AWOC facilitator. If you need additional help, send an e-mail to the address provided. When we answer, we will CC your local facilitator and may consider your question for our FAQ page. We strongly recommend that you take the exam as soon as possible after completing Lesson 2.

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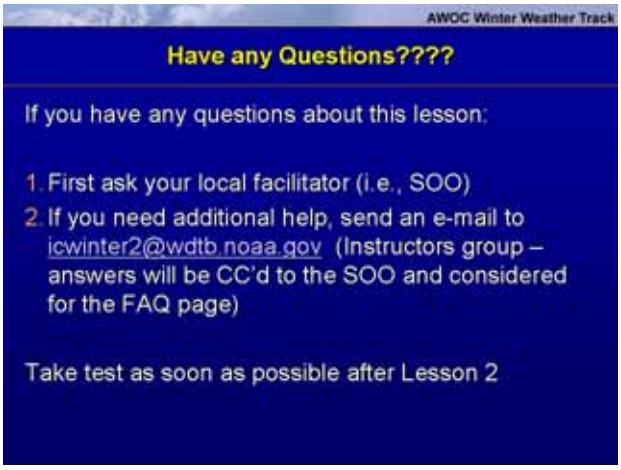

IC Winter 3: User Needs to Mitigate Societal Impacts

1. IC3.1: User Impacts

Instructor Notes: Welcome to the AWOC Winter Track Instructional Component 3, Lesson 1. This presentation, entitled Significant Impacts to Users, should last approximately 25 minutes. While much of this lesson may cover material that you've seen before, some of the content contains information you might not have thought of or have been exposed to before.

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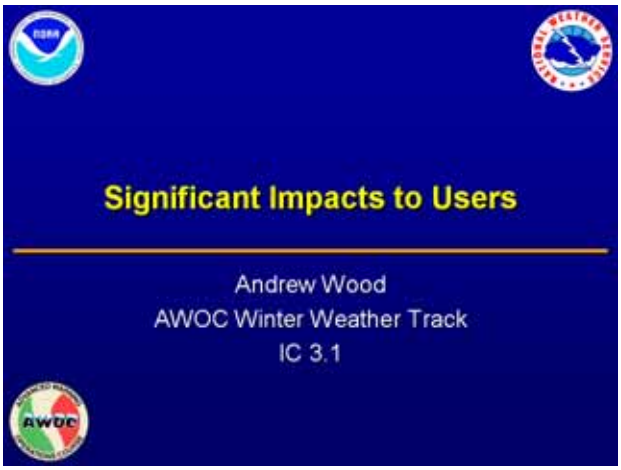

2. Collaborators and Reviewers For This Lesson

Instructor Notes: This IC is the end result of the input and effort of several people. Everyone listed here helped in some capacity, such as helping to define the scope and outline of the lesson, assisting in the development of lesson content, or in reviewing the draft and final presentations. All of their efforts are greatly appreciated.

Student Notes:

3. Learning Objectives for IC 3, Lesson 1

Instructor Notes: There are three learning objectives for this lesson. The first objective is that by the end of the lesson, you should be able to identify the weather information that is most critical to communicate to users for their mitigation efforts. Second, you should be able to explain how some of the variations in these variables can have different impacts on users. Lastly, you should be able to identify how certain “sub-advisory” winter weather events can have significant societal impacts.

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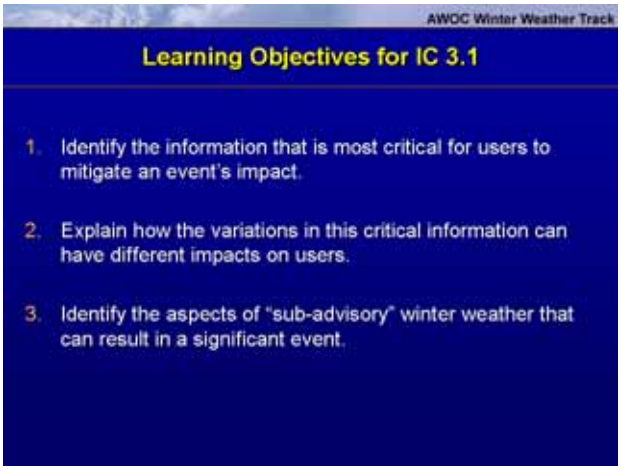

4. Why Winter Weather Events Are Critical to So Many Users

Instructor Notes: It’s understood that winter weather events have significant impacts to users throughout a majority of the country. Large sections of the US (including almost every state) average at least one day of snow or other freezing precipitation type per year. Approximately 70% of the US land area receives at least 5” average snowfall each year, affecting nearly 70% of the US population (FHWA, 2005) with significant societal impacts. For instance, in 1999 approximately 63,000 injuries and 680 deaths in traffic accidents occurred when snow and ice were present on roadways (Mahoney, 2003). In 2001, those numbers were 95,000 and 1,100, respectively (FHWA, 2005). As a result of the large numbers of people impacted, there are a multitude of issues that our users must address to mitigate the impact of winter weather events.

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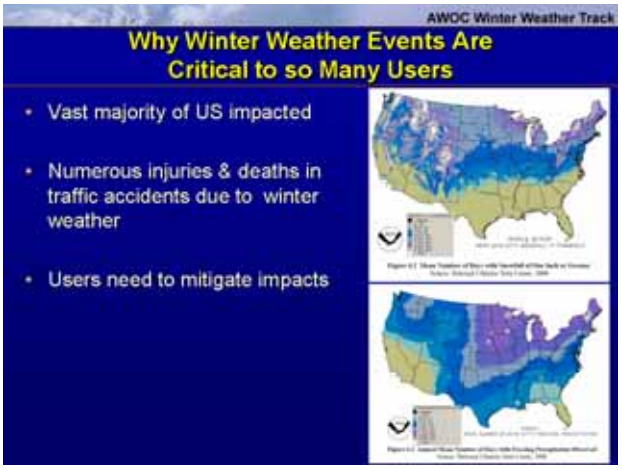

5. Critical Information That Users Need to Mitigate a Significant Event

Instructor Notes: Generally speaking, most users receive “enough” information about winter weather events. In fact, many think they receive too much information. That’s why it is important that we emphasize the most critical information that our users need in our products. Timing information is important, such as when an event will start, when it will stop, and when will any significant changes occur during the event. Other topics users might have questions on include: What will the expected precipitation intensity, type, and accumulation be? Will strong winds result in blowing snow or will there be any other reduced visibility issues? Lastly, what will the ground and near-ground air temperatures be like? All of these variables can significantly impact the severity and our users’ experiences of an event. They need to know which will be the most important, and may define, the upcoming event and why.

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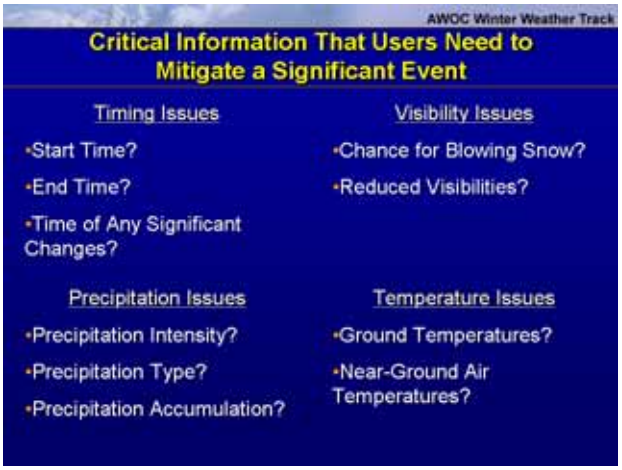

6. Impacts from Diurnal Variations

Instructor Notes: One reason that timing impacts are important are diurnal variations. Ground and near-ground temperatures are just one example of a diurnal variation that can greatly influence an event's severity and impacts. People generally understand the more mundane stuff, such as paved surfaces getting warmed up in sunny and partly cloudy conditions. They are less likely to know about how different weather phenomena are affected by the diurnal cycle. Examples include freezing rain, freezing drizzle, and lake effect snow showers, all of which have a diurnal maximum in the pre-dawn and early morning hours (Cortinas et al., 2004; Strapp et al., 1996; Kristovich and Spinar, 2005). Occasionally taking a moment to explain these dependences to our users, and how they can impact the significance of an event, is beneficial to them. Society is diurnal, too. Winter events that occur during daylight hours are more likely to affect travelers, commuters, and most businesses in some way. While daytime events generally impact more people, significant impacts can occur during nocturnal events. These impacts range from getting less ground truth reports in the middle of the night to problems affecting a variety of commercial enterprises. Impacts to commerce include commercial truck drivers tendency to drive at night because there is less traffic, many ground and air shipment companies transporting packages at night, and even 24-7 grocery and convenience stores receiving and stocking inventory at night.

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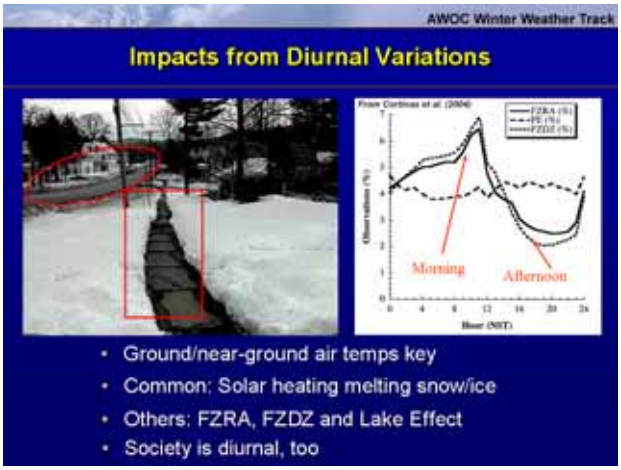

7. Information on Seasonality Impacts

Instructor Notes: Besides time of day, there are also timing impacts due to the seasonality of the event. Often the first storm of the season each year catches people off guard, even if the event only results in an inch or two of accumulation (DeVoir, 2004). Mills and Andrey (2002) suggest that there is a heightened road collision risk during the first snowfall of the season because people are out of practice driving in those conditions. If the first event is unseasonably early it can make matters worse if there are still leaves on trees in the area. While total accumulations are often smaller on roadways, these events usually result in a significant increase in damage to trees, power lines, and related dam-

age due to falling tree limbs. Heightened wording in products and forecasts for these events can be helpful to users.

Student Notes:

8. Information on Precipitation Intensity Variations

Instructor Notes: Snow accumulation values are the most common precipitation info available to users. Just as important, but less reported, is precipitation intensity. The problem is snow intensity can often be a better indication of event severity. After all, 6” of snow in 3 hours will usually produce more societal impacts than 6” in 12 hours. HPC has experimental societal impact products available on-line showing the probability of snowfall intensities greater than 1”/hr., 2”/hr., and 3”/hr. that you might find helpful. When discussing intensities with users in mind, you don’t have to shy away from discussing technical details such as strength of forcing, precipitation microphysics, etc. Some users may get a little intimidated by such discussions, many of our high-end, regular users depend on this information when it is clear and concisely stated. The consistent communication of precipitation intensity information to users is vital, especially when changes in snow intensity occur unexpectedly. The most difficult traffic problems are often caused by changes in snow intensity, precipitation type changeover, etc. These changes can lead to blinding snowfall, rapidly deteriorating road conditions, and increased driver anxiety and confusion (DeVoir, 2004).

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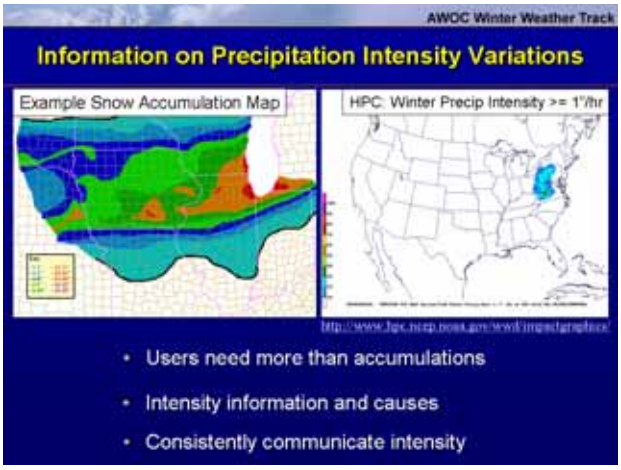


9. Greatest General Risk vs. Catastrophic Risk

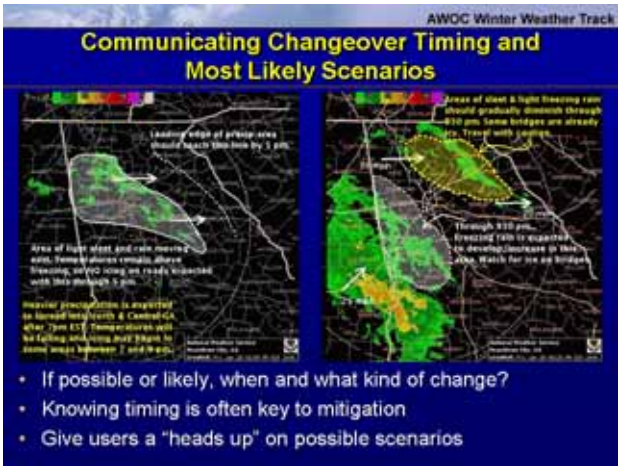
Instructor Notes: Risks from winter event impacts will vary from region to region. What may seem like extreme winter precipitation totals in one area may seem like no big deal elsewhere, and vice versa. After all, a 12” snow in the southeast US can quickly become catastrophic while in other parts of the US that snowfall may only be an inconvenience. It’s important to remember that just because a region has a greater likelihood of snow or ice occurring, that doesn’t mean that the same region has the greatest risk of a significant, or even catastrophic, event in terms of impacts. For example, days with freezing rain generally occur twice as frequently in the northeast US than in other areas in the central and eastern US (Cortinas et al., 2004). But, between 1949 and 2000, the Deep South had the greatest percentage of ice storms with an excess of 1 million dollars in insured property losses (using 2000 USD; Changnon, 2003). The duration of most continuous freezing precipitation events is less than 2 hours, but nearly 10% of events last longer than 4 hours (Cortinas et al., 2004). These longer events are the ones most likely to result in significant damages in terms of dollars and, hence, generally cause the greatest societal impacts. It’s important in our products to clearly differentiate between a common event and a potentially more damaging event (when our confidence is high that such an event will occur).

Student Notes:

10. Communicating Changeover Timing and Most Likely Scenarios

Instructor Notes: Users need to know if a change in precip type is possible, when it will likely occur and what type of changeover will likely happen. Since the changeover region in most systems is usually long and narrow, often resulting in short transition periods, user mitigation is closely dependent on knowing the correct timing. In the case of events where there is a prolonged transition between types, or even multiple changes in type, it is critical that the possibility of such a changeover be communicated to users as accurately as possible. Giving users a “heads up” to whether a forecast changeover is common or uncommon, what the range of possibilities are, etc., can also help. Graphical products, like the Graphicasts shown here can be a great way to communicate changeover timing. These graphics are taken from two different times during a freezing rain event. The first image highlights the rain showers moving in and when the freezing precipitation should begin. The second graphic is for several hours later in the same event, showing what freezing has occurred and where future freezing is likely.

Student Notes:



11. Rapid Temperature Changes: The Two Extremes

Instructor Notes: Rapid temperature changes can result in two very different, but significant, user impacts. The first change we'll discuss is a rapid temperature decrease. Whenever there is winter precipitation falling, or has recently fallen, a rapid drop in near-ground temperature (especially if the temperature drop is not well communicated in forecasts or other products) can cause nightmares for ground transportation. Even drops of 5-10 degrees F that occur more quickly than forecast can be problematic. Such a situation could result in a road treatment strategy no longer being effective at the lower temperature. One such event, highlighted by Wolf et al. (2004), resulted in road crews having to continually treat roads much longer than initially anticipated (resulting in much greater costs) until the sun helped melt the snow and ice on the roads (several hours after the precipitation had ceased). Rapid warm ups can also have substantial user impacts. Rapid warm-ups during "January thaws" or later on in Spring can result in everything from isolated thin ice accidents to flooding, structural damage to bridges (especially in the case of ice jams), and other related impacts. The magnitude of impacts from such warm-ups depend on how quickly they occur, how thick the ice is on lakes and rivers, whether the ground is still frozen (i.e., more runoff), and if there is sufficient lead time that mitigation efforts can be implemented prior to the melt.

Student Notes:

12. Timing Impacts: Relationship to Transportation

Instructor Notes: Earlier we discussed how impacts of events will be greater during the day, especially weekdays, then at night. Traffic volume is at its highest during the morning and evening "rush hour" and, to a lesser extent, on weekend afternoons. Events occurring at these times have the greatest potential for impacts, especially for more marginal events and in areas that regularly experience winter weather. High impact events are also possible during the week at midday if the event is stronger than forecast, businesses and schools simultaneously release early, and a dramatic increase in traffic volume occurs at the height of the storm (Call, 2005). Common travel days around many holidays will have greater traffic volume than on "non-holiday" days. Similarly, weekend

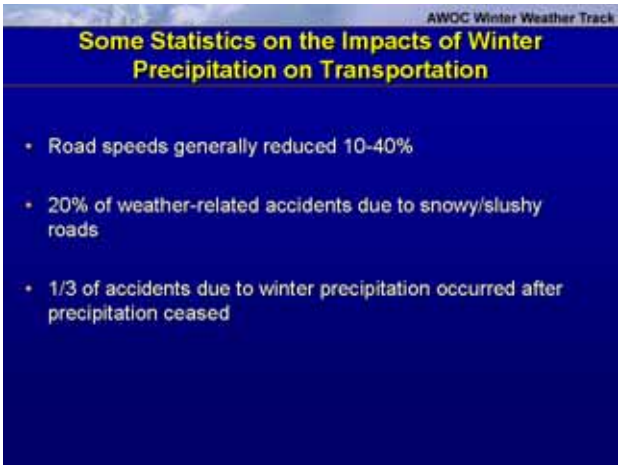
traffic in December, especially around major shopping areas, will be substantially higher than most other weekends during the year. Other special events (i.e., sporting events, New Year's celebrations, etc.) can also significantly enhance traffic volume in certain areas at normally low volume times. It is important to keep these high volume times in mind because most road maintenance crews treat roads so that they are in optimal condition for these times. This strategy usually requires them to treat interstate highways and other major routes (or snow routes) in the few hours prior to rush hour. That will allow enough time for the chemicals to dissolve or dry depending on their treatment strategy. So, when it comes down to timing impacts, any forecasts errors (or even good forecasts communicated poorly) will have higher sensitivities just prior to and during these high volume periods of the day.

Student Notes:

13. Some Statistics on the Impacts of Winter Precipitation on Transportation

Instructor Notes: The accumulation of winter precipitation can be considered the primary adverse weather condition for all facets of the transportation sector (Zubrick, 2004). For instance, average arterial road speeds decline 30-40% on snowy or slushy pavement; Freeway speeds are reduced by 10% in light snow and 40% in heavy snow (FHWA, 2005). In 2001, 20% of weather-related vehicle accidents occurred on snowy or slushy roads, 1/3 of which occurred after frozen precipitation stopped falling (FHWA, 2005). Knapp et al. (2000) found that both snowfall intensity and time of exposure to winter conditions had a positive relationship to crash frequency. Clearly, frozen precipitation accumulation on roadways is important.

Student Notes:



14. Impacts to Aviation: Observations of Freezing Rain and Drizzle

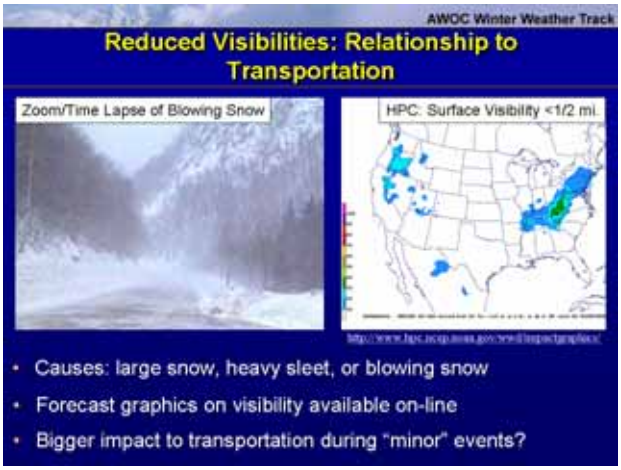
Instructor Notes: The impacts of winter precipitation extend past road transportation. In-flight icing is one of the biggest issues with regards to aviation, and more money is spent researching improvements to in-flight icing forecasts than any other aviation forecast issue. While in-flight icing observations are less numerous then they are at the surface, research indicates ice pellets, freezing rain, and freezing drizzle observed at the ground provide a strong indication of in-flight icing conditions (Bernstein et al., 1997, 1998; Bernstein and McDonough, 2000; Hanesiak and Stewart, 1995; Zerr, 1997). This relationship between surface and in-flight icing conditions is especially important with regards to freezing drizzle, which can be difficult to detect at most distances from the WSR-88D even in clear air mode (Zubrick, 2004).

Student Notes:

15. Reduced Visibilities: Relationship to Transportation

Instructor Notes: Visibilities can be quickly reduced by large aggregate snow flakes or even heavy sleet. Many large, multiple-vehicle traffic accidents occur during events where accumulations were generally light, but the snow's intensity and winds resulted in localized white-out conditions (DeVoir, 2004). Plus, in some regions with strong winds and significant, powdery snow packs, it is possible for near blizzard conditions to exist when there is little or no snow falling in that area. HPC's web site has forecast graphics available on-line for users (and forecasters) to be better aware of such visibility hazards. Knapp et al. (2000) found that total snowfall and the square of the maximum wind gust speed had an inverse relationship to traffic volume (with an average volume reduction of ~30%). However, wind gust speed had no significant relationship to accident rates. The events included in the study had more significant durations and intensities with (snow-falls of at least 4 hours with estimated intensity of at least 0.20" LE/hr.) then the average event. When these results are compared to other meteorological case studies and research (DeVoir, 2004;Zubrick, 2004; and others), it can be inferred that reduced visibilities may have a bigger impact on road traffic during minor events when more people are out on the roads.

Student Notes:

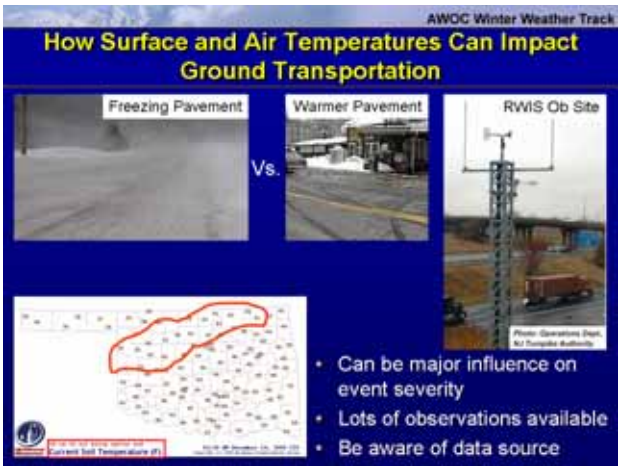


16. How Surface and Air Temperatures Can Impact Ground Transportation

Instructor Notes: Small changes in ground and near-ground air temperatures can play a major role in impact severity. Events that might otherwise be significant, or even catastrophic, can have minimal impacts when ground temperatures are above freezing. There is currently a large volume of observations available for different roadway sensors and local mesonets that can provide information about ground temperatures. You have to be careful what you're looking at, though. There can be some subtle differences (such as bare soil vs. sod ground temperature) that can have a significant impact on data you

are looking at. For instance, a 10 cm sod temperature probe may be measuring a 10 cm ground temperature in the low 40s, but the surface temperature is really around freezing (with snow sticking to the ground in places). Similarly, road sensors will read warmer nighttime temperatures than bridge sensors. Road Weather Information System (RWIS) sites also tend to record lower wind speeds than might be expected, especially when winds are below 12 kts because these sites usually are less exposed to the wind (Pisano et al., 2004).

Student Notes:



17. Learning Interaction 1

Instructor Notes: Take a few moments to complete this interactive quiz.

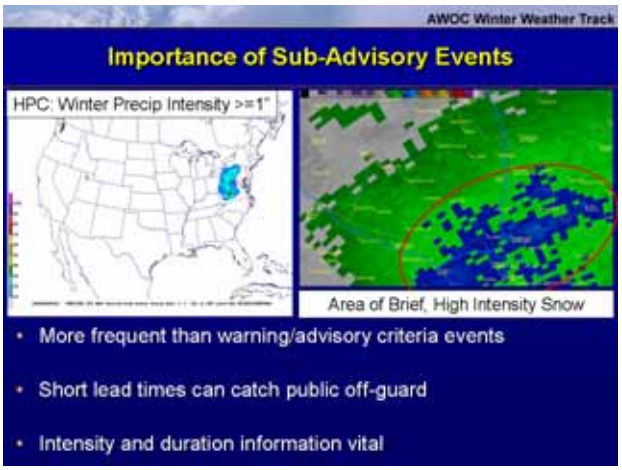
Student Notes:

18. Importance of Sub-Advisory Events

Instructor Notes: Recent research has focused more and more on evaluating the impacts of high-end snow events on people to rate a storms significance (Kocin and Uccelini, 2004; Call, 2005). From a user's standpoint, however, "minor" (meteorologically speaking) winter weather events can still be very significant. These "sub-advisory"

events occur much more frequently than advisory or warning criteria events and may not arouse much public concern. However, if the possibility of adverse conditions exist in such an event, even for only 5-10 minutes, they can have adverse consequences on transportation. This is especially true if they occur during high traffic volume times with little advance warning. These subtle, light winter events will generally have short lead times. The forecast models may not pickup on specific details of the event until 12 hours or less prior to verification (Zubrick, 2004). Another aspect of these events that is challenging is this: what products do you issue? It is difficult to issue a Watch, Warning, or Advisory product if you know criteria will not be met. Often Short Term Forecasts do not receive the same media attention that WWA products do, and may not prove effective. A quick look at a daily forecast by the public probably will not provide them with sufficient information to avoid potential impacts (DeVoir, 2004). In events like these, communicating intensity and duration of snowfall is vital. Some research suggests mitigating the impacts of these “routine adverse weather” events would yield the biggest economic impacts (Colgan, 2005). It is crucial to consistently use terminology to distinguish high intensity events from more ordinary “snow showers”.

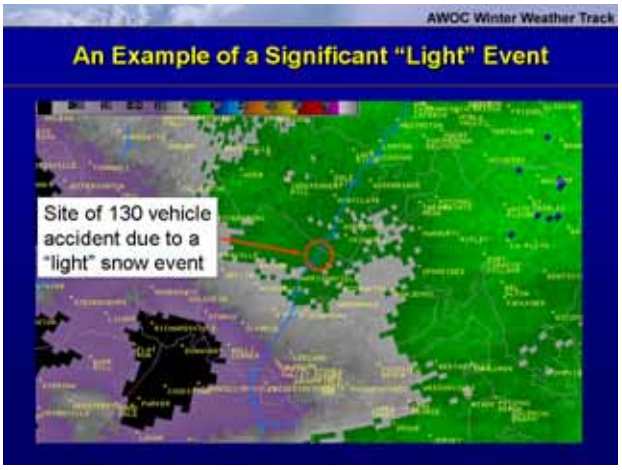
Student Notes:



19. An Example of a Significant “Light” Event

Instructor Notes: This loop of radar images show an example of a significant sub-advisory, or “light”, event. The loop is for a 40-minute period during a two-hour event that produced 2-3” of snow over northern VA. In the highlighted area, there was a multi-vehicle crash between Garrisonville and Dumfries along I-95 involving over 130 vehicles during “white out” conditions. During this two-hour event, there were at least 3 other multi-vehicle crashes involving at least 20 vehicles in the area between Washington D.C. and Richmond, VA.

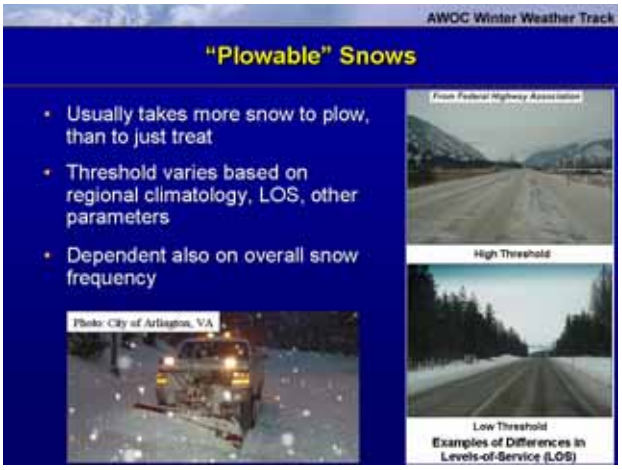
Student Notes:



20. "Plowable" Snows

Instructor Notes: Another way to look at "sub-advisory" events is whether or not it is a "plowable" snow. While road crews may be sent out to chemically treat roads when there's only a trace, plows may not be utilized unless a significant amount of snowfall is expected. Plowing represents an added cost for road maintenance as well as private citizens who have contracts to have driveways and parking lots plowed based on accumulation totals. Just like advisory and warning criteria, the thresholds for plowing snow are variable across the US. A common threshold for secondary and rural roads is 3" (Hallowell and Blaisdell, 2003), while highways and primary snow routes will likely have a lower threshold because of their Level-of-Service (or LOS). Many major cities have the goal of keeping their designated snow routes as snow free as possible during most events. These threshold values will vary regionally due to climatology, from city to city (due to size), and during the day due to traffic volume. In CWAs where there is generally a low frequency of winter weather events (say 5 or less on average each season), there are likely to be limited resources for plowing and treating roadways. These areas are likely to have a greater disparity between "plowable" thresholds for primary snow routes and other roads. For example, Charlotte, NC (which averages under 7"/yr. of snow) has in their winter weather plan that they will not plow most roads until accumulations reach at least 4" (FHWA, 2005).

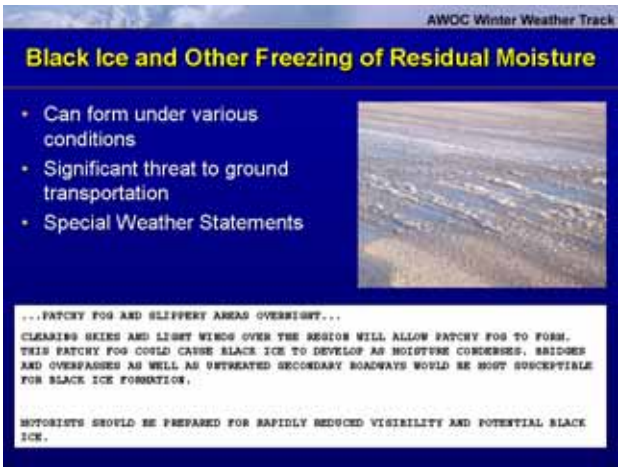
Student Notes:



21. Black Ice and Other Freezing of Residual Moisture

Instructor Notes: Another adverse condition that falls into the "sub-advisory" category is the freezing of residual moisture on roadways (more popularly known as "black ice"). It is important to remember that "black ice" or similar conditions can be caused in many ways (i.e., freezing rain, ice fog, or even frost or freezing of dew on road surfaces). Many times patches of black ice can form simply because there is just enough traffic to melt a very light snow as it falls, but not enough to prevent it from refreezing. Remember that nearly 1/3 of winter weather related automobile accidents occur after precipitation has stopped. Black ice is a likely cause of many of those accidents, making it. Special Weather Statements can be very useful products to issue if the conditions for black ice formation are clearly evident. The problem is that most of the time black ice will form when there is little advance warning of these conditions.

Student Notes:

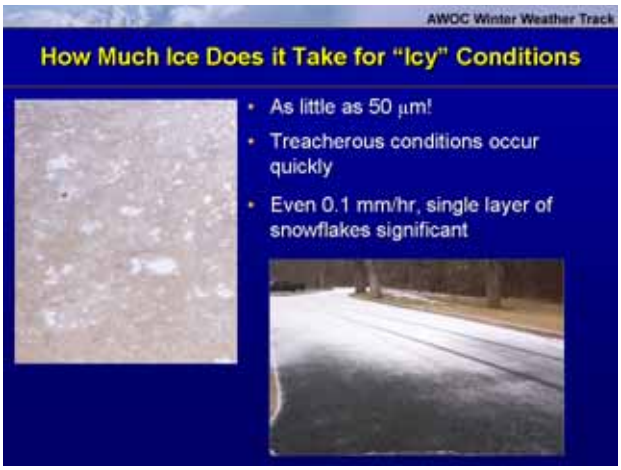


22. How Much Ice Does it Take for "Icy" Conditions

Instructor Notes: So how much ice does it take to create treacherous conditions? Well, not very much. Laboratory testing has shown than the grip between tires and asphalt is

dangerously reduced when ice exceeds 50 micrometers in thickness (Nicolas, 1996). During a typical light freezing rain event (say ~1 mm/hr.), it only takes a few minutes for that much ice to accumulate (Partanen et al., 2003). That means light precipitation events with as little as 0.1 mm/hr. can be important, from a user's perspective, if there is a chance for freezing on roadways. Even a single layer of snowflakes can reduce friction significantly and require treatment (Mahoney, 2003). As with other "light" events, communicating the potential threat to users is critical.

Student Notes:



23. Learning Interaction 2

Instructor Notes: Take a few moments to complete this interactive quiz.

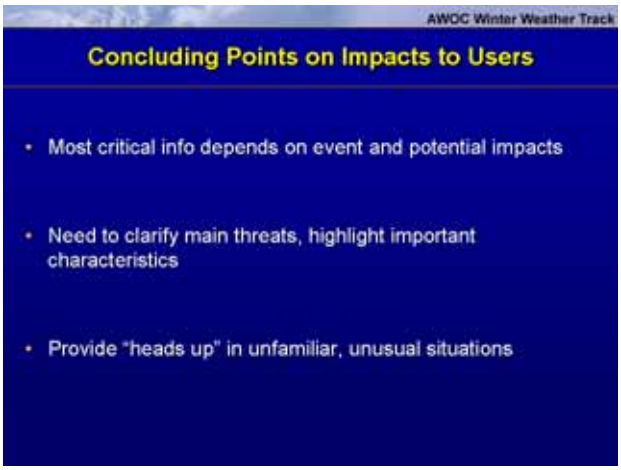
Student Notes:

24. Concluding Points on Impacts to Users

Instructor Notes: From a user's perspective, the need for information about a future or occurring event varies depending on the event and the potential impacts. Most users feel they receive too much weather information, so any way that we can clarify what the main threats of an event are can be helpful to them. It's important to communicate this infor-

mation as clearly as possible, highlighting particularly important characteristics of the event. Users also find it helpful to know if events are unusual or uncommon, so that they can adjust their preparations accordingly. Even just providing some value added information for the first winter event of the season can be helpful to them.

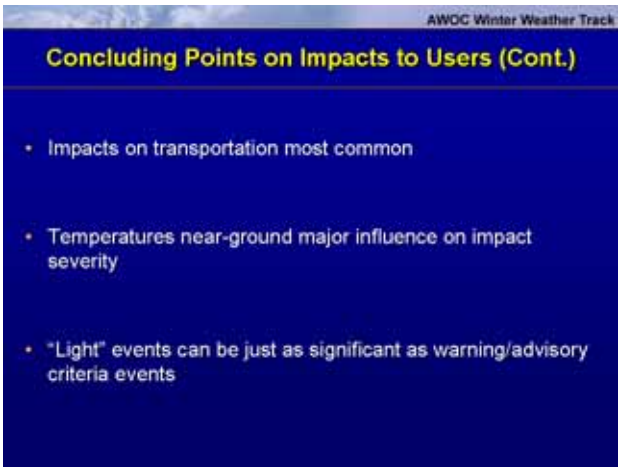
Student Notes:



25. Concluding Points on Impacts to Users (Cont.)

Instructor Notes: Transportation impacts of winter weather events are probably most commonly felt throughout society. Of all the meteorological factors, ground and near-ground air temperatures are as crucial as any other when looking at impacts to ground transportation. When everything else is equal, above or below freezing ground temperatures could mean the difference between minimal or severe impacts. It's also important to characterize "light" events in detail to users. These events are much more frequent than warning or advisory criteria events, and they can have just as much of an impact.

Student Notes:



26. References Cited in This Lesson

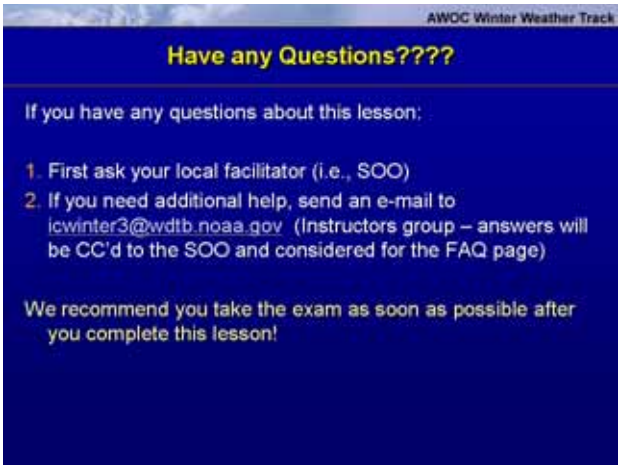
Instructor Notes: This slide contains a list of all the references cited in the slides, mentioned by the speaker, or placed in the speaker notes. The full references are listed at the end of the student handouts for IC 3, lesson 1.

Student Notes:

27. Have any Questions????

Instructor Notes: If you have any questions about this lesson, first ask your local AWOC facilitator. If you need additional help, send an E-mail to the address provided. When we answer, we will CC your local facilitator and may consider your question for our FAQ page. We strongly recommend that you take the exam as soon as possible after completing Lesson 3.

Student Notes:



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1. IC3.2: User Issues, Constraints, and Responses

Instructor Notes: Welcome to the AWOC Winter Track Instructional Component 3, Lesson 2. This presentation, entitled User Issues, Constraints, and Responses, should last approximately 20 minutes. A common theme that will be touched on often during this lesson is the importance of knowing what your local users need or do to mitigate a winter weather event's impacts.

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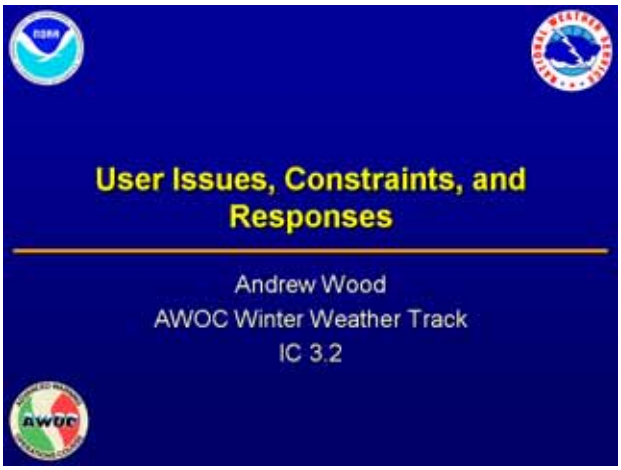
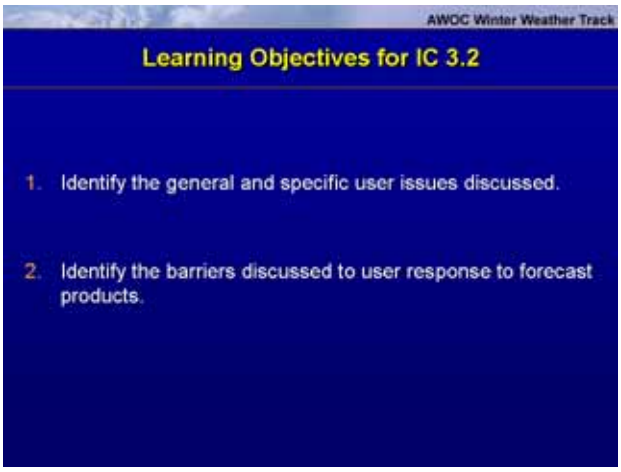


2. Learning Objectives for IC 3, Lesson 2

Instructor Notes: There are two objectives with this lesson. The first objective is, by the end of the lesson, you should be able to identify the user issues discussed that affect the general population and specific user groups. The second objective is to identify the barriers to user response of forecast products discussed in this lesson.

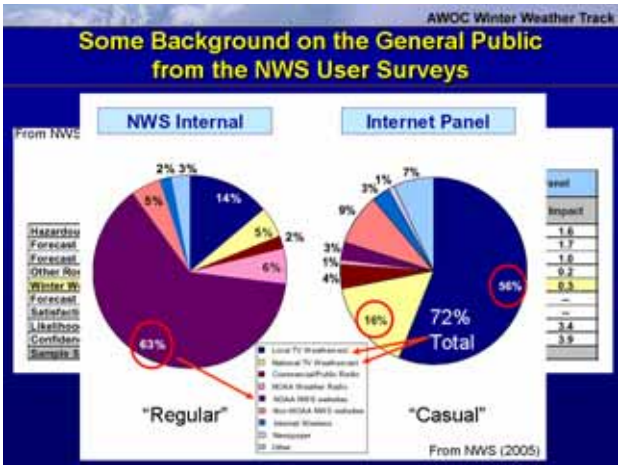
Student Notes:



3. Some Background on the General Public from the NWS User Surveys

Instructor Notes: Across the board, winter weather products and services were rated high by NWS users (NWS, 2005). The general public portion of the user survey was noteworthy because it was made up of two different groups of people. The first group regularly obtain weather information directly from the NWS web site, while the other group better reflect the nation as a whole who primarily get there weather information from TV and only casually access NWS web sites, if at all. The “regular” user group was most likely to obtain weather information from the NWS primarily for personal safety and property protection, work activities, or transportation decisions. The “casual” user group was as likely to obtain weather information primarily to select what to wear on a given day as they were for all of the other categories previously mentioned combined. With these differences in mind, these groups had two significant traits in common. Both groups rated highly accuracy and sufficient lead time for NWS winter weather watch and warning products. They also listed transportation as a primary reason for obtaining weather information in similar levels of importance (26% an 18%, respectively).

Student Notes:



4. Some General User Issues with Regards to Winter Weather Information

Instructor Notes: One thing that was clear from the NWS user surveys is that one size does not fit all. However, there are a few generalizations that can be made. In the previous lesson, we mentioned that many users can get overwhelmed with weather information that they don’t need. While they may get extensive weather information about an impending event, most users are left wanting for more pertinent weather information. For instance, many users want more information during an event on snow totals and intensities. Others want more detailed info in short-term forecasts. A lot of times it’s not more information they want, but clearer information. A common example users stated was wanting to see watch, warning, and advisory (WWA) products that are more cohesive

from CWA to CWA during a given event. Another issue for users is media dissemination of NWS products. Approximately 70% of casual users primarily receive their weather information from local and national TV broadcasts. To reach that user segment, we need to get products to the media in a timely and accurate manner. A good guideline is getting watch, warning, and advisory products (along with any updates and changes) out an hour before the main news broadcasts by local media (DeVoir, 2004; NWS, 2003). This goal gives the media enough time to incorporate the products into their broadcasts and allows time for them to follow up with any questions they might have. These guidelines are even more important if an event is forecast to occur on a Monday. Many people do not pay attention to weather information on the weekends and may not tune into news of an impending event until Sunday night or even Monday morning. A third issue deals with information on transportation impacts. Many people are looking for a “heads up” on what major airports, highways and other major arterial roads are impacted by an event. These details do not need to be extensive, just informative.

Student Notes:

5. Interactive Quiz #1

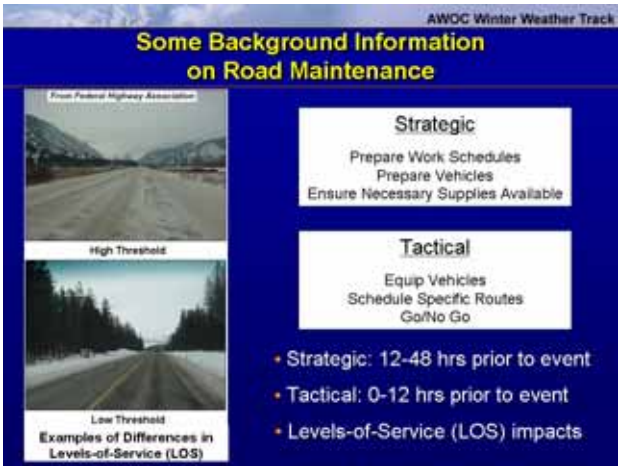
Instructor Notes: Take a few moments to complete this interactive quiz.

Student Notes:

6. Some Background Information on Road Maintenance

Instructor Notes: Let's start with a quick primer on road maintenance. Road crews generally have two significant time frames where they need weather information. The first timeframe is the 12-48 hours prior to an event where they will do most of their strategic planning. The other timeframe is in the 12 hours (especially the last three hours) leading up to the event where they do most of their tactical planning. Examples of activities that occur during each timeframe are available on the slide. How roads are treated will depend on their levels-of-service (LOS). Many major roadways with high traffic volume often require bare pavement LOS. Rural roads will generally have higher thresholds (3" or more), with secondary roads usually somewhere in the middle. In areas where snow is less common, and snow removal resources are limited, LOS classification may focus solely on roads that are designated as "snow routes" and leave other roadways untreated until after precipitation has ceased (if they are treated at all) because of equipment or budgetary limitations.

Student Notes:



7. How Good Forecasts Can Mitigate Impacts: Snow Removal Near Donner's Pass

Instructor Notes: Every year, over $2 Billion across the US is spent on snow and ice removal (FHWA and Aurora, 2005), including stocking of material, purchasing equipment, and scheduling crews. If resources are used to mitigate an event that is either overforecast or a total false alarm, then those resources would be depleted unnecessarily. If a forecast of a single large snow does not pan out, it can consume most, if not all, of a small organizations snow removal budget for a winter season in some areas. If crews are not prepared for an event (due to a poor or miscommunicated forecast, etc.), snow removal may cost more due to the need to hire extra contractors (at greater costs) or due to use of more chemicals and equipment for longer periods of time. In some cases, small variations in an event can lead to substantially higher or lower costs. An example is the

costs for road crews in the vicinity of Donner Pass in the Sierra Nevada, which vary depending on the snow level. The largest section of I-80 in this region is located between 5,000 and 6,000 ft. MSL. An accurate forecast of the snow level being at or above 6,000 ft. (vs. at or below 5.000 ft.) can save CDOT approximately $50,000 per event (Carter et al., 2003). Those dollars add up quickly when you average over a hundred inches/yr. of snow over numerous events.

Student Notes:

8. Typical Substances Used for Road Treatment Applications

Instructor Notes: Roads can be treated many ways: with road treatment chemicals (such as salt) that lower the freezing point of water, by plowing, with sand for improving traction, or combinations of each. Road crews also have the option to pretreat (often referred to anti-icing) or treat during the event (also called de-icing). The substances used to treat roads depends on a variety of factors including costs, weather conditions, and treatment strategy. Different salts (like NaCl, CaCl, and MaCl) are used when road temperatures are lower. NaCl is the most commonly used treatment mostly because it is the cheapest. However, it and other salts can be environmentally damaging. Generally, road salts are used in just enough quantities to keep snow, or slush, from turning to ice. Acetates (like CMA and KAc), which are more environmentally friendly, are being used more frequently on highways and other major roads where the goal is to keep the roads snow free. They are more expensive than other treatments and are generally only effective while road temperatures are 23 F or higher. A third option is to use sand, which is often mixed with salt treatments at colder temperatures (especially below 10 F) to help with traction. (Transportation Research Board, 1991)

Student Notes:

9. More Information on Road Treatments

Instructor Notes: Acetates are generally used as anti-icing treatments, meaning they are applied as a liquid well prior to an event (and allowed to dry on roads) in hopes of preventing ice formation. This pretreatment can also be helpful in areas where snow is not plowed right away, as the snow will generally insulate the ground and keep it from getting below 23 F (if it was originally warmer than that). For de-icing, salts are used more often. They are applied shortly before an event begins or after it has started to melt snow and ice.

Student Notes:

10. Impacts on Road Treatment Applications

Instructor Notes: Many things can impact road treatment applications. For instance, road traffic can cause treatments to splatter off the road, having a detrimental impact. In high enough volumes, however, traffic may help melt frozen precipitation. More (or less) liquid equivalent precipitation, especially if precipitation starts as rain, can dilute treatment more than intended. Strong winds can also blow solid treatment off roads and significant temperature changes can render certain treatment strategies ineffective.

(Hallowell and Blaisdell, 2003) Mechanical equipment is more impacted by snow density. Wetter, or higher liquid equivalent, snow takes more of a toll on snow removal equipment, which most local governments keep in service past their life expectancy, than dryer snow (Call, 2005). If there have been a series of wetter snowfalls recently, there may be a higher percentage of equipment problems during an event.

Student Notes:

11. Sector Specific Issues: Municipalities and Road Maintenance

Instructor Notes: Having discussed road maintenance in some detail, let's move onto some of the specific issues municipalities and road crews face during winter weather events. While they need weather information during both strategic and tactical time frames, more detail is needed during the tactical time frame. Even if they only get 2-3 hours lead time on specifics, say where the rain-snow line will be or a heavier mesoscale snowband will set up, a plan of attack can often be developed based upon their strategic planning. They could also use good real-time information on precipitation rate and total accumulations (Mahoney, 2003). If an event is evolving in a manner different than forecast, even in small or subtle ways, it can have a huge impact on their operations. Road temperature is obviously critical to treatment because of the chemicals used. Crews also need to know about the possibility of strong winds (> 18 kts) or if precipitation in an area will start as rain, as both of these factors can reduce the effectiveness of road treatments (Pisano et al., 2004). Road crews also benefit from the judicious use of terms such as snow bursts and squalls, as it makes them more aware of the possibility of quickly changing conditions (DeVoir, 2004).

Student Notes:

12. Sector Specific Issues: Transportation

Instructor Notes: The needs of the general traveler or commuter differ a little bit from those of maintenance crews. Many commuters rely on the media or web sites for traffic information on weather delays. Smaller events usually result in greater delays (as much as 3-8 times as long) during rush hour vs. low volume times. Larger events can cause increases in commuting times of up to 100% or more. A new development in the last few years for many travelers is the 511 system, or the National Traveler Information Telephone Number. By the end of 2005, 511 was expected to be accessible by approximately 40% of the US population (DOT, 2005), primarily in the intermountain west, northern plains, and along the east coast. The 511 system is capable of relaying NWS warning and advisory products through phone services as well as via roadside displays, which can be a great resource for many longer distance travelers. Commercial transportation interests usually are looking for weather information out to at least 48 hours, with more detailed information at 24 hours (Truckerweather.com, 2005). That provides them the time they need to make changes in drivers routes to get them from point A to point B in the safest and most cost-effective way possible. While many companies in this sector rely on private forecasts, Winter Watch/Warning/Advisory products are still useful to them and fit well into their timing needs.

Student Notes:

13. Sector Specific Issues: Aviation

Instructor Notes: Within the aviation community, the biggest area of concern is probably icing. It's certainly their biggest area of research (FAA, 2005). One of the FAA's future goals is to reduce the FAR for icing forecasts as standard icing products tend to outline too large a volume for icing conditions. Other research shows that the impact of ice and snow on aircraft performance depends on the liquid water equivalent of precipitation. The FAA is testing out some decision-making hardware and software systems to help airport and airline staff best determine liquid equivalent of precipitation so that they can plan their anti-icing activities accordingly to be more cost-effective and safe. Besides icing, low ceilings and visibilities are the other major concerns for the aviation community. Adverse ceiling and visibility conditions are cited as contributing factors in over 35% of all weather-related accidents in the US civilian aviation sector (Herzegh et al., 2002). Their goal is to improve the availability of ceiling and visibility from point data to a gridded system of observations and forecasts. Lastly, it's important to note some important timing issues with respect to commercial aviation. If a significant winter event occurs at a major hub airport, a commercial airline needs to know by 8 pm local time the day before the event, regardless of when the next day that event will occur, to successfully mitigate the impacts of the event. At least 24 hours lead time is preferred by most airlines, though. The airport itself needs at least 12 hours to spin up their mitigation efforts. It's important to remember that, even if an airport doesn't close during winter weather, flights are still likely to be cancelled due to de-icing operations. Given the same conditions, southern airports will likely have more flight cancellations during a winter event because they are less efficient at deicing operations (Qualley, 2006).

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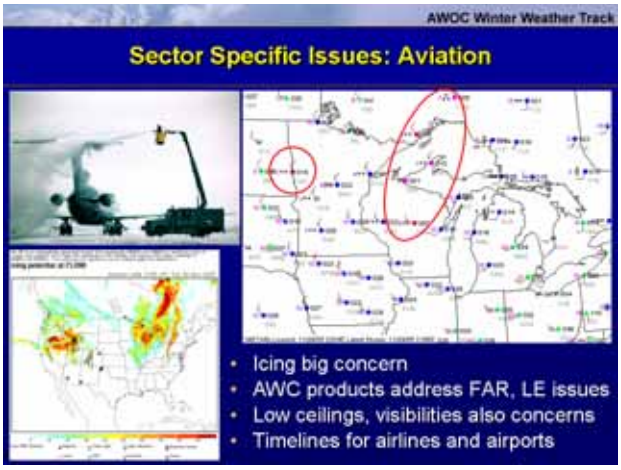

14. Sector Specific Impacts: Emergency Managers

Instructor Notes: EMs, as a group, can be very knowledgeable about meteorology (although certainly not all of them are). While other user groups may comment that they get too much information, many EMs can't seem to get enough. The NWS survey of EMs indicate that many of them will ensemble as much weather information as they can find. They clearly rely on NWS products for winter events, giving these products a very high satisfaction score. But they also cited numerous other weather information providers as helping them do their job. There was a desire from them to actually see experimental forecast products that are discussed in NWS products and discussions. They also feel strongly about specific information since most EMs are only concerned with their local area. Several explicitly commented on the more specific threat winter warning and advisory products as a positive development. In the NWS surveys, many EMs expressed a desire for more coordination and communication between the NWS and them. Since many EMs utilize newer technologies to stay in touch with what's going on, they also expressed a desire for a more technological solution to the coordination and communication issue. Therefore, they prefer graphic and text combination products that are easy to understand, especially if they can download them on their cell phones, PDAs, etc.

Student Notes:

15. An Example of NWS & EMs Mitigating Societal Impacts: After the January 1998 Ice Storm

Instructor Notes: Here's an example of an office coordinating with local emergency managers to help them mitigate impacts. This WSW was issued following a massive ice storm that struck parts of the NE US and southern Canada back in January, 1998. The Maine Emergency Management Agency had asked the NWS to extend the WSW, despite sunny skies, because of the threat of falling, ice-laden tree limbs and power lines. Continuing the warnings in this circumstance kept the public aware and informed of the threat from this extreme event. Take a moment to view the text. When you are finished, push the play button to advance to the next slide.

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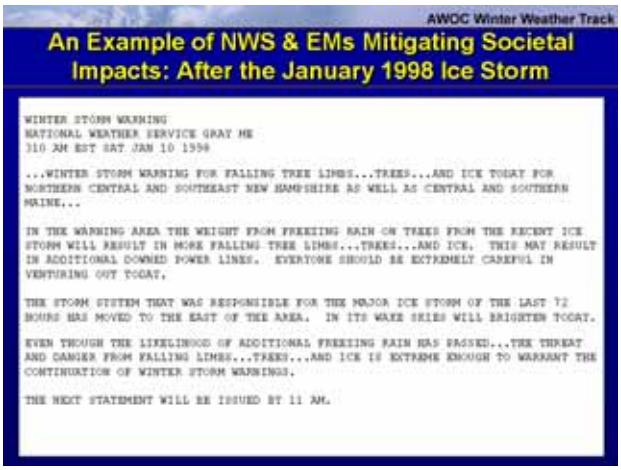
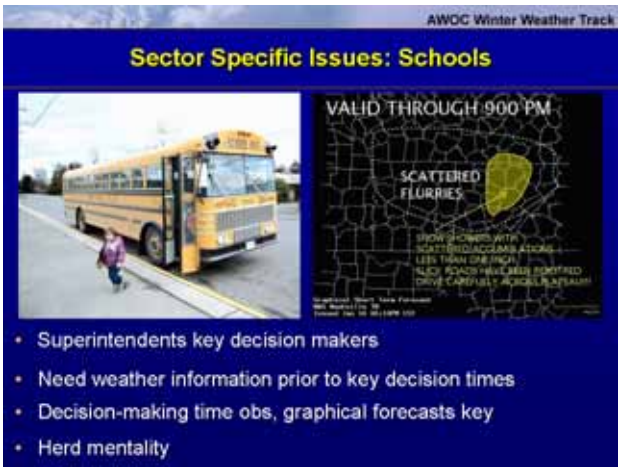


16. Sector Specific Issues: Schools

Instructor Notes: Another important user group is all of the local school districts and superintendents, who are generally the winter weather school closing decision-makers. Some of the details of their decision-making process varies regionally. For instance, some schools make closing decisions for winter weather the night before, while others wait until a couple of hours before school starts. Other schools have rules in place that once school starts, they will not do an early release, while others will not hesitate to conduct an early release. What is common among all schools is that they need to get weather information prior to their key decision-making times. For some, this time will be by the late night news, while for others it will be before 6 am that day. For schools that conduct early dismissals, those decisions are usually made between 11 am and 1 pm. When it comes to their decision-making process, a study by Czrnetzki (2003) showed that the primary factor in a superintendent's decision-making process was often the ongoing weather while they were making their decision. Many will personally drive roads in their area to determine if they are safe. Other factors, such as extremely low wind chills (~-35 F or lower) in rural areas, can lead to closures as well, even if the roads are drivable. Other influential factors in their decision-making were graphical weather forecasts

on TV and the Internet, as well as decisions made by other superintendents. As a result, there can be a bit of a herd mentality in some areas if it is a close call on closure, with certain bellwether decision-makers sticking their necks out and then others following suit. These cases are especially common if, for example, smaller school districts share resources with each other, or with a larger school district, and an early release is necessitated by weather conditions.

Student Notes:



17. Learning Interaction #2

Instructor Notes: Take a few moments to complete this quiz.

Student Notes:

18. Utilization: User Responses to Forecast Information

Instructor Notes: The previous slides have discussed some of the user issues and constraints that are out there. These last few slides will discuss user response. The general public has a great influence on a given event's impact based solely on their behavior (i.e., do they just stay home during a heavy snow event; Call, 2005). Utilization can range

from reception of information to the information actually affecting some aspect of behavior to solve a problem (Shafer, 2005). As we have stated previously, our users have a lot of weather information available to them. A critical question we can ask ourselves is how much do we need to concern ourselves with whether or not, or even how much, our forecasts are used? Is delivery of information to a decision-maker sufficient to consider our part as finished? Considering how much outreach and public education is done by NWS staff throughout the country (including on their own time) it's clear most, if not all, feel an obligation to do more. But can anything be done in the hours leading up to an event to improve utilization of our products?

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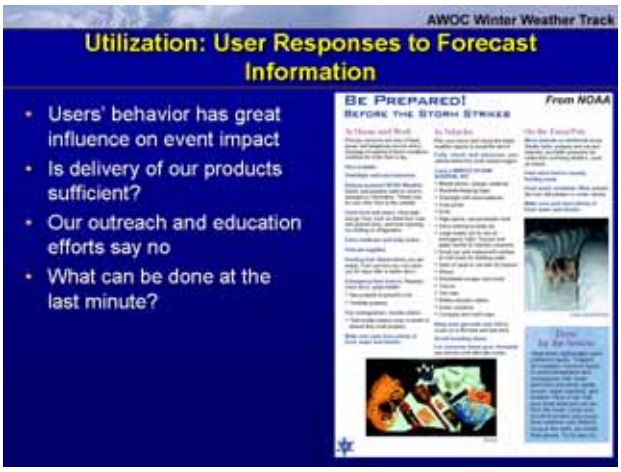
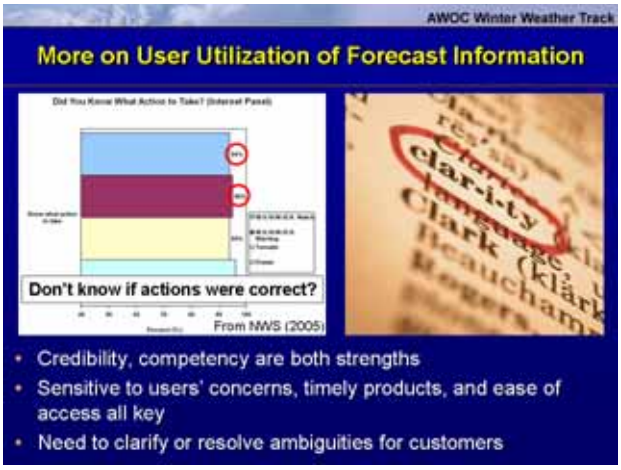


19. More on User Utilization of Forecast Information

Instructor Notes: Information usage cannot always be easily identified (Weiss, 1979). For instance, almost 95% of the general public believe they know what action to take based upon winter weather watch and warnings, but only 75-80% say that they at least usually take action based on their issuance (NWS, 2005). And that gap doesn't even take into account people who acted but acted incorrectly. If anything, utilization research suggests (and the user survey statistics back it up) that we already do a lot of things right. We are seen by most people as a competent and credible organization which provides a quality product and have strong relationships with our regular, or high usage, customers. Each of these traits, if they were not present, would be barriers to utilization. As long as we maintain these strengths, we are sensitive to the concerns of our users, and we make our products available in an easy to access and timely fashion, we should maintain our good standing. To improve, we should focus on making our products clarify or resolve ambiguities for our customers.

Student Notes:



20. Risk Perception and Personal Experience Important Part of User Response

Instructor Notes: Part of the issue of utilization also comes down to personal experience. People who are most likely to use our products are those who have experienced significant winter weather in the recent past. With this experience comes a better awareness of and greater likelihood to act upon potential weather-related impacts (Stewart, 2006). While significant portions of the US experience winter weather events regularly, a given area may not have recently experienced impacts similar to an upcoming forecast event. Even if they have, maybe they didn't personally experience the impacts of the previous events. People without these experiences of personal impact may be disinclined to utilize our products due to a low perception of personal risk (Yarnal et al., 2005). One way to overcome such a barrier is to highlight potential risks to users and put the possible impacts of the event in context for them. It is best however, to avoid reference to specific past events unless confidence is very high that the upcoming event will be similar to the referenced event and it is clearly the most effective way to put the event in context.

Student Notes:

21. One Way to Tie it All Together: Call-To-Action Statements

Instructor Notes: One possible way to overcome users' barriers to utilization is through Call-to-Action statements. The text listed on this slide represent several different examples from watches, warnings, advisories, and statements. The first couple are fairly generic and are quite common to many winter products. The subsequent statements are a little more rare, depending on the portion of the country you live in and the severity of the event. Take a moment to review the statements. When you are finished, click the play button to advance to the next slide.

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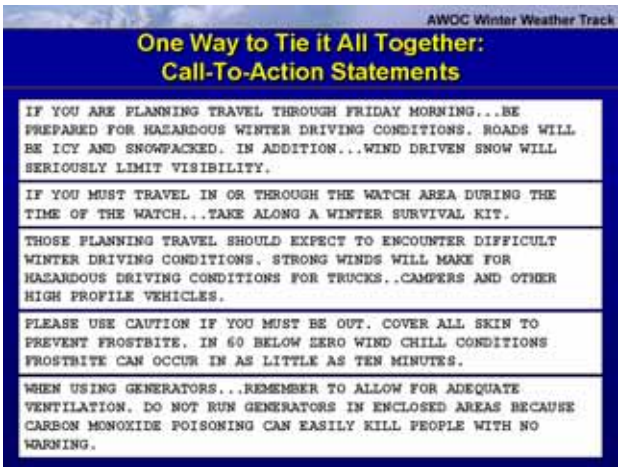

22. Concluding Comments on User Issues, Constraints, and Responses

Instructor Notes: For users, getting the right information is a critical issue. For some there is too much and for others there is not enough. What is important is that we do what we can to help users sift through the abundant weather information available to them. In doing so, it is important to remember that one size does not fit all. There are some common themes that run across all groups, such as impacts on transportation that affect almost all user groups. There were other specific needs and/or wants from individual groups discussed as well. User response is a trickier issue. Statistics from the NWS surveys suggest that our users think we are doing very well when it comes to our winter weather products and services. The survey suggests that there is a strong understanding and application of our winter weather watch and warning products. We already do many of the things an organization should do to improve usability, so where do we go from here? Besides keep on keeping on, we can try two things. Working to make sure our products help users clarify or resolve any ambiguities they have in their decision-making and communicate the potential personal risks for an impending event.

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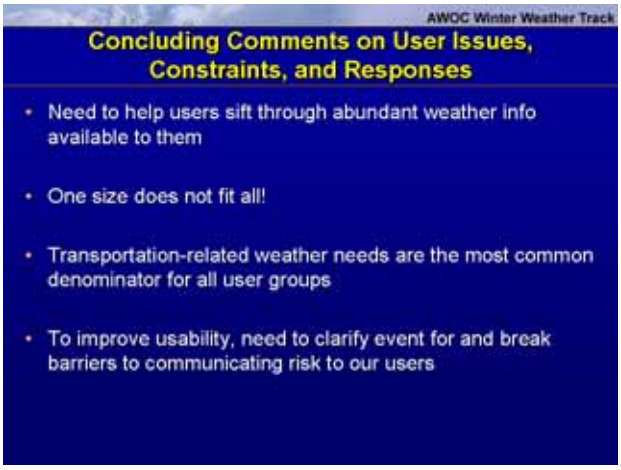
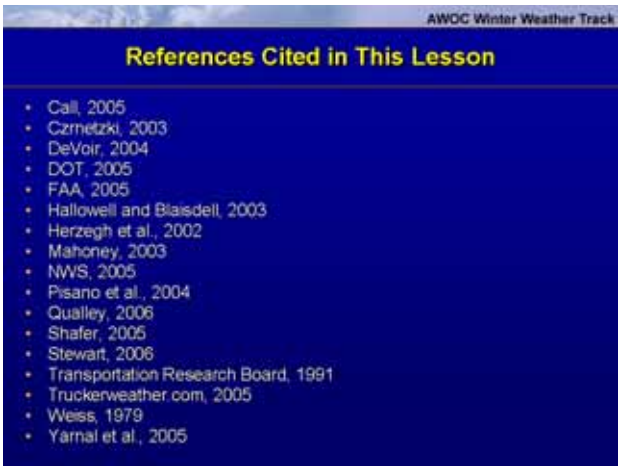


23. References Cited in This Lesson

Instructor Notes: This slide contains a list of all the references cited in the slides, mentioned by the speaker, or placed in the speaker notes. The full references are listed at the end of the student handouts for IC 3, Lesson 2.

Student Notes:



24. Have any Questions????

Instructor Notes: If you have any questions about this lesson, first ask your local AWOC facilitator. If you need additional help, send an E-mail to the address provided. When we answer, we will CC your local facilitator and may consider your question for our FAQ page. We strongly recommend that you take the exam as soon as possible after completing this lesson.

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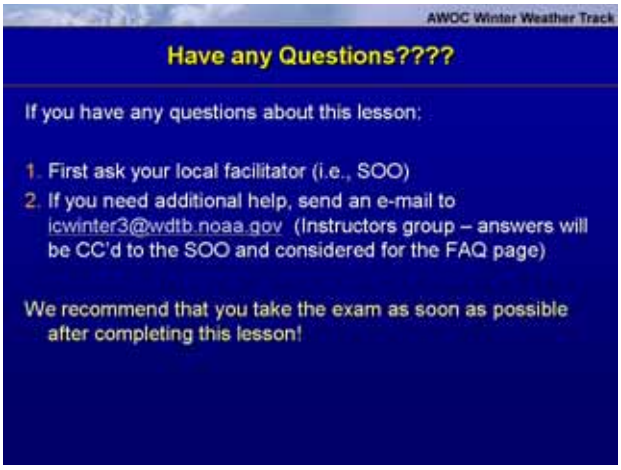

IC3.2: References

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1. IC3.3: Conveying Forecast Confidence

Instructor Notes: Welcome to the AWOC Winter Track Instructional Component 3, Lesson 3. This presentation, entitled Conveying Forecast Confidence, should last approximately 15 minutes.

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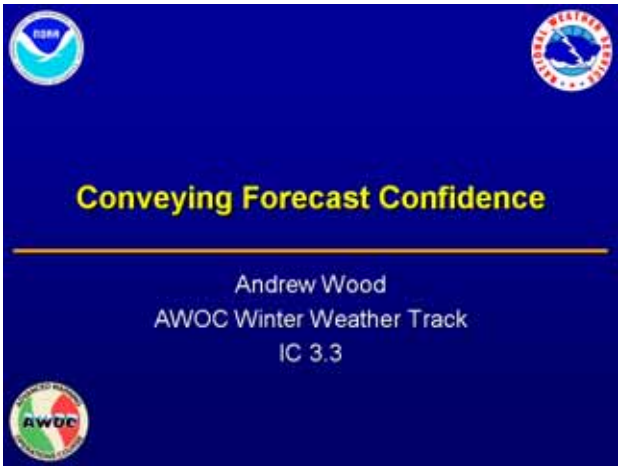
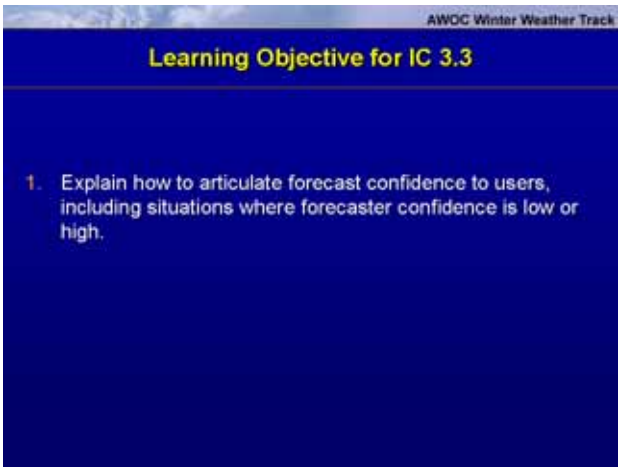


2. Learning Objective for IC 3, Lesson 3

Instructor Notes: There is one learning objective with this lesson. By the end of this lesson, you should be able to explain how to articulate forecast confidence to users, including situations where forecaster confidence is low or high.

Student Notes:



3. Performance Objective for IC 3

Instructor Notes: There is also one performance objective with this lesson. For a given event, you should be able to apply the best practices presented in discussions and products with regards to high and low certainty forecasts.

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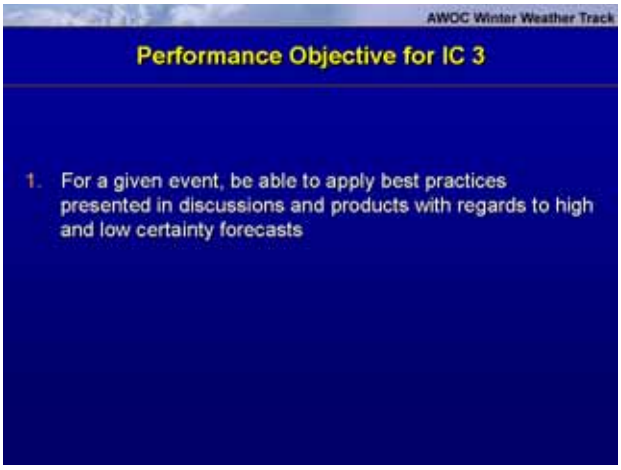
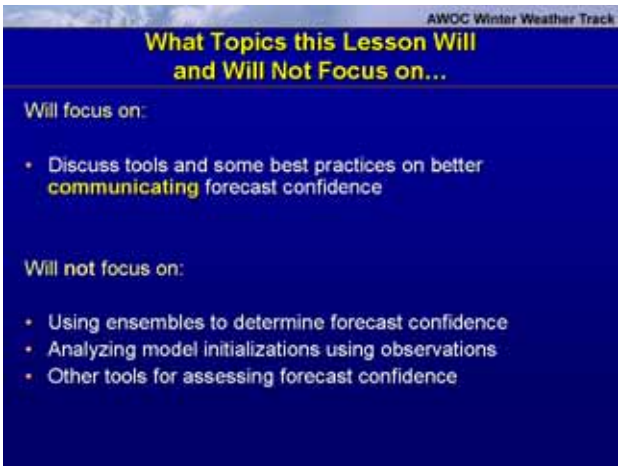


4. What Topics this Lesson Will and Will Not Focus on…

Instructor Notes: It's important, for starters, to note what topics this lesson will and will not cover. This lesson will discuss some ways to better communicate forecast confidence to users once that confidence has been determined. This lesson will not go into detail on using ensembles to determine forecast confidence. That will be covered in IC 6, Lesson 3. Nor will it discuss in detail analyzing model initializations using observations or other tools for assessing forecast confidence.

Student Notes:

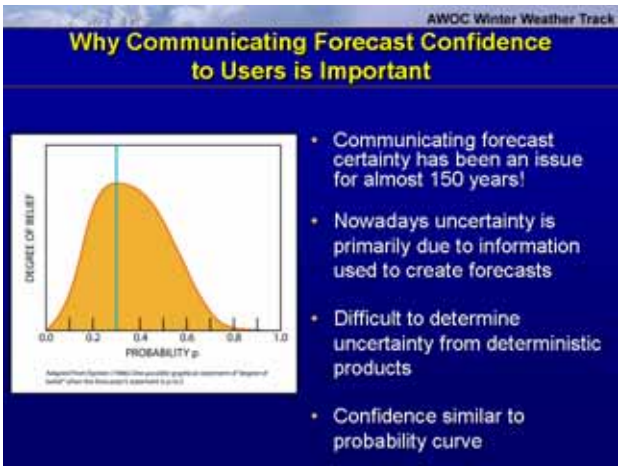


5. Why Communicating Forecast Confidence to Users is Important

Instructor Notes: Conveying forecast confidence is a critical part of winter weather forecasting. In many parts of the US, winter precipitation is a common occurrence during the cold season. Back in Lesson 1, we discussed how even light events can be significant in the right context. Users across the board need some guidance as to how confi-

dent, or certain, NWS meteorologists are in the forecasts and products they issue. This issue is not a new one, as its been around since the first U.S. weather observers issued forecasts almost 150 years ago. The primary difference between now and then is that, for much of that time, uncertainties were largely in the knowledge base of the forecaster about the atmosphere. Nowadays, the uncertainties are more in the knowledge or information base a forecaster uses (such as NWP) to create a forecast (Murphy, 1998). By their nature, many NWS products and services are deterministic. In contrast, forecaster certainty, or degree of belief in a forecast, can best be thought of as a probability curve. Such a curve would be tall with a sharp drop off for high certainty forecasts and flatter and wider for lower confidence forecasts. Conveying that mental curve to users helps distinguish “what’s likely” from “what’s possible”. Whether we like it or not, our users have a mental degree of belief in our forecasts based upon their past experiences (Epstein, 1966).

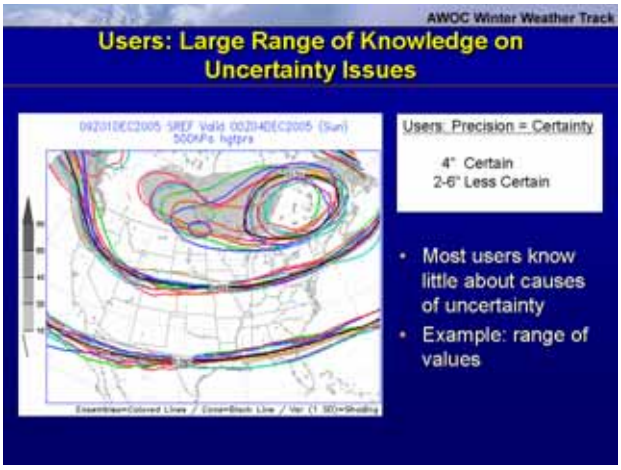
Student Notes:



6. Users: Large Range of Knowledge on Uncertainty Issues

Instructor Notes: Not much of the general public are knowledgeable users of meteorological products. Most people lack an understanding about the causes of forecast uncertainty. This lack of knowledge is due mostly to users unfamiliarity with the forecast process itself. While we may not believe it, many users think a forecaster must be fairly certain if they are providing exact information. For instance, a forecast that states city A will get about 2” of snow will be considered more certain than a forecast of 1-3”. Both forecasts could be from the same person, but the difference in perceived certainty will be based on the exactness of the forecast. Fortunately for us, forecasts are standard enough that users usually don’t see large variations in forecast totals from forecaster to forecaster. This example does remind us that our users may see our forecast differently than we do because they are not involved in the process. This difference in perception is especially true for forecast certainty issues.

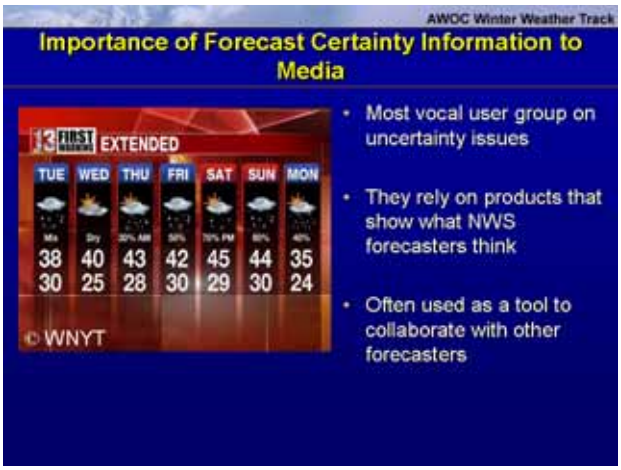
Student Notes:



7. Importance of Forecast Certainty Information to Media

Instructor Notes: Our more regular users, especially the media, have a much better handle on this issue. Of all the user groups, they may be the most vocal about forecast certainty issues. In the NWS User Surveys of the Media (NWS, 2003), a recurring theme was the importance that local media placed on products (such as Short Term Forecasts, Area Forecast Discussions, etc.) that can provide a view into the thinking of the NWS forecaster. Since many media-based forecasters often work by themselves, these products are often how they collaborate with other forecasters. They can compare their own thinking to these products and get a better understanding of the reasoning used in their own forecasts.

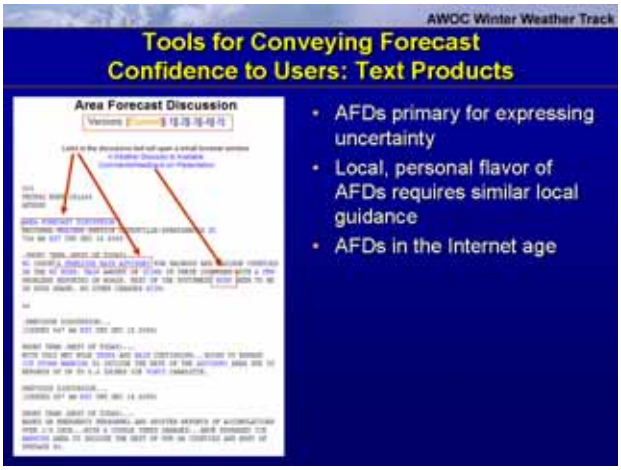
Student Notes:



8. Tools for Conveying Forecast Confidence to Users: Text Products

Instructor Notes: Since most text products are deterministic in nature, quantifying and communicating uncertainty to our users in those products can be a big challenge. That's why AFDs, as a generally free-format, narrative product, are so important. It is one of the best ways for forecasters to express what they are thinking with regard to their forecast and why (NWS ERS, 2004). NWS Surveys from the past few years indicate that more users are relying on AFDs for this information than in the past. There is no reason to think this trend will stop anytime soon. Because of their nature, AFDs show a local, even personal, flavor. As a result, trying to provide individual, detailed guidance on better using AFDs to convey forecast certainty would be futile in this type of training delivery. That kind of assistance, if needed, really has to come from within the WFO. That being said, there are some general (or big picture) good practices that can be passed along. For starters, more regular users often access AFDs on-line now. As a result, there are some trends in how AFDs are being displayed (and will be displayed in the future). Such features as links to previous versions of AFDs are common practice now. Some forecast offices have also started adding URL links to the body of their AFDs that appear on-line. These links go to other products as well as to a glossary of technical terms and abbreviations. Using links in this way is a powerful tool to both help inexperienced users of AFDs as well as all users who want to quickly move from product to product. While not occurring operationally yet, it will only be a matter of time when AFDs, as well as other products, are converted from "ALL CAPS" to standard text for web usage. Such a change, when it occurs, will be very welcome to users who often commented on the readability issues of "ALL CAPS" (NWS, 2005).

Student Notes:



9. Interactive Quiz #1

Instructor Notes: Take a moment to complete this interactive quiz.

Student Notes:

10. Importance of Clarity in Conveying Forecast Confidence

Instructor Notes: Making AFDs more accessible has also made them more visible. This higher visibility can tempt people to simplify the content of AFDs. NWS surveys and utilization research strongly suggest that it is clarity, not simplicity, that users want in AFDs. The following are some general comments on how AFDs can be made clearer, which will help better convey certainty. For instance, a crucial element to clear writing is to try and write as naturally as possible, no matter what that style is. Another important way to improve clarity is to minimize or eliminate abbreviations in AFDs. Some forecasters have been using abbreviations so long that they probably don't realize how often they use them. It has, in fact, become natural to them. The problem with abbreviations is that they can be overused and they make AFDs much less readable. Occasional abbreviations where the context of their usage makes their meaning obvious are certainly acceptable. What you don't want, from a users standpoint, is to have a product that looks like you abbreviated every other word. Another good practice to develop is simple organization and revision. There are many basic organizational techniques that can be used to boost readability, such as breaking out key information into separate blocks of text, using headlines to highlight key information, or even just making each period or forecast issue of the discussion a separate paragraph. Don't forget to spend some time revising the discussion, too. Consider having another forecaster on shift with you read the discussion or try to read your own writing as a user might. Most important is to catch obvious typos, repetitions, etc., that can have a negative impact on users.

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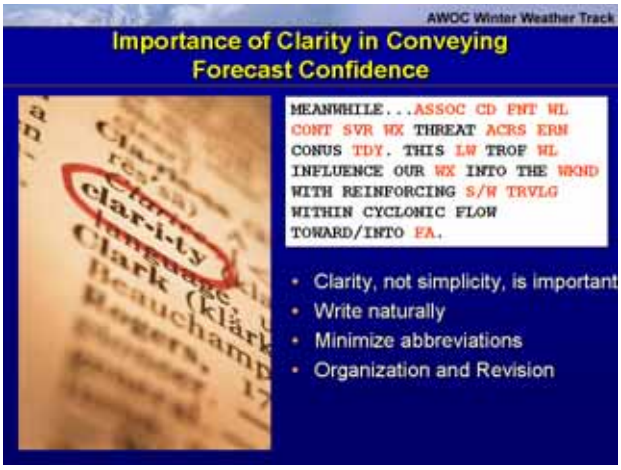
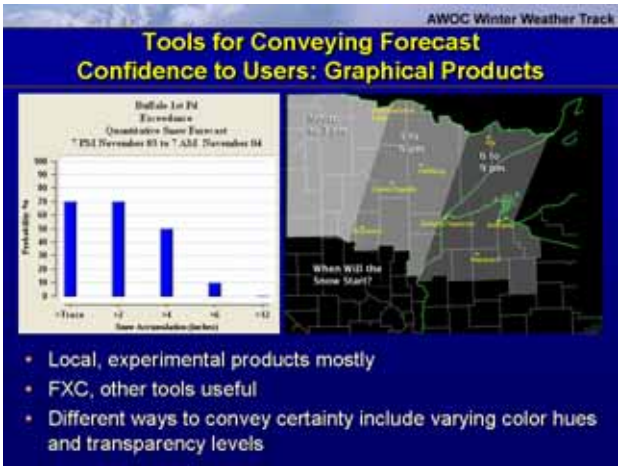


11. Tools for Conveying Forecast Confidence to Users: Graphical Products

Instructor Notes: AFDs are not the only tool available to forecasters to clarify uncertainty. Many WFOs have developed local graphical products, some of which are experimental, to try to communicate forecast threat information to users. Some of the more common ones for winter weather forecasting involve visualizations of probabilistic snowfall totals. Others utilize applications like FXC so that D2D-like displays with simple annotations can be generated quickly with minimal effort on a forecaster's part. Just about any visualization tool can be useful to generate bar charts or other products if that graphic conveys certainty (or uncertainty) in forecast details. The National Academy of Sciences workshop (2003) on communicating uncertainties in weather information encouraged the development of graphical products to convey threat information to the public. Not all graphical products are a "home run", so to speak. "Spaghetti" charts and similar ensemble-type displays can help visually represent the range of values to an expert, but may intimidate the average user and be difficult to interpret. Maps similar to SPC convective outlooks (with low, middle, and high classifications) are more user friendly, but forecasters may be hesitant to label something "low confidence." An effective way to communicate uncertainty can be to display a variable using different color hues or levels of transparency to display probabilities (such as graphics that use filled contours to illustrate ensemble "spread"). Such continuous value displays are more inviting to users and can convey significant details to them.

Student Notes:



12. AFDs: Examples of Effectively Stated Forecast Certainty

Instructor Notes: Forecast certainty issues can be addressed in many ways. Some offices may use language that explicitly states "high confidence" or "low confidence", etc. Others may use different language to convey confidence. Regardless of what system your office uses, what is most important is to clearly state what the key issues are with

the forecast and your expert analysis on those issues. The goal should be for users, especially regular users, to correctly interpret your products. In these examples, you see language that state forecast confidence explicitly and implicitly, as well as discussing how forecast certainty is trending. The last text box is a little different than the others. It presents an example where there is mixed certainty. These situations are not only challenging to forecast, but can also be challenging to communicate. If customer utilization of our forecasts and products is one of our ultimate goals, then it's only natural that we may be apprehensive at times to admit to forecast uncertainty. But these cases are when clarity is most crucial. When you are finished reviewing the text, please push the play button to advance to the next slide.

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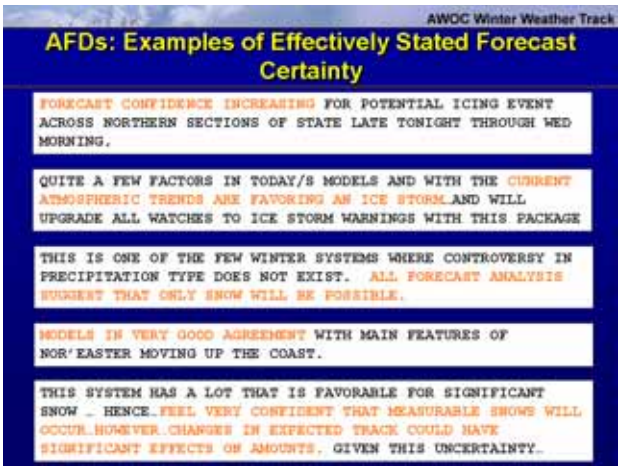

13. Examples of Value-Added Text Clarifying Event Impacts and Forecast Certainty Issues

Instructor Notes: There will always be a bit of conflict between saying more is more (say, adding a sentence to further illustrate your thinking) and less is more (being concise so that your thought process is clearer). When considering using value-added wording in discussions and other products, be specific and concise. Also, make sure the text, in fact, adds the desired value. You want the additional text to be informative, but not seem like a tangent. These examples add value by discussing details of forecast techniques, event impacts, model diagnosis, conceptual models, and even where to get important information on road conditions. When you are finished reviewing the text, please push the play button to advance to the next slide.

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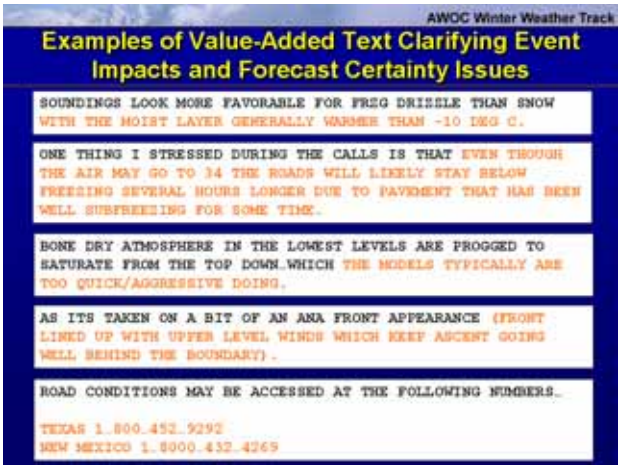

14. Examples of Graphical Products Conveying Forecast Confidence to Users

Instructor Notes: Graphical examples of conveying forecast certainty can be found all over. The “Today’s National Forecast” graphic is an example that most people probably don’t think about, but is really good at conveying levels of certainty among other things. Different types of lines and fills are used to indicate intensity differences, text captions indicate variations in likelihood, and color is even used to differentiate between different precipitation types and threats. The graphic in the upper right is a more obvious example of communicating forecast certainty by highlighting areas where snow chances are likely, possible, and not likely. As stated previously, exactness conveys a higher level of confidence than a range of values. The bottom graphic uses approximate times that are exact for the passage of the sub-freezing air through the CWA. This graphic also does an excellent job at using color fills to distinguish between regions of the map and color coding of text to help users clearly identify what the answer to the question is based upon what region of the CWA they live in.

Student Notes:

15. Need to Communicate the Different Factors that Lead to Variations in Forecast Confidence

Instructor Notes: Some phenomena result in greater forecast uncertainty than others. It can, at times, be beneficial to discuss details of conceptual models that may seem basic to you, but may help users better understand why a particular situation is inherently more uncertain than most cases. Most issues that have significant impacts on forecast confidence are well-known to forecasters. The vast majority of thorough AFDs are more than sufficient at communicating most basic guidance issues to users. What can be helpful is to discuss more details of any experimental or local models, products, etc., that you utilize as clearly as possible. If such a product is available on-line to the public, consider explicitly telling them where it is available so that they can see exactly what you are talking about. Similarly with initialization issues, consider explicitly mentioning your reasoning for suspecting an initialization issue, including going into some details. When you are finished reviewing the text, please push the play button to advance to the next slide.

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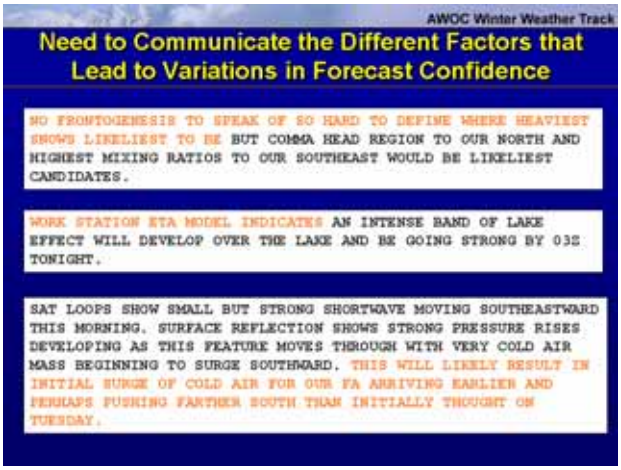

16. Eastern Region Guidelines: When Forecast Confidence is High

Instructor Notes: A couple of years ago, an Eastern Region (ER) team of forecasters put together some best practices with regards to winter weather forecasting, including guidelines for situations when forecast confidence is high. In general, forecast confidence is high when model errors build slowly with time and there is good consistency between different models, separate runs of the same model, and/or different members of an ensemble forecast. Other high forecast confidence signs will be model initialization fitting well with observations and model forecasts supported by either forecaster's conceptual model of similar events or with climatology. If you have a high degree of confidence in a forecast of a winter weather event, make sure it's clear in your discussions and other products, when pertinent. These situations allow for increasing the lead times for using language with high levels of specificity. A common issue that can arise with an upcoming,

significant event is the desire to put the forecast into context. After all, it's important, from a utilization standpoint, for events to be put into context. One way to do this is to make reference to historical storms. Generally, such references should be avoided unless confidence is high that a similar event to the historical one is very likely to occur. This advice is certainly not new, but important. Using historical references may be interpreted by users that the upcoming event will be just like the historical one, even if you are trying to make a completely different point.

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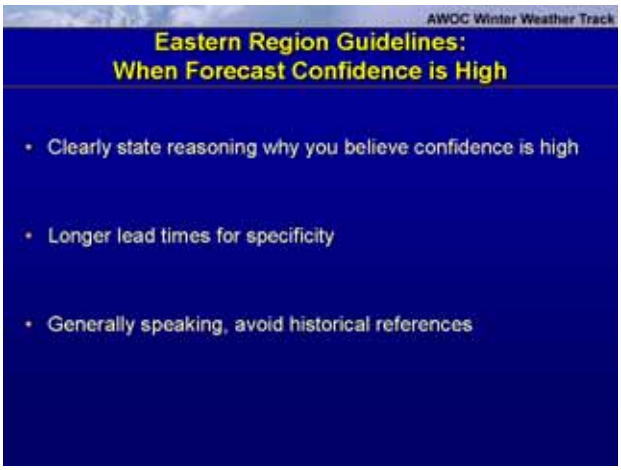

17. Eastern Region Guidelines: When Forecast Confidence is Low

Instructor Notes: Similarly, these ER guidelines also include tips for when forecast confidence is low. In general, forecast confidence is low when model errors build rapidly with time and there is a lack of consistency between different models, separate runs of the same model, and/or different members of an ensemble forecast. There may be other issues, such as model initialization problems or the possibility of a "rare" event, that lead to lower confidence. In such events, it is helpful from the user's standpoint, to clearly state what the "problem(s) of the day" are. Use sound reasoning and lay out the situation in a clear and concise manner so that users understand what ambiguities exist and why. Such a situation calls for using less specific language in warning and advisory products. If only some aspects of a forecast have low certainty, then try to be precise in those aspects of the forecast where confidence is higher. Examples would be in a climatologically favored area or if event timing is fairly certain. Then you can expand specificity in other areas over time as forecast confidence increases.

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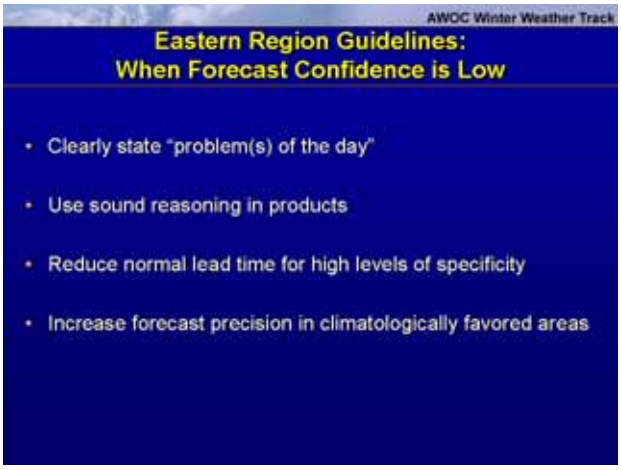

18. Low Forecast Confidence: A Remaining Question

Instructor Notes: When it comes to low confidence forecasts, there is one remaining question to be answered and it is a challenging one. Say that there is an impending event that, based on several different meteorological factors, could be very significant for your CWA, but is legitimately a low confidence forecast. If you want to use explicit language to communicate forecaster certainty, and you believe the most likely forecast is a significant event, do you issue a low forecast confidence for, say, a foot of snow? If you do, will your users act upon your warnings? Depending on your personality, situations like this one could keep you up at night! One way to address such a situation is to present a range of possibilities. This approach, when communicated clearly and effectively, can be beneficial at clarifying the threats to our users. The danger in such an approach is that, if not communicated effectively, you can wind up confusing users so that they either read into our products what they want to, or worse, they don't understand what the real threats are. Another way to address it may be by changing the framework by which we state forecast certainty. Instead of stating forecast confidence or certainty, maybe forecasts should be thought of in terms of degrees of difficulty (Craven, 2006). In doing so, a "high" degree of difficulty would be equivalent to a "low" forecast confidence, and vice versa. Such a classification would allow the meteorologist to maintain scientific integrity without appearing clueless. Research is underway (Craven, 2005) to see if such a system would be a more effective way to communicate all levels of forecast uncertainty to regular users. These are certainly not the only ways to address this issue, either.

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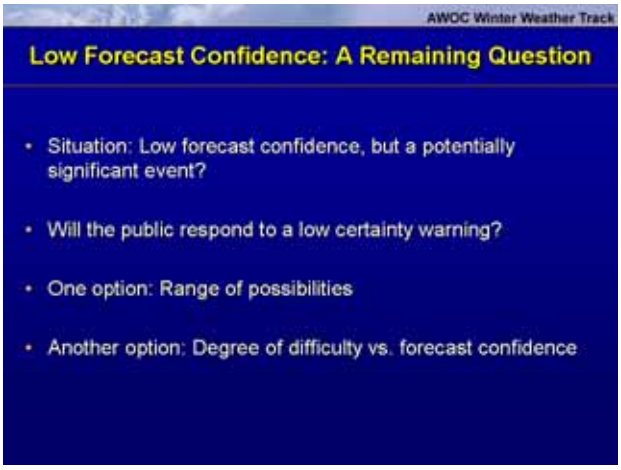

19. Learning Interaction #2

Instructor Notes: Take a moment to complete this interactive quiz.

Student Notes:

20. Concluding Comments on Conveying Forecast Confidence

Instructor Notes: Although many of our products are deterministic in nature, it is important to be able to convey some indication of forecast confidence in products. When thinking of forecast confidence, it helps to think of it as a probability curve. The taller and thinner the curve, the higher the forecast confidence. The flatter and wider the curve, the lower the forecast confidence. When creating text and graphical products for users, you are trying to describe that “curve” to them. The products need to clarify that curve to users and explain why it looks the way it does. Some simple, general tips were included in this lesson that might help with that clarification for both text and graphical products. Lastly, some guidelines produced by experts in Eastern Region on conveying high and low degrees of forecast confidence were presented.

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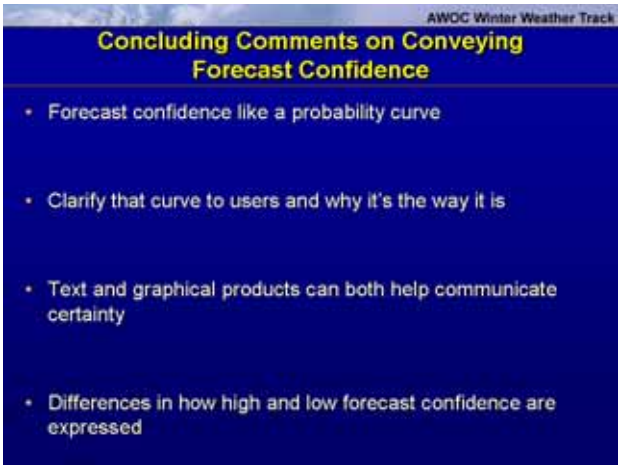

21. References

Instructor Notes: This slide contains a list of all the references cited in the slides, mentioned by the speaker, or placed in the speaker notes. The full references are listed at the end of the student handouts for IC 3, Lesson 3.

Student Notes:

22. Have any Questions????

Instructor Notes: If you have any questions about this lesson, first ask your local AWOC facilitator. If you need additional help, send an E-mail to the address provided. When we answer, we will CC your local facilitator and may consider your question for our FAQ page. We strongly recommend that you take the exam as soon as possible after completing this lesson.

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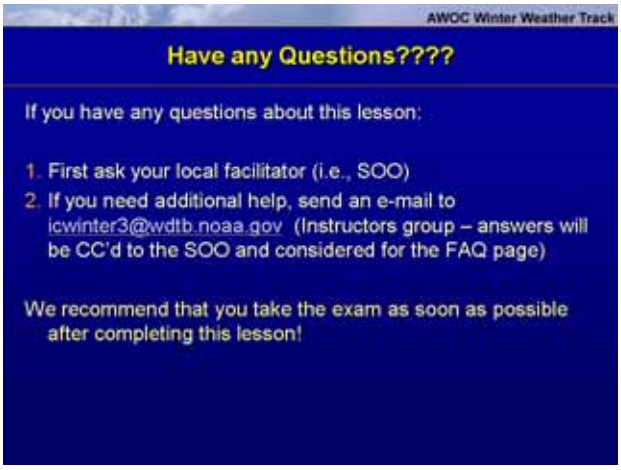

IC3.3: References

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IC Winter 4: Climatology

1. IC4.1 Part1: ENSO

Instructor Notes: Welcome to the first Lesson in Instructional Component 4, Climatology, in Advanced Warning Operations Course – Winter Weather Track. This first lesson will provide you an overview of the physical mechanisms responsible for slowly evolving large-scale winter events, and show you where to look to find the current climate system conditions and see predictions of the coming winter season. Specifically, In this first "sub-lesson, 1.1" we will look at El Niño, La Niña, and the Southern Oscillation, and see what effects these conditions have on US winter weather. In sub-lesson 1.2, we will discuss another, less well-known phenomenon known as the Madden-Julian Oscillation, and see it's effects on winter weather in the US. In sub-lesson 1.3, we will find out what "Teleconnections" are and why they are important in discerning expected winter weather, and finally, in sub-lesson 1.4, we'll take a look at products available from the Climate Prediction Center and the Climate Diagnostics Center that will help you in monitoring the current and expected state of the climate system which in turn will help you in the forecast process (or funnel) during the winter. Now let's start with ENSO.

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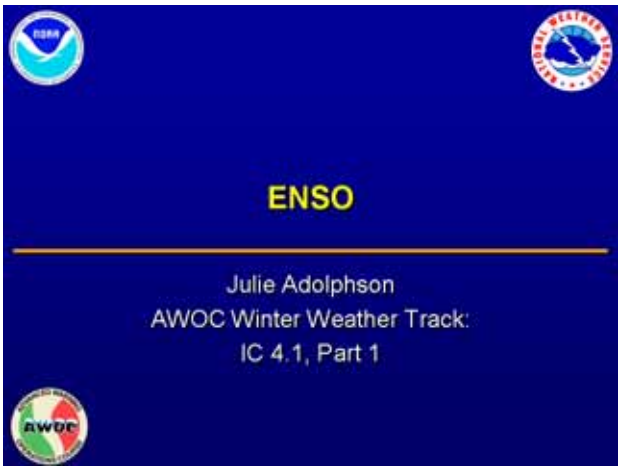

2. Purpose of Lesson 1.1

Instructor Notes: In this lesson we will discuss large temporal and spatial scale phenomena such as El Niño and La Niña, and how they influence US winter weather. We will also see their bearing on the evolution of winter time synoptic scale systems. I should mention right up front that the correlation between ENSO and expected winter time conditions is highest during moderate or strong episodes of ENSO.

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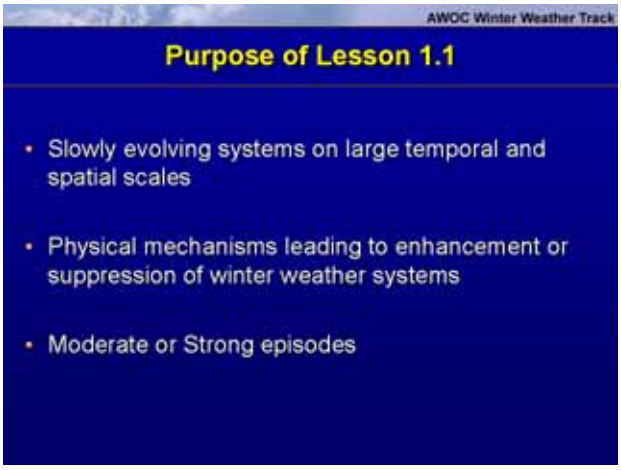
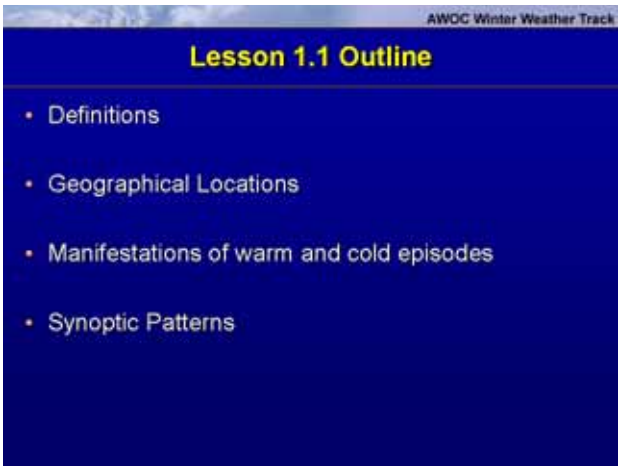


3. Lesson 1.1 Outline

Instructor Notes: We'll start with some definitions, see just where we find evidence of these phenomena, see what happens during warm and cold episodes, and then the expected synoptic patterns which occur during ENSO.

Student Notes:



4. IC 4 Lesson 1.1 Learning Objectives

Instructor Notes: We will focus on helping you look at the "big picture" in space and time to help you assess the potential for upcoming winter storms in your area of responsibility. We'll see how these "slowly evolving" systems initiate and how they influence weather in the US. We'll also see how these phenomena are monitored, and in later sections we'll take a look at resources you can use to assess the state of the climate system and what the latest predictions are for the medium and longer ranges.

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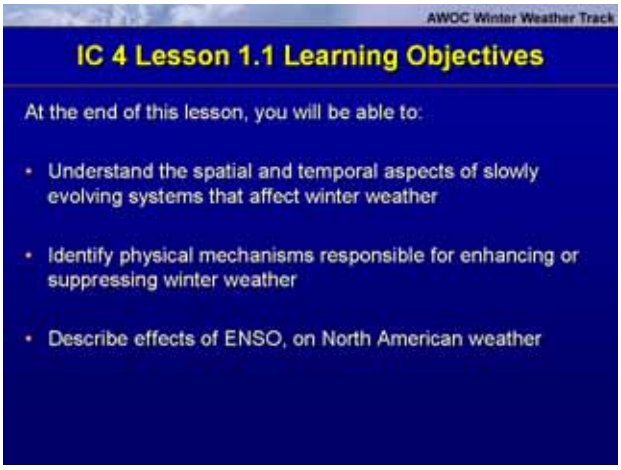

5. Performance Objectives

Instructor Notes: After this lesson you should be able to investigate the current state of the atmosphere in large temporal and spatial scales and correlate them to the potential (or lack thereof) of increased/decreased winter storms and the relationship between the "mode" of the climate system and what to expect for the season in terms of temperature and precipitation anomalies (or lack thereof). You will understand the mechanisms that contribute to an increased/decreased probability of winter time storms in your area. Finally, you will be able to distinguish between different types of teleconnections and understand what significance they have in the winter for the US.

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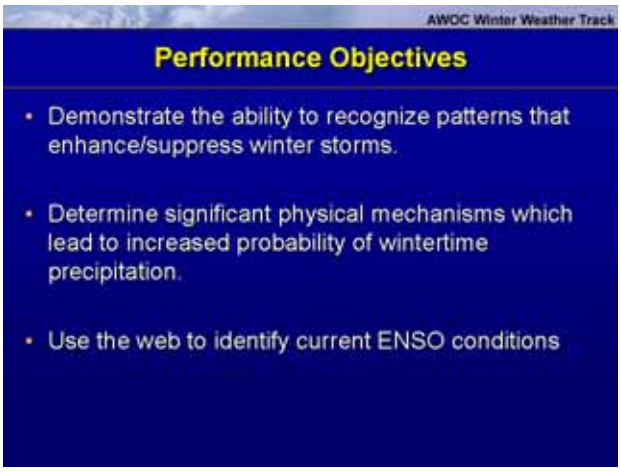
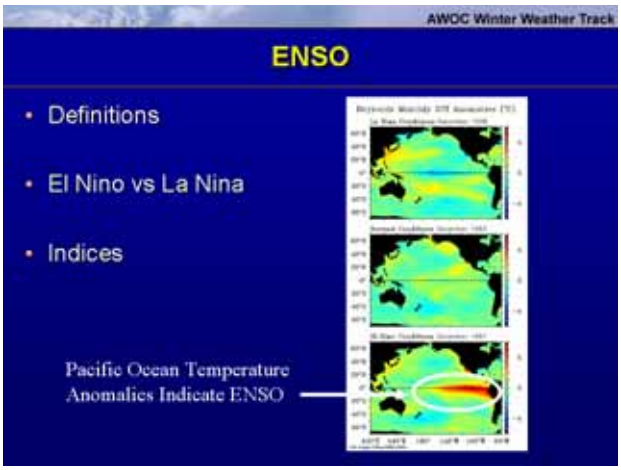


6. ENSO

Instructor Notes: This phenomenon was first noticed by coastal residents of Peru, which is the location of one of the world's most productive fisheries. Typically, in the first months of each year, a warm southward current modified the normally cool waters. But every few years, this warming started early (in December), was far stronger, and lasted much longer. Torrential rains fell on typically arid land. The productive fisheries failed.

This is El Niño, "the Christ child," so named because of its frequent late December appearance. Originally thought to affect only the narrow strip of water off Peru, it is now recognized as a large scale oceanic warming that affects most of the tropical Pacific. (Note: This image is from http://www.nhc.noaa.gov/aboutsst.shtml)

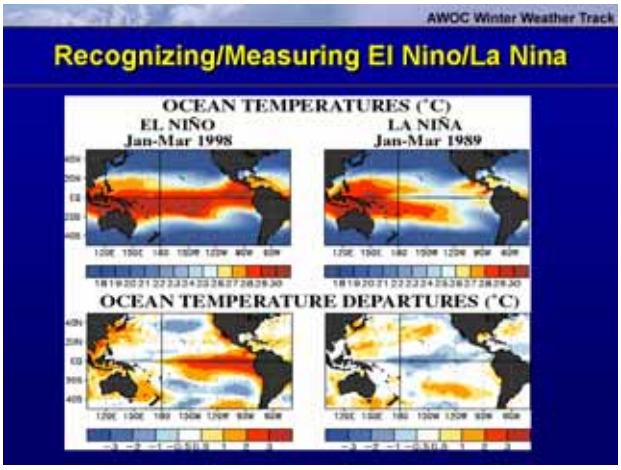
Student Notes:



7. Recognizing/Measuring El Niño/La Niña

Instructor Notes: El Niño episodes (left hand column) reflect periods of exceptionally warm sea surface temperatures across the eastern tropical Pacific. La Niña episodes (right hand column) represent periods of below-average sea-surface temperatures across the eastern tropical Pacific. These episodes typically last approximately 9-12 months. Sea-surface temperature (top) and departure (bottom) maps for December - February during strong El Niño and La Niña episodes are shown above.During a strong El Niño ocean temperatures can average 2 degrees C – 3.5 degrees C (4 degrees F - 6 degrees F) above normal between the date line and the west coast of South America (bottom left map). These areas of exceptionally warm waters coincide with the regions of above-average tropical rainfall. During La Niña temperatures average 1 degrees C - 3 degrees C (2 degrees F - 6 degrees F) below normal between the date line and the west coast of South America. This large region of below-average temperatures coincides with the area of well below-average tropical rainfall.For both El Niño and La Niña the tropical rainfall, wind, and air pressure patterns over the equatorial Pacific Ocean are most strongly linked to the underlying sea-surface temperatures, and vice versa, during December-April. During this period the El Niño and La Niña conditions are typically strongest, and have the strongest impacts on U.S. weather patterns. El Niño and La Niña episodes typically last approximately 9-12 months. They often begin to form during June-August, reach peak strength during December-April, and then decay during May-July of the next year. However, some prolonged episodes have lasted 2 years and even as long as 3-4 years. While their periodicity can be quite irregular, El Niño and La Niña occurs every 3-5 years on average. (Note: image from http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensocycle/enso_cycle.shtml) This page only goes to products but not further.

Student Notes:



8. Identifying/Monitoring ENSO - Indices

Instructor Notes: One of the primary indicators of the oceanic state of ENSO is illustrated with Pacific SSTs. There are several Niño "regions" used to describe the state of the ocean. Niño 3.4 is the most often used index, stretching along the equator from 170 W to 120 W longitude, 5N to 5S latitude. Niño 3.4 captures the biggest changes in SSTs between ENSO events. (note: data shown from http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensocycle/enso_cycle.shtml)

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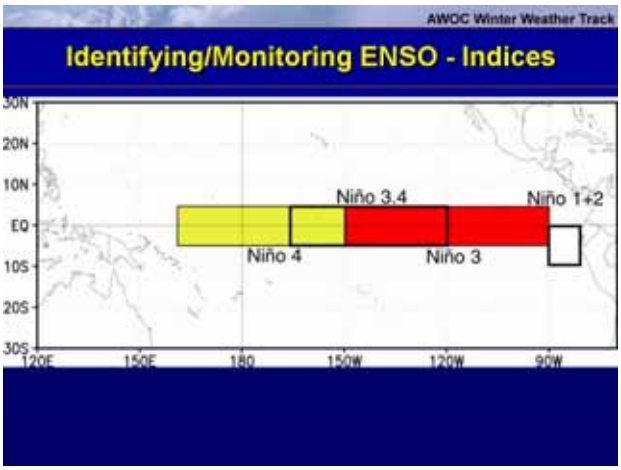
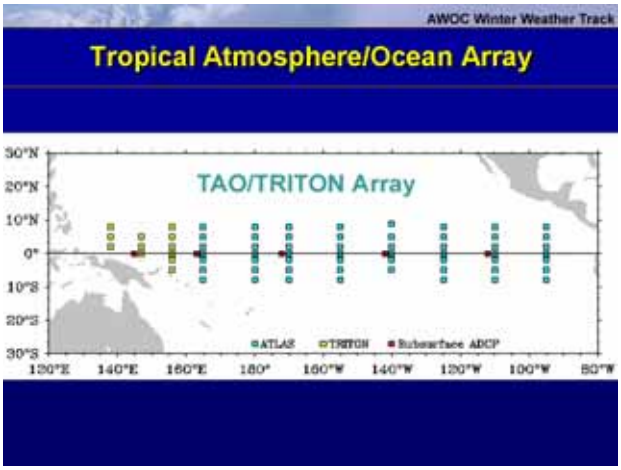


9. Tropical Atmosphere/Ocean Array

Instructor Notes: An inadequate understanding of the relevant physical processes and a lack of observational data covering vast areas of tropical oceans has hindered monitoring efforts in the past. Significant improvement of the observational data base was brought about by the Tropical Atmosphere/Ocean (TAO) array of 70 instrument buoys moored throughout the equatorial Pacific Ocean. Beginning in 1985 after the 1982-83 unforecasted El Niño event and completed in 1994, the TAO array gathers surface mete-

orological and oceanographic data and records ocean temperature to a depth of 500 meters (1650 feet). (note: figure from http://www.pmel.noaa.gov/tao/)

Student Notes:



10. Oceanic Niño Index (ONI)

Instructor Notes: Based on the principal measure for monitoring, assessment, and prediction of ENSO (SST departures from average in the Niño 3.4 region). Three-month running-mean values of SST departures from average in the Niño 3.4 region, based on a set of improved homogeneous historical SST analyses (Extended Reconstructed SST – ERSST.v2). The methodology is described in Smith and Reynolds, 2003, J. Climate, 16, 1495-1510. Used to place current conditions in historical perspective. NOAA operational definitions of El Niño and La Niña are keyed to the index. (note: figure from http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensocycle/enso_cycle.shtml)

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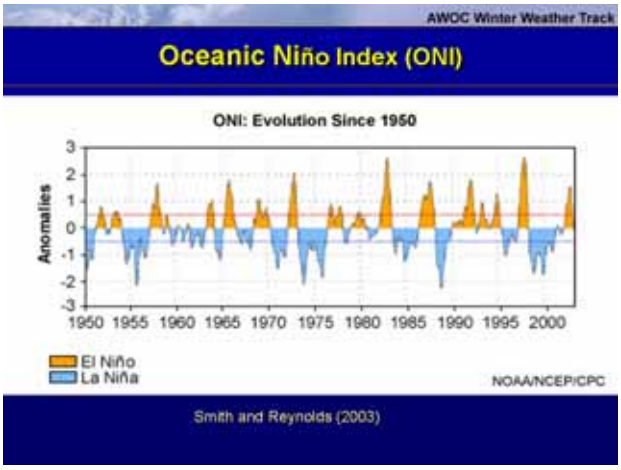

11. So What is the “SO”?

Instructor Notes: It was the atmospheric part of ENSO, i.e. the Southern Oscillation, that first attracted the attention of scientists. Sir Gilbert Walker documented and named

the SO in the 1930s. The clearest sign of the SO is the inverse relationship between surface air pressure at two sites: Darwin, Australia, and the South Pacific island of Tahiti. So Why do we have ENSO? The basic answer is that it appears to be a necessary mechanism for maintaining long-term climate stability (i.e. transport heat from the Tropics to the higher latitudes). El Niño acts to more effectively remove heat from the large tropical Pacific Ocean, and transfer this heat to higher latitudes via the atmospheric circulation. El Niño-like events can occur in the tropical Atlantic, but much less frequently and with minimal regional impacts. (note: data from http://www.earthscape.org/t1/heb01/)

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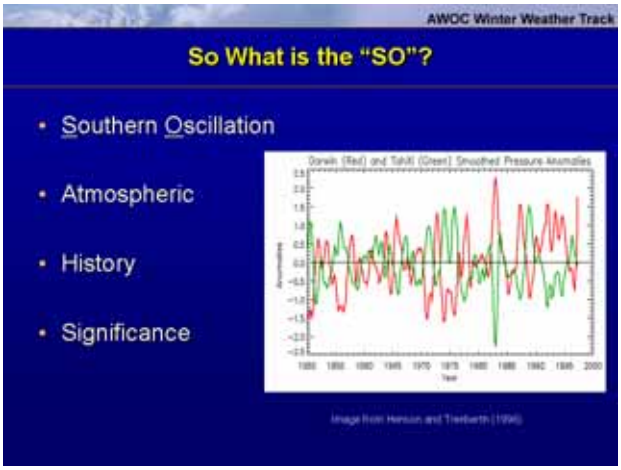

12. The Location of ENSO

Instructor Notes: Convection in the tropics is the "bridge" which translates the SST anomalies (El Niño or La Niña) into an atmospheric response, as identified by the Southern Oscillation.

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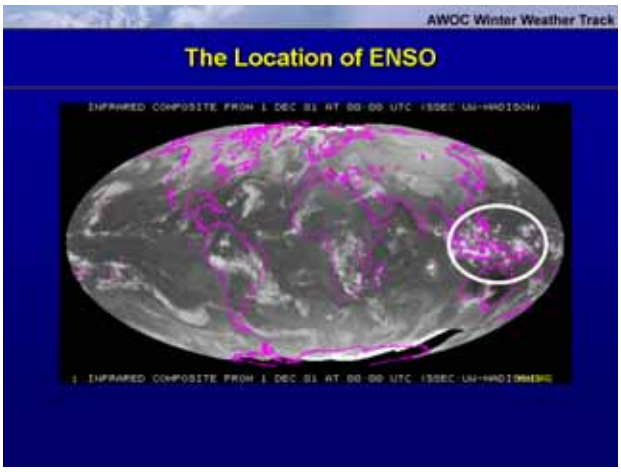

13. Normal Conditions

Instructor Notes: This two-dimensional picture was extended vertically by Jacob Bjerknes in 1969. He noted that trade winds across the tropical Pacific flow from east to west. To complete the loop, he theorized, air must rise above the western Pacific, flow back east at high altitudes, then descend over the eastern Pacific. Bjerknes called this the Walker circulation; he also was the first to recognize that it was intimately connected to the oceanic changes of El Niño and La Niña. (note: figure from http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensocycle/enso_cycle.shtml)

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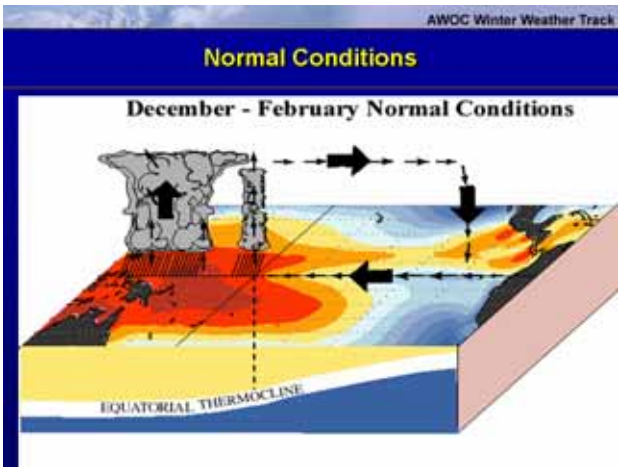

14. El Niño Conditions

Instructor Notes: Near the end of each calendar year ocean surface temperatures warm along the coasts of Ecuador and northern Peru. Local residents referred to this seasonal warming as “El Niño”, meaning The Child, due to its appearance around the Christmas season. Every two to seven years a much stronger warming appears, which is often accompanied by beneficial rainfall in the arid coastal regions of these two countries. Over time the term “El Niño” began to be used in reference to these major warm episodes. El Niño is closely related to a global atmospheric oscillation known as the Southern Oscillation (SO). During El Niño episodes lower than normal pressure is observed over the eastern tropical Pacific and higher than normal pressure is found over Indonesia and northern Australia. This pattern of pressure is associated with weaker than normal near-surface equatorial easterly (east-to-west) winds. These features characterize the warm phase of the SO, which is often referred to as an El Niño/Southern Oscillation (ENSO) episode. During warm (ENSO) episodes the normal patterns of tropical precipitation and atmospheric circulation become disrupted. The abnormally warm waters in the equatorial central and eastern Pacific give rise to enhanced cloudiness and rainfall in that region, especially during the boreal winter and spring seasons. At the same time, rainfall is reduced over Indonesia, Malaysia and northern Australia. Thus, the normal Walker Circulation during winter and spring, which features rising air, cloudiness and rainfall over the region of Indonesia and the western Pacific, and sinking air over the

equatorial eastern Pacific, becomes weaker than normal, and for strong warm episodes it may actually reverse.

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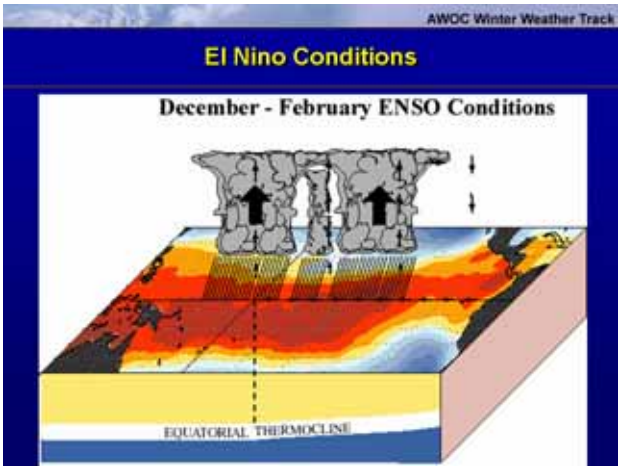

15. La Niña Conditions

Instructor Notes: At times ocean surface temperatures in the equatorial central Pacific are colder than normal. These cold episodes, sometimes referred to as La Niña episodes, are characterized by lower than normal pressure over Indonesia and northern Australia and higher than normal pressure over the eastern tropical Pacific. This pressure pattern is associated with enhanced near-surface equatorial easterly winds over the central and eastern equatorial Pacific. During cold (La Niña) episodes the normal patterns of tropical precipitation and atmospheric circulation become disrupted. The abnormally cold waters in the equatorial central give rise to suppressed cloudiness and rainfall in that region, especially during the Northern Hemisphere winter and spring seasons. At the same time, rainfall is enhanced over Indonesia, Malaysia and northern Australia. Thus, the normal Walker Circulation during winter and spring, which features rising air, cloudiness and rainfall over the region of Indonesia and the western Pacific, and sinking air over the equatorial eastern Pacific, becomes stronger than normal.

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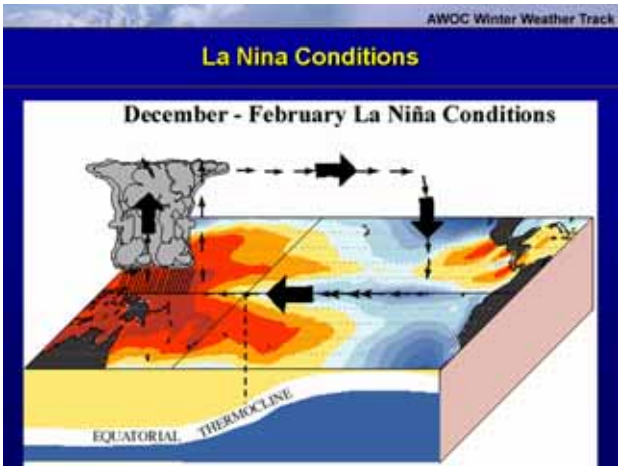
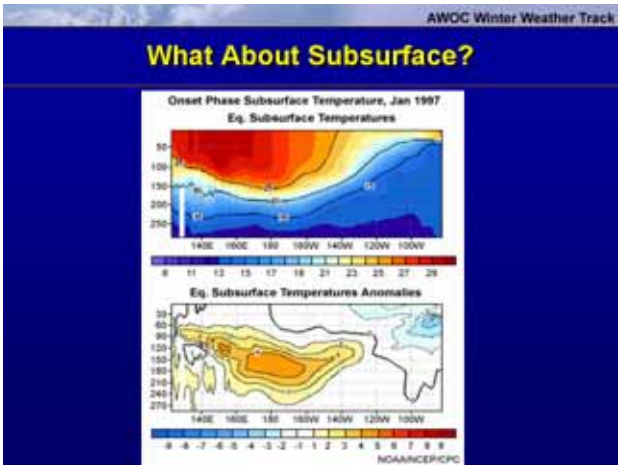


16. What About Subsurface?

Instructor Notes: The evolution of the El Niño and La Niña, as well as the transition between the extreme phases of the ENSO cycle, depends greatly on the subsurface ocean temperature structure and the variability of the low-level winds. As an El Niño episode evolves, significant changes occur in both the subsurface temperatures and in the depth of the oceanic thermocline (The thermocline separates the warm upper ocean from the cold deep ocean waters.). In the early stages of El Niño episodes the oceanic thermocline is deeper than normal in the western and central equatorial Pacific, in association with an abnormally deep pool of warm ocean water throughout the region. As El Niño episodes progress to the mature phase, the depth of the thermocline gradually decreases in the central and western equatorial Pacific and increases in the eastern equatorial Pacific, in response to weaker-than-average low-level easterly winds. As a result, subsurface temperatures become cooler than normal in the western equatorial Pacific, and warmer than normal across the eastern equatorial Pacific. In the latter stages of El Niño episodes, both the depth of the thermocline and subsurface temperatures become less than normal throughout most of the equatorial Pacific as the heat in the upper ocean is gradually depleted. Thus, the warmer than normal temperatures become increasingly confined to a shallow layer near the ocean surface in the eastern equatorial Pacific, setting the stage for a transition to either a neutral state or to a La Niña episode. This transition process is critically dependent on the evolution of the low-level atmospheric winds. For example, if the easterly winds strengthen sufficiently, they can produce upwelling over the eastern equatorial Pacific, bringing the cold ocean waters to the surface. If the drop in sea surface temperatures is sufficiently large, it can lead to the onset of La Niña conditions. Conversely, in the early stages of La Niña episodes the thermocline is generally shallower than normal across the equatorial Pacific. The thermocline gradually deepens in the western Pacific during the mature phase of La Niña episodes, and in the central Pacific during the latter stages of the episode. As a result, the subsurface temperatures become warmer than normal in these regions, while the ocean surface temperatures remain colder than normal. This decrease in the overall volume of abnormally cold ocean waters indicates an increase in the upper ocean heat content, and results in conditions more favorable for a transition to either a neutral state or to an El Niño episode. Once again the critical factors in the transition are the low-level winds and the subsurface temperature structure. The persistent easterly trade winds are a key ingredient in the ENSO process. Trade winds push water toward the western Pacific. The sea level in the Philippines is normally about 60 centimeters (23 inches) higher than the sea level on the southern coast of Panama. They also allow the westward-flowing water to remain near the surface and gradually heat. This gives the water's destination-the western Pacific-the warmest ocean surface on Earth. As warm surface water collects in the western Pacific, it tends to push down the thermocline, the boundary separating well-mixed surface waters from deeper, colder waters.

Student Notes:



17. An Adjustment to the Jet Stream

Instructor Notes: The primary atmospheric response to these SST anomalies is an adjustment to the jet stream as the Walker circulation adjusts due to new convective patterns. Convection tends to be longer lived over SSTs of 28 degrees C or greater. Thus a shift in warm SSTs eastward will have a dramatic effect on where convection will be longer lived and hence, adjust the location of the jet stream.

Student Notes:

18. January-March Upper-Level (200-hPa) Circulation Variability during El Niño Episodes

Instructor Notes: Relative to ENSO-neutral (above), El Niño features are stronger than average with westerly winds over the subtropical eastern Pacific, and a southward shifted jet stream over the east Pacific and the contiguous US, with increased westerly winds and storminess over the Southwest and Gulf Coast states. (note: figures prepared by Climate Prediction Center)

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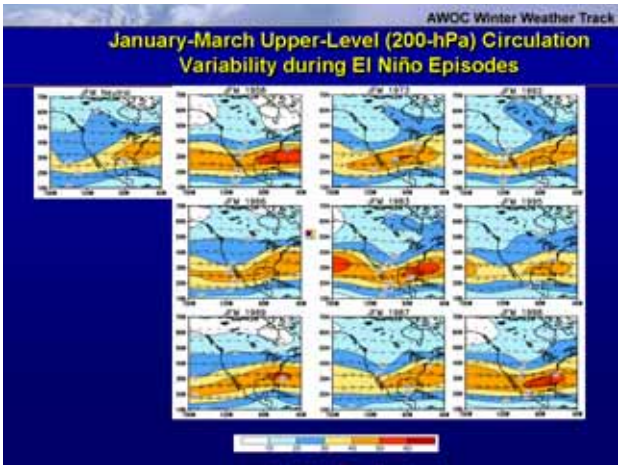

19. Typical El Niño Winter Pattern

Instructor Notes: During winter El Niño episodes feature a strong jet stream and storm track across the southern part of the United States, and less storminess and milder-than-average conditions across the North. El Niño episodes are associated with four prominent changes in the wintertime atmospheric flow across the eastern North Pacific and North America. The first is an eastward extension and southern shift of the East Asian jet stream from the International Date Line to the southwestern United States. The second is a more west-to-east flow of jet stream winds than normal across the United States. The third is a southward shift of the storm track from the northern to the southern part of the United States. The fourth is a southward and eastward shift of the main region of cyclone formation to just west of California. This shift results in an exceptionally stormy winter and increased precipitation across California and the southern U.S, and less stormy conditions across the northern part of the country. Also, there is an enhanced flow of marine air into western North America, along with a reduced northerly flow of cold air from Canada to the United States. These conditions result in a milder than normal winter across the northern states and western Canada. (note: figure from http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensocycle/enso_cycle.shtml)

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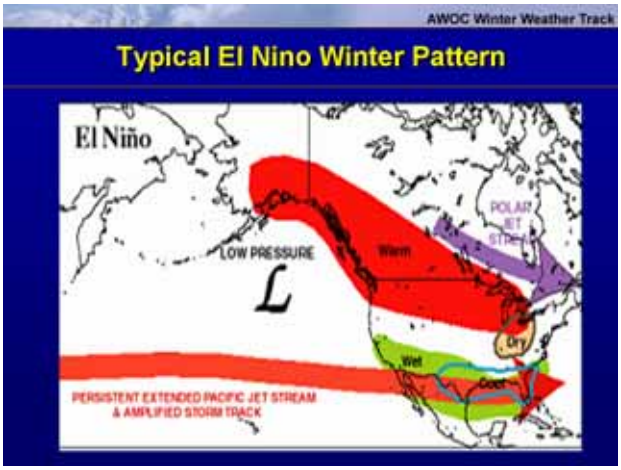

20. El Niño

Instructor Notes: During the winter, in the Tropics, El Niño episodes are associated with increased rainfall across the east-central and eastern Pacific and with drier than normal conditions over northern Australia, Indonesia and the Philippines. Elsewhere, wetter than normal conditions tend to be observed along coastal Ecuador, northwestern Peru, southern Brazil, central Argentina, and equatorial eastern Africa. El Niño episodes also contribute to large-scale temperature departures throughout the world, with most of the affected regions experiencing abnormally warm conditions during NH winter. Some of the most prominent temperature departures include: 1) warmer than normal conditions across southeastern Asia, southeastern Africa, Japan, southern Alaska and western/ central Canada, southeastern Brazil and southeastern Australia and cooler than normal conditions along the Gulf coast of the United States. (note: Data from CPC)

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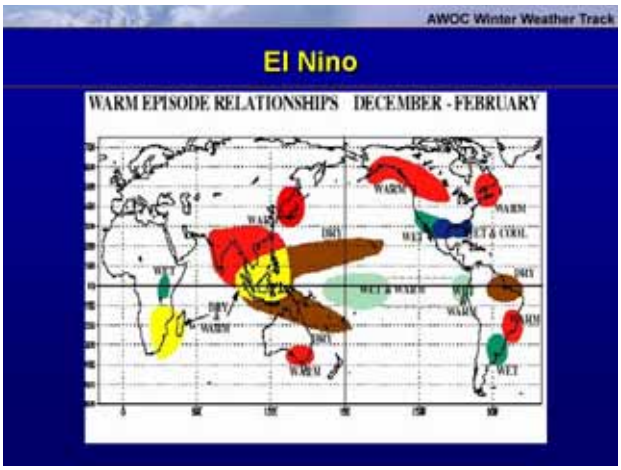

21. Example: El Niño of 1998

Instructor Notes: During El Niño, rainfall and thunderstorm activity diminishes over the western equatorial Pacific, and increases over the eastern half of the tropical Pacific. This area of increased rainfall occurs where the exceptionally warm ocean waters have reached about 28 degrees C or 82 degrees F. This overall pattern of rainfall departures spans nearly one-half the distance around the globe, and is responsible for many of the global weather impacts caused by El Niño. In the left-hand panel the seasonal rainfall totals during the strong El Niño conditions of January-March 1998 are shown for over the Pacific Ocean, the United States, and South America. The heaviest rainfall [in units of millimeters (mm)] is shown by the darker green and blue colors, and lowest rainfall is shown by the lighter green colors. Since 25.4 mm is equal to one inch of rain, we see that the rainfall totals are more than 800 mm just south of the equator along the International Date Line (indicated by the 180 label), which is more than 31 1/2 inches of rain. And nearly double the normal amount. In the right-hand panel the January-March 1998 seasonal rainfall departures from average are shown. The areas with well above average rainfall are shown by darker green colors, and the areas with well below-average rainfall

are shown by the darker brown and yellow colors. The rainfall departures are shown in units of 100 millimeters. We see that the seasonal rainfall totals were more than 400 mm above normal just south of the equator along the International Date Line (indicated by the 180 label), which is more than 15 3/4 inches above normal. Considerable rainfall also occurred farther north (near 40 degrees N) over the central and eastern North Pacific, and across the western and southeastern United States. These areas lie along the main wintertime storm track, which brings above-average rainfall to the western and south-eastern United States. In contrast, the seasonal rainfall totals over the western Pacific just north of the equator were less than 100 mm during the season (see left-hand panel), which is more than 800 mm (or 31 1/2) inches) below normal. This extreme dryness led to a series of major uncontrolled wildfires in Indonesia. (note: figure from http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensocycle/enso_cycle.shtml)

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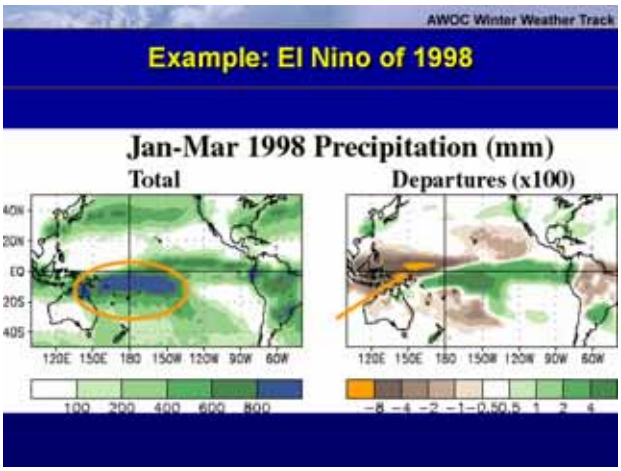

22. January-March Upper-Level (200-hPa) Circulation Variability during La Niña Episodes

Instructor Notes: Relative to ENSO-neutral (above) La Niña often features weaker than average westerly winds over the subtropical eastern Pacific (red circled regions), a Note a northward shifted jet stream over the east Pacific with increased westerly winds over the Pacific NW, and considerable event-to-event variability in the position of the jet stream along the East Coast.

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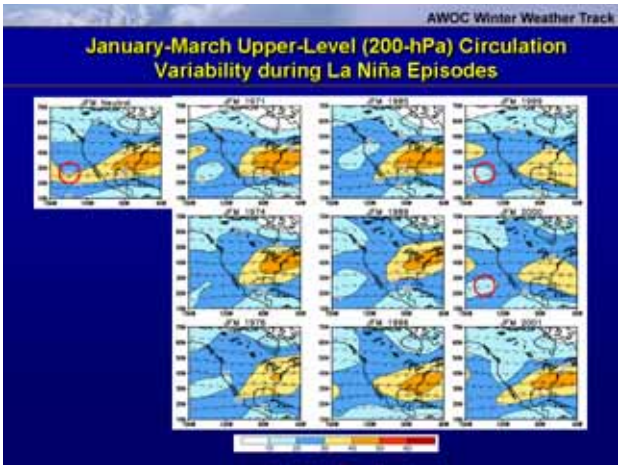

23. Typical Winter La Niña Pattern

Instructor Notes: La Niña episodes are associated with three prominent changes in the wintertime atmospheric flow across the eastern North Pacific and North America. The first is an amplification of the climatological mean wave pattern and increased meridional flow across the continent and the eastern North Pacific. The second is increased blocking activity over the high latitudes of the eastern North Pacific. The third is a highly variable strength of the jet stream over the eastern North Pacific, with the mean jet position entering North America in the northwestern United States/ southwestern Canada. Accompanying these conditions, large portions of central North America experience increased storminess, and an increased frequency of significant cold-air outbreaks, while the southern states experiences less storminess and precipitation. Also, there tend to be considerable month-to-month variations in temperature, rainfall and storminess across central North America during the winter and spring seasons, in response to the more variable atmospheric circulation throughout the period. (figure from http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensocycle/enso_cycle.shtml)

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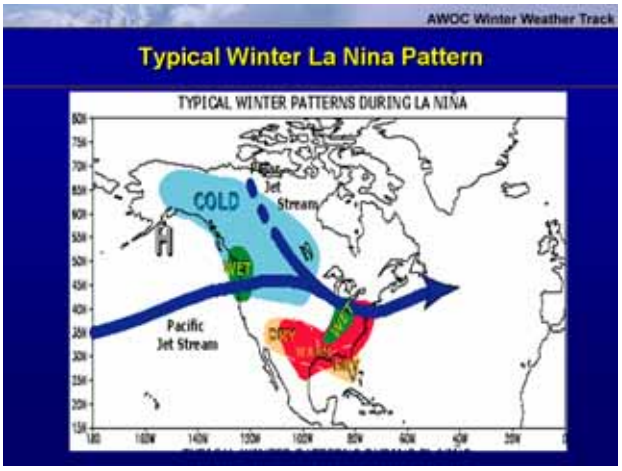

24. What About La Niña?

Instructor Notes: During La Niña episodes rainfall is enhanced across the western equatorial Pacific, Indonesia and the Philippines and is nearly absent across the eastern equatorial Pacific. Elsewhere, wetter than normal conditions tend to be observed during December-February (DJF) over northern South America and southern Africa, and during June-August (JJA) over southeastern Australia. Drier than normal conditions are generally observed along coastal Ecuador, northwestern Peru and equatorial eastern Africa during DJF, and over southern Brazil and central Argentina during JJA. La Niña episodes also contribute to large-scale temperature departures throughout the world, with most of the affected regions experiencing abnormally cool conditions. Some of the most prominent temperature departures include: 1) below-normal temperatures during December-February over southeastern Africa, Japan, southern Alaska and western/central Canada, and southeastern Brazil; 2) cooler than normal conditions during June-August across India and southeastern Asia, along the west coast of South America, across the Gulf of Guinea region, and across northern South America and portions of central America; and 3) warmer than normal conditions during December-February along the Gulf coast of the United States.

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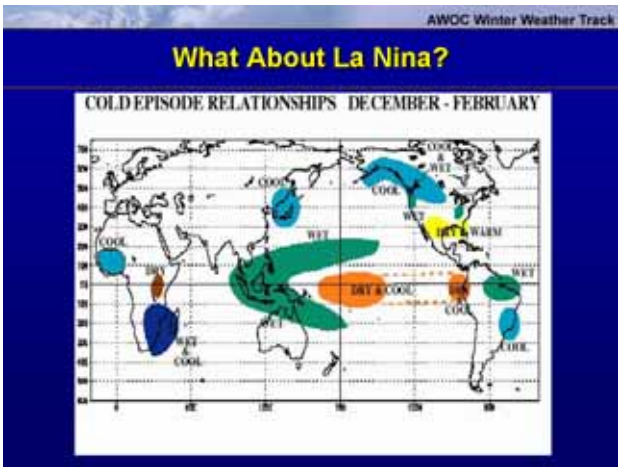
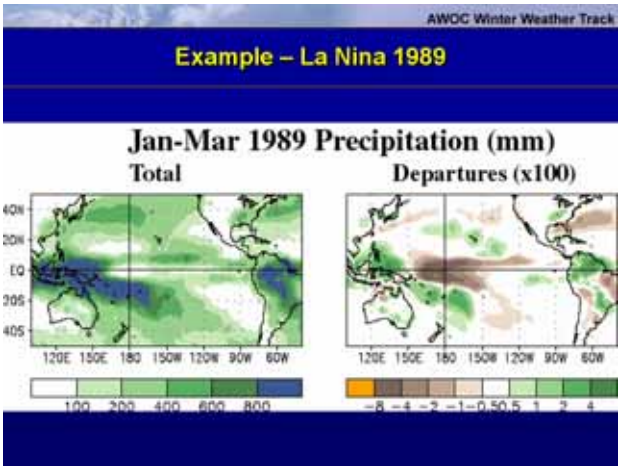


25. Example – La Niña 1989

Instructor Notes: During La Niña, rainfall and thunderstorm activity diminishes over the central equatorial Pacific, and becomes confined to Indonesia and the western Pacific. The area experiencing a reduction in rainfall generally coincides quite well with the area of abnormally cold ocean surface temperatures. This overall pattern of rainfall departures spans nearly one-half the way around the globe, and is responsible for many of the global weather impacts caused by La Niña. In the left-hand panel (from CPC web site) you can see the seasonal rainfall totals over the Pacific Ocean, the United States, and South America during January-March 1989 when strong La Niña conditions were present. The heaviest rainfall is shown by the darker green and blue colors, and lowest rainfall is shown by the lighter green colors. The rainfall totals are shown in units of millimeters

(mm). Since 25.4 mm is equal to 1 inch of rain, we see that the rainfall totals are more than 800 mm over the western tropical Pacific and Indonesia, which is more than 31 1/2 inches of rain. In the right-hand panel you can see the January-March 1989 seasonal rainfall departures from average for strong La Niña conditions. The areas where the rainfall is well above average are shown by darker green colors, and the areas where the rainfall is most below average are shown by the darker brown and yellow colors. These rainfall departures are shown in units of 100 millimeters. We see that rainfall totals were more than 200-400 mm above normal over the western tropical Pacific and Indonesia during the season, which is roughly 8-16 inches above normal! We also see well below-average rainfall across the central tropical Pacific, where totals in some areas were more than 400 mm (15 3/4 inches) below normal.

Student Notes:



26. Jet Stream Affects

Instructor Notes: Pacific ocean temperatures (from CPC), tropical rainfall and vertical motion patterns greatly affect the distribution of atmospheric heating across the tropical and subtropical Pacific. Normally, the strongest heating and warmest air temperatures coincide with the warmest ocean waters and heaviest rainfall. This atmospheric heating helps determine the overall north-south temperature differences in both hemispheres, which significantly affects the strength and location of the jet streams over both the North and South Pacific. This influence on the jet streams tends to be most pronounced during the respective hemisphere's winter season, when both the location and eastward extent of the jets (to just east of the date line) exhibit a strong relationship to the pattern of tropical heating. These jet streams are then a major factor controlling the winter weather patterns and storm tracks in the middle latitudes over both North and South America.

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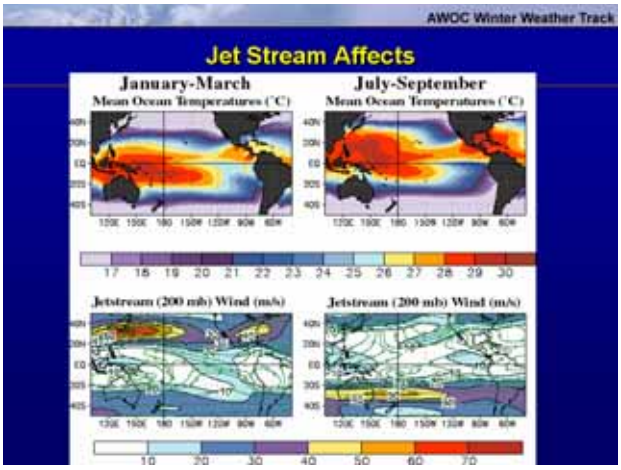
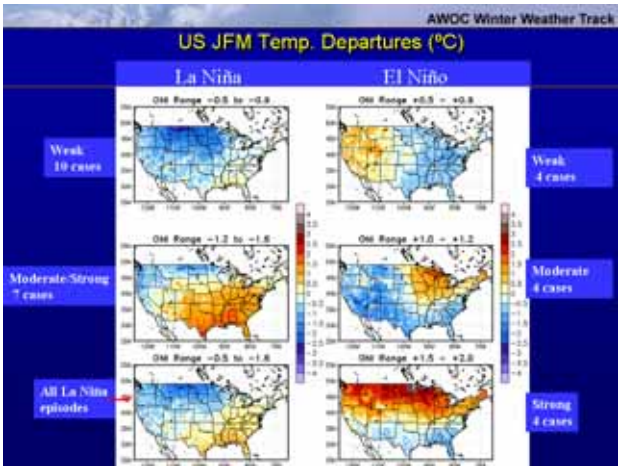


27. US JFM Temp. Departures (Degrees C)

Instructor Notes: This diagram (from CPC) shows temp departures for a number of ENSO cases. You can see on the left hand side, La Niña, that temperature departures were greater in the northern tier during weak cases. Contrast that with strong El Niño, where the northern tier had a very strong warmer than normal signal.

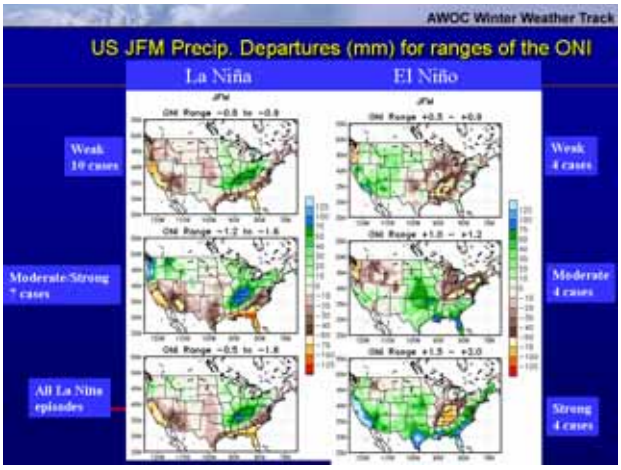
Student Notes:



28. US JFM Precip. Departures (mm) for Ranges of the ONI

Instructor Notes: Now here are the precipitation departures for the different ENSO cases. Here we see the highest departure from normal precipitation conditions in CA are seen in the weak La Niña cases in the upper left corner. However, we do find the largest wet bias occurred during La Niña in western KY and TN in the moderate and strong cases (the left middle image). For El Niño, the Pac NW drier conditions are most pronounced in the moderate cases as is true for the OH and MS valleys. The wetter than normal signals in CA are also correlated with stronger El Niño cases.

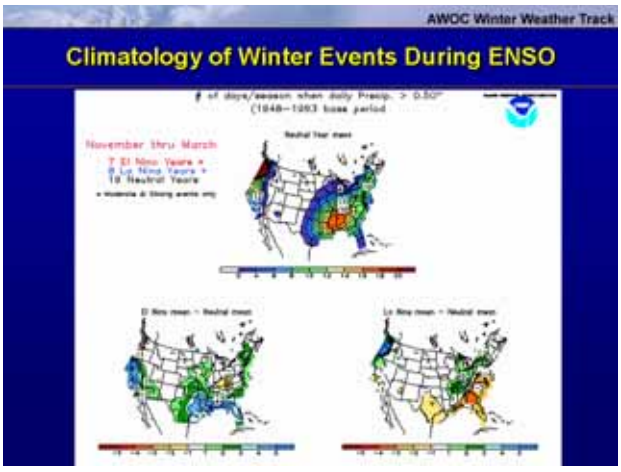
Student Notes:



29. Climatology of Winter Events During ENSO

Instructor Notes: Shown from CPC web site are the mean number of days per season (November - March 1948 through 1993) in which precipitation exceeded 0.50 inches for Neutral years (top). Lower left map is the difference in this quantity between El Niño years and Neutral years. Lower right map is the difference in this quantity between La Niña years and Neutral years. Data are analyzed on a 2 degree latitude x 22 degree longitude grid.

Student Notes:



30. Snowfall During ENSO

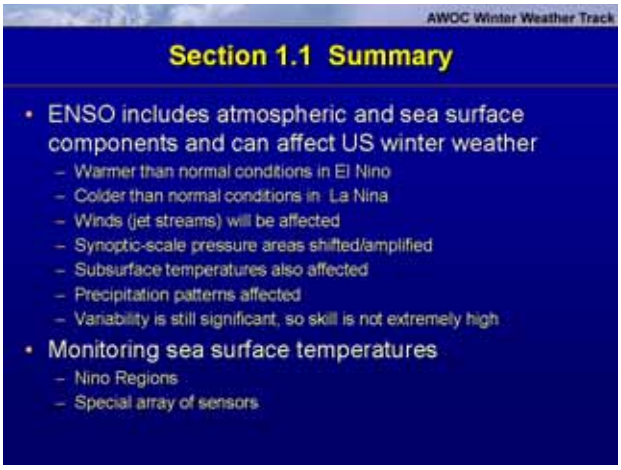
Instructor Notes: Displayed from CPC, here is the mean seasonal snowfall (November - March 1948 through 1993) in inches for Neutral years (top). The lower left map is the difference in snowfall between El Niño years and Neutral years. The lower right map is the difference in fall between La Niña years and Neutral years. Data are analyzed on a 2 degree x 2 degree grid.

Student Notes:

31. Section 1.1 Summary

Instructor Notes: The El Niño/La Niña and Southern Oscillation ENSO, is typically referred to as the “800 lb. Gorilla” of climate predictability, in that if a moderate strong cold/warm episode occurs, the effects on US weather, particularly in the winter are well documented. It is important to note that other factors (such as teleconnections, the Madden Julian Oscillation, and other large scale influences) can all have an effect on the pattern in any given winter. Nonetheless, we can “isolate” the effects of ENSO on the winter weather in the US. These effects include during El Niño: warmer temperatures across the northern US and colder than normal conditions in the southern US. Precipitation patterns are also affected, with an increase in precipitation noted in the south, while drier conditions typically prevail across the north. During La Niña, cooler and wetter conditions are common in the pacific northwest and into the Great Lakes, while warmer and drier conditions occur in the southern US. It is important to remember that there is a lot of variability from one ENSO event to another, so forecasting synoptic scale events can be quite challenging. Monitoring the sea surface and subsurface temperatures are an important component in determining the state of ENSO and forecasting subsequent seasonal impacts. Scientists use “Niño regions,” especially the Niño 3.4 region to determine what mode the climate system is in and to assess trends or “anomalies.” A special array of sensors have been placed in the tropical pacific to keep close watch of the oceanic temperatures and winds. In the next session we’ll explore another phenomenon which affects winter weather in the US…The Madden Julian Oscillation.

Student Notes:



32. ENSO Quiz

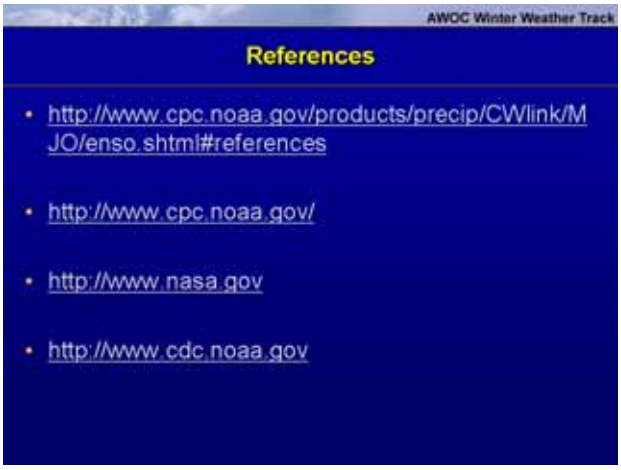
Instructor Notes: Please take a moment to complete this quiz.

Student Notes:

33. References

Instructor Notes: Here are some web sites that you might find useful regarding ENSO.

Student Notes:



34. Acknowledgements

Instructor Notes: I'd like to thank the following individuals for the assistance in creating this lesson: Mike Staudenmaier, SOO/Flagstaff Tom Salem, SOO/Glasgow Tony Haffer, MIC/Phoenix

Student Notes:

35. Questions???

Instructor Notes: After going through this lesson if you have any questions, first ask your SOO. Your SOO is your local facilitator and should be able to help answer many questions. If you need additional info from what your SOO provided, send an E-mail to the address on the slide. This address sends the message to all the instructors involved with this IC. Our answer will be CC'd to your SOO so that they can answer any similar questions that come up in the future. We may also consider the question and answer for our FAQ page.

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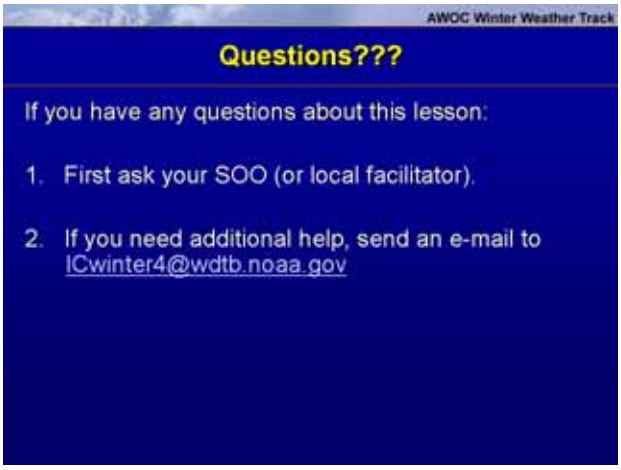

1. IC4.1 Part 2: The Madden-Julian Oscillation

Instructor Notes: In this lesson we will discuss the Madden-Julian Oscillation or the MJO and it's affect on the climate system and in particular winter time precipitation in the US.

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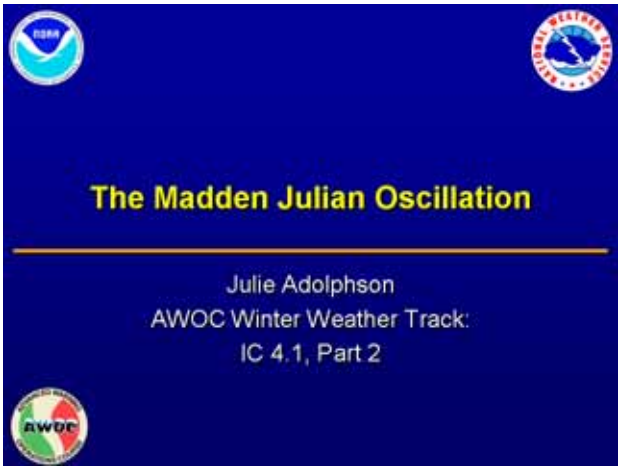

2. IC 4 Lesson 1.2 Learning Objectives

Instructor Notes: We will focus on helping you look at the "big picture" in space and time to help you assess the potential for upcoming winter storms in your area of responsibility. You will understand the size and time scale of the Madden-Julian Oscillation, as well as identify the physical nature of this phenomena and how if affects winter weather in the US. You will be able to describe the effects of the MJO on weather during the winter in your area.

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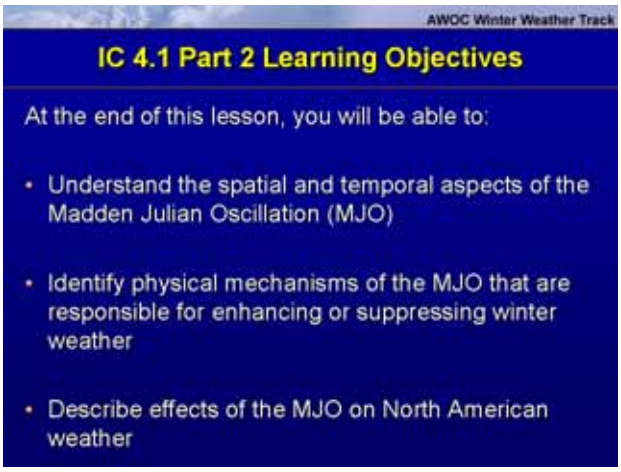

3. Performance Objectives

Instructor Notes: After this lesson you should be able to investigate the current state of the atmosphere in large temporal and spatial scales and correlate them to the potential (or lack thereof) of increased/decreased winter storms and the relationship between the strength of the MJO activity and what to expect for the season in terms of temperature and precipitation anomalies (or lack thereof). You will understand how the MJO can contribute to an increased/decreased probability of winter time storms in your area. Finally, you will be able to use different data sets to determine how active the Madden-Julian Oscillation is at any given time, and understand its significance to winter weather in the US.

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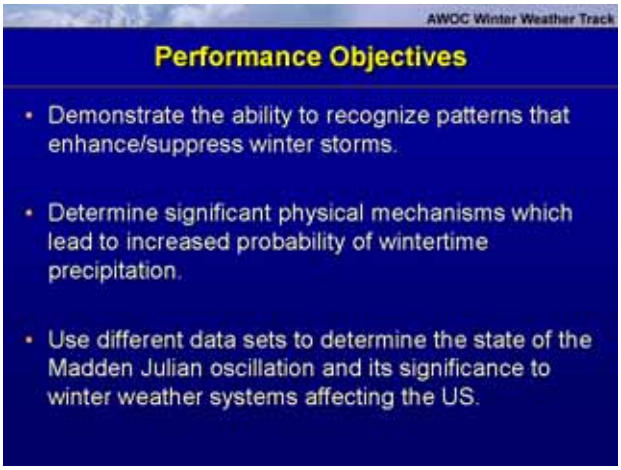

4. Section 1.2 Madden-Julian Oscillation

Instructor Notes: Here is an outline for this section. We'll define the Madden-Julian Oscillation or the "MJO", find out how we monitor it, and then further investigate the effects that the MJO has on the winter weather in the US.

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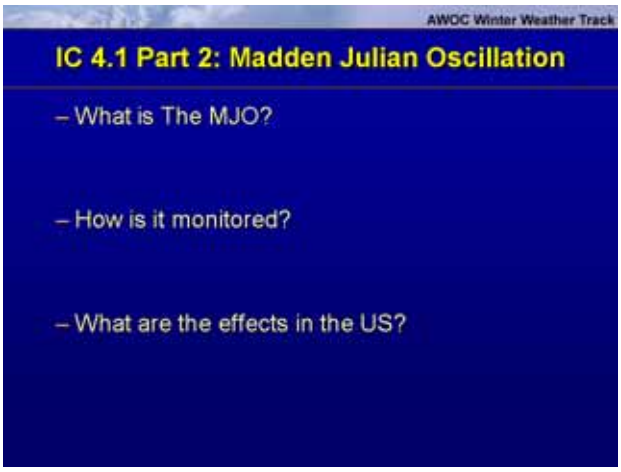

5. The Madden-Julian Oscillation

Instructor Notes: Large and complex cloud systems have been shown to move from the Indian Ocean into the central Pacific Ocean at 5-10 m/s with time scales from ~30 to 60 days. These cloud systems have been shown to directly affect Indian rainfall and tropical storm formation, along with effects even in globally averaged quantities and mid-latitude weather. These cloud systems have been identified as being associated with the Madden-Julian Oscillation (MJO).

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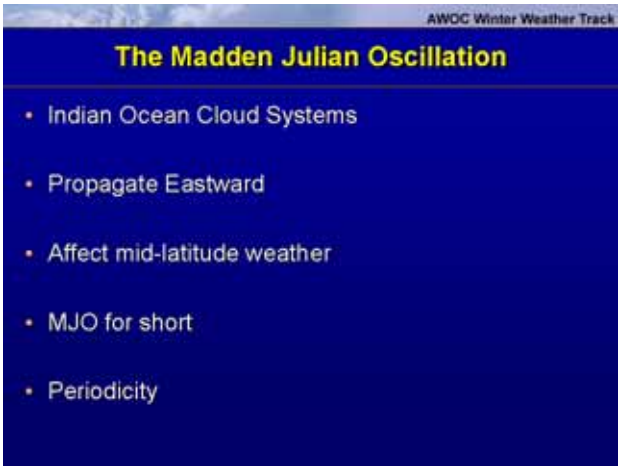

6. So Just What Is MJO?

Instructor Notes: In 1971, Roland Madden and Paul Julian discovered a 30-60 day oscillation when analyzing zonal wind anomalies in the tropical Pacific. They used ten years of pressure records at Canton (at 2.8 degrees S in the Pacific) and upper level winds at Singapore. The MJO gained significant attention after the 1992-1993 El Niño event. The MJO turns out to be the main intra-annual fluctuation that explains weather variations in the tropics. The MJO affects the entire tropical troposphere but is most evident in the Indian and western Pacific Oceans. The MJO involves variations in wind, sea surface temperature (SST), cloudiness, and rainfall. Because of the strong forcing of convection in the tropics, the MJO can have strong effects in the mid-latitudes, similar to effects from ENSO, but on shorter time-scales.

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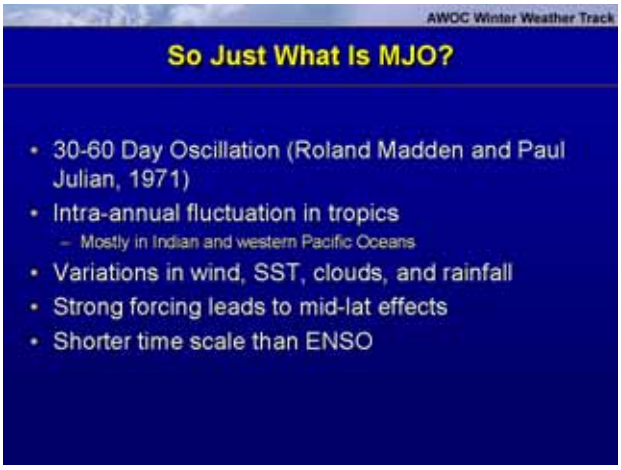

7. OLR Animation of the MJO Life Cycle

Instructor Notes: OLR stands for Outgoing Longwave Radiation. The blue and green area is where OLR is suppressed, this is because increased convection is preventing OLR. Alternatively, the orange area is where OLR is enhanced because there is relatively little convection. Note the propagation of the areas in the animation are from west to east, and that the areas of convection diminish as they move over the cooler waters of the eastern tropical Pacific. (Note: the reference for this graphic is Matthews, A. J., 2000: Quart. J. Roy. Meteorol. Soc., 126, 2637-2651).

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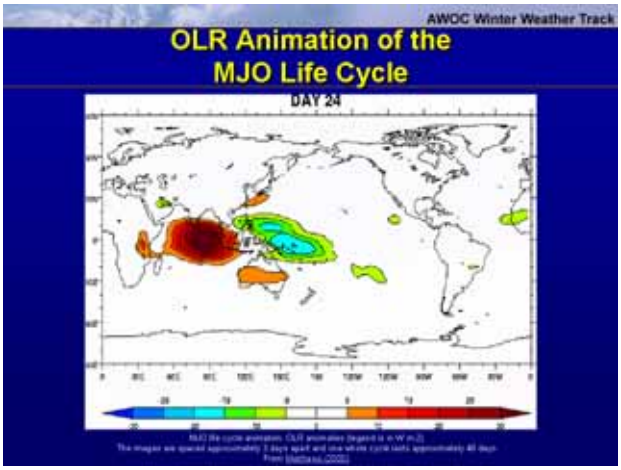

8. Idealized MJO Dynamics

Instructor Notes: Convection forms, leading to anticyclones developing aloft, then cyclonic circulations form, enhancing subsidence ahead. Surface air flows toward enhanced convection regions. In the upper troposphere, anomalous easterlies exit the west side of the enhanced convection. When suppressed convection is strong from the Indian Ocean to the middle Pacific Ocean, anomalous cyclonic circulations at 200 mb (the red area at 200 mb) trail the region of suppressed convection. Similarly, anticyclonic

circulations at 200 mb (the blue area at 200 mb) trail the enhanced convection region once it becomes strong in the Indian and western Pacific Oceans. Circulation couplets in the opposite sense are produced at surface, but they are much weaker than the ones aloft. The zonal circulation and horizontal circulation patterns are important processes by which the MJO shuffles mass around the tropics. (Note: the reference for this image is Rui, H. and B. Wang, 1990: Development characteristics and dynamic structure of tropical intraseasonal convection anomalies, J. Atmos. Sci., 47, 357-379.)

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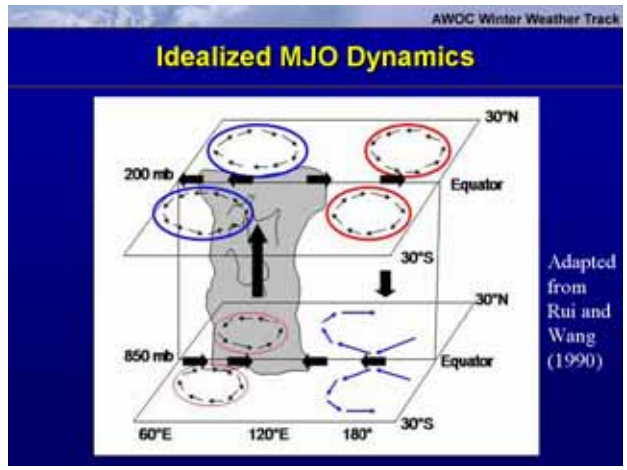

9. Structure of a Madden-Julian Wave

Instructor Notes: Where the trade winds flow into convection we see a lowering pressure (the red areas) and upward vertical motion; and also slightly warmer SSTs. Convection and the associated Kelvin wave move eastward across this area. The structure of the MJO wave is comprised of two regimes. One regime has upper-level divergence, and low-level convergence, which leads to rising motion and the visible convection which can be seen in satellite imagery. You can see this well in F, G, H, A, and B…where you see the upward motion and well-developed convective cloud mass. The other regime has upper-level convergence and low-level divergence, leading to sinking air and suppressed convection. This is most notable in C, D, and E where you see the downward arrows and surface divergence dominating. This results in higher surface pressures, depicted in blue, which are propagating along with the trade winds. Specifically, within the center of suppressed convection, clear skies associated with a stronger-than-normal trade wind inversion allow more shortwave radiation to reach the ocean surface, causing a slight SST increase as the wave travels eastward. The Trade winds too are stronger than normal, explaining enhanced evaporation from the sea surface. A fast Kelvin signal moves across the Pacific in G-A representing the easterly inflow into the onset of convection over the west Pacific. Kelvin waves propagate eastward, while equatorially trapped Rossby waves propagate westward creating downward motion via upper-level convergence. Propagating westward is a Kelvin wave response to the convection; Kelvin wave energy travels faster, catches up to convection to the west, and after it passes, a weakening of the convection is noted. Easterly winds (and the evaporation rate) weaken near the western edge of the suppressed convection region, leading to low-level moisture

convergence. See this in the top diagram, labeled ‘F.’ This triggers deep convection, leading to the visible portion of the MJO, i.e. the region of enhanced convection. There can be multiple areas of convection, especially when the active center is over the western hemisphere, e.g., dateline, South America, Africa. Also, the Kelvin-Rossby wave response to convection can give multiple suppressed centers. One last thing to note in this diagram is the absence of visible convection in the far right of the image. Recall that I mentioned that convection from the MJO is often significantly diminished as it propagates over cooler ocean waters in the eastern pacific. It is important however, to remember that the “waves” associated with an MJO are still present, even if clouds and convection are not visible, and that the “waves” associated with the MJO do indeed continue to propagate around the globe. (Note: the reference is Madden, R. A., and P. R. Julian, 1971: Detection of a 40-50 day oscillation in the zonal wind in the tropical Pacific.J. Atmos. Sci., 28, 702-708. Madden, R. A. and P. R. Julian, 1972: JAS, 29, 1109-1123.)

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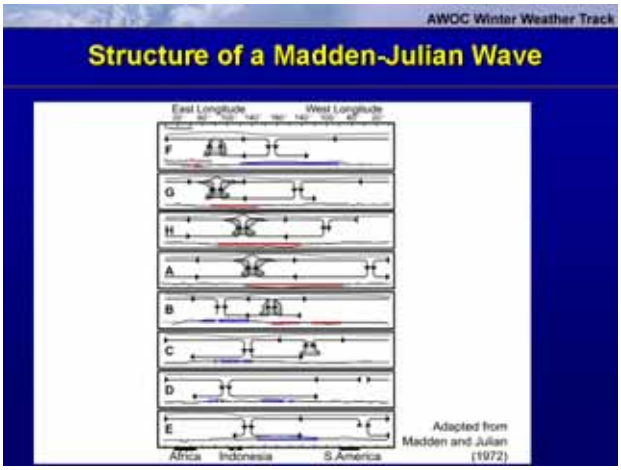

10. Make-up of an MJO Cloud Mass

Instructor Notes: Satellite imagery is helpful in determining the state of MJO, especially time loops of satellite imagery. MJO is characterized by "super cloud clusters" that move eastward (recall this is the latitude of trade winds and Kelvin waves propagating).

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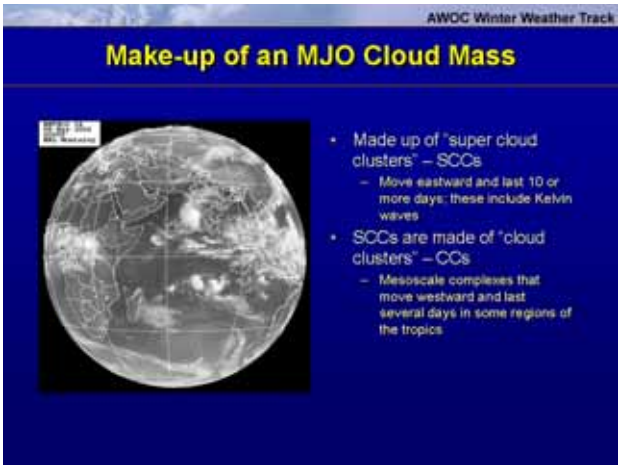

11. Does the MJO Really Circumnavigate the Globe?

Instructor Notes: The convection is TRIGGERED in the eastern Indian Ocean and propagates eastward. Convection dies out in the eastern Pacific due to cold SSTs.

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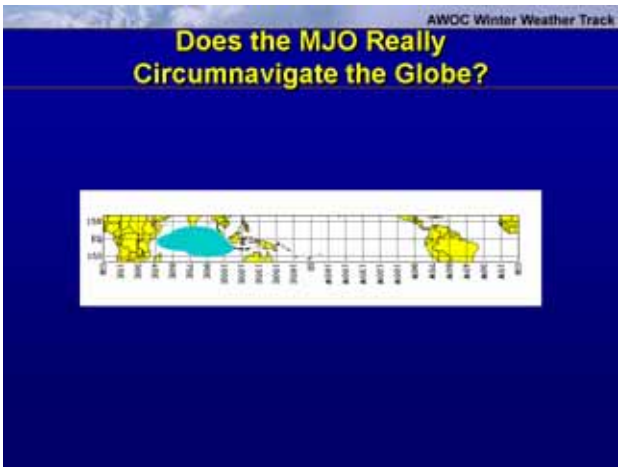

12. Does the MJO Really Circumnavigate the Globe?

Instructor Notes: This is a diagram of OLR in time (date on Y-axis) and space (longitude on X-axis), thus depicting the MJO activity from April through mid-May. Using mathematical techniques, we are able to depict Kelvin waves, the green contours, moving through the convection (OLR) and continuing to move eastward quickly (as dry Kelvin waves), only to emerge back around the globe, possibly enhancing the next burst of MJO activity as they pass through the area. Rossby waves are the black contours that move west with time. The region of upper-level divergence with an associated region of upper-level convergence CAN travel all the way around the world as a Kelvin Wave. There is a spectrum of these waves (e.g., different phase speeds) depending on the convective signal that accompanies them. Associated with the propagation of these convective anomalies, both in the heating in the tropics due to the convection itself, but also due to the

divergence aloft which remains well after the convection is over, the MJO involves variations in the global circulation. The MJO can interact with, modulate, and even help to initiate an El Niño episode. Strong MJO events can also affect the wintertime jet stream and atmospheric circulation features over the north Pacific and western North America. As a result, it has an important impact on storminess and temperatures over the U.S.

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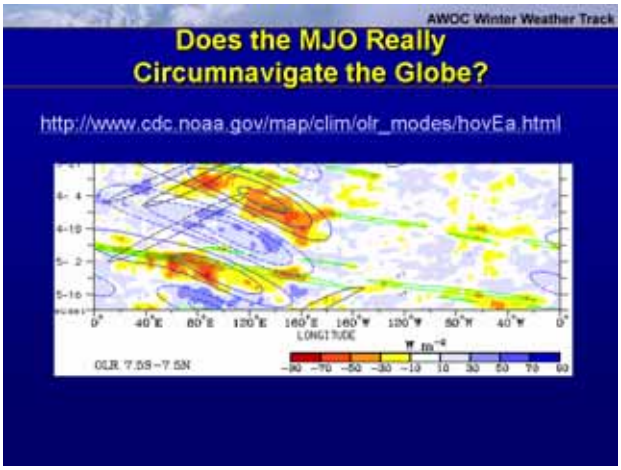

13. Who Cares What Happens in the Tropics?

Instructor Notes: Deep persistent convection in the tropics (the large red area at around 100 E) can excite a Rossby wave train (the purple Hs and Ls) that moves rapidly away from the tropics. These Rossby waves, depending on the current “weather” pattern, can enhance or break blocking patterns and lead to enhancements or weakening of the current jet stream. Note, for example the strong High and Low couplet near the dateline. You can see the enhanced jet stream in this area. The Rossby waves can get involved with and organize synoptic wavetrains in mid-latitudes. This has obvious effects on the wintertime precipitation over the U.S. It is important to note, however, that MJO variability and the overall weather pattern during a given MJO varies; therefore, the synoptic pattern during a given MJO will also be variable. As the MJO event moves eastward, so does the Rossby wave train forcing, enhancing winter time synoptic scale systems as it moves. (note: Reference is Kiladis, G. N., and K. M. Weickmann, 1997: Horizontal structure and seasonality of large-scale circulations associated with submonthly tropical convection. Mon. Wea. Rev., 125, 1997-2013.)

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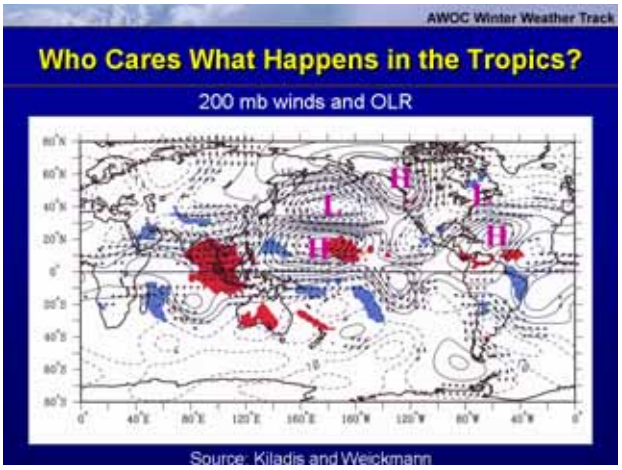

14. The Difference Between Kelvin and Rossby Waves

Instructor Notes: Kelvin waves move eastward along the equator at 10-15 m/s and are often produced as a response to an abrupt wind change (easterlies to westerlies), typically from a local convective flare-up or forcing from the extratropics. They have certain time and space scales that we discussed earlier. The major, or 'long' waves (also known as Planetary Waves or Rossby Waves) we see on upper air maps are produced largely because the atmosphere in motion encounters barriers to its progress, and is forced to ascend (by the changing surface level), then allowed to descend (under gravitational influence), and the resultant “squashing” and “stretching” respectively of the air columns involved lead to alterations to the rates of “spin” of the air flow (vorticity). These variations in the rate of spin must be balanced on a rotating earth for the system to remain stable -- assuming there are no other forces at work. The principle is known as, the Conservation of Absolute Vorticity, and was investigated by Carl-Gustav Rossby and others in the late 1930's. When considering the northern hemisphere, air that is forced to ascend tends to turn to the left, and as it descends again, it tends to turn to the right, inducing a ridge/trough pattern in the broadscale westerlies. These long waves are often known as Rossby waves, after the person who did so much to investigate their character. Major mountain chains provide obvious sources of such deflection, and the Rockies and the Andes, which lie astride the westerly flow in each hemisphere, provide good examples. These long-waves are key elements in the atmospheric circulation, and can be traced well into the stratosphere. At any one time, there are between 3 and 7 such waves, the number in any particular latitude band dependent upon a fine balance between the speed of the airflow through the trough/ridge system and the wavelength. The symmetric Rossby wave moves westward at 7-9 m/s and may be forced by trade wind or pressure surges over the eastern oceans. The restoring force for atmospheric Rossby waves is the Coriolis force.

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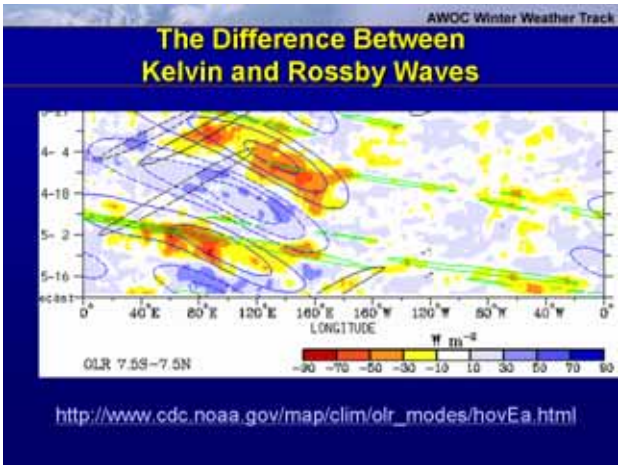

15. How are MJO Events Triggered?

Instructor Notes: The idealized description is simplistic, and isolates it from other variations. In reality, the speed and size of each event are variable, and not all of the elements of the MJO -- convection, zonal wind, moisture convergence, and SST anomalies -- are always visible. It is only when the 30-60 day oscillations are extracted from a series of MJO events that an idealized picture of the MJO emerges. The MJO exhibits a mixed Kelvin-Rossby wave structure over the eastern hemisphere, but over the western hemisphere, it shows a Kelvin wave structure except where convection anomalies get large and stationary, e.g., South America. It moves through the eastern hemisphere at around 5 m/s and through the western hemisphere at a higher speed (at least 15 m/s). How exactly the anomaly propagates from the dateline to Africa (i.e. through the western hemisphere) is not well understood. The oscillation is stronger in the northern hemisphere winter. It is also in this season that the negative OLR anomalies are most likely to propagate along the equator from the Indian Ocean to the central Pacific Ocean. In the northern hemisphere summer, many of the anomalies veer away from the tropics before they make it to the central Pacific.

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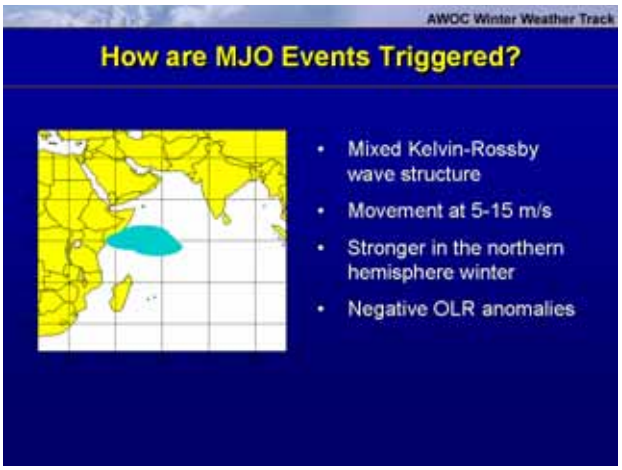

16. Natural Variability with the MJO

Instructor Notes: There is strong year-to-year variability in MJO activity, with long periods of strong activity followed by periods in which the oscillation is weak or absent. This interannual variability of the MJO is partly linked to the ENSO cycle. Strong MJO activity is often observed during weak La Niña years or during ENSO-neutral years, while weak or absent MJO activity is typically associated with moderate to strong El Niño episodes. Since each MJO occurs in a different synoptic pattern, the effects of the MJO on the extratropics tend to also be different from MJO to MJO, making forecasting of effects difficult. The MJO has been shown to have been an important player in initiating or ending of several ENSO events. Why doesn't EVERY MJO trigger an El Niño event? Could be the Charge/Discharge Theory, which states that: MJO is the TRIGGER—it happens much more often than the El Niño event itself, and not every trigger is exactly right. Even when the trigger is right, maybe ocean conditions are not yet right. Once things have charged up properly, and the ocean-atmospheric coupled system is ready, an El Niño occurs. MJOs may play a role in the transition to an El Niño or La Niña. This means they help determine details of the timing and/or amplitude of a warming or cooling event. However, the transitional stage of an ENSO event is complicated and the MJO's role is still being investigated. MJOs were prominent during the 1996-97 northern winter at the early stage of the 1997-98 El Niño and this led to heightened awareness of a possible MJO-ENSO link. The 1996-97 MJO activity was by some measures the greatest in the ~30 year record of outgoing longwave radiation.

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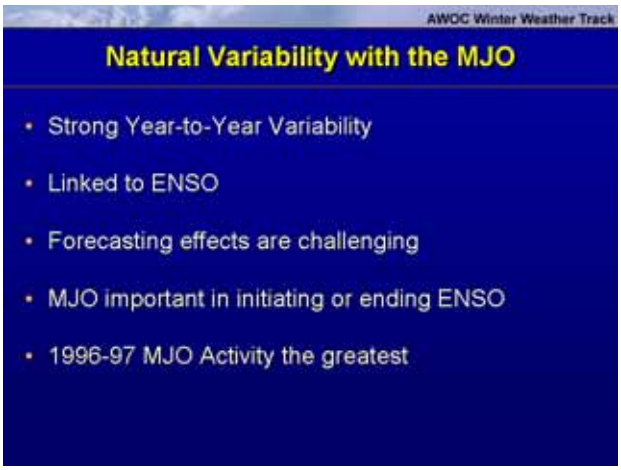

17. Monitoring and Predicting the MJO

Instructor Notes: Due to its slowly evolving nature, accurate prediction of the MJO and its effects is fundamentally related to our ability to monitor the feature and to assess its relative position and strength. Dynamical models generally do not predict the MJO well, partly because of the inherent difficulties that still remain regarding the correct mathematical treatment of tropical convective (rainfall) processes. Satellite-derived data are

used to indicate regions of strong tropical convective activity, and regions in which the convective activity departs substantially from the long-term mean.

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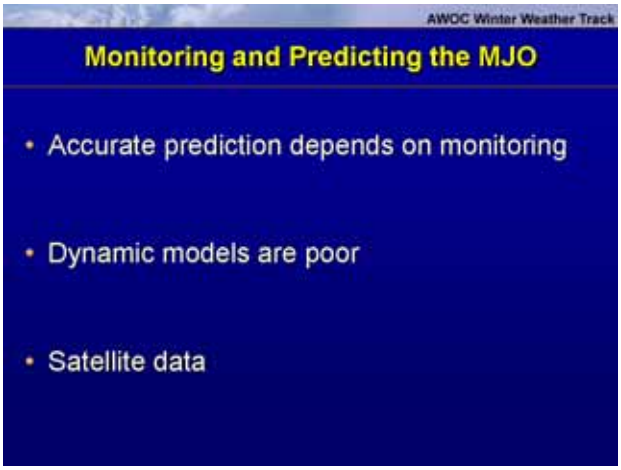

18. Monitoring and Predicting the MJO

Instructor Notes: A second fundamental data source used to monitor the MJO is the global radiosonde network which provides crucial information regarding the atmospheric winds, temperature, moisture, and pressure at many levels of the atmosphere. There are several diagnostic variables that allow us to directly monitor the MJO. The variables are often displayed in time-longitude format so as to reveal the propagation, amplitude and location of the MJO-related features. Typical variables include: 1) Outgoing Longwave Radiation, which is a satellite-derived measure of tropical convection and rainfall, 2) Velocity Potential, which is a derived quantity that isolates the divergent component of the wind at upper levels of the atmosphere, 3) Upper-level and lower-level wind anomalies, which show the large-scale cyclones and anticyclones (i.e., wave numbers 1-3) that straddle the convection, and 4) 500 mb height anomalies, which can represent the atmospheric response in midlatitudes.

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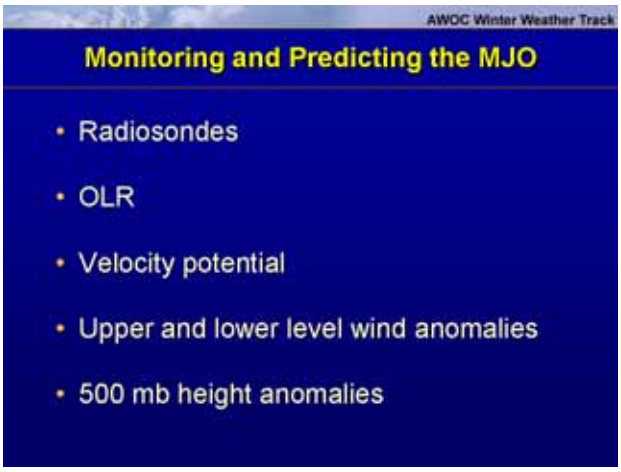

19. Outgoing Longwave Radiation (OLR)

Instructor Notes: Most tropical rainfall is convective. Deep convective cloud tops are very cold so they emit only small amounts of longwave radiation. The MJO is most obvious in the variation of OLR, as measured by an infrared sensor on a satellite. OLR anomalies in the eastern hemisphere propagate to the east at around 5 m/s with a recurrence interval of about 30 to 60 days. The OLR signal is weaker in the western hemisphere. The blue areas on the right image show propagating areas of OLR suppressed areas (ie, MJOs) The MJO activity is quite variable as shown above on the left. (For more information see http://www.cdc.noaa.gov/map/images/olr/olrmodes.hov.combine.anom.gif (diagram on right), and http://www.bom.gov.au/bmrc/clfor/cfstaff/matw/maproom/RMM/ts.PCvar91drm.gif (diagram on left))

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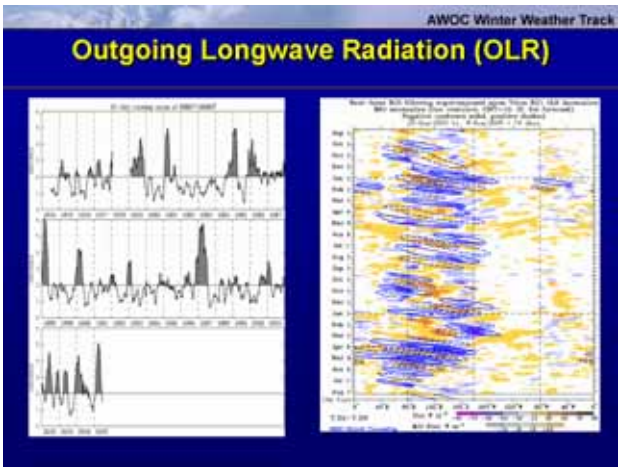

20. Finding the MJO Signal

Instructor Notes: The upper panel shows the total daily mean OLR field; the middle panel shows the same field but with the annual cycle (i.e., mean 27 March field) subtracted, and in the lower panel the OLR data have been passed through a 20-200 day bandpass filter. Individual MJO events follow the same general pattern as the composite MJO life cycle that has been presented, with negative OLR anomalies moving eastward from the Indian Ocean to the western Pacific, followed by positive OLR anomalies. However, there are also large differences between the individual events. (Note: figure reference is Matthews, A. J., Hoskins, B. J., Slingo, J. M., & Blackburn, M. (1996). Development of convection along the SPCZ within a madden-julian oscillation. Quarterly Journal of the Royal Meteorological Society, Berkshire, England, 122(531), 669-688.)

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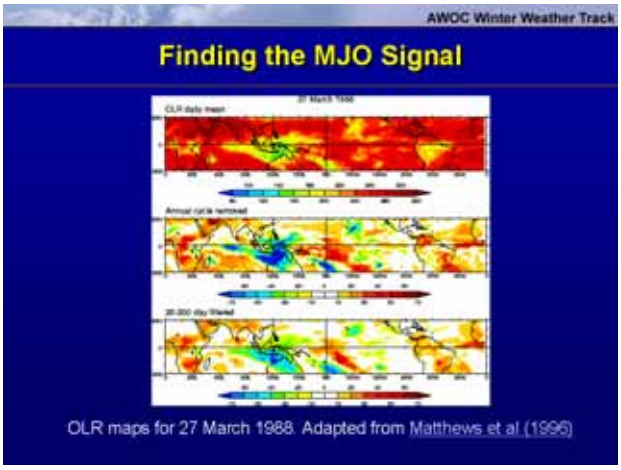

21. Velocity Potential Anomalies

Instructor Notes: Velocity potential anomalies at 150 or 200 mb are proportional to upper level divergence and convergence; the green contours correspond to regions of large-scale upper-level divergence where convection tends to be enhanced; whereas the brown contours correspond to areas of upper-level convergence, where convection is suppressed. Using plan view maps such as this helps scientists locate and track MJO activity. (note: the reference for this image is http://www.cpc.ncep.noaa.gov/products/precip/CWlink/ir_anim_monthly.shtml)

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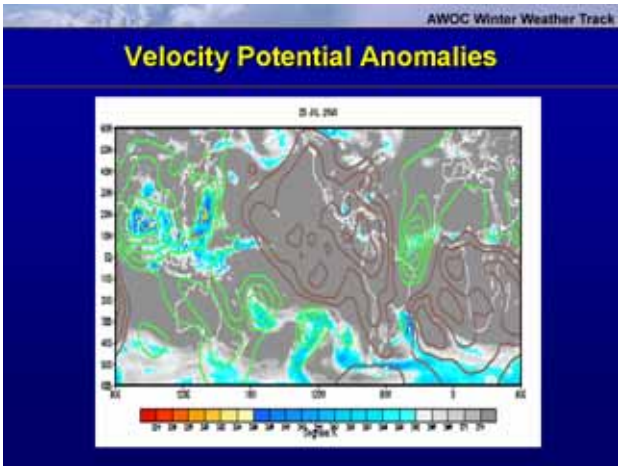

22. Wind Anomalies

Instructor Notes: Examining wind anomalies both in the low levels (weakening easterlies or westerly wind bursts) and especially at high levels (cyclonic and anticyclonic circulations) can be useful in identifying the strength and the possible large-scale mid-latitude effects of an MJO event. (Reference is http://www.cdc.noaa.gov/map/clim/glb-cir.quick.shtml)

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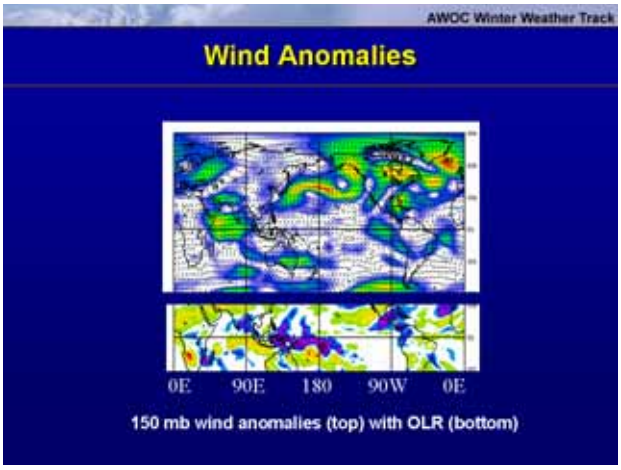
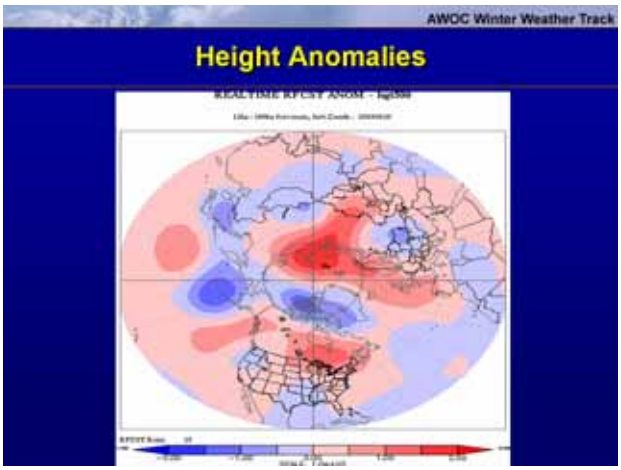


23. Height Anomalies

Instructor Notes: Look for the tilt of the waves, a resultant pattern which can then affect the background weather pattern. Using height anomalies can highlight the Rossby wave train effects that can occur with vigorous long-lived convection in tropical regions. Time-longitude diagrams of 250 mb height anomalies averaged between 30-60 N can be used to monitor synoptic wave activity and to diagnose MJO-related impacts. (Note: web site where this data comes from is http://www.cdc.noaa.gov/MJO/Forecasts/)

Student Notes:



24. Wheeler Diagram

Instructor Notes: Based on analyses of 200 mb zonal wind, 850 mb zonal wind and OLR, eight different phases of the MJO were defined by Wheeler and Hendon (2004). The Wheeler Diagram plots the location of the center of active convection of the MJO in a representative phase space. A point's distance from the origin is a measure of the MJO signal strength. This graphic shows a strong MJO propagating into the western hemisphere during late May 2005 (red line) and then weakening as it approaches Africa. MJO activity remained weak during most of June and July 2005. The index can be used for

forecasting the MJO and for diagnosing local weather conditions for the different MJO phases. You should be aware that sometimes there are problems with this diagram, particularly when the atmosphere is transitioning from one ENSO state to another. Therefore, what may look like an MJO signal, may not actually be one. This was the case in Jan/Feb 2006, as we transitioned from neutral to La Niña conditions. Later, you will be given references to find real time Wheeler plots and all of the other data you've been shown in this lesson. (note: reference is "An All-Season Real-Time Multivariate MJO Index: Development of an Index for Monitoring and Prediction: Matthew C. Wheeler and Harry H. Hendon, 2004: Monthly Weather Review, 132, 1917-1932.)

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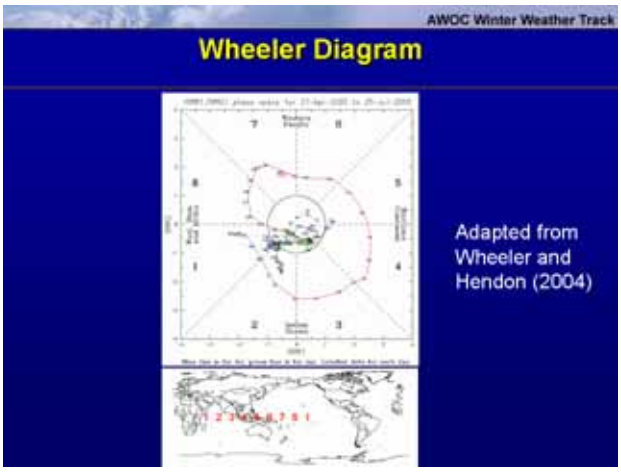

25. Synoptic Model of the MJO

Instructor Notes: The MJO, assuming it is significant and large enough, can produce persistent (1-3 week) changes in the atmospheric flow that can be anticipated based on its oscillatory behavior. These changes can influence the development and propagation of synoptic-scale weather systems, i.e. they influence and interact with the storm tracks. The MJO life cycle can be broken down into stages (phases) using an index based on the location of the MJO's tropical convection anomaly. The atmosphere's observed large-scale circulation and/or local weather anomalies can then be averaged over many cases to produce a "composite" anomaly for each stage. Because the MJO extratropical signal is weak there are large variations of the actual circulation or weather observed in individual cases. Other processes may overwhelm or mask the MJO signal.

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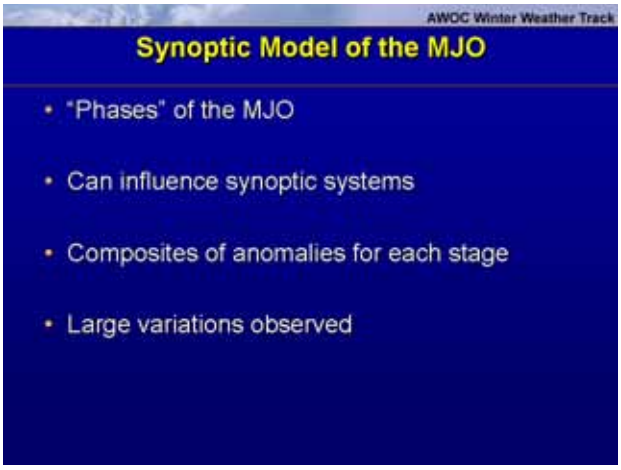

26. Potential Impacts on the U.S.

Instructor Notes: The MJO can have significant impacts on the wintertime atmospheric circulation over the North Pacific and western North America. The strongest impacts of intraseasonal variability on the U.S. occur during the winter months over the western U.S. During the winter this region receives the bulk of its annual precipitation. Storms in this region can last for several days or more and are often accompanied by persistent atmospheric circulation features. From these studies it is known that extreme precipitation events can occur at all phases of the ENSO cycle, but the largest fraction of these events occur during La Niña episodes and during ENSO-neutral winters. In these winters there is a stronger linkage between the MJO events and extreme west coast precipitation events It is also a contributor to blocking activity (i.e. atmospheric circulation features that persist near the same location for several days or more) and block evolution over the high latitudes of the North Pacific, which is another important component of winter weather patterns over North America. In any given year there are periods of enhanced / suppressed tropical storm/hurricane activity within the season. There is evidence that the MJO modulates this activity by providing a large-scale environment that can be favorable or unfavorable for development. The strongest tropical cyclones tend to develop when the MJO favors enhanced precipitation. As the MJO progresses eastward, the favored region for tropical cyclone activity also shifts eastward from the western Pacific to the eastern Pacific and finally to the Atlantic basin, assuming other environmental factors are favorable for tropical disturbances to form and persist. Velocity Potential graphics are very useful for viewing this. Since tropical cyclones will be covered in future AWOC training, we will not cover more about them here.

Instructor Notes:

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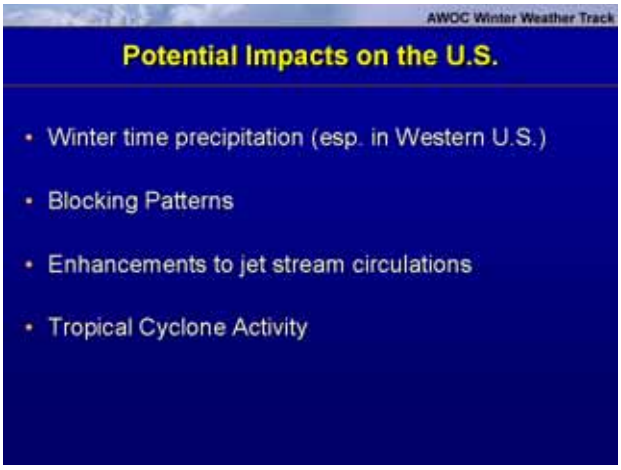

27. Heavy West Coast Precipitation Events

Instructor Notes: The typical scenario linking the pattern of tropical rainfall associated with the MJO to extreme precipitation events along the West Coast features a progressive (i.e. eastward moving) circulation pattern in the tropics and a retrograding (i.e. westward moving) circulation pattern in the midlatitudes of the North Pacific. The MJO is more likely to generate this type of event when a positive PNA pattern is already in place. (note: The figure comes from http://www.cpc.ncep.noaa.gov/products/intraseasonal/intraseasonal_faq.html)

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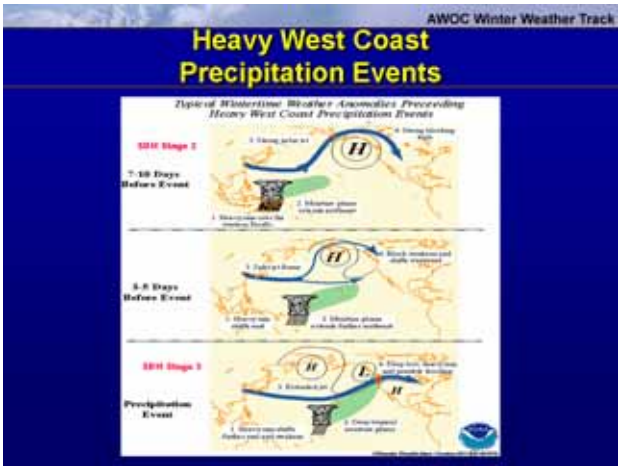

28. General Relationship Between Persistent Tropical Convection and West Coast Precipitation

Instructor Notes: If you think about the further west the disturbance is, then you will envision that the Low that develops is also further west. Therefore, the downstream ridging from this will also be further west and then the resulting precipitation will be further north. It is important to note that the overall linkage between the MJO and extreme west

coast precipitation events weakens as the region of interest shifts southward along the west coast of the United States. (note: The figure comes from http://www.cpc.ncep.noaa.gov/products/intraseasonal/intraseasonal_faq.html)

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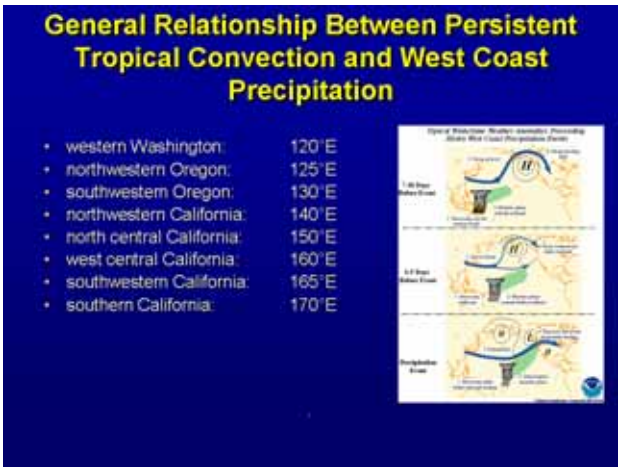

29. Summary

Instructor Notes: The MJO is a naturally occurring phenomenon which moves from the Indian Ocean into the central Pacific Ocean at 5-10 m/s with time scales from ~30 to 60 days. The MJO has been shown to directly affect Indian rainfall and tropical storm formation, along with effects even in globally averaged quantities and mid-latitude weather. Numerical models handle tropical convection poorly, so long-range forecasts will typically be underdone with jet stream energy, or not anticipate mid-latitude blocking forced by the tropical heating.

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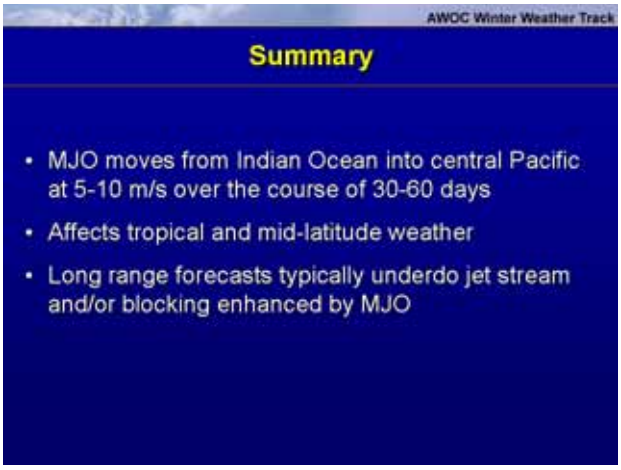

30. Summary

Instructor Notes: Because each MJO is different, and the global pattern which the MJO is occurring in is also different, the resultant modifications to the weather pattern can be

difficult to predict. However, the location of the tropical heating does lead to some “more likely” scenarios, as shown through research. The MJO typically leads to increased variability, especially in the winter. It can produce ENSO-like features on time scales of approximately 30-60 days. The MJO is most active during ENSO-neutral and weak-ENSO winters, and influences the occurrence of extreme weather events, such as floods, along the Pacific Northwest Coast. Monitoring CPC products and discussions regarding the MJO can lead to possible improvements in the long-range forecasts issued by the NWS, in a probabilistic sense.

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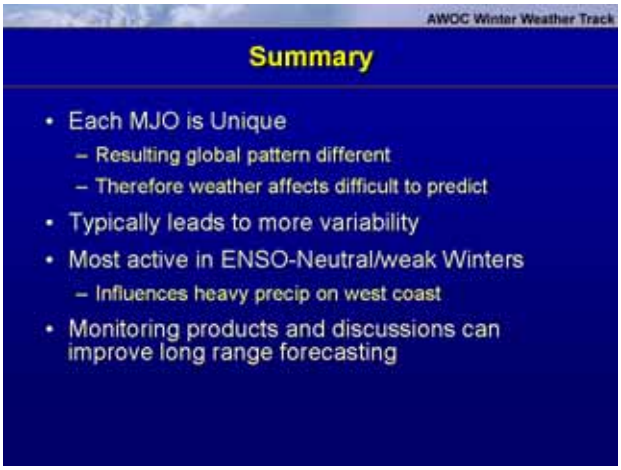


31. MJO Quiz

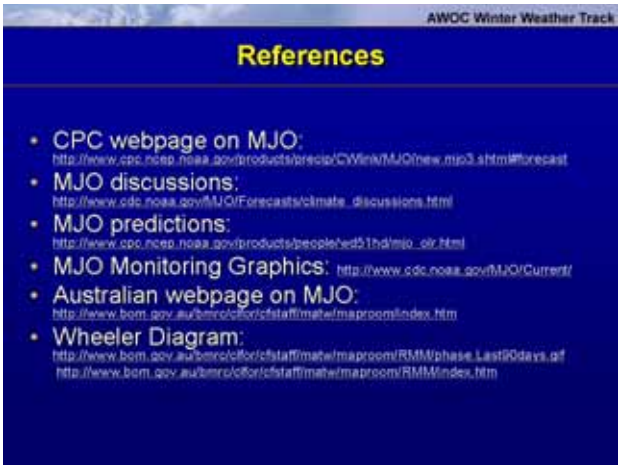
Instructor Notes: Take a moment to complete this interactive quiz.

Student Notes:

32. References

Instructor Notes: Here are some references on MJO that you may want investigate further.

Student Notes:



33. Acknowledgements

Instructor Notes: I would like to thank the following individuals for their support in the creation of this module: Mike Staudenmaier, SOO/Flagstaff Tom Salem, SOO/Glasgow Tony Haffer, MIC/Phoenix Dr. Klaus Weickmann, Meteorologist/CDC

Student Notes:

34. Questions???

Instructor Notes: After going through this lesson if you have any questions, first ask your SOO. Your SOO is your local facilitator and should be able to help answer many questions. If you need additional info from what your SOO provided, send an E-mail to the address on the slide. This address sends the message to all the instructors involved with this IC. Our answer will be CC'd to your SOO so that they can answer any similar questions that come up in the future. We may also consider the question and answer for our FAQ page.

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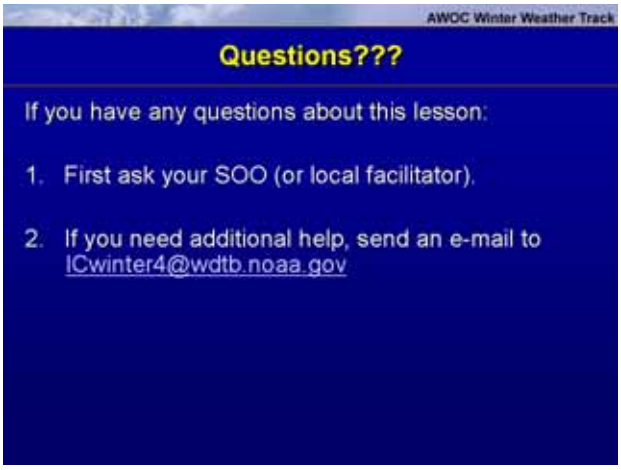

1. IC4.1 Part 3: Climatology - Teleconnections

Instructor Notes: Welcome to the third sub lesson in Instructional Component 4, Climatology. In this lesson we'll discuss some "Teleconnections" and how they affect winter weather in the US.

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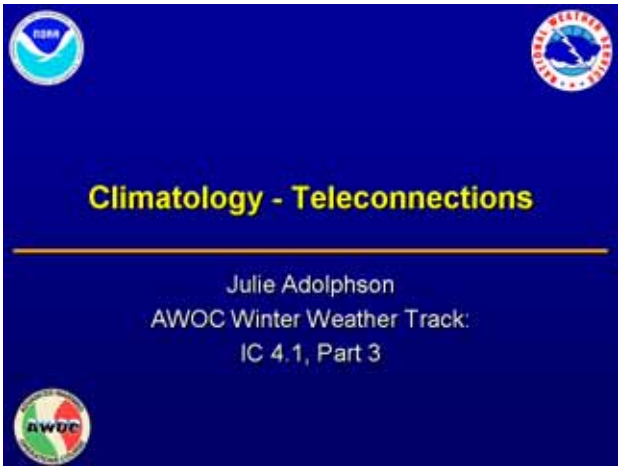

2. Purpose of Lesson 1.3

Instructor Notes: We've already discussed the importance of understanding slowly evolving systems on large space and time scales…El Niño, La Niña, Southern Oscillation and the MJO, in lessons 1.1 and 1.2. In this lesson, 1.3, we'll take a look at "teleconnections" which are correlations or "patterns" in space and time of atmospheric parameters such as sea level pressure or 500 mb heights. We'll take a look at a few of these patterns and see how they are monitored and what their effect is on U.S. weather. I should point out that while observing what "phase (positive or negative)" a particular teleconnection is currently in is straightforward, prediction is another matter all together, just as we saw with the MJO and ENSO.

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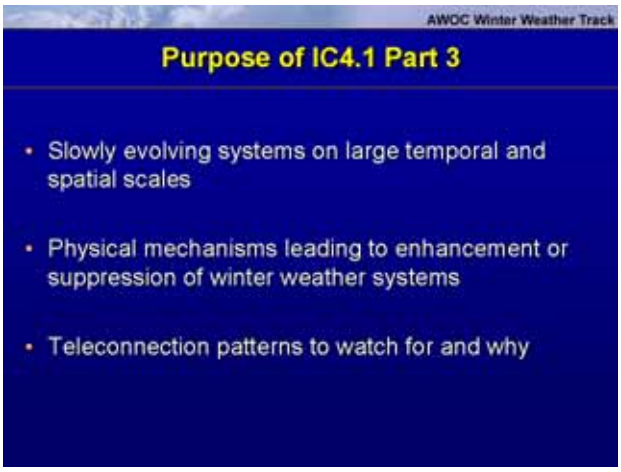

3. IC 4 Lesson 1.3 Learning Objectives

Instructor Notes: We will focus on helping you look at the "big picture" in space and time to help you assess the potential for upcoming winter storms in your area of responsibility. We'll see how these "slowly evolving" correlations, called teleconnections manifest themselves and how they influence weather in the US. We'll also see how these phenomena are monitored, and in later sections we'll take a look at resources you can use to assess the state of the climate system and what the latest predictions are for the medium and longer ranges.

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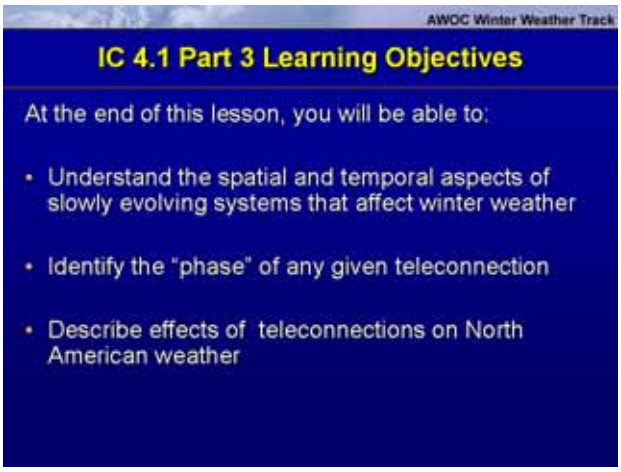

4. Performance Objectives

Instructor Notes: After this lesson you should be able to investigate the current state of the atmosphere in large temporal and spatial scales and correlate that to the potential for winter storms. Also, you will be able to determine the "mode" of the climate system and what to expect for the winter season in terms of temperature and precipitation anomalies (or lack thereof). You will understand the mechanisms that contribute to a higher or lower probability of winter storms in your area. Finally, you will be able to distinguish between different types of teleconnections and understand what significance they have in the winter for the US.

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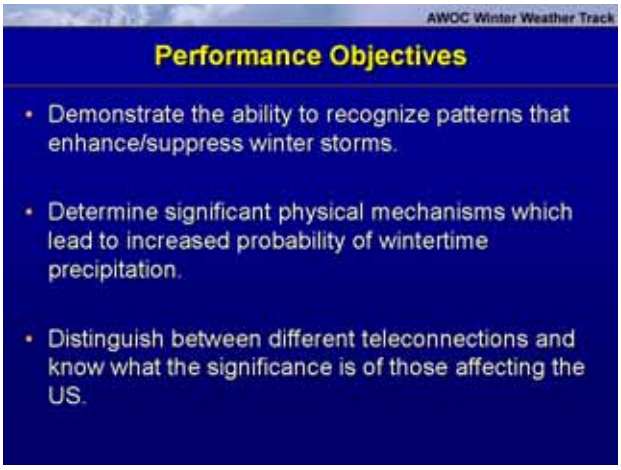

5. Lesson 1.3 Outline

Instructor Notes: In this lesson we will discuss “teleconnections.” We will define them, and find out where they occur, how we measure their state, and what is their effect is on U.S. weather.

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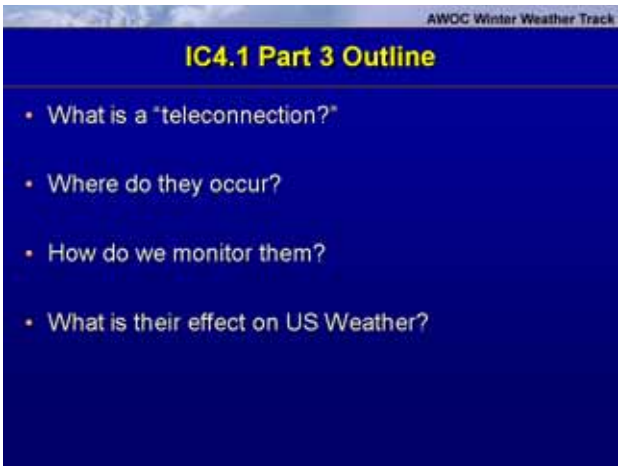

6. Teleconnections

Instructor Notes: A teleconnection is a strong statistical relationship between weather in different parts of the globe. For example, there appears to be a teleconnection between the tropics and North America during ENSO. There are several teleconnections that are important to the weather in the US. For example, Pacific-North American or PNA, the Arctic Oscillation or AO, the North Atlantic Oscillation or NAO, and Tropical Northern Hemisphere or TNH. We'll look at the patterns associated with these teleconnections and also look at "indices" which are used to determine whether the pattern is in a negative or positive phase. There are other teleconnections, such as the Pacific Decadal (or PDO) and the Antarctic Oscillation or AAO that we will not cover in this lesson. As I mentioned earlier, the predictability of teleconnections is very challenging…the mod-

els struggle to accurately predict these patterns, and much work is still needed even in the ensemble prediction system to improve the skill of predicting the "phase" and amplitude of any given teleconnection pattern. The term "teleconnection pattern" refers to a recurring and persistent, large-scale pattern of pressure and circulation anomalies that span vast geographical areas. Teleconnection patterns are also referred to as preferred modes of low-frequency (or long time scale) variability. Although these patterns typically last for several weeks to several months, they can sometimes be prominent for several consecutive years, thus reflecting an important part of both the interannual and interdecadal variability of the atmospheric circulation. Many of the teleconnection patterns are also planetary-scale in nature, and span entire ocean basins and continents. For example, some patterns span the entire North Pacific basin, while others extend from eastern North America to central Europe. All teleconnection patterns are a naturally occurring aspect of our chaotic atmospheric system, and can arise primarily as a reflection of internal atmospheric dynamics. Additionally, some of these patterns, particularly those over the North Pacific, are also sometimes forced by changes in tropical sea-surface temperatures and tropical convection associated with both the ENSO cycle (Mo and Livezey 1986, Barnston and Livezey 1991) and the Madden-Julian Oscillation (MJO). Teleconnection patterns reflect large-scale changes in the atmospheric wave and jet stream patterns, and influence temperature, rainfall, storm tracks, and jet stream location/ intensity over vast areas. Thus, they are often the culprit responsible for abnormal weather patterns occurring simultaneously over seemingly vast distances. For example, the 1995/ 1996 winter was very cold and snowy over much of eastern North America, while northern Europe and Scandinavia were cold and southern Europe/ northern Africa experienced very wet and stormy conditions. These conditions were all partly related to the same teleconnection pattern: a strong negative phase of the NAO. The Climate Prediction Center routinely monitors the primary teleconnection patterns and is involved in continuing research to better understand their role in the global climate system. Ten prominent teleconnection patterns can be identified in the Northern Hemisphere extratropics throughout the year, and all of these patterns have appeared previously in the meteorological literature (Barnston and Livezey 1987). References: (Mo, K. C., Livezey R. E., 1986: Tropical-extratropical geopotential height teleconnections during the Northern Hemisphere winter. Monthly Weather Review., 114, 2488-2515. Barnston, A. G., Livezey R. E., 1987: Classification, seasonality and persistence of low-frequency atmospheric circulation patterns. Monthly Weather Review.,115, 1083-1126. Barnston, A. G., Livezey R. E., Halpert M. S., 1991. Modulation of Southern Oscillation-Northern Hemisphere midwinter climate relationships by the QBO. Journal of Climate., 4, 203-217.)

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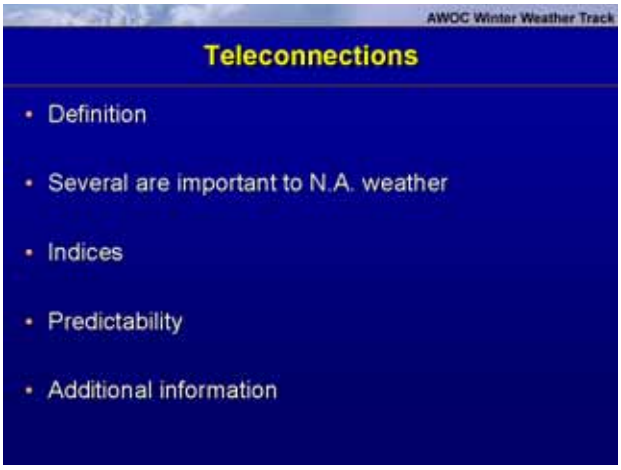

7. The Tropical/Northern Hemisphere (TNH)

Instructor Notes: The Tropical/ Northern Hemisphere (TNH) pattern was first classified by Mo and Livezey (1986), and appears as a prominent wintertime mode during December-February. The positive phase of the TNH pattern features above-average heights over the Gulf of Alaska and from the Gulf of Mexico northeastward across the western North Atlantic, and below-average heights throughout eastern Canada. The TNH pattern reflects large-scale changes in both the location and eastward extent of the Pacific jet stream, and also in the strength and position of the climatological mean Hudson Bay Low. Thus, the pattern significantly modulates the flow of marine air into North America, as well as the southward transport of cold Canadian air into the north-central United States.

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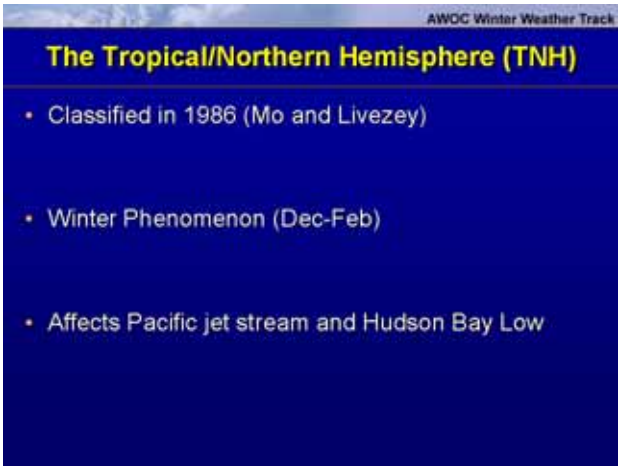

8. TNH (Continued)

Instructor Notes: The positive phase of the TNH pattern is associated with below-average surface temperatures throughout the western and central United States, and across central and eastern Canada. It is also associated with above-average precipitation

across the central and eastern subtropical North Pacific, and below-average precipitation in the western United States and across Cuba, the Bahama Islands, and much of the central North Atlantic Ocean. The negative phase of the TNH pattern is often observed during December and January during El Niño conditions (Barnston et al. 1991). One recent example of this is the 1994/95 winter season, when mature Pacific warm episode conditions and a strong negative phase of the TNH pattern were present. During this period, the mean Hudson Bay trough was much weaker than normal and shifted north-eastward toward the Labrador Sea. Additionally, the Pacific jet stream was much stronger than normal and shifted southward to central California, well south of its climatological mean position in the Pacific Northwest. This flow pattern brought well above-normal temperatures to eastern North America and above-normal rainfall to the southwestern United States.

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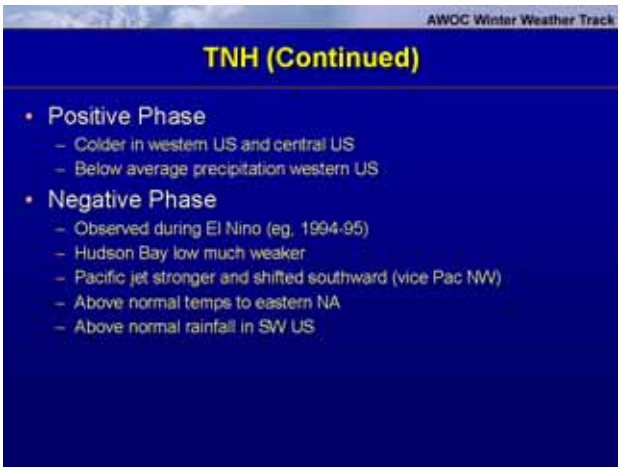

9. Height Anomalies for +TNH

Instructor Notes: This diagram of 500 mb height anomalies in January represents the positive phase of the TNH. The loading pattern (or statistical representation) for January is displayed so that the plotted value at each grid point represents the temporal correlation between the monthly standardized height anomalies at that point and the teleconnection pattern time series valid for the specified month. (note: figures on next 3 slides from http://www.cpc.ncep.noaa.gov/data/teledoc/tnh_map.shtml)

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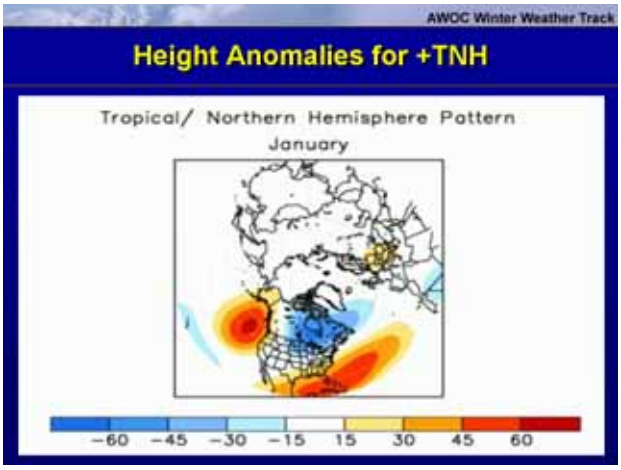

10. Positive Phase of TNH

Instructor Notes: Maps showing correlation during 1950-2000 between the teleconnection index and monthly surface temperature departures for the three months centered on the month of interest. For example, the January pattern shows the correlation between the January values of the teleconnection index and the monthly temperature departures during December, January, and February. Notice the blue, or colder area over much of the US and eastern Canada, which I mentioned previously.

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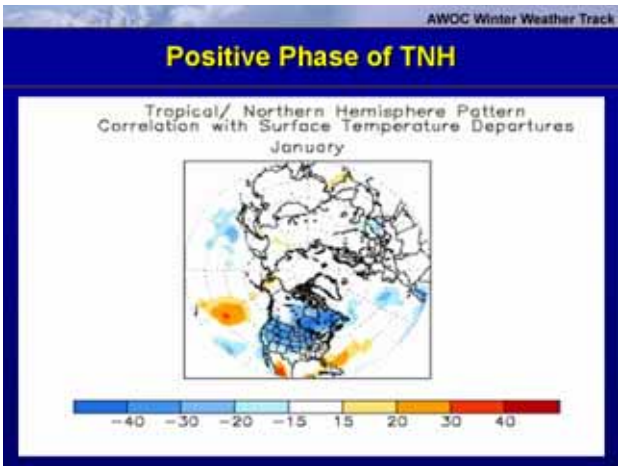

11. Precipitation Pattern with +TNH

Instructor Notes: Maps showing correlation during 1950-2000 between the teleconnection index and monthly precipitation departures for the three months centered on the month of interest. For example, the January pattern shows the correlation between the January values of the teleconnection index and the monthly precipitation departures during December, January, and February.

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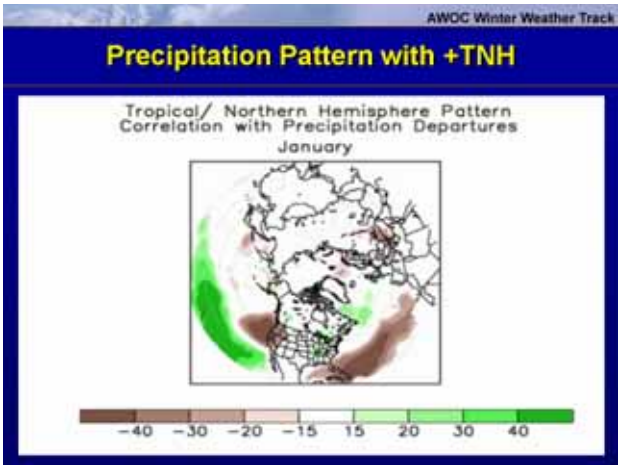
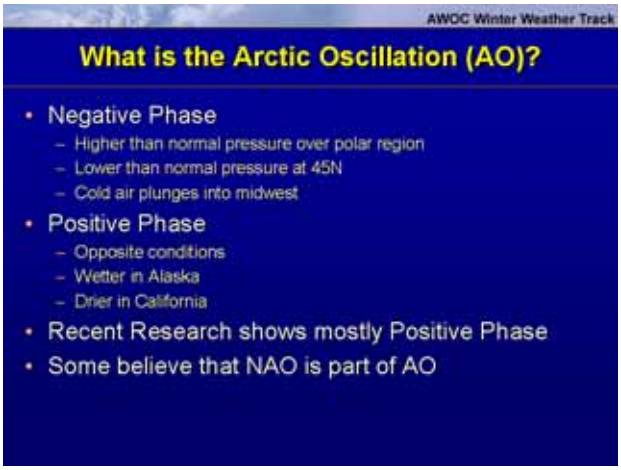


12. What is the Arctic Oscillation (AO)?

Instructor Notes: The AO is a pattern in which atmospheric surface pressure at polar and middle latitudes fluctuates between negative and positive phases. The negative phase brings higher-than-normal pressure over the polar region and lower-than-normal pressure at about 45 degrees north latitude. The negative phase allows cold air to plunge into the Midwestern United States and western Europe, and storms bring rain to the Mediterranean. The positive phase brings the opposite conditions, steering ocean storms farther north and bringing wetter weather to Alaska, Scotland and Scandinavia and drier conditions to areas such as California, Spain and the Middle East. In recent years research has shown, the AO has been mostly in its positive phase. Some researchers argue that the North Atlantic Oscillation is in fact part of the AO. If you think about the differences, it's really only the fact that for AO the pressure differences are taken further north than that of the NAO. The bottom line is: The effects on US weather should be basically the same.

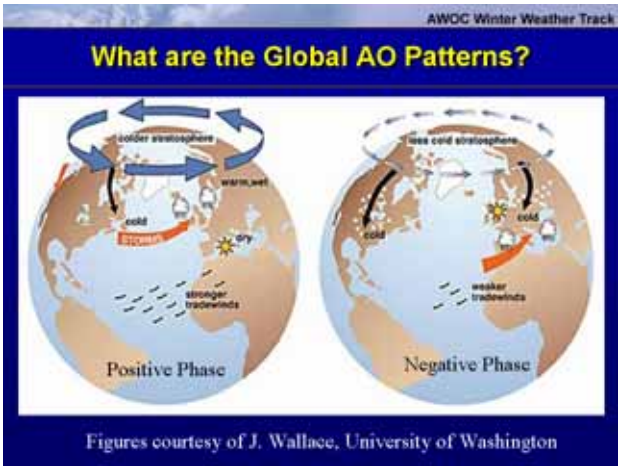
Student Notes:



13. What are the Global AO Patterns?

Instructor Notes: Here is a conceptual model of the AO adapted from the University of Washington. You can see here that in the positive phase, there are more storms across the north Atlantic into northern Europe, and stronger trade winds off the African continent and into the eastern Atlantic. During the negative phase, you see the colder air into the midwest and Europe. (note: figure from http://nsidc.org/arcticmet/patterns/arctic_oscillation.html)

Student Notes:



14. What are the AO Characteristics at 500 mb?

Instructor Notes: This diagram is the 500 mb heights and anomalies for different phases of the Arctic Oscillation. The top image shows the heights lines at 500 mb, with the shading being the anomalous (shaded) 500 mb height values when the AO is in the positive phase. The middle image shows AO neutral conditions, and the bottom image is AO negative anomalies at 500 mb. Note the lower than normal heights in the northern hemisphere polar region when the AO is in the positive phase, and the above normal heights in Pacific basin and the eastern US and into the Atlantic basin and Europe. During the negative phase you see the lower than normal heights over the midwest and Atlantic and Pacific basins, with the polar region and northern Atlantic having above normal heights. (note figure from http://www.cpc.ncep.noaa.gov/research_papers/ncep_cpc_atlas/8/table_ao.html)

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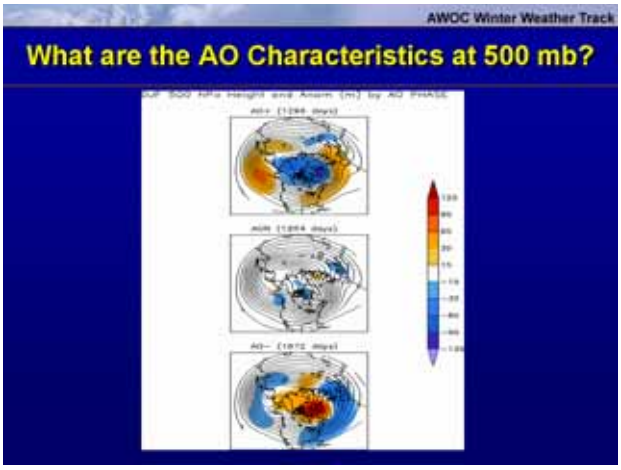

15. Are there Temp Departures for AO Modes?

Instructor Notes: The top image shows US temperature anomalies in DJF for AO+. The middle is for AO neutral. The bottom image shows surface temps when AO is negative. (figure from http://www.cpc.ncep.noaa.gov/research_papers/ncep_cpc_atlas/8/table_ao.html)

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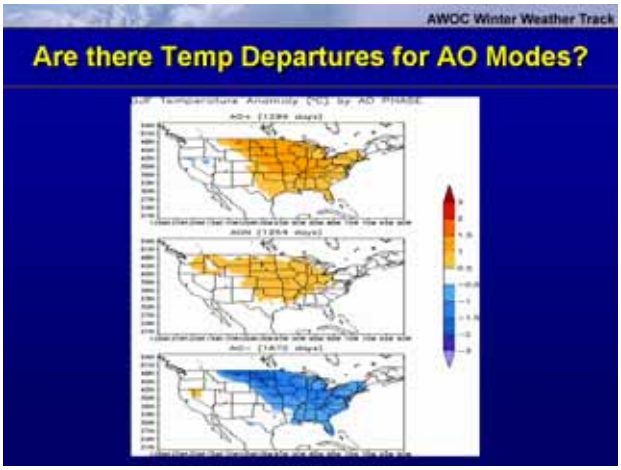
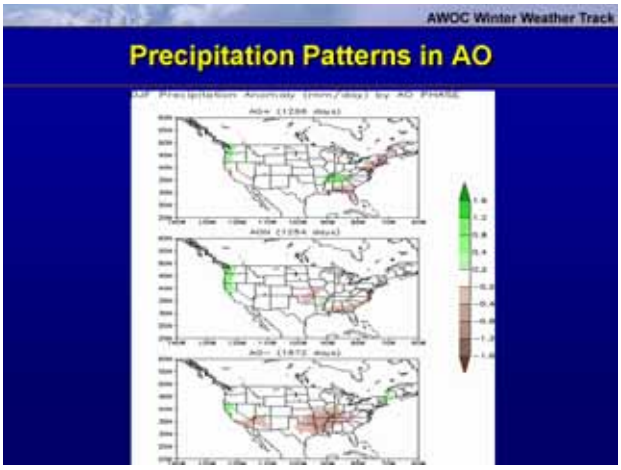


16. Precipitation Patterns in AO

Instructor Notes: This image shows precipitation patterns associated with different phases of AO. The top diagram is for positive phase, the middle is for neutral and the bottom is for negative. Notice the biggest area with the most contrast between positive and negative is in the southeast US. Precipitation tends to be a much more “noisy” signal in many studies of climate variability. (note: figure from http://www.cpc.ncep.noaa.gov/research_papers/ncep_cpc_atlas/8/table_ao.html)

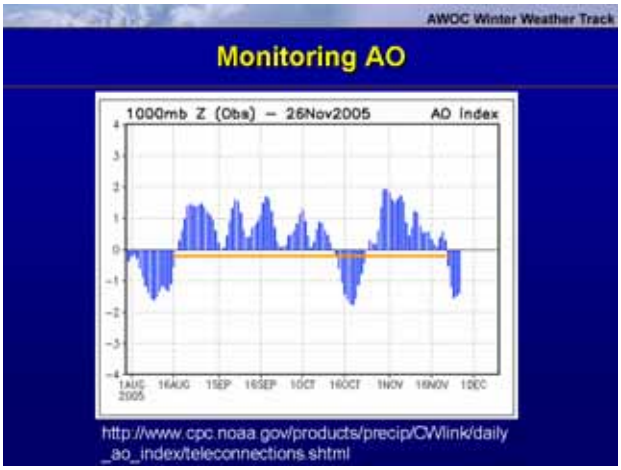
Student Notes:



17. Monitoring AO

Instructor Notes: In order to monitor and predict the phases of teleconnection patterns, indices have been developed such as you see here. The daily AO index is constructed by projecting the daily (00Z) 1000mb height anomalies poleward of 20°N onto AO loading pattern (climatology) that we discussed previously. Since the AO has the largest variability during the cold season, the loading pattern primarily captures characteristics of the cold season AO pattern, which you saw in the height and temperature patterns on previous slides.The daily AO index and its forecasts using GFS and Ensemble mean forecast data are shown for the previous 120 days, so in this case the plot is from the beginning of August to late November. Each daily value has been standardized by the standard deviation of the monthly AO index from 1979-2000. You can see that as mentioned previously, the AO has been mostly in a positive phase. You can read more about the construction of the AO index at the website listed at the bottom of this slide. (note: figure from http://www.cpc.noaa.gov/products/precip/CWlink/daily_ao_index/ao_index.html)

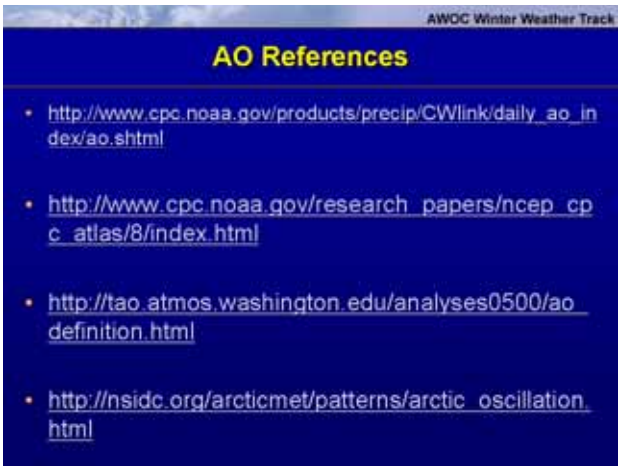
Student Notes:



18. AO References

Instructor Notes: Here are a list of web sites you can visit to get more information on the Arctic Oscillation.

Student Notes:



19. Teleconnection Quiz #1

Instructor Notes: Take a few moments to complete this interactive quiz.

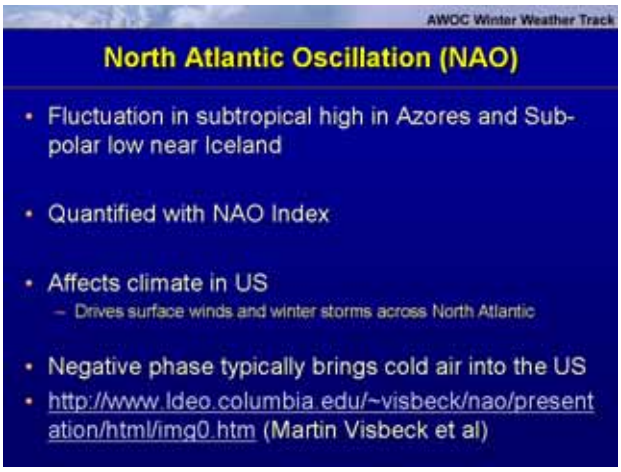
Student Notes:

20. North Atlantic Oscillation (NAO)

Instructor Notes: The NAO is a large-scale fluctuation in atmospheric pressure between the subtropical high pressure system located near the Azores in the Atlantic Ocean and the sub-polar low pressure system near Iceland and is quantified in the NAO Index, which we will discuss further in just a minute. The surface pressure drives surface winds and wintertime storms from west to east across the North Atlantic affecting climate from New England to western Europe, and as far eastward as central Siberia and the

eastern Mediterranean and southward to West Africa. It is considered either “the largest” or “one of the largest” oscillations in the Northern Hemisphere. It is a large-scale mode of natural climate variability having large impacts on weather and climate in the North Atlantic region and surrounding continents. It is most pronounced during winter and accounts for more than one-third of the total variance in sea-level pressure (Cayan, 1992a) The link at the bottom of the page is a tutorial from Columbia University.

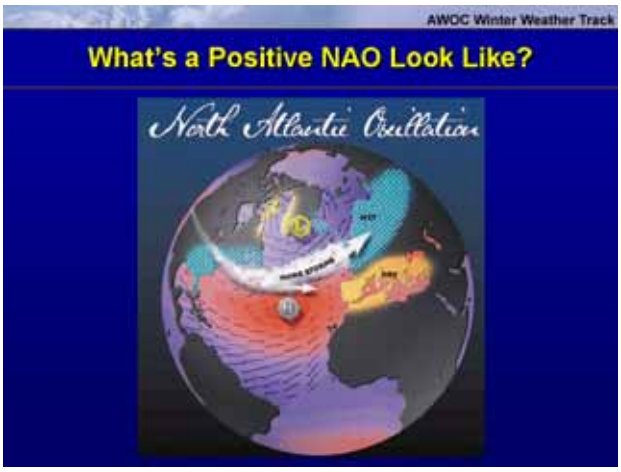
Student Notes:



21. What’s a Positive NAO Look Like?

Instructor Notes: Here is a picture of the NAO in it’s positive phase with Low pressure over Greenland and subtropical high pressure entrenched over the Azores. You can see the wetter than normal conditions that prevail over the eastern third of the US and into northern Europe and Siberia, while drier than normal conditions occur in the Mediterranean region. (note: figure from http://www.ldeo.columbia.edu/NAO/main.html)

Student Notes:



22. What's a Negative NAO Look Like?

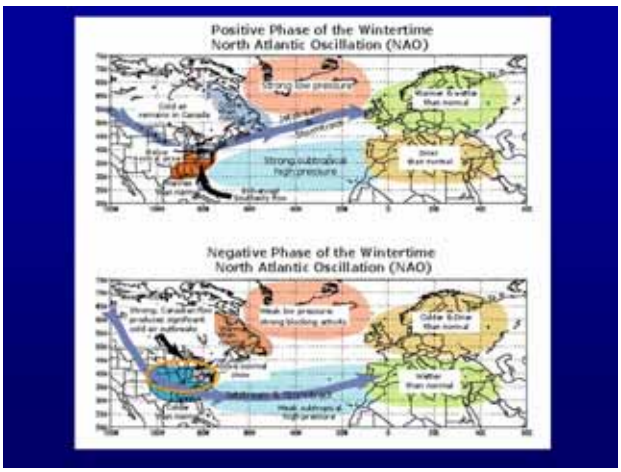
Instructor Notes: In the negative phase of the NAO, the lows and highs mentioned previously are much weaker. Colder air intrudes into the eastern US, but drier conditions prevail there as well as in northern Europe and into Siberia. Wetter conditions are seen in southern Europe and the Mediterranean. (NOTE: Figure from http://www.ldeo.columbia.edu/NAO/main.html)

Student Notes:

23. Phases of the Wintertime NAO

Instructor Notes: Here are typical conditions over the Atlantic and associated land masses. You can see the effects of the jet stream during the positive phase (top drawing) and the negative phase (bottom drawing). Notice the increased meridional nature of the jet over the lee side of the Rockies in the negative phase, which allows for increased intrusions of cold air into the eastern ½ of the US.

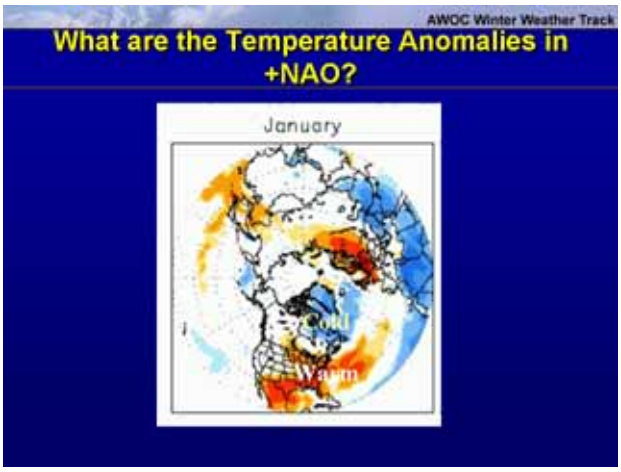
Student Notes:



24. What are the Temperature Anomalies in +NAO?

Instructor Notes: During the positive phase of the NAO, cold air remains over Canada, and warmer temps are seen over much of the continental US, especially in the eastern half and along the deep south. In the negative phase (not shown) Canadian air is allowed into the US and so the orange is replaced by blue.

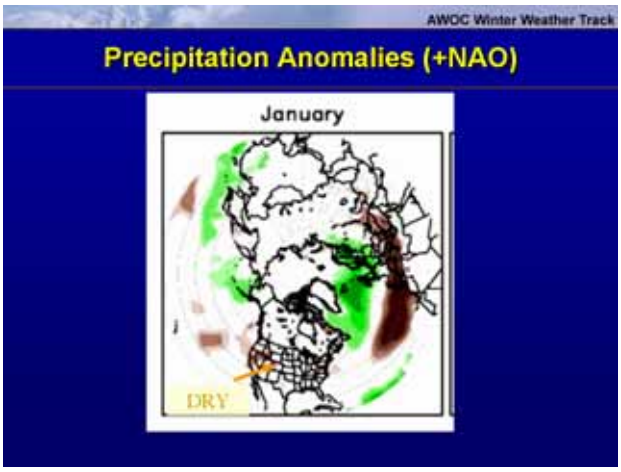
Student Notes:



25. Precipitation Anomalies (+NAO)

Instructor Notes: As we saw in AO, the precipitation signals for the US in +NAO (or -NAO for that matter) are not strong. Much stronger signals show up southeast of Iceland (wetter in +NAO) and the Mediterranean (drier in +NAO). There are somewhat drier conditions noted in the western US and into the eastern Pacific. Meanwhile somewhat wetter conditions prevail along the Aleutian chain and into the Bering Sea.

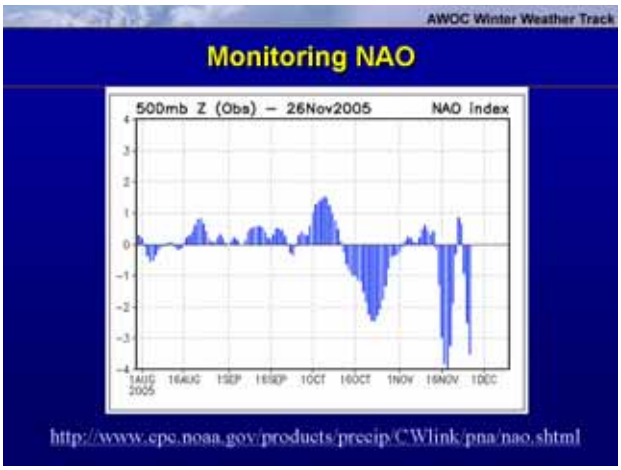
Student Notes:



26. Monitoring NAO

Instructor Notes: The daily NAO index corresponds to the NAO patterns, which vary from one month to the next. This index, like that for other teleconnection patterns is derived through a mathematical expression that considers a time series of atmospheric parameters (such as 500 mb heights in this case). The link at the bottom of this slide has further information about the methodology used to calculate the daily NAO index. The daily NAO index for the past 120 days is shown in this diagram. Each daily value has been standardized by the standard deviation of the monthly NAO index from 1950 to 2000.

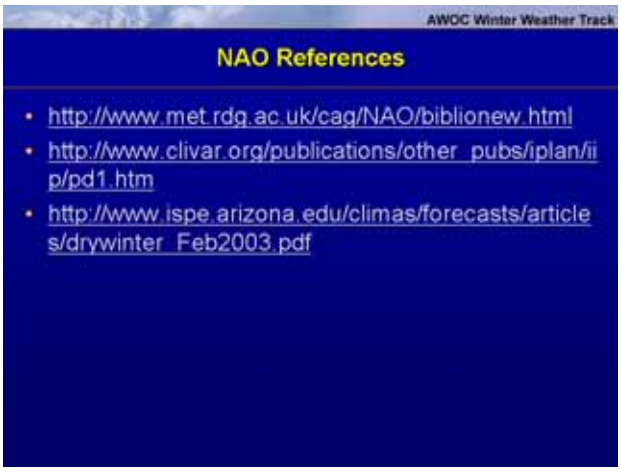
Student Notes:



27. NAO References

Instructor Notes: Here are a few references on the NAO.

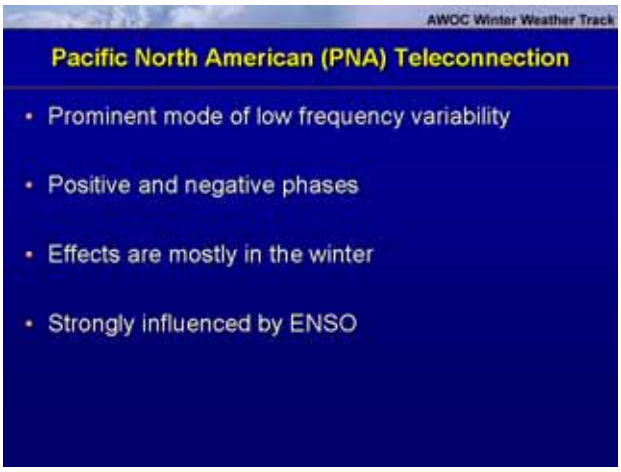
Student Notes:



28. Pacific North American (PNA) Teleconnection

Instructor Notes: The Pacific/ North American teleconnection pattern (PNA) is one of the most prominent modes of low-frequency variability in the Northern Hemisphere extra-tropics. Although the PNA pattern is a natural internal mode of climate variability, it is also strongly influenced by the El Niño/ Southern Oscillation (ENSO) phenomenon. The positive phase of the PNA pattern tends to be associated with Pacific warm episodes (El Niño), and the negative phase tends to be associated with Pacific cold episodes (La Niña).

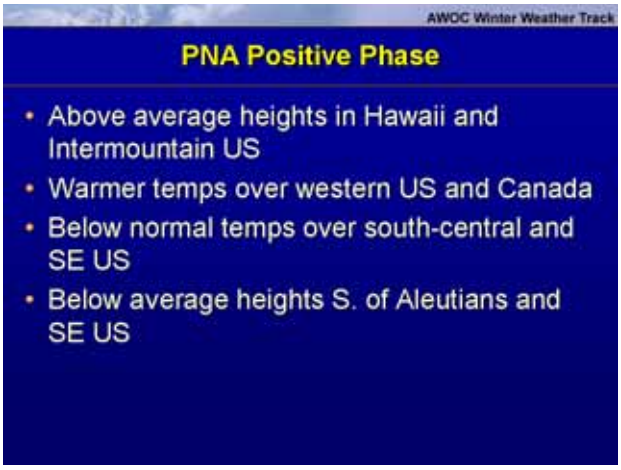
Student Notes:



29. PNA Positive Phase

Instructor Notes: The positive phase of the PNA pattern features above-average heights in the vicinity of Hawaii and over the intermountain region of North America, and below-average heights located south of the Aleutian Islands and over the southeastern United States. The PNA pattern is also associated with strong fluctuations in the strength and location of the East Asian jet stream. The positive phase is associated with an enhanced East Asian jet stream and with an eastward shift in the jet exit region toward the western United States. The positive phase of the PNA pattern is associated with above-average temperatures over western Canada and the extreme western United States, and below-average temperatures across the south-central and southeastern U.S., particularly during the wintertime. The associated precipitation anomalies include above-average totals in the Gulf of Alaska extending into the Pacific Northwestern United States, and below-average totals over the upper Midwestern United States.

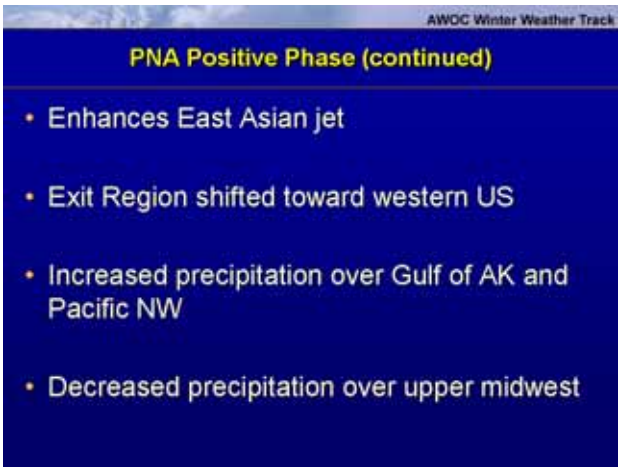
Student Notes:



30. PNA Positive Phase (continued)

Instructor Notes: Some of the other effects of the PNA are an enhancement in the east Asian jet which can enhance storm systems that enter the western US by the exit region of the East Asian (EA) jet. Also, increased vertical motion can be found over the Gulf of AK courtesy of this enhanced EA jet. Meanwhile, the upper Midwest of the US will have more ridging which will mean drier and warmer conditions there.

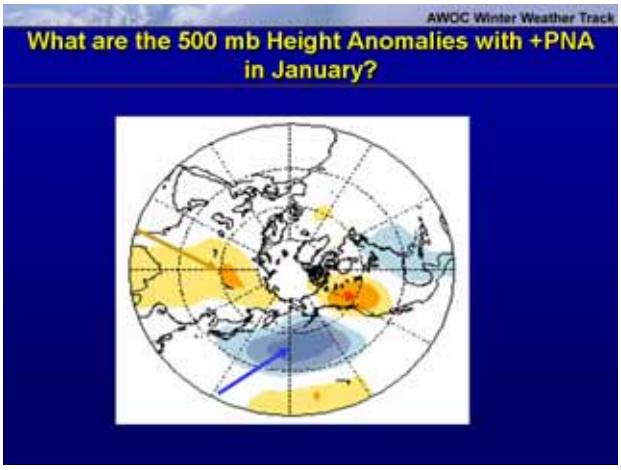
Student Notes:



31. What are the 500 mb Height Anomalies with +PNA in January?

Instructor Notes: Here is a diagram which shows the departures from normal of the 500 mb heights in January during a positive phase of the PNA. Notice the lower than normal heights over much of the Pacific basin, while higher than normal heights extend into the western US and Canada.

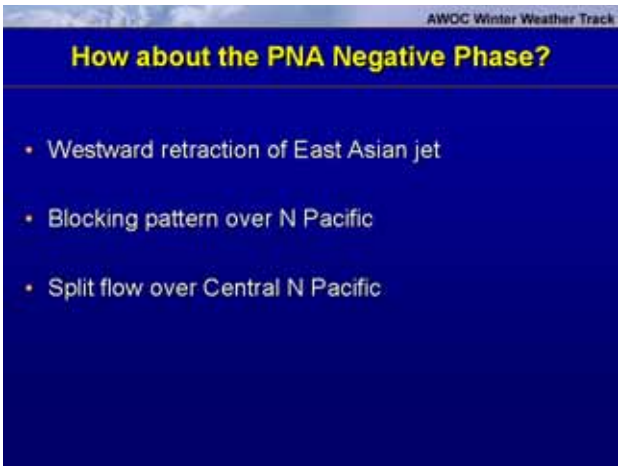
Student Notes:



32. How about the PNA Negative Phase?

Instructor Notes: During the PNA negative phase, the EA jet will retrograde back westward which will result in a blocking ridge over the North Pacific. This tends to lead to a split jet over the central Pacific and into the western US.

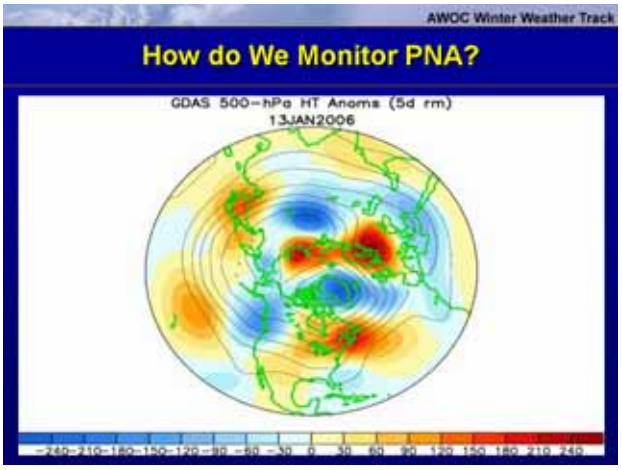
Student Notes:



33. How do We Monitor PNA?

Instructor Notes: To monitor the PNA, we look at 500-hPa heights and anomalies. If significant departures are noted in the height patterns, we determine that the PNA teleconnection is in a positive or negative phase. To better see the phase, like in the NAO, there is a index that is plotted on CPC's web site. On the web site, there is an animation with each frame being a five-day mean, centered on the date indicated in the title, of 500-hPa heights and anomalies from the NCEP Global Data Assimilation System (GDAS). Contour interval for heights is 120 m, anomalies are indicated by shading. Anomalies are departures from the 1979-95 daily base period means.

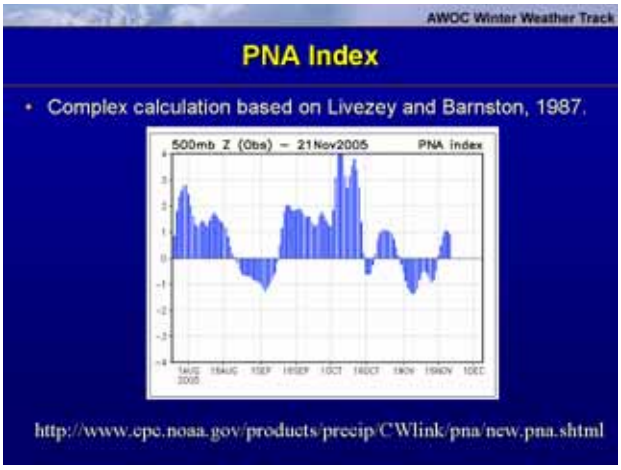
Student Notes:



34. PNA Index

Instructor Notes: The procedure used to calculate the daily PNA and NAO teleconnection indices is based on the Rotated Principal Component Analysis (RPCA) used by Barnston and Livezey (1987, Mon. Wea. Rev., 115, 1083-1126). This procedure isolates the primary teleconnection patterns for all months and allows time series of the patterns to be constructed. To obtain the teleconnection patterns, the RPCA technique is applied to monthly standardized 500-mb height anomalies between January 1950 and December 2000. The monthly teleconnection patterns are now linearly interpolated to the day in question, and therefore account for the seasonality inherent in the NAO and PNA patterns. The daily teleconnection indices are now calculated using the Least Squares regression approach identical to that used for the monthly indices. Therefore, all of the teleconnection patterns valid for the day in question are now recognized when calculating the PNA and NAO indices. The daily indices now represent the combination of teleconnection patterns that accounts for the most spatial variance of the observed anomaly map on any given day. Previously, the indices represented the spatial correlation between the annual mean loading pattern of the NAO or PNA and the daily height anomalies, and did not account for the spatial overlap that exists amongst the various teleconnection patterns.

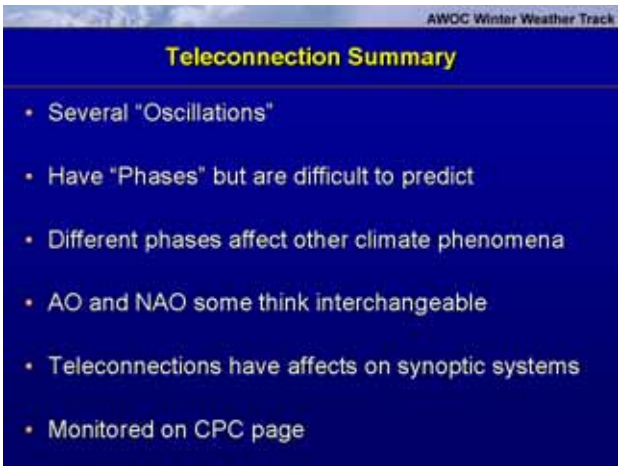
Student Notes:



35. Teleconnection Summary

Instructor Notes: “Teleconnections” are atmospheric relationships that are measured by looking at different levels in the atmosphere and comparing the current state with the “normal” through complex mathematics. The mode that a particular teleconnection is in is called a “phase”. There are positive and negative “phases” each of which have ramifications to the synoptic scale weather patterns. We will discuss more about the monitoring of teleconnections in the next section called CPC/CDC products.

Student Notes:



36. Teleconnections Quiz #2

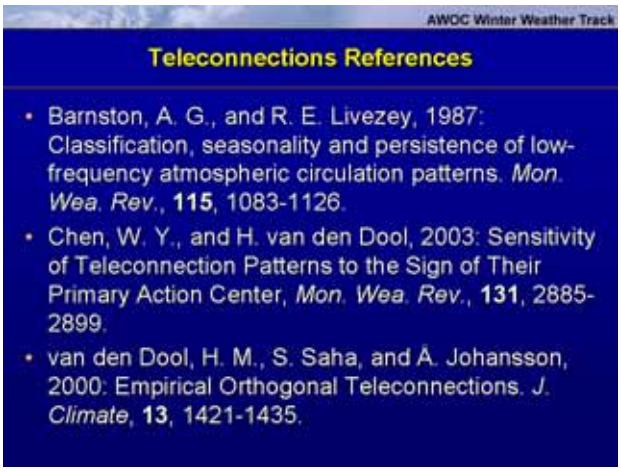
Instructor Notes: Take a few moments to complete this interactive quiz.

Student Notes:

37. Teleconnections References

Instructor Notes: Here are some references on teleconnections.

Student Notes:



38. Acknowledgements

Instructor Notes: I'd like to thank the following individuals for the support in creating this section: Mike Staudenmaier, SOO/Flagstaff, Tom Salem, SOO/Glasgow, Tony Haffer, MIC/Phoenix

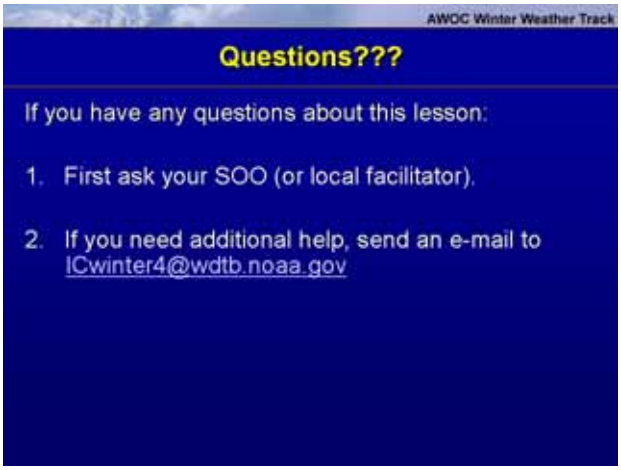
Student Notes:

39. Questions???

Instructor Notes: After going through this lesson if you have any questions, first ask your SOO. Your SOO is your local facilitator and should be able to help answer many questions. If you need additional info from what your SOO provided, send an E-mail to the address on the slide. This address sends the message to all the instructors involved with this IC. Our answer will be CC'd to your SOO so that they can answer any similar

questions that come up in the future. We may also consider the question and answer for our FAQ page.

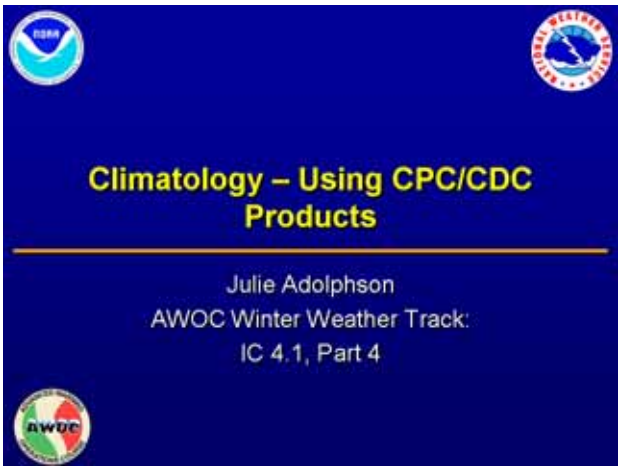
Student Notes:



1. IC4.1 Part 4: Climatology – Using CPC/CDC Products

Instructor Notes: In this section, we will review Climate Prediction Center and Climate Diagnostics Center products that can help you identify the current and forecast state of the climate system in order to better anticipate slowly evolving winter time weather. We will look at web resources from these two organizations that will assist you in determining important features which may affect you in the medium ranges of the forecast timeline.

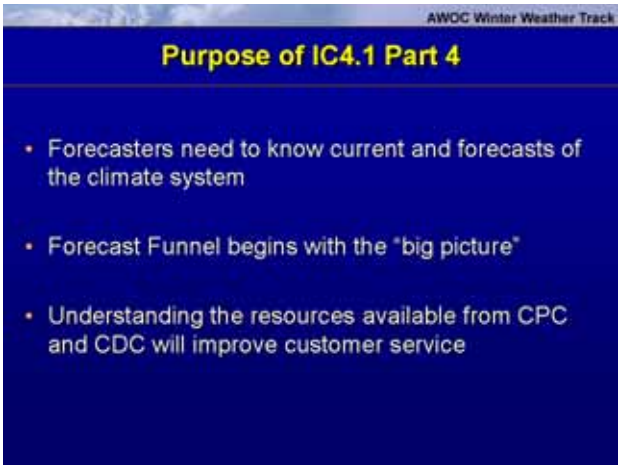
Student Notes:



2. Purpose of Lesson 1.4

Instructor Notes: In this lesson we will go through some of the products available from the Climate Prediction Center and Climate Diagnostics Center which specialize in monitoring and predicting slowly evolving patterns of large scale phenomenon. Using these centers will help you with the forecast funnel process of starting large and tapering down to smaller space and time scales. Finally, with the help of the CPC and CDC products, you'll be better able to explain the state and predictive nature of the climate system and therefore better serve your customers.

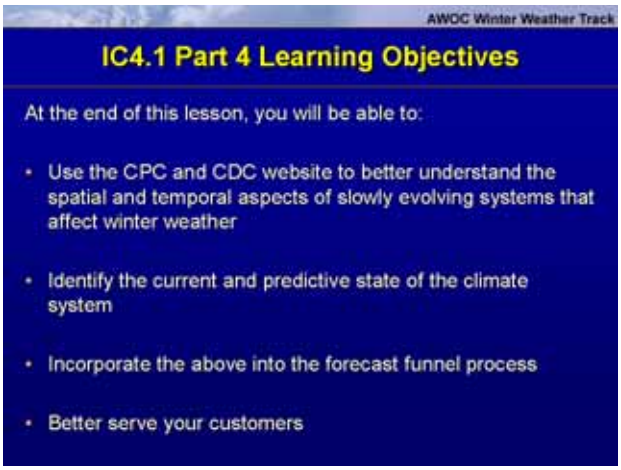
Student Notes:



3. IC 4 Lesson 1.4 Learning Objectives

Instructor Notes: We will focus on helping you look at the "big picture" in space and time…to help you assess the potential for upcoming winter storms in your area of responsibility. You'll be better able to use the web sites to see how these "slowly evolving" systems initiate and how they influence weather in the US. We'll also see how these phenomena are monitored, and we'll take a look at resources you can use to assess the state of the climate system and what the latest predictions are for the medium and longer ranges. You'll then be able to incorporate this knowledge into your forecast funnel process. Of course, the ultimate goal of increasing your skills and knowledge is to better serve your customers.

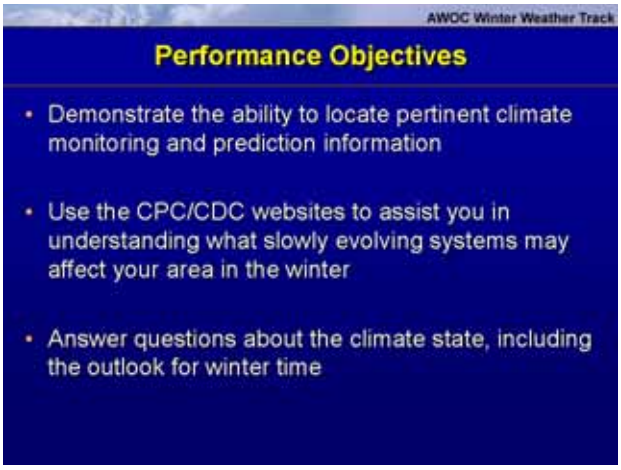
Student Notes:



4. Performance Objectives

Instructor Notes: After this lesson you should be familiar the resources available on CPC and CDC web sites and be able to incorporate the information into the forecast funnel process. Further, you should be able to better answer questions from your customers on what to expect in the coming winter.

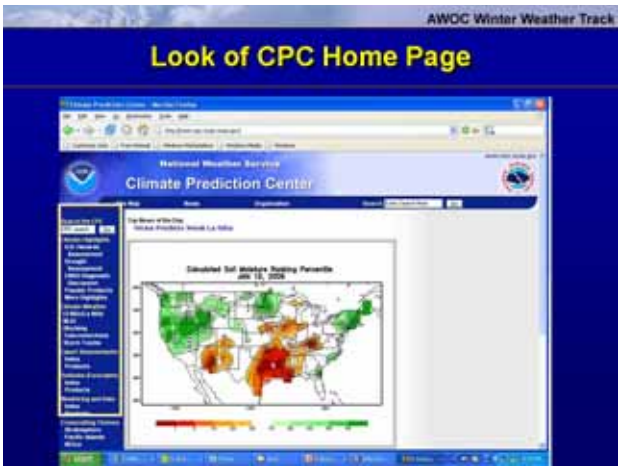
Student Notes:



5. Look of CPC Home Page

Instructor Notes: Here is the “front page” of the Climate Prediction Center’s web site. Note, it has the traditional layout with the left-hand margin containing a list of topics that we will discuss further in this lesson.

Student Notes:



6. Most Popular Products

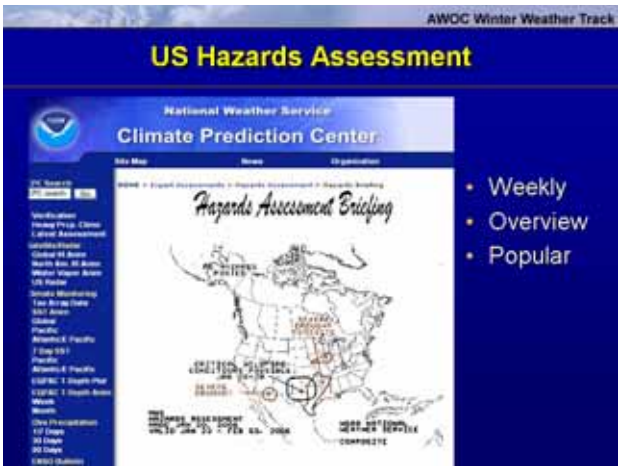
Instructor Notes: Here is a list of some of the most popular medium and long range products available under "Most Popular Products." We won't look at all of them, but let's take a moment to look at the "United States Hazards Assessment" and the "El Niño Discussion." (Note: These sites are from http://www.cpc.ncep.noaa.gov/products/predictions/threats/index.html).

Student Notes:

7. US Hazards Assessment

Instructor Notes: This is an example of the weekly hazards assessment. This is popular with emergency managers and other officials. I want to point out that before the product is published, there is a teleconference call that is attended by at least some regional representatives. Also of interest is the side menu, which has useful links that are used to help hazard assessment forecasters diagnose the climate/weather and then create the product. You may want to bookmark this page.

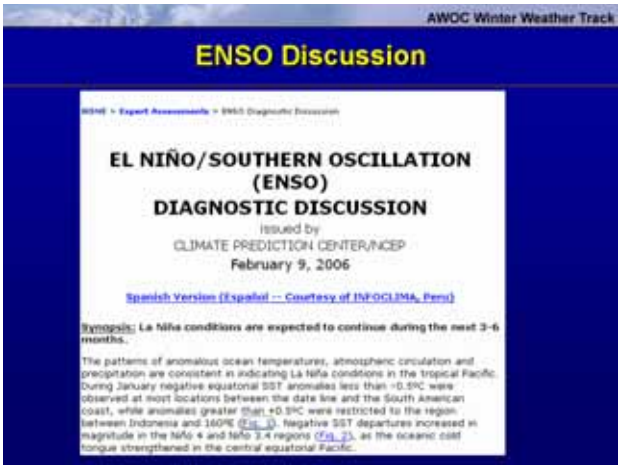
Student Notes:



8. ENSO Discussion

Instructor Notes: Updated Monthly, this ENSO discussion (at http://www.cpc.noaa.gov/products/analysis_monitoring/enso_advisory/index.html) has links to graphical depictions of data such as SST anomalies, OLR diagrams, etc.

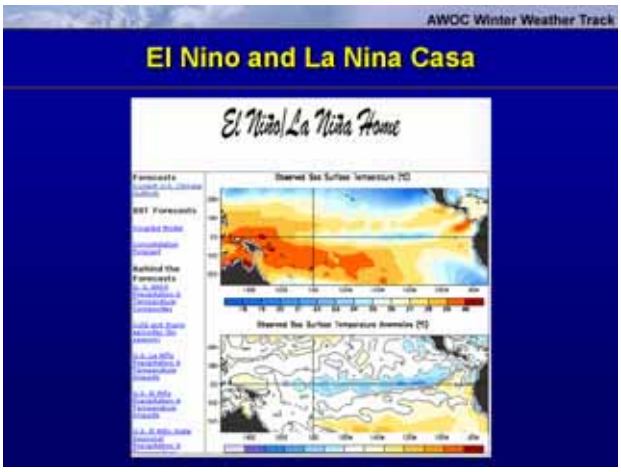
Student Notes:



9. El Niño and La Niña Casa

Instructor Notes: Also from the “Most Popular Products Link” is the “El Niño and La Niña” home, where you will find a lot of useful links on the left hand side as well as the current SST and anomalies. You can however, click from the main page of CPC on the left hand side under: “Climate-Weather, El Niño/La Niña” and the next slide shows what that page looks like.

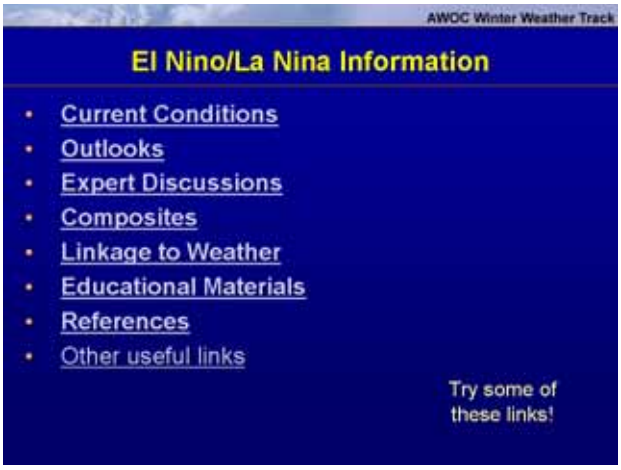
Student Notes:



10. El Niño/La Niña Information

Instructor Notes: Here is the CPC's main ENSO page with links to a wealth of information on ENSO for all ages. Many of CPCs links are formatted with these topic headings so that they are easily recalled. They contain current and forecast information on the topic referenced, as well as links to text products such as expert discussions, composite maps of the phenomena listed, and many other educational materials and references. (Note: These are found from http://www.cpc.ncep.noaa.gov/products/outreach/other-mat.shtml).

Student Notes:



11. Climate-Weather: El Niño/La Niña

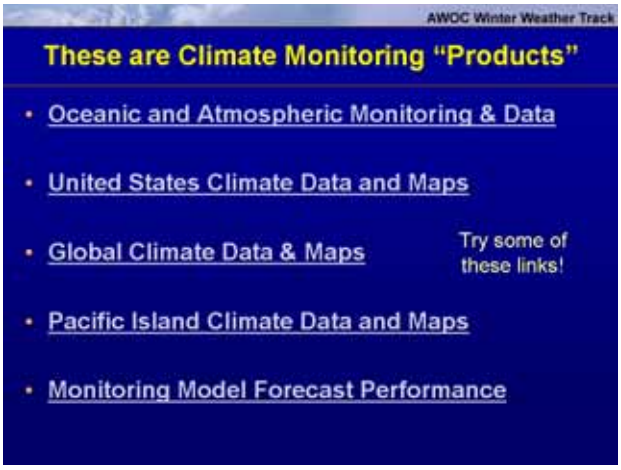
Instructor Notes: As I mentioned in the previous slide, this ENSO page has a wealth of information. It scrolls for a couple of more pages of current conditions to help you assess the state of ENSO and answer questions from your customers.

Student Notes:

12. These are Climate Monitoring "Products"

Instructor Notes: On the left hand side (the blue margin) of the CPC main page, you will find a listing called: "Monitoring and Data" and sub menu under that, which has "Index" and "Products" This slide shows what is under the "Products" tab. There are other useful links which are under the climate monitoring section (blue left side menu of CPC's home page). We'll take a look at the first and last links listed here, and you should browse the others at your convenience.

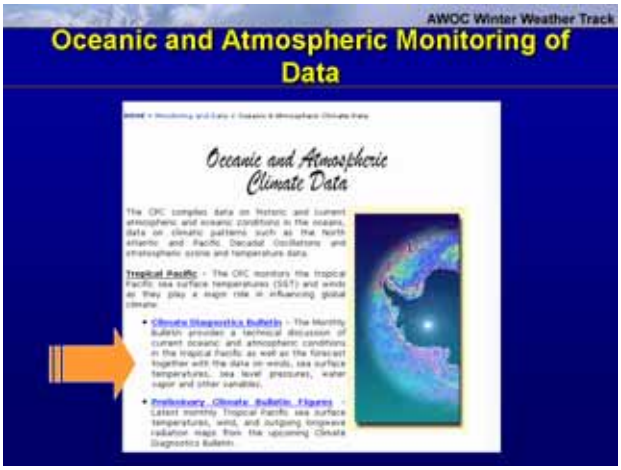
Student Notes:



13. Oceanic and Atmospheric Monitoring of Data

Instructor Notes: In the "Monitoring" link you will find a host of information such as the Climate Diagnostic Bulletin including figures that support the bulletin. On the next two slides we'll see what else is available on this page for monitoring the state of the climate system.

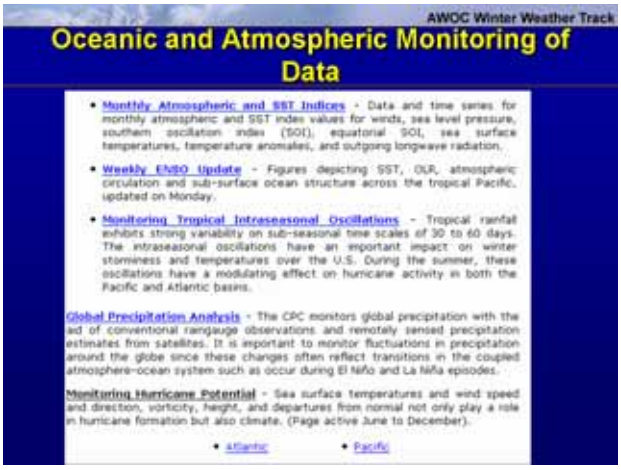
Student Notes:



14. Oceanic and Atmospheric Monitoring of Data

Instructor Notes: You will also find monthly values listed here regarding atmospheric and oceanic indices...a weekly update on ENSO based on SST, OLR and other parameters, info on intra-seasonal oscillations (aka MJO), precip analysis, and hurricane potential.

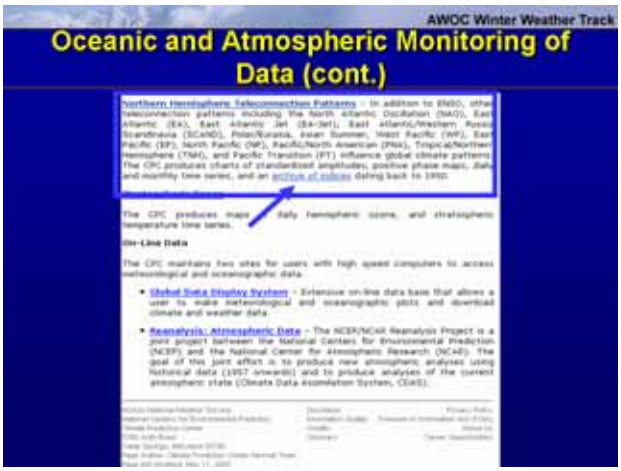
Student Notes:



15. Oceanic and Atmospheric Monitoring of Data (Cont.)

Instructor Notes: This is the end of the monitoring data page...you have to scroll down to see that Teleconnections are linked here including some indices archived. You may want to engage in some correlation studies using this page. Unlike the left hand menu link (which only shows the indices and a link to individual teleconnections) this link also has information on how the indices are calculated.

Student Notes:



16. Monitoring Forecast Performance

Instructor Notes: Here is the “Last Link” on the Monitoring and Data “Products” list: “Monitoring Forecast Performance.” Here you have the opportunity to review skill scores of various forecasts.

Student Notes:

17. Expert Assessments – ENSO Update

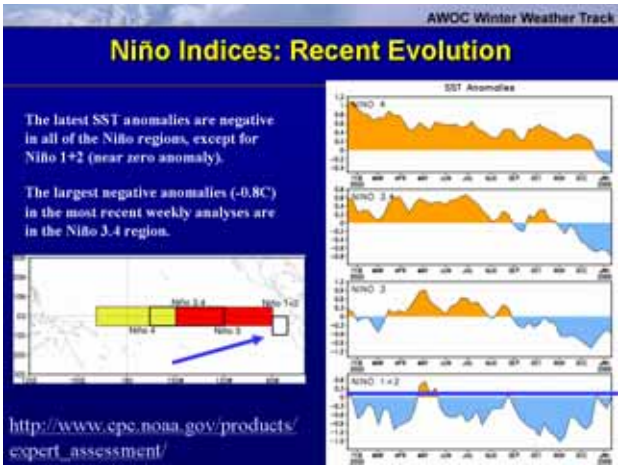
Instructor Notes: You can download a weekly ENSO update from the “Expert Assessments – Products” list on the left hand side of the CPC main menu. There are many links on this page, we’ll talk mainly about the above list for the Weekly ENSO update, which is really a PowerPoint presentation which has current conditions, forecasts and some other useful background information.

Student Notes:

18. Niño Indices: Recent Evolution

Instructor Notes: Here is an example of material you will find in the "weekly update" expert assessment we talked about on the previous slide. The diagram on the left shows areas in the tropical Pacific, called Niño regions which are used by scientists to identify the state of ENSO. On the right is a plot of these Niño regions' SST anomalies. The orange areas are above normal SSTs, while the blue shows below normal temperatures. The plot is from Feb 2005 to January 2006. Now let's move on to a discussion of other climate products found on CPC/CDC, in other words, let's talk again about monitoring/ predicting MJO activity.

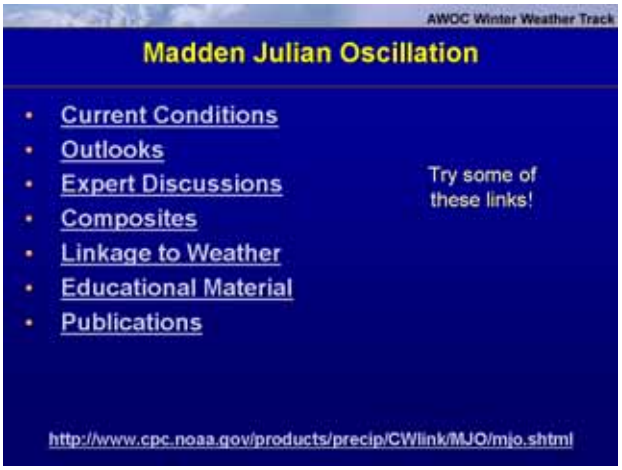
Student Notes:



19. Madden Julian Oscillation

Instructor Notes: Underneath the “ENSO” listing on the left hand side of the “Climate-Weather Link” you will find “MJO” If you click on that, you’ll get this list plus other information on the current and predicted state of the MJO. For more information on the MJO, see IC4 sub-lesson 1.2.

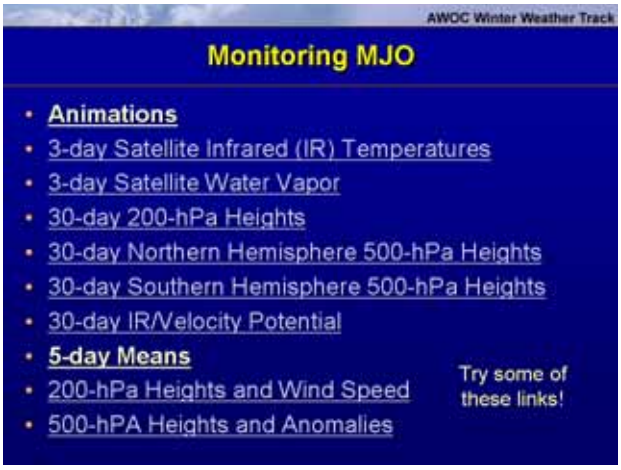
Student Notes:



20. Monitoring MJO

Instructor Notes: The next two slides have many links to data which scientists use to monitor the MJO. Take a few minutes to look over the list and consider more in-depth viewing of this data when you want to analyze the current state of the atmosphere and in particular how the tropics and extratropics oceans/atmosphere are behaving; this could be part of your forecast funnel in the winter to assess/predict the potential for large scale slowly evolving long wave patterns to set up and affect the development and track of synoptic systems.

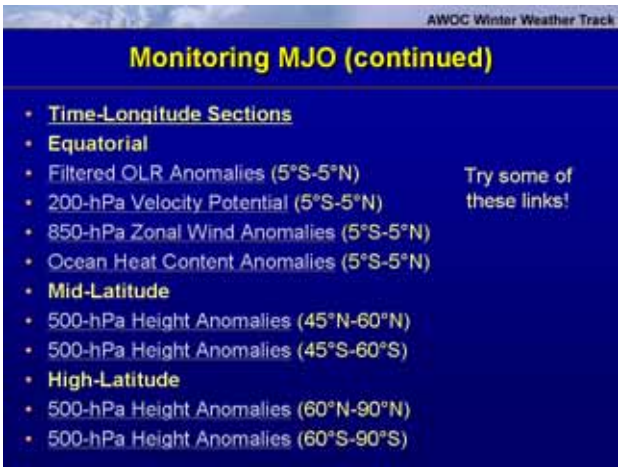
Student Notes:



21. Monitoring MJO (continued)

Instructor Notes: As mentioned in the previous slide you should spend some time reviewing the data to assess the current state of the MJO. In particular, these links contain plots of time series of Outgoing Longwave Radiation, winds (including anomalies), and heights of the 500 mb pressure surface (also including anomalies), all of which are tools you can use to determine the MJO activity.

Student Notes:



22. CDC and Other MJO Resources

Instructor Notes: Here is a list of some of the resources you can use to find out more about the MJO and forecasting it's effects. The first one is a "blog" or comment(s) by the Science and Operations Officer in Dodge City, KS, Ed Berry. Ed updates this "discussion" whenever something of interest is occurring in the climate system, in particular with regard to the MJO*. The rest are either CPC or CDC links to useful information. The next slide offers information on an "Interactive Tool" that you may find useful in your climate studies and outreach services.

Instructor Notes:

Instructor Notes: *Note: Ed Berry's log is an unofficial climate related product. Refer to the CPC for all official climate related forecast and diagnostic products disseminated by NOAA.

Student Notes:

23. Interactive MJO Forecasts from CDC

Instructor Notes: Here is a list of some of the resources you can use to find out more about the MJO and forecasting it's effects. The first one is a "blog" or comment(s) by the Science and Operations Officer in Dodge City, KS, Ed Berry. Ed updates this "discussion" whenever something of interest is occurring in the climate system, in particular with regard to the MJO*. The rest are either CPC or CDC links to useful information. The next slide offers information on an "Interactive Tool" that you may find useful in your climate studies and outreach services. *Note: Ed Berry's log is an unofficial climate related product. Refer to the CPC for all official climate related forecast and diagnostic products disseminated by NOAA.

Student Notes:

24. Other Interactive Forecasts

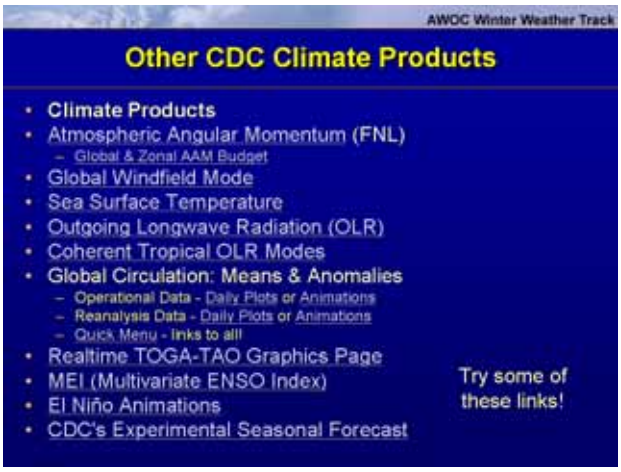
Instructor Notes: Here is another one of CDC's interactive pages. On this particular page, you can plot a time series for a given station, parameter, and level. These types of analyses can be used to depict expected conditions for different stages of the MJO, for example. Again, you might find these pages useful in conducting local studies or answering questions posed by your customers, particularly for questions regarding effects of the state of the climate system on seasonal forecasts.

Student Notes:

25. Other CDC Climate Products

Instructor Notes: The Climate Diagnostics Center offers the products listed here in addition to many others. You should spend some time visiting these pages and you may want to bookmark some in your favorite browser.

Student Notes:



26. Teleconnections

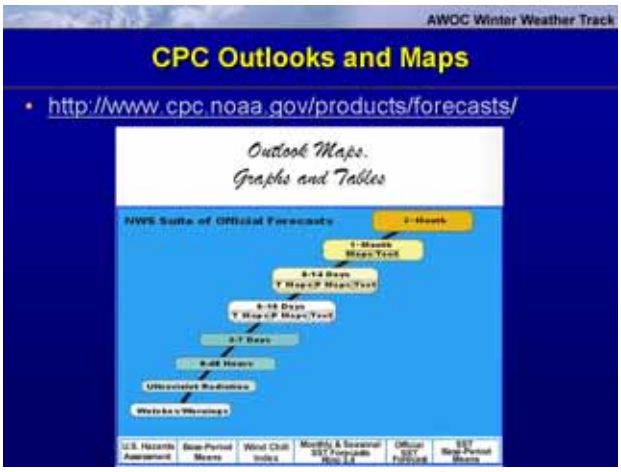
Instructor Notes: As with the other climate phenomena such as ENSO and the MJO, teleconnections have a section that shows current teleconnection indices, and other information such as education materials. Here's what the top level page looks like, and the link for entering the CPC teleconnection area is given at the top of this slide. (note: this page is found from http://www.cpc.ncep.noaa.gov/products/precip/CWlink/daily_ao_index/teleconnections.shtml)

Student Notes:

27. CPC Outlooks and Maps

Instructor Notes: This is a popular page from CPC as it ties all spatial and temporal product in the NWS suite. It makes it easy to go to any forecast level that you are interested in at any given time.

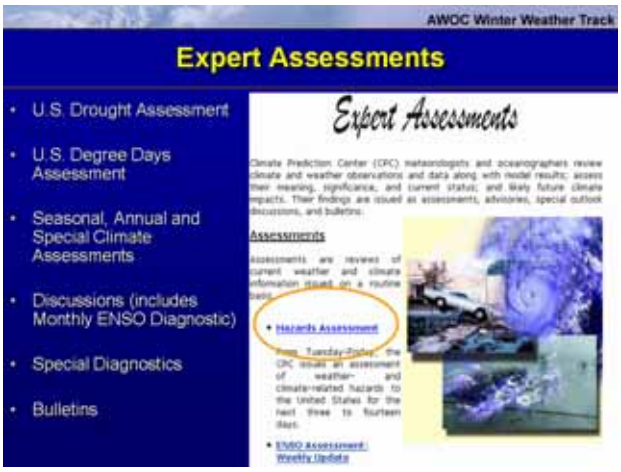
Student Notes:



28. Expert Assessments

Instructor Notes: You will find this list of "Discussions" by clicking on the Expert Assessments, and then "Products" on the left hand side of the main CPC page. Scroll down past the previous mentioned items (hazards assessment and ENSO weekly bulletin) to find these other categories. The CPC issues the ENSO Diagnostic Discussion around the middle of the month. The discussion addresses the current oceanic and atmospheric conditions in the Pacific and the seasonal climate outlook for the following one to three seasons. An online archive of the ENSO Diagnostic Discussions (since 2001) is also available. Also on this list, the CPC posts the Winter Outlook in October, which reviews climate influences on the upcoming winter season and the likely weather impacts on various regions of the United States. Also on this page is a set of "bulletins" like the crop bulletin and the "extratropical highlights" which are useful for explaining what has happened over the previous month. http://www.cpc.ncep.noaa.gov/products/expert_assessment/

Student Notes:

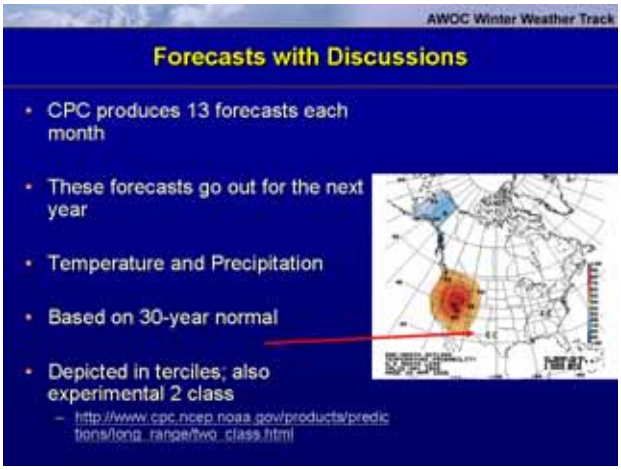


29. Forecasts with Discussions

Instructor Notes: Monthly and seasonal forecasts are updated each month. The monthly forecast is issued on the last day of each month. The seasonal forecast is published after the CPC forecaster has a conference call with many partners including IRI and CDC. The forecast is released at around 8:30am each month on the Thursday that is closest to, but not before the 15th of the month. The "terciles" mean that the forecast is compared to three classes of conditions: those that were above the average, those near the average, and those below. If you take all of the observations in a 30 year period, you can divide the probabilities into these categories. If you see EC on the map, it means that you have a 33% chance of having above normal, near normal, or below normal conditions. Note that if you have an above (below) normal shaded area, you must subtract the amount of the shading that is above 33% from the opposite, and leave the near normal alone all the way down to 3%. For example, if the above normal contour is 40%, then you have a 33% chance of near normal, and a 26% chance of below normal conditions com-

pared to the average. CPC is currently experimenting with a 2-class system. The purpose for making these versions of the outlooks available is to afford users an opportunity to refer the outlooks to a more familiar two outcome system, where odds equal or differ from 50-50. These maps are representations of the official, 3-category outlooks and may contain less information than the Official maps.

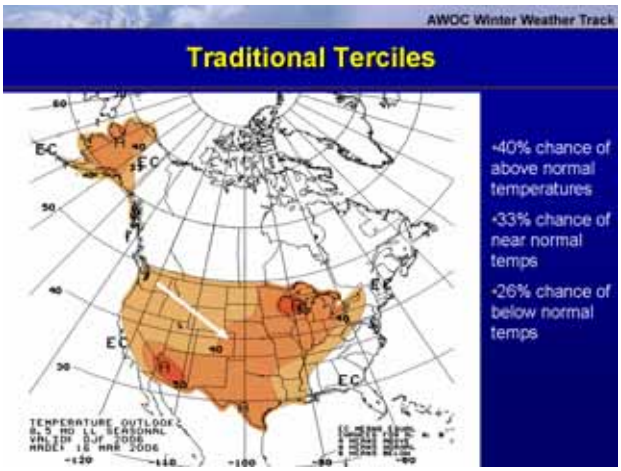
Student Notes:



30. Traditional Terciles

Instructor Notes: Here is an example of the temperature forecast for December, January, and February (or DJF) which was made on March 16th 2006. This is the traditional tercile forecast. In other words, let's look at the midwestern US, where there is a 40- contour. This means that there is a 40% chance of above normal temperatures, a 33% chance of near normal temperatures, and a 26% chance of below normal temperatures. Now let's take a look at the experimental 2-class system.

Student Notes:



31. Experimental 2-Class System

Instructor Notes: This is the experimental 2-class system, in which the comparison is made on a 50-50 percent chance. In other words, look at the same area as we did in the previous slide. Notice that we now have a 60-contour. This means that we have a 60 percent chance of above normal and a 40 percent chance of below normal. You might be wondering about the “normal” category. Let’s use an example to illustrate what happens in this situation. Say, for example, the normal temperature for this season is 50 deg F. In this two class system, what is the chance of the temperature being 50 deg F? Did you guess zero? If you did, you’d be right, because the probability of any single value is zero. If you find this confusing, you may want to discuss it with your SOO or your climate services focal point.

Student Notes:

32. Seasonal Forecasts

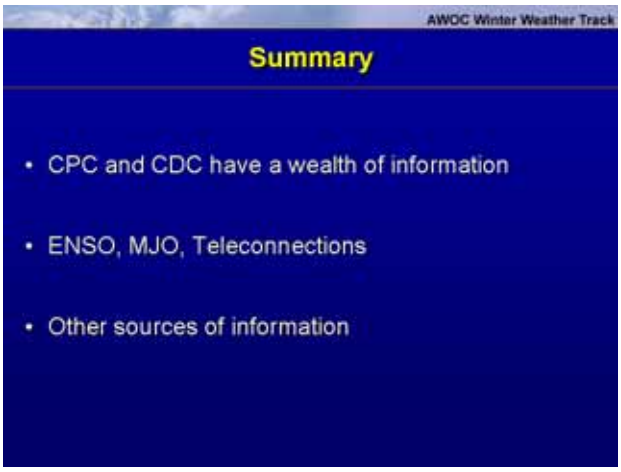
Instructor Notes: Here is a list of the seasonal forecasts made by CPC. You get to this page by clicking on the "Outlooks" then "Products" then the top choice, called "3-month" The forecasts listed here are often referred to as "leads" meaning the time the forecast is valid for an equivalent time as the lead. For example, the 1.5 month outlook would be called the 1.5 month "lead". This list also contains links to skills for each lead, normals for some first order stations, and Probability of Exceedence plots for temperature and precipitation. (Note: the website is from http://www.cpc.ncep.noaa.gov/products/predictions/90day)

Student Notes:

33. Summary

Instructor Notes: The CPC and CDC have a wealth of information, including the current and forecast states of the climate system, and information regarding many of the phenomena we covered in the 3 other sub-lessons in this instructional component 4, lesson 1. There have been several teletraining sessions which highlight the medium and long range forecasting techniques and also how to navigate the CPC web page. If you weren't able to attend these sessions, speak with your SOO who can show you how to view teletraining in a "local mode." Also, consider asking your climate services focal point for more information, particularly if they have attended the climate services workshops, such as the Climate Variability or the Climate Operations Courses. I hope you will take some time to browse these websites and consider engaging in a local study climate and its variability in your area.

Student Notes:



34. CPC Quiz

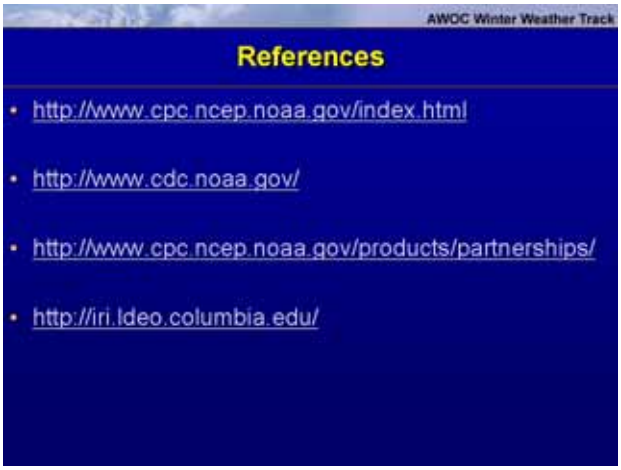
Instructor Notes: Take a few moments to complete this quiz.

Student Notes:

35. References

Instructor Notes: Here are some links…the first two are the main pages for CPC and CDC. The third is a link which takes you to partners' web sites from CPC's page. The final link is the International Research Institute (IRI) who closely coordinates with CPC and also models the global climate system and issues climate products.

Student Notes:



36. Acknowledgements

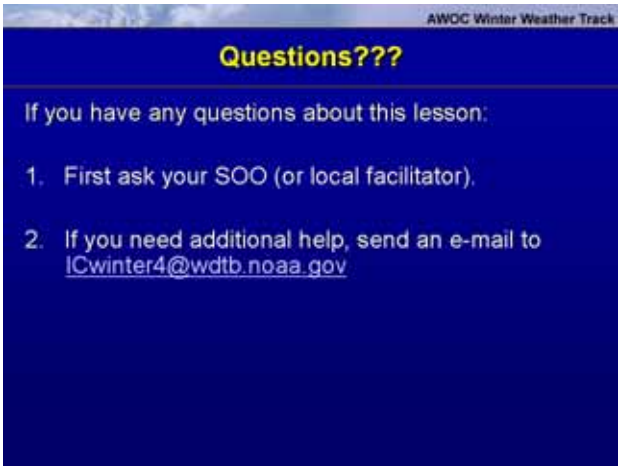
Instructor Notes: I'd like to thank the following individuals for their support in the creation of this lesson: Mike Staudenmaier, SOO/Flagstaff Tom Salem, SOO/Glasgow Tony Haffer, MIC/Phoenix

Student Notes:

37. Questions???

Instructor Notes: After going through this lesson if you have any questions, first ask your SOO. Your SOO is your local facilitator and should be able to help answer many questions. If you need additional info from what your SOO provided, send an E-mail to the address on the slide. This address sends the message to all the instructors involved with this IC. Our answer will be CC'd to your SOO so that they can answer any similar questions that come up in the future. We may also consider the question and answer for our FAQ page.

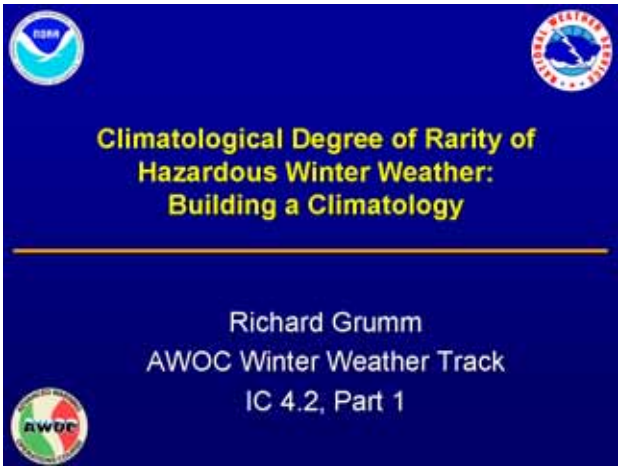
Student Notes:



1. IC4.2 Part 1: Building a Climatology

Instructor Notes: Welcome IC 4 lesson 2 part 1…My name is Richard Grumm and in this module we will cover …The Climatological degree of rarity of hazardous weather—building a climatology.

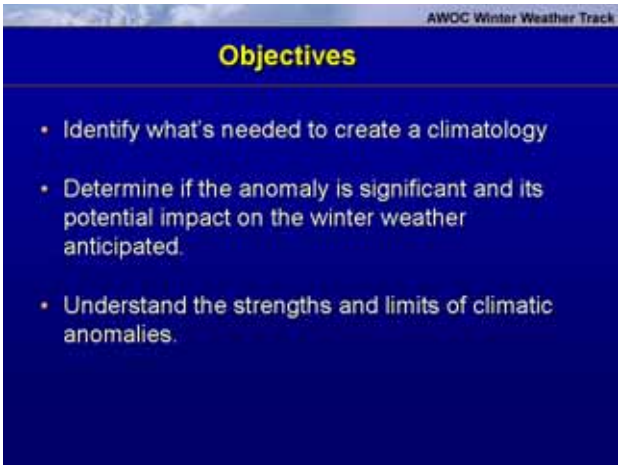
Student Notes:



2. Objectives

Instructor Notes: Our objectives are to help understand how to create a useful climatology using the NCEP/NCAR global re-analysis (GR) data. We will talk a little about the newer, high resolution North American Regional Re-analysis (NARR) data too. We will attempt to quantify if an anomaly is significant and its potential impact on the weather situation at hand. The direct applications will vary around the United States based on which features affect winter storms the most in your area. Several examples will be presented to help you understand how to apply Standardized anomalies to determine if an event may be significant or not. Finally, we will apply the climatic means and standard deviations to model data. This will allow you to gage your system against the climatology. However, it is important to understand the limitations of using the low resolution global re-analysis (GR) data when examining forecasts from higher resolution NWP output.

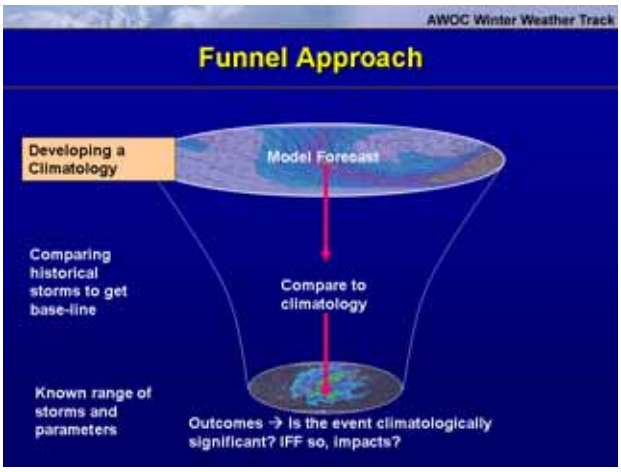
Student Notes:



3. Funnel Approach

Instructor Notes: We will take a funnel approach to this process. First, we will cover the key aspects of developing a climatology. We will then show how this climatology can help define the features associated with significant storms. Then we can determine the known ranges and parameters to examine. Then, using a forecast approach, we can compare the NWP output from deterministic models and ensembles to see how a forecast storm compares to the climatology. This should provide us a measure of how normal or abnormal the event may be so we can gage its potential impact. Our goal is to be able to discriminate between an ordinary winter storm and a potentially significant winter storm.

Student Notes:

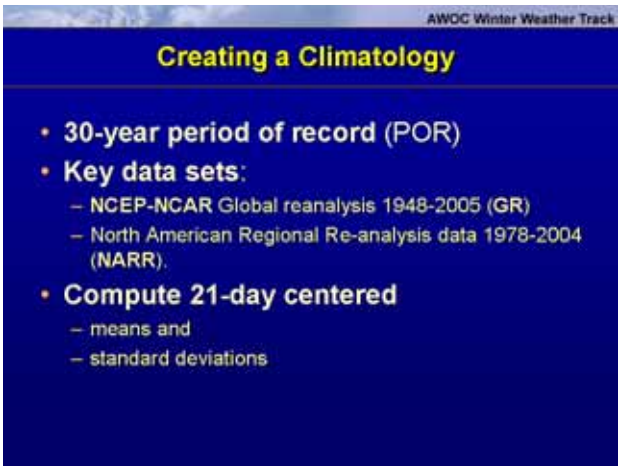


4. Creating a Climatology

Instructor Notes: Most standards for climatological data sets require a recent 30-year period of record, simply called POR. This is covered in two papers in the references including the MWR paper by Hart and Grumm (2001). A good POR is critical for using climatic data. Most of the data presented here will be from the NCEP/NCAR re-analysis project and will be referred to as the Global Re-analysis. This is a global data set at 2.5 X

2.5 degree resolution. The data is quite coarse. However, a new data set, the North American Regional Re-analysis data set is now available. The GR data has a temporal resolution of 6-hourly data. Means and standard deviations were compute by each 6-hour time period using a 21-day centered mean calculation. This smoothes the data, avoids choppy transitions, and ensures the data sample is large enough. The GR data extends from 1948 to about 5 days from the current day. This provides good case study capabilities. The means and standard deviations are available and well documented.

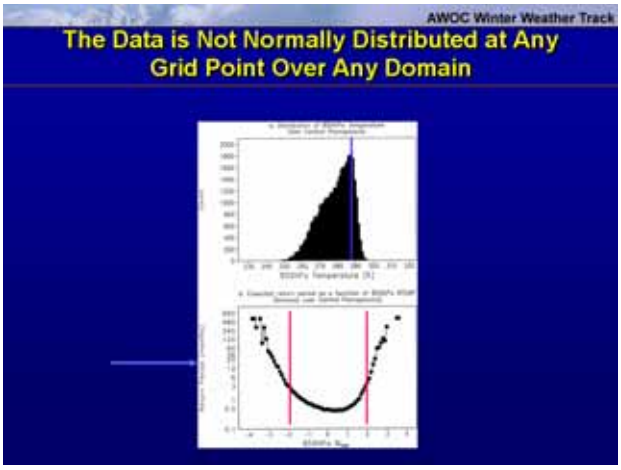
Student Notes:



5. The Data is Not Normally Distributed at any Grid Point Over any Domain

Instructor Notes: The figure above shows the 850 hPa temperatures at a point in central Pennsylvania. These data show that the absolute temperatures are skewed. Data rules about a normal distribution do not fully apply. The mode skewed well to the warm side. Using the counts we can arrive at a frequency of occurrence. Based on the number of months or years of data we can assign return periods as we have done in the lower image (blue arrow). The lower image shows the departures from normal of the 850 hPa temperatures at this point and the return period. These data are also skewed. Note that most of the time the 850 hPa temperature anomalies lie between 2 and -2 SDs from normal. With the current data, there is a long return time between -4 and +4 SD events. There have been more -3 to -4SD events than +3 to +4SD events, a part of the skewed nature of these data.

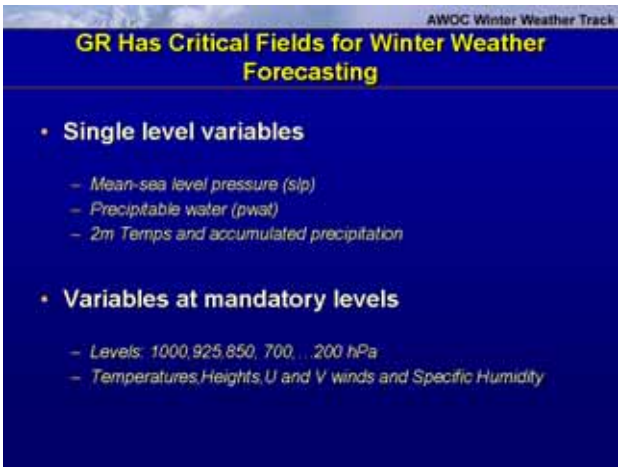
Student Notes:



6. GR Has Critical Fields for Winter Weather Forecasting

Instructor Notes: The GR data has many fields including singular fields such as MSLP, 2m temperatures, accumulated precipitation, and PWAT. Multi-level fields such has heights, temperatures, U-wind, V-wind, and specific humidity are available at mandatory levels. All these fields have climatologies which can be used to accomplish case studies and to compare to operational model forecasts.

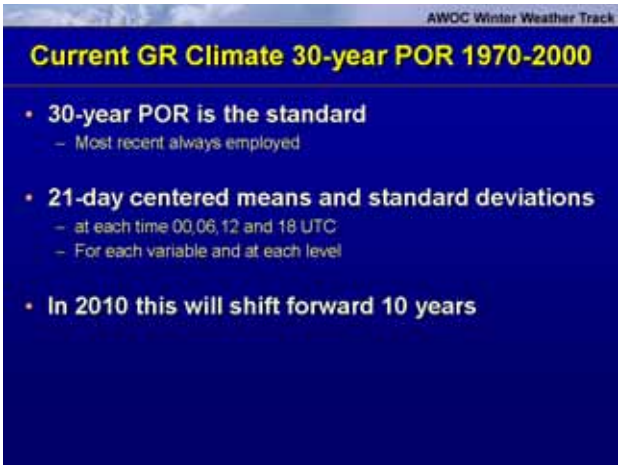
Student Notes:



7. Current GR Climate 30-Year POR 1970-2000

Instructor Notes: The Current GR climatology has means and standard deviations for all fields. They are for each 6-hourly time period and represent a 21 day mean centered on that date. This eliminates noise using daily values and sharp transitions from month-to-month if monthly values were used. The NARR data has more fields and higher spatial and temporal resolution. However, a robust set of 21-day centered means and standard deviations is not available and a 30-year POR is still a few years off.

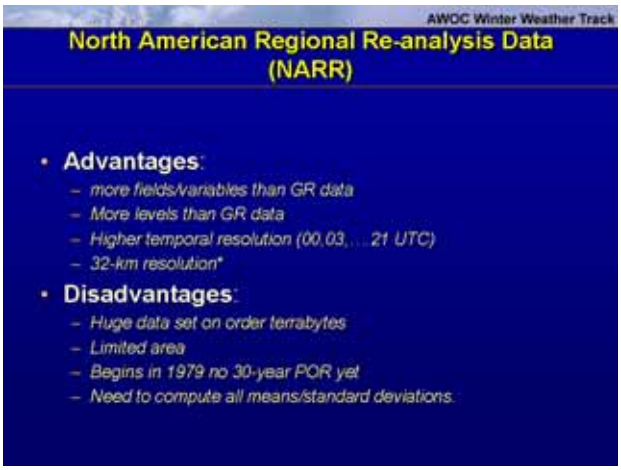
Student Notes:



8. North American Regional Re-Analysis Data (NARR)

Instructor Notes: In the near future, we will do case studies and examine model forecast compared to NARR fields. This high resolution data set has far more fields, more vertical levels, and is available in 3-hour time increments. The higher spatial and temporal resolution of these data will allow for more mesoscale diagnosis of past cases and capture focused anomalies better than the GR data. This data also will allow local mesoscale modeling studies. This data set has several disadvantages including a limited area focused over North America and the data only goes back to 1979. Thus, pre 1979 case studies cannot be conducted and there is not a good 30-year POR yet in the data set to build reliable means and standard deviations.

Student Notes:

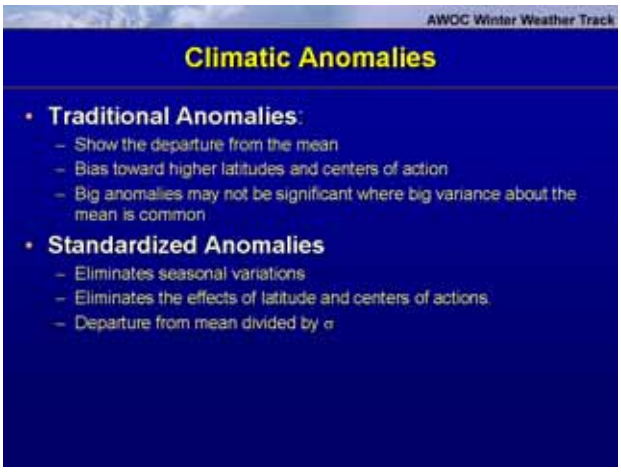


9. Climatic Anomalies

Instructor Notes: Most forecasters are used to the more traditional anomaly where a simple departure from the mean is shown. As a rule, bigger values will occur at higher latitudes. Thus a 200 m below normal 500 hPa low center in the Gulf of Alaska may be quite ordinary while a 90 m below normal 500 hPa low center over the Golan Heights

might be climatically significant. Standardized anomalies allow us to probe into the significance of an anomaly quickly eliminating seasonal and latitudinal influences. Lets look at this closer…

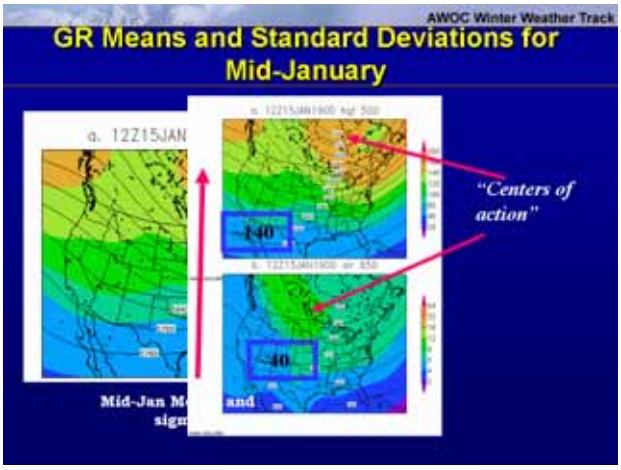
Student Notes:



10. GR Means and Standard Deviations for Mid-January

Instructor Notes: This image shows the 500 mb mean heights and the value of 1 standard deviation (meters) on 15 January. The 1900 date is just a place holder these are 21-day centered mean values. Generally, the 500 mb height decrease poleward and the value of 1 SD increase poleward. The latter also appears to have some longitudinal effects. Lets look an example. Over the Gulf coast…the mean height is about 5760 m and 1 SD is about 40 m. So, plus or minus 1 SD is a range of 5720 to 5800. Near James Bay…the mean height is about 5220 m and 1 SD is a whopping 140 m. Our +/- SD range would be 5080 to 5360 m. -----This is the kind of information we want to leverage with standardized anomalies. The 500 and 850 charts show us the centers of action…note the mean low is associated with large values of 1 SD and the baroclinic zone over the western plains is another "center of action". We have two effects…latitudinal and "centers of action".

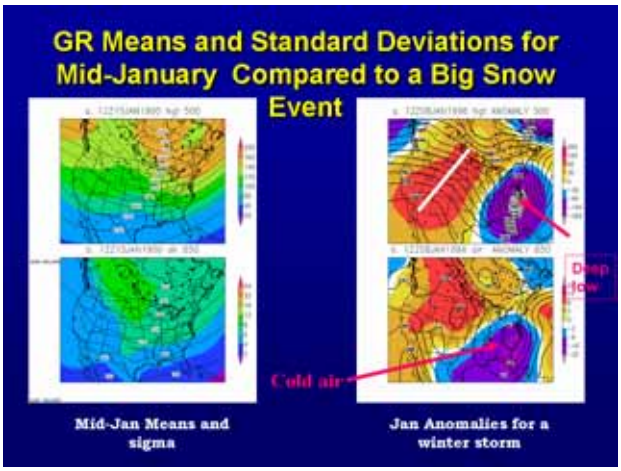
Student Notes:



11. GR Means and Standard Deviations for Mid-January Compared to a Big Snow Event

Instructor Notes: Now we will compare the data for a single day relative to the climatology (on the right). This was a major snow storm along the East Coast in 7-8 January 1996 and this particular image is from 1200 UTC 8 January 1996. Note that we have some big anomalies at 500 mb. We have the deep trough in the east (purple and gray colors) and a large ridge in the west. Both appear to be "anomalous". At 850 mb we see a cold surge in the southeastern United States and warm air over the western US. Our goal now is to assign some meaning to these data by dividing out what 1 standard deviation is from the data on the right hand side.

Student Notes:

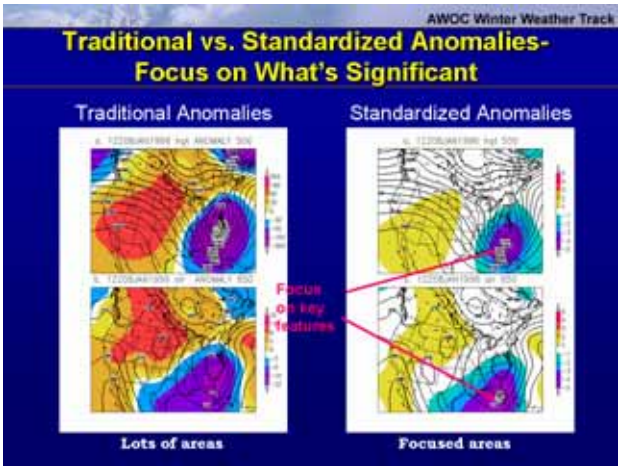


12. Traditional Verse Standardized Anomalies-Focus on What's Significant

Instructor Notes: Here we see the traditional anomalies on the left and the standardized anomalies on the right. They are for the same time, a big East Coast winter storm

from January 1996. Note how the traditional anomalies show lots of areas of concern. The largest anomalies appear in the trough and ridge. When these anomalies are standardized, by dividing by the value of 1 standard deviation, a more coherent pattern begins to emerge. On the standardized anomaly chart, we can clearly see the areas where the anomalies depart the greatest from normal and gauge how significant the values on the left are. They key is to determine significant areas where the atmosphere is showing big departures. Then we can quickly identify the significant weather events. Standardized anomalies allow us to do this quickly.

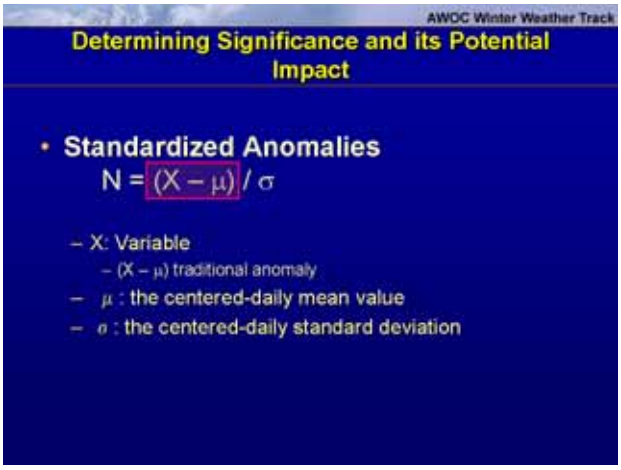
Student Notes:



13. Determining Significance and its Potential Impact

Instructor Notes: The equation above shows how we compute standardized anomalies (N). Note that the traditional anomaly is buried in the equation. It contains useful information. They key difference between the traditional and standardized anomaly is that we divide the former by 1 standard deviation to arrive at the latter. We can compute standardized anomalies for variables, such as sea level pressure, temperatures, heights, u and v winds, and other fields. We can compute these quantities over the various vertical levels arriving at a value for N at each level for each variable. N can be computed at a point over a domain.

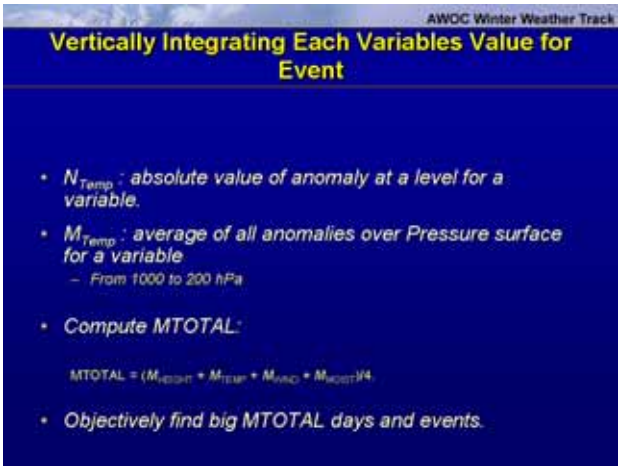
Student Notes:



14. Vertically Integrating Each Variables Value for Event

Instructor Notes: Research has shown that big events, such as the super storm of March 1993, are synoptically significant, and anomalies occur in many fields. One way to measure this is to compute anomalies for variable and at each level and come up with a Mean (M) value for that variable integrated over all levels. The integration is pressure weighted. We can get M for each variable and then equally weight them and arrive at an MTOTAL. We do this for temperatures, heights, moisture, and wind. The wind has two components including the U and V winds, but their average is equally weighted to the other fields. It turns out Big MTOTALS are associated with most historic events in the literature. We will show some examples. There is some value to M and N values for more mesoscale weather events.

Student Notes:



15. Interactive Quiz #1

Instructor Notes: Take a moment to complete this quiz.

Student Notes:

16. Re-Analysis Ranking by MTOTAL, 1948-2005

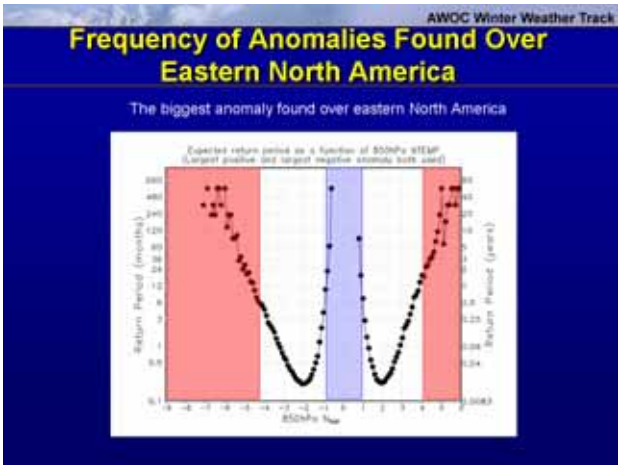
Instructor Notes: This is table showing the top 20 MTOTAL events from 1948-2005. It is interesting to note that most of the big storms were found in the published literature, pointing out how these larger events tend to be significant. Read data and convey information as an example for the 1st 5 events through the big 1998 ice storm.

Student Notes:

17. Frequency of Anomalies Found over the Eastern North America

Instructor Notes: This is the distribution over eastern North America of 850 hPa temperature anomalies. Large positive and negative anomalies are rare events as are values close to 0. This implies there is some type of anomaly over the region most of the time. The data shows both the POSITIVE and NEGATIVE VALUES. Taken over a large domain, finding values near 0 is RARE! This is not true for a single point. Both cold and warm anomalies peak at around -2 and +2 standard deviations respectively. Note both the warm and cold anomalies are skewed.

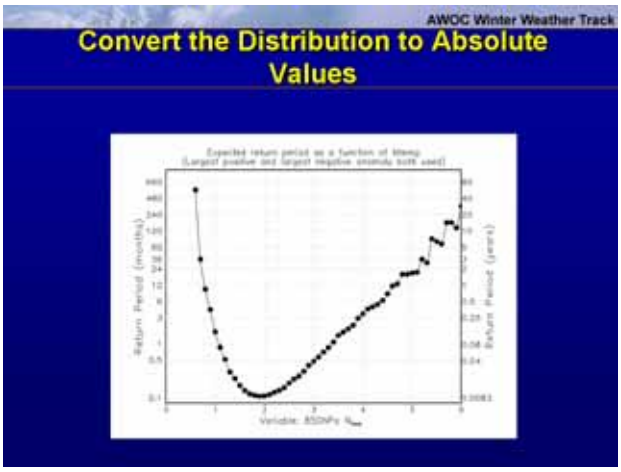
Student Notes:



18. Convert the Distribution to Absolute Values

Instructor Notes: These data are the same as in the previous figure except taking only the absolute values. Like M-VALUES, this case is at 1 level (850mb). In this case, the distribution shows that around 2 standard deviations departures from normal typically are observed over the eastern United States. Large events, NTOTAL over 5 are quite rare as are values much below 1. These data imply there should be some area of anomalies near +/-2 over the eastern US on any given day. Similar values are found for western North America. But getting these values into your CWA or over a point is not as frequent an event. This is an area still to be exploited.

Student Notes:

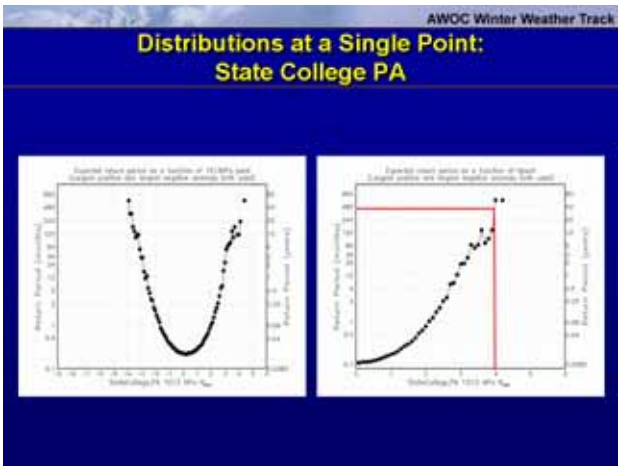


19. Distributions at a Single Point: State College, PA

Instructor Notes: This data is at a point showing precipitable water values. The data is for 1948-2005. Unlike over an area, the distribution shows values at or near zero occur quite typically. The NTOTAL for this variable looks similar to what one would expect over a region though fewer extreme values have occurred at this point than might be found over a regional domain. Note that a 4SD event has a return period of around 40 years at

State College, but it has a 3-month return period over the eastern United States! There have been no 5SD events yet which are observed every 2 years over the eastern United States. This data have applications at points and could be used at a local office. When a big anomaly is over your forecast region may be when these values are significant.

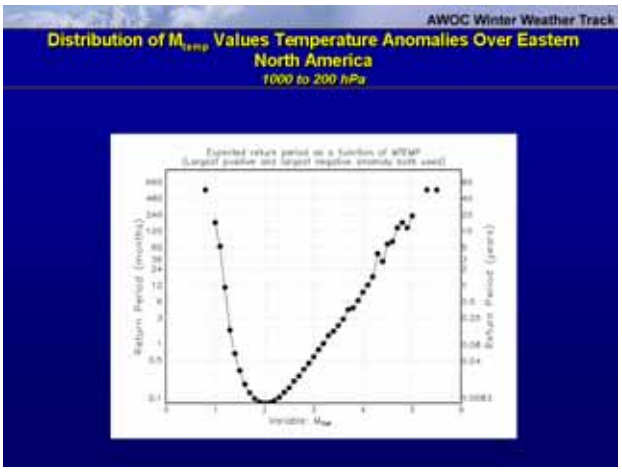
Student Notes:



20. Distribution of M_{temp} Values Temperature Anomalies Over Eastern North America: 1000 to 200 hPa

Instructor Notes: MTOTAL for temperatures is the sum of each level's NTOTAL values. The sum in the GR data is 1000 to 200 hPa and includes 925 hPa values. M can be computed for all variables, and a mean MTOTAL is derived. This allows cases to be rated. All tropical cases need to be removed!

Student Notes:



21. Interactive Quiz #2

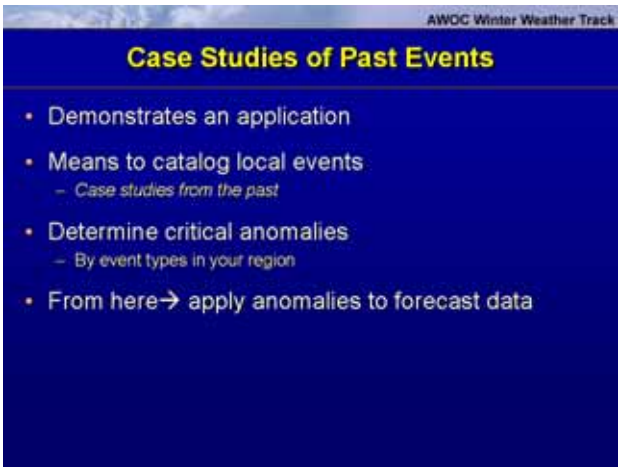
Instructor Notes: Take a moment to complete this interactive quiz.

Student Notes:

22. Case Studies of Past Events

Instructor Notes: We will now look at a quick case study using the superstorm of 1993. It will demonstrate how to use these data. I will show you that you have the means to catalog local events and do case studies to find which anomaly fields are significant to your forecast problems. You can determine critical anomalies by event types and seasons in your region. From here lets look at the #3 case.

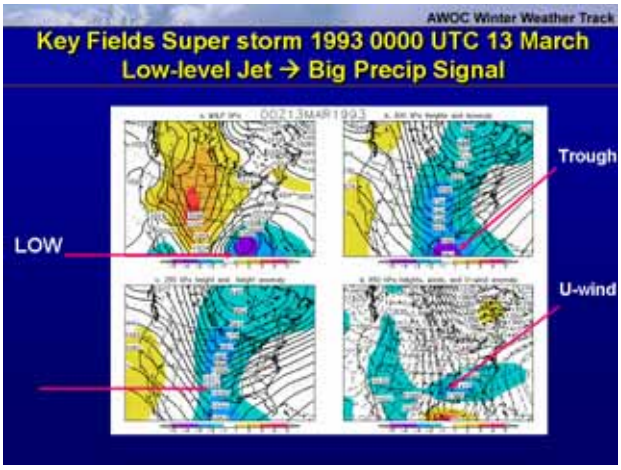
Student Notes:



23. Key Fields Super Storm 1993 0000 UTC 13 March: Low-Level Jet --> Big Precip Signal

Instructor Notes: We have select fields from the GR and the standardized anomalies for 0000 UTC 13 March 1993…the superstorm. Note the deep and anomalous low in the Gulf of Mexico. -3SD anomalies are pretty impressive and the deep 500 and 250 hPa trough. And at 850 mb note the anomalous U-wind anomalies…Many snow and heavy rain storms have this anomalous easterly wind in them at 850 hPa.

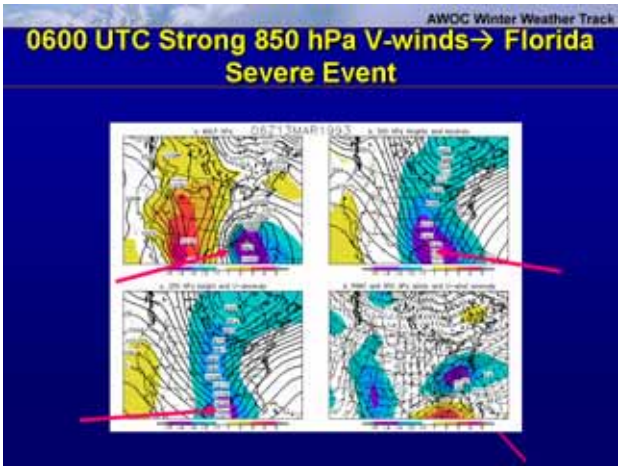
Student Notes:



24. 0600 UTC Strong 850 hPa V-Winds: Florida Severe Event

Instructor Notes: We now move 6-hours into the future. The low is much deeper now as is the 500 mb height anomalies. The easterly wind anomalies are in the -4 SD below normal range. We say -4 SD because there is an EASTERLY not a WESTERLY anomaly in the U winds. Now if we switch images…we can see the 850 hPa V-wind anomalies. These data show the strong southerly jet in the warm moist air. We now have precipitable water shown too. A strong southerly jet has been shown as another heavy rain feature and in the warm season with unstable air…a severe weather signature…Florida had severe weather with this event.

Student Notes:

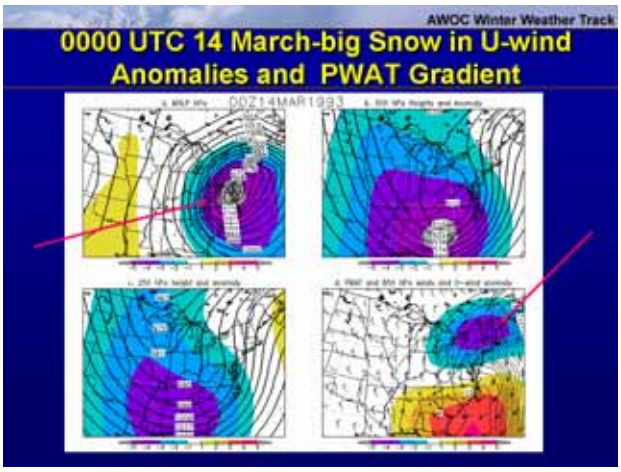


25. 0000 UTC 14 March-Big Snow in U-Wind Anomalies and PWAT Gradient

Instructor Notes: We move up the coast to see the storm over the Northeast. Note the more than -5 SD anomalous low over the Mid-Atlantic region and the large swath of

above normal easterlies north of the surface cyclone at 850 mb. This anomalous U-winds are a good signature in nearly all northeastern United States heavy snow cases. Recently, we have noted some heavy snow storms, such as October 2005 in the northern plains associated with strong easterly wind anomalies. Similarly, a major snow storm in Colorado in March 2003 also had some anomalous low-level 850 mb winds. Lets see how this looked in the NARR data.

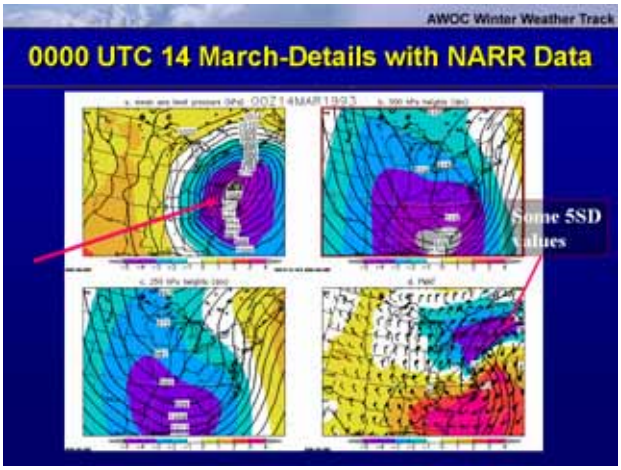
Student Notes:



26. 0000 UTC 14 March-Details with NARR Data

Instructor Notes: This image is really the same as the previous image except all the contours are from the 32km NARR data. We computed the departures from normal using the GR data. I do not have good means and standard deviations of all the fields yet. Note the stronger low and better area of the low center. Note the cut-off 500 hPa low that was really not as defined in the GR data. Some observations: NARR fields are more sensitive and provide more detail at lower levels. As the 500 and 250 hPa charts show…changes are less aloft. Wind field details can and do emerge. Look close and see the -5SD anomaly area over NH. Some time soon we will have standardized anomalies at this scale too. This looks like what NAM data might look compared to GR anomalies.

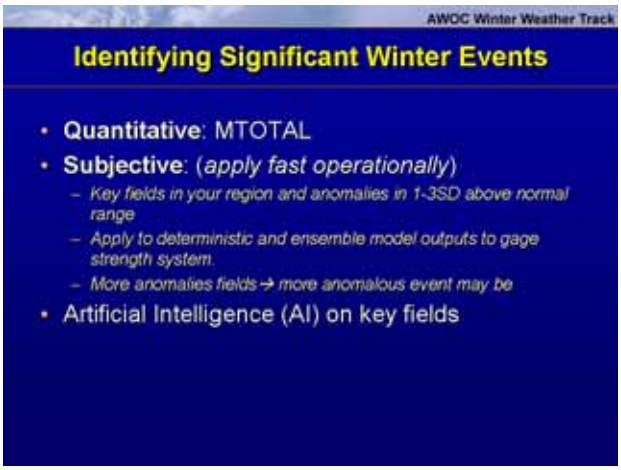
Student Notes:



27. Identifying Significant Winter Events

Instructor Notes: To identify significant events we could apply the MTOTAL method. It's quantitative but who will do it for you? So, do it subjectively: know the key fields in your region, relate these to key forecast fields, display these relative to ensemble or model output, and get a grasp on the significance of an event. In the future, artificial intelligence programs will help us out here too.

Student Notes:



28. Winter Storms East of Rockies

Instructor Notes: Here are some observations. Many of these were published in WAF back in 2001 and a paper…just on snow storms is in review for East Coast storms.

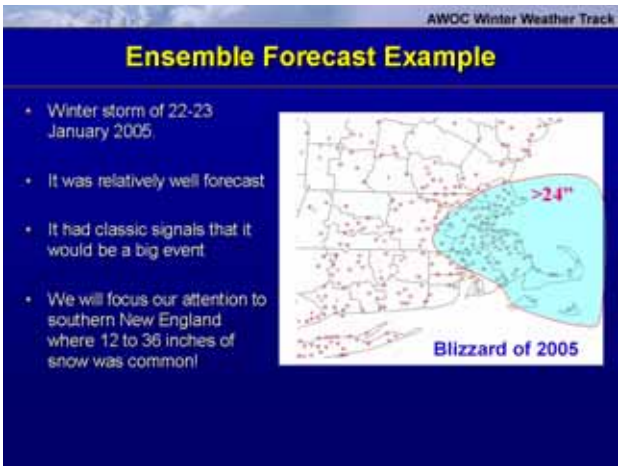
Student Notes:

29. Ensemble Forecast Example

Instructor Notes: Lets look at a forecast example using NCEP short range ensemble data…we might get more impressive results from one model. We will use the winter

storm of 22-23 January 2005. This event was well forecast though early forecasts tracked the low and snow threat too far south. It had classic signals of a big snow, a large and anomalous low-level easterly jet north of the cyclone center. We will focus on New England where 12 to 36 inches of snow, quite impressive, was common.

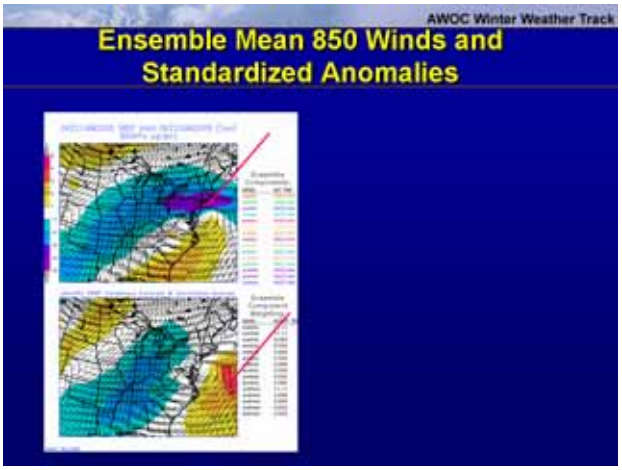
Student Notes:



30. Ensemble Mean 850 Winds and Standardized Anomalies

Instructor Notes: Here are some forecasts compared to the GR data. Focus on the upper charts which show the 850 mb U wind anomalies and the ensemble mean winds. The lower panels show the V-winds anomalies. You can see the above normal southerly winds over the Atlantic in the lower left panel. But we want to focus on the highly anomalous 850 mb easterly winds, and in an ensemble mean forecast at that! These are 45 hour forecasts. The ensemble mean had a -4 to -5 SD wind anomaly over NY and NJ. This was too far north and not strong enough!

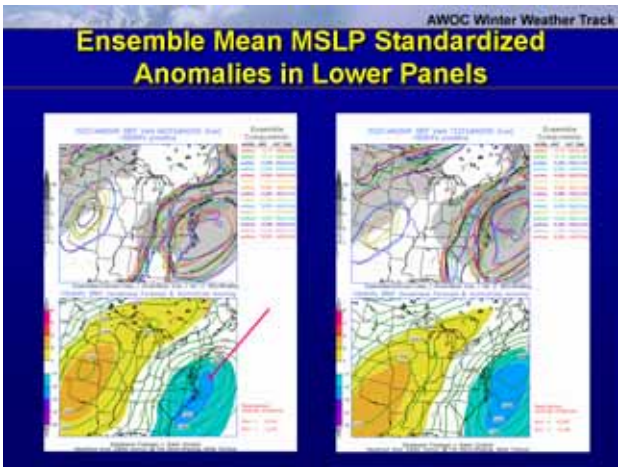
Student Notes:



31. Ensemble Mean MSLP Standardized Anomalies in Lower Panels

Instructor Notes: Same times here but mean-sea level pressure forecasts and anomalies. The upper panels show the plots of all the models used to get the mean, and until you take lesson 6, just let this tell you that there was not total agreement by all the models used here on the low intensity and position. But in the mean the low was forecast to be -2 to -3 SDs below normal. That strong U-wind anomaly was in the gradient north of our low. The old cold conveyer was forecast well. Lets look at forecasts initialized 12 hours later in the next page.

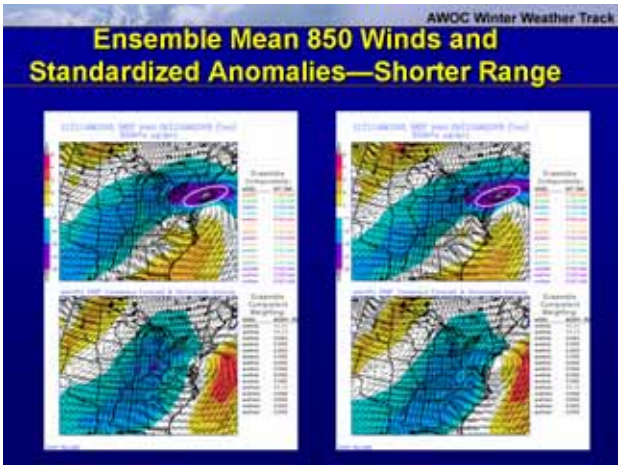
Student Notes:



32. Ensemble Mean 850 Winds and Standardized Anomalies—Shorter Range

Instructor Notes: What a difference 12 hours can make! These forecasts were initialized at 21 UTC on 21 January. Our 850 mb jet is strong now and farther north. We see some -5SD anomalies in the forecast valid at 06Z on the 23 over CT. 3 hours later the -5SD area expands over RI and SE MA too. In early 2005, NCEP did not produce PWAT fields with the trimmed SREF files used to produce these images. But they do now, and it would have helped here to see these fields. The key point here is a key field associated with BIG PRECIPITATION and BIG snow events had an incredibly large anomaly value where it snowed big amounts! The screaming message in these terse images is that this event had the potential to be bit more than your normal January snow fall. We could gage this on just how anomalous a key field in the 850 mb U winds were from normal.

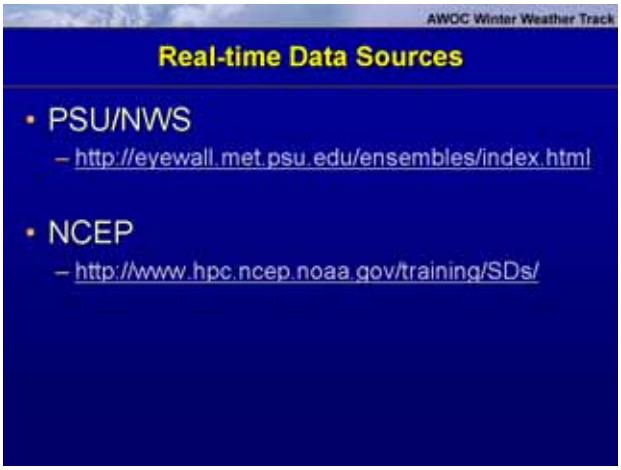
Student Notes:



33. Real-Time Data Sources

Instructor Notes: Links to real-time data.

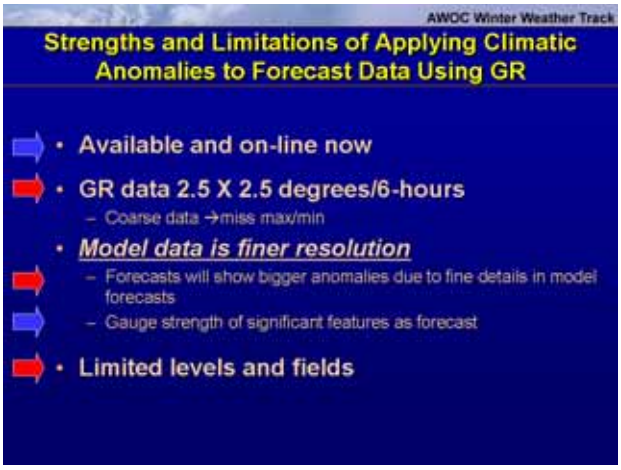
Student Notes:



34. Strengths and Limitations of Applying Climatic Anomalies to Forecast Data Using GR

Instructor Notes: Some strengths and weaknesses of applying climatic anomalies using the GR data should be noted. Strengths: The data is available now! The data goes back to 1948 so you can do lots of case studies We can use it now to gage the strength synoptic scale systems. Weaknesses: Data is only on a 2.5x2.5 degree grid…coarse model data we use is of much finer We could miss the details and local max/min. Limited levels.

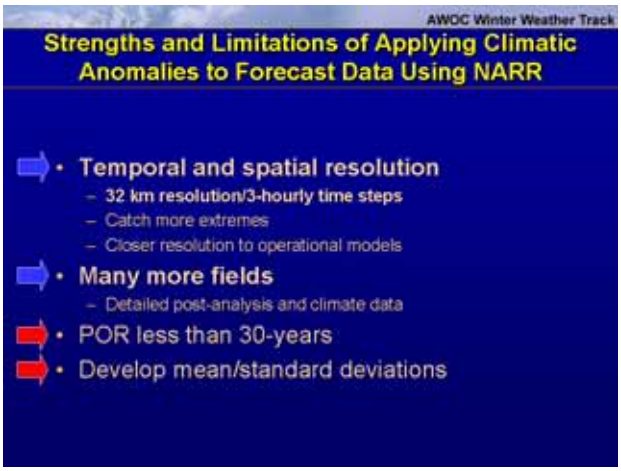
Student Notes:



35. Strengths and Limitations of Applying Climatic Anomalies to Forecast Data Using NARR

Instructor Notes: Some strengths and weaknesses of applying climatic anomalies using the NARR data should be noted. Strengths: The data, for case studies and meso model re-runs is available now! 32km grid higher temporal resolution at 3-hourly intervals! Scale closer to our operational models. Has many more fields and levels than the GR data It should catch more of the local/regional extremes. Weaknesses POR is still not 30 years long. Means are available, but you need to make your own standard deviations. These data sets can be enormous requiring over 6 GB of space to store all the data. Limits most users to case study archives.

Student Notes:



36. Interactive Quiz #3

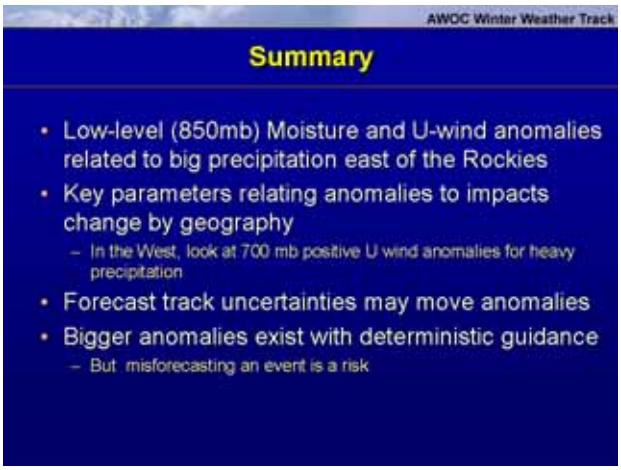
Instructor Notes: Take a moment to complete this quiz.

Student Notes:

37. Summary

Instructor Notes: Low-level (850mb) moisture and U-wind anomalies related to big precipitation east of the Rockies when you're north of the low. Key parameters relating anomalies to impacts change by geography. For example, in the West, look at positive 700 mb U wind anomalies. Forecast track uncertainties may move anomalies. Bigger anomalies exist with deterministic guidance, but misforecasting an event is a risk. Go with probabilistic forecasting to reduce your risk of large forecast errors. You can leverage the anomaly data and know parameters to gage if a storm or winter weather event will be in the range of ordinary or extraordinary.

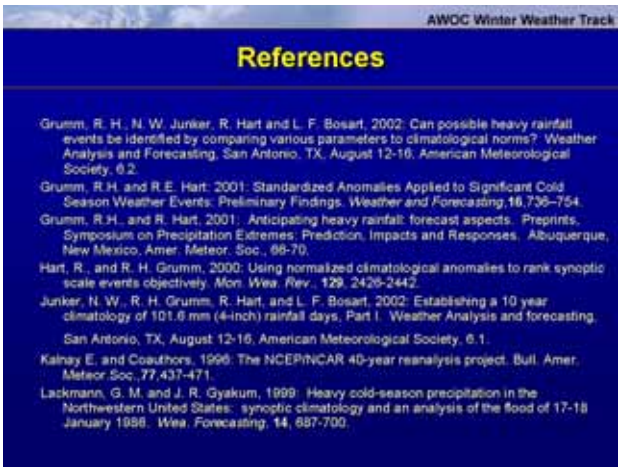
Student Notes:



38. References

Instructor Notes: Here are a few references you may want to check out.

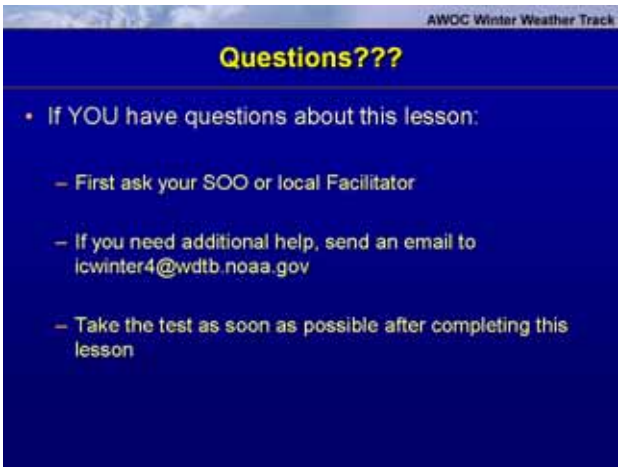
Student Notes:



39. Questions???

Instructor Notes: Current E-mail: icwinter4@wdtb.noaa.gov

Student Notes:



IC4.2 Part 1: Optional Job Sheet

Accessing Anomaly Information Using the Internet

Objectives:

1) become familiar with forecast anomaly resources on the Internet
2) review anomalies from a previous event using the Internet

Data: Internet

Instructions: Review the following websites to become familiar with using online anomaly resources to identify significant anomalies. Recall from IC4 Lesson 2 that significant standardized anomalies normally range from 2-3 standard deviations from normal. Values of 4 to 5 standard deviations from normal are considerably rarer. Values over 6 standard deviations are rarer still, and they are normally associated with deep tropical storms. Although the current weather being analyzed may not have anomalous winter weather, it is still useful to learn how and where to access anomaly information on the web. Bookmark the sites you find useful.

1) If you are investigating CONUS weather, go to the following website to view current anomaly forecasts for ensemble data or some individual model runs (site may take up to a minute to load):

http://eyewall.met.psu.edu/ensembles/index.html

1. Select “MREF” as the “Model” and “NOAM/500H” for the field. Move the scrollbar on the right side of the browser down to include the bottom image and the player buttons (“<” and “>”) at the top. Then step through the loop. Look for significant 500mb height anomalies (bottom) and ensemble spread (top). Low confidence in the strength of the anomaly occurs where ensemble spread (top) is correlated with the anomaly. High confidence in the strength of the anomaly occurs where ensemble spread (top) is not correlated with the anomaly.
2. Select “SREF” as the “Model” and “US/MSLP” as the field, and step through the loop. Look for significant anomalies in the pressure field, and gauge the confidence in the anomaly by looking at the correlation between the anomaly and the spread as in #1.
3. Select “SREF” as the “Model” and “US/850T” as the field, and step through the loop. Look for significant 850mb temperature anomalies, and gauge the confidence in the anomaly by looking at the correlation between the anomaly and the spread as in #1.

4. Select “SREF” as the “Model” and “US/850WIND” as the field, and step through the loop. Look for significant 850mb u anomalies (top image) and v anomalies (bottom image).

2) If you are investigating OCONUS weather, go to the following website to view current anomaly forecasts for *individual model runs*:

http://www.hpc.ncep.noaa.gov/training/SDs/

1. Select the “500 hPa Heights” link or the “Previous Cycle 500 hPa” link under the “GFS Forecast“ heading. Look for significant 500mb height anomalies in the GFS forecast.
2. Select the “850 hPa Temperatures” link or the “Previous Cycle 850 hPa” link under the “GFS Forecast“ heading. Look for significant 850mb temperature anomalies in the GFS forecast.

3) Now that you are done accessing forecast data, it is time to look up anomaly information on an event of your choice. For both CONUS & OCONUS weather, go to the following website to view archived anomaly information from the NCEP reanalysis data:

http://www.hpc.ncep.noaa.gov/ncepreanal/

1. Recall a memorable event or pick one at random, and enter the cycle time (00 or 12) and date (e.g. Current Date: 1993 03 14 00 for the “superstorm”).
2. Click the “+” or “-“ above the “CYCLE” category to step forward or backward 12 hours to the next analysis time. The top left panel is the 200mb height and isotachs plot. The top right panel is the 500mb heights and the standardized anomaly 500mb heights. The lower left panel is the 850mb heights, 850mb temperatures and the standardized anomaly 850mb temperatures. The bottom right is the 1000mb heights, precipitable water, and standardized anomaly of precipitable water.
3. To play a loop of data, enter the current date and end date, and click the “Loop” button. (e.g. Current Date: 1993 03 12 00 End Date: 1993 03 15 00 for the “superstorm”).

4) Now go to another useful website to view the interactive Global re-analysis data for a memorable event at:

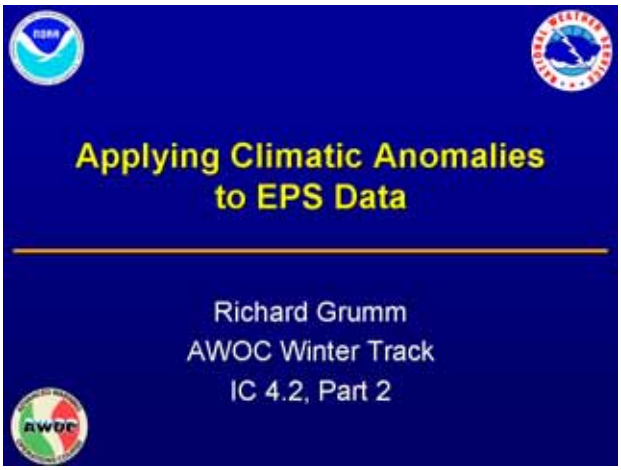
http://hart.met.psu.edu/meteo497/mapper.html

1. Data is available in 6-hour increments for many different variables. Pick the time to include the hour, day and month of the memorable event from 3. The default case is the super storm of March 1993.
2. The “Map Time Set” provides a loop of variables before and after the date entered. Pick “1 Day Before/After”.
3. Pick the display “Region” (e.g. North America).
4. Select the variables for the 4 panel chart (e.g. “Heights” or “U-winds”).
5. You can select the plot size, but the default “Medium” should be fine.
6. You must use the Plot button to make the image. Be patient as the program uses raw data to create images. Feel free to peruse other variables/dates.

1. IC4.2 Part 2: Applying Climatic Anomalies to EPS Data

Instructor Notes: Hello, my name is Richard Grumm, in this module we will examine using climatic anomalies to forecast winter storms.

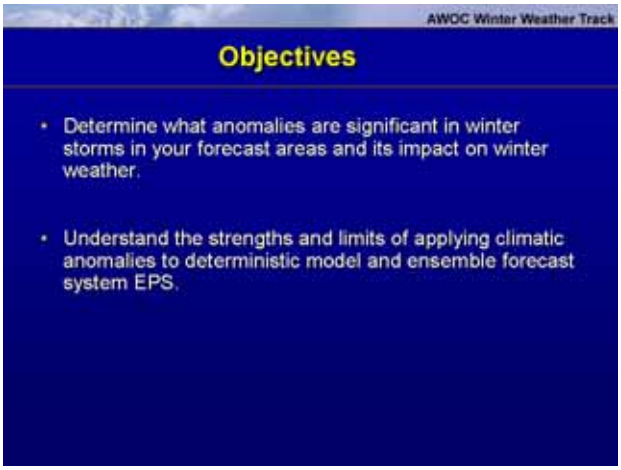
Student Notes:



2. Objectives

Instructor Notes: We will determine what anomalies are significant in winter storms. Some local and regional research may be required to refine this for your forecast area as what we show here may not apply to your area of responsibility. We will look at a forecast, and examine some of the problems one might encounter using anomalies with model or ensemble prediction data.

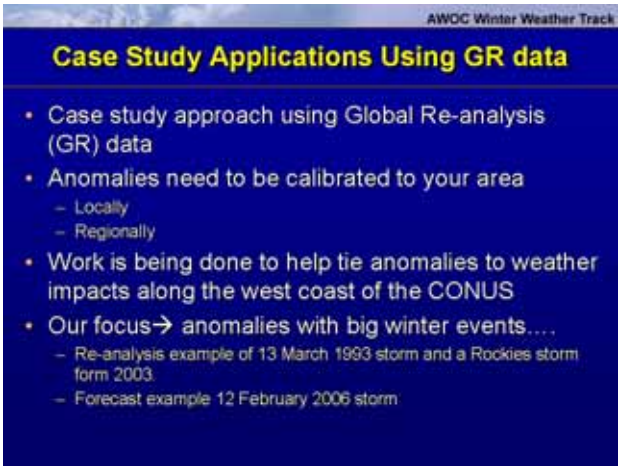
Student Notes:



3. Case Study Applications Using GR Data

Instructor Notes: We will take a case study approach using Global Re-analysis data (GR). This talk cannot address the concerns of all users as the proximity of oceans and terrain will dictate which anomalies are important to you. Clearly, in along the Pacific coast, southwesterly winds and high pwat into the terrain are going to be big signals in winter precipitation events. Wes Junker, with some help from a cast of many is working on this specific issue. You can learn by case studies with GR data…re-running the WRF against data for some of your favorite cases. Our focus is on anomalies with winter storms. We will use two cases showing re-analysis data and one using Ensemble data. We will look at some examples and harness 7 years of using these types of data.

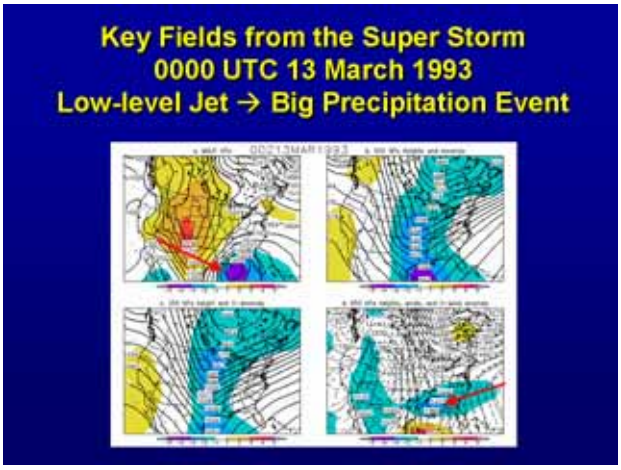
Student Notes:



4. Key Fields Super Storm 1993 0000 UTC 13 March Low-Level Jet: Big Precipitation Event

Instructor Notes: Our first case is the Super storm. It had lots of anomalies and the type we associate with major East Coast Winter storms (ECWS). Things of note from Kocin and Uccellini (2004 book), Grumm and Hart (2001) and Stuart and Grumm (~2006) include: deep strong surface cyclone, strong low-level easterly flow ahead of the low, strong southerly flow in warm sector to transport moisture. Easterly flow east of Rockies is a common method to get moist air into play for regions including the upslope from the front range all the way to the east coast. In the western Plains and eastern Rockies you may have to use 700 hPa winds instead of 850 hPa winds.

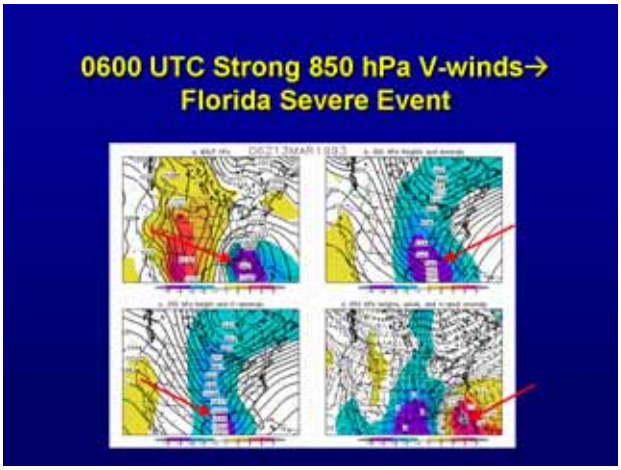
Student Notes:



5. 0600 UTC Strong 850 hPa V-Winds: Florida Severe Event

Instructor Notes: You can see the anomalous sea level pressures (>5 SD below normal). The anomalous 500mb height anomaly is in the upper right panel and the lower left panel shows the very low 250 mb height anomaly. In the lower right, very strong V-wind positive anomalies of > 5 standard deviations indicate much stronger than typical southerly low-level jet.

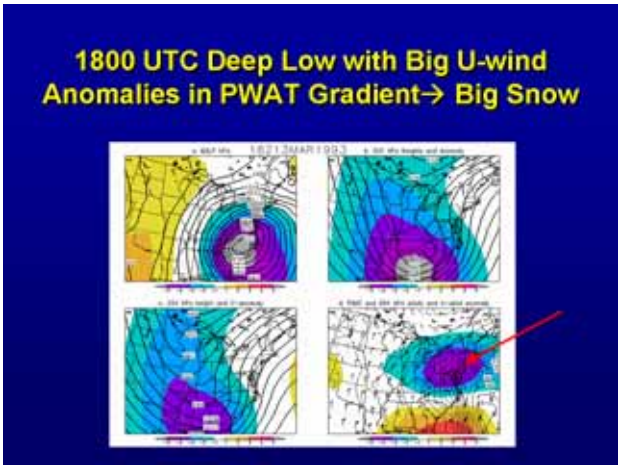
Student Notes:



6. 1800 UTC Deep Low with Big U-Wind Anomalies in PWAT Gradient: Big Snow

Instructor Notes: The anomalies got out of control as the storm developed and deepened. We say areas of 5 Standard Deviation departures from normal. Our surface cyclone was over 5 SDs below normal in the GR data. Note the strong U-wind anomaly on the cold side of our cyclone in the general region where the heavy snow was observed.

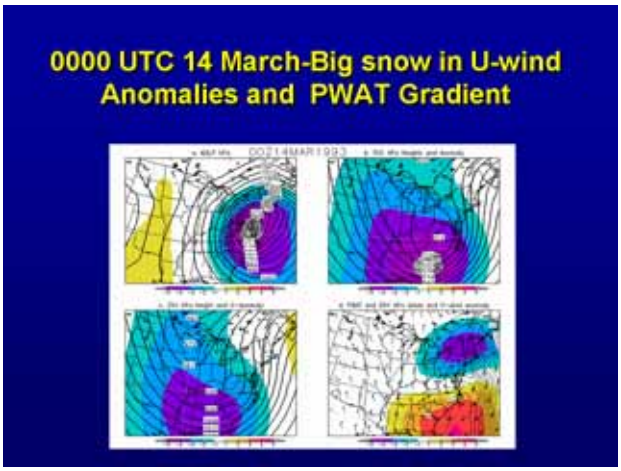
Student Notes:



7. 0000 UTC 14 March-Big Snow in U-Wind Anomalies and PWAT Gradient

Instructor Notes: The large anomalies continued as the storm moved up the coast. The classic anomalous low-level jet in the cold air is clearly visible. This storm had many large anomalies. Model re-runs showed similar anomalies with this storm. In the future, we hope to run the WRF off the NARR data to see how large the forecast anomalies may have been compared to 32 km rather than 2.5 degree data.

Student Notes:



8. Rocky Mountain Region Snows

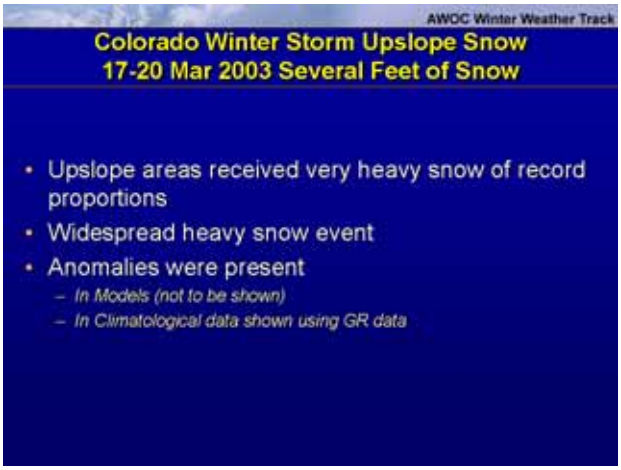
Instructor Notes: Work is still progressing relating the anomalies to weather in the Rockies. These following storms did have very large negative U anomalies at 700 mb. Oct 25-27, 1997 March 3-5, 1990 17-20 Mar 2003. We will look at the March 17, 2003 storm. Anomalies work in the Rockies too using the GR as an example…

Student Notes:

9. Colorado Winter Storm Upslope Snow 17-20 Mar 2003 Several Feet of Snow

Instructor Notes: We will examine a particularly big snow storm. It has the same U-wind anomalies as the ECWS's show…but sometimes you have to look a bit higher such as 700 hPa. This u-wind anomaly issue is not unique and was observed and forecast in a big Oct. 2005 snow in eastern MT and ND.

Student Notes:

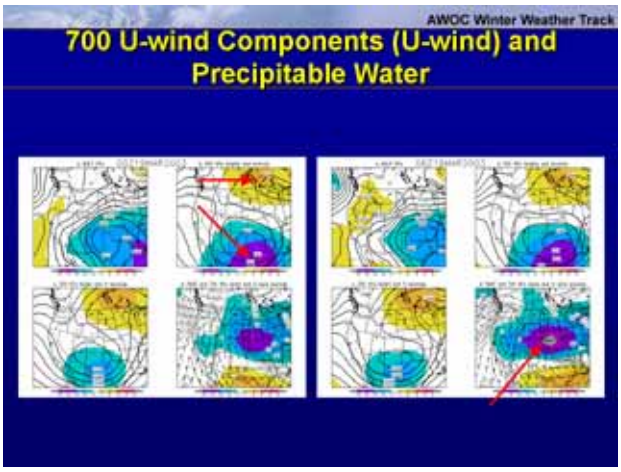


10. 700 U-Wind Components (U-Wind) and Precipitable Water

Instructor Notes: The 4-panel charts are laid out similarly to the 13 March, 1993 storm along the east coast, however we use the 700mb U wind anomaly. You can see the lower right panels of both times, a strong negative 700 mb U wind anomaly that corresponds to the easterly upslope component of the wind. The 06 UTC chart shows -5 SD values indicating how unusual it was to get easterly 700 mb winds of that magnitude. Those easterly winds were transporting high Precipitable Water (PW, black contours) upslope. The

upper right panel shows an anomalously deep closed low at 500mb and anomalously high heights in southern Ontario implying the unusual nature of getting a blocking pattern of this strength. We see the classic large anomalies in the GR data.

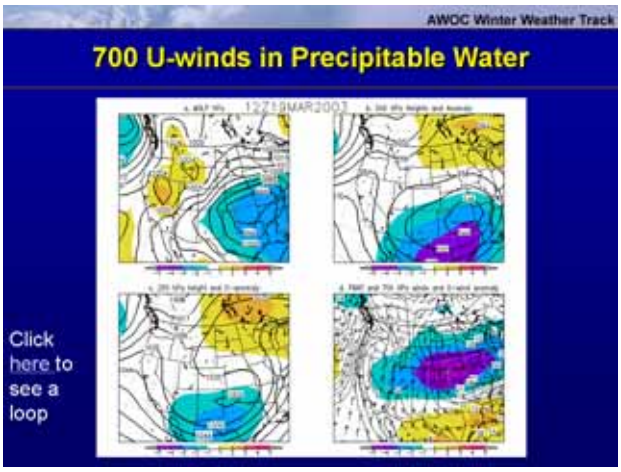
Student Notes:



11. 700 U-Winds in Precipitable Water

Instructor Notes: Here is a closer look at the 700 mb U wind anomalies and the precipitable water values.

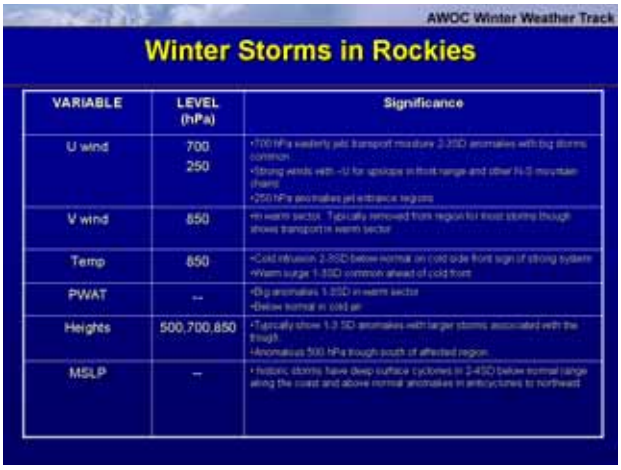
Student Notes:



12. Winter Storms in Rockies

Instructor Notes: Some general forecast rules and implications for the eastern United States. These actually apply to heavy precipitation events in general too. Advance this slide manually.

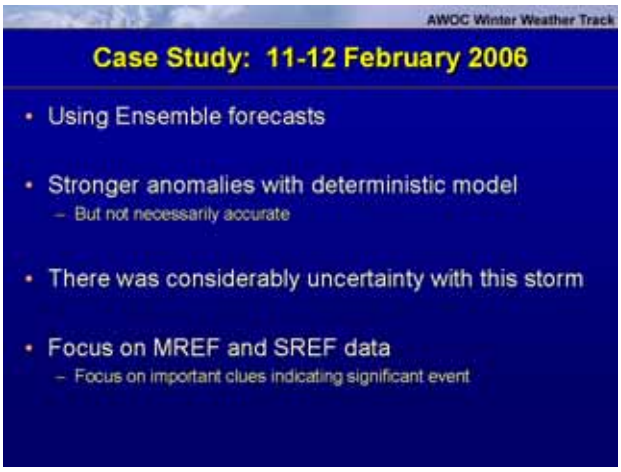
Student Notes:



13. Case Study: 11-12 February 2006

Instructor Notes: So let's apply all these anomalies to forecast data. We will use the 11-12 February 2006 ECWS and focus on ensemble prediction system (EPS) data. Why EPS data…there was, and nearly always is, uncertainty in the forecasts. This keeps the anomalies lower at longer ranges compared to a single deterministic model. But the lower values are due to real uncertainty and big anomalies in a single model may cause the forecaster to get too optimistic. In this case…the storm was not well forecast beyond about 5 days. It appeared with the 12Z 8 Feb 2006 GFS though it was in the 00Z 8 Feb and 06Z 8 Feb MREF…as more of a near miss in most members. SREFs had some problems with SREF-ETA members. Storm "appeared" on 8 February in GFS so limited lead time MREFs did a bit better than GFS We will show a mix of MREF and SREF data for brevity.

Student Notes:



14. Snow Fall 26.9 Inches in Central Park, NYC

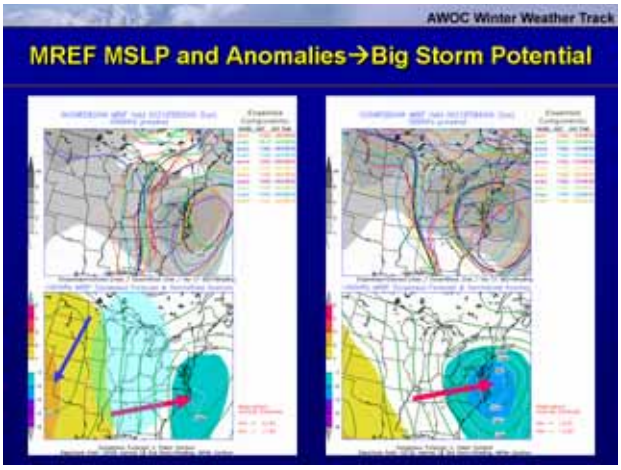
Instructor Notes: Here is a snowfall image. There were some 20+ inch amounts, and NYC had a record snowfall of 26.9 inches which set the all-time record for snowfall. There were some intense bands, but those are mesoscale details we will avoid.

Student Notes:

15. MREF MSLP and Anomalies: Big Storm Potential

Instructor Notes: These data are from MREF forecasts initialized at 06Z and 12Z 8 February, 2006. Quite early on the GFS was not really predicting much of a storm yet, but the MREF showed a big storm. scooting just off shore, a near miss of an anomalous storm. We will ignore the spaghetti plots at the top of each image. Suffice to say they show us that there was considerable uncertainty in these forecasts. The ensemble mean MSLP forecast on the lower right side shows a deep surface cyclone and a strong anticyclone to the west. These two features have been associated with major East Coast winter storms. Between them we can infer strong cold advection. The intrusion of cold air is another important predictor of major East Coast storms. The MREF initialized 6 hours later showed a deeper storm closer to the coast implying an increased threat of a winter storm. Our key point here is that the ensembles predicted a storm and a storm that would have a cyclone with below normal pressure, a characteristic of a major storm.

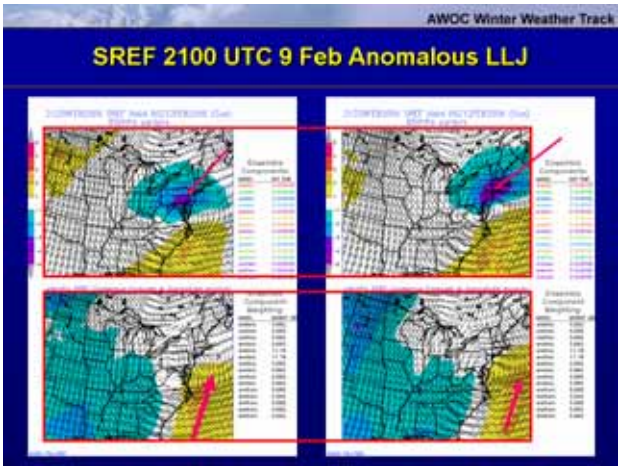
Student Notes:



16. SREF 2100 UTC 9 Feb. Anomalous LLJ

Instructor Notes: We quickly move to SREF data the next day. MREF data showed similar features, but we want details fast in our case study. The upper panels show the 850 hPa winds and U-wind anomalies. The lower panels show the same winds but Vwind anomalies from SREF forecasts initialized at 21 UTC 9 February 2006. One thing we should note is that forecasts from this time were the most optimistic for heavy snow farther west and a more westward cyclone track. The purple values are very large anomalies which have been shown to be associated with areas of strong FGEN and banded precipitation. These features are common in nearly ALL major ECWS's. We can see the anomalous easterly jet north of the low and the southerly jet in the warm sector. Most major storms have both anomalies. The strong southerly jet is important in bringing moisture into the system. Later forecasts show the focus of the anomalous low-level jet over southern New England, NY and NJ. These areas did see very heavy snow. We can also see our southerly wind anomaly in the warm sector at this time. If we compared these anomalies to a single EPS member, the NAM or GFS we would find these anomalies are low because: we are using an ensemble mean, disagreement among members...uncertainty reduces the winds and spread the wealth to a larger area.

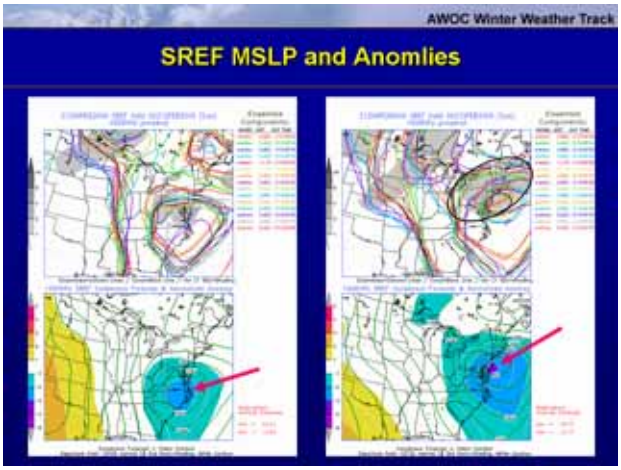
Student Notes:



17. SREF MSLP and Anomalies

Instructor Notes: These images show the MSLP evolution. These are SREF images and the upper panels show the spaghetti plots. Note there is considerable uncertainty in these forecasts as indicated by the shading showing the spread of the field indicated by the shading. The differences in the forecasts limit or reduce the anomaly values relative to a singe deterministic model. We will focus on the anomalies in the lower panels. Note the earlier forecast shows an anomalous MSLP center over North Carolina and Virginia. Also note the anomalous anticyclone (yellow) to the west. The later forecast, on the right shows even a deeper surface cyclone. There is an implied strong easterly wind north of the surface cyclone. These SREF data 32km data compared to very coarse GR anomalies. We might gain more using NARR data in the future. The key here is that our SREF system predicted a mean pressure field that indicated a cyclone with MSLP values showing an anomalous surface cyclone.

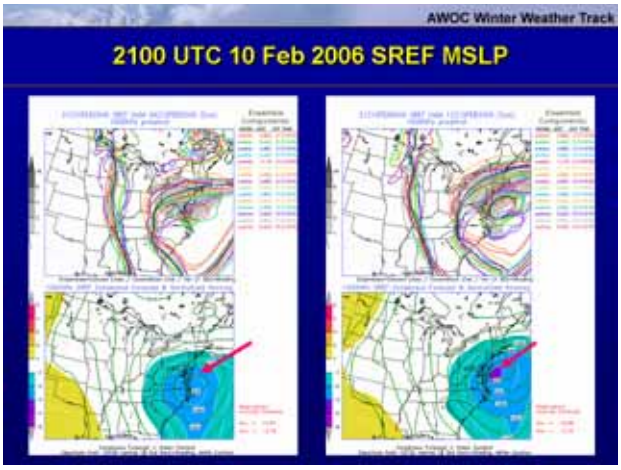
Student Notes:



18. 2100 UTC 10 Feb. 2006 SREF MSLP

Instructor Notes: In these images we have moved forward 1 full day…the SREF's are now initialized at 2100 UTC 10 February. There is less spread in the MSLP forecasts as the uncertainty decreases with shorter forecast length. Thus, we see larger anomalies in our MSLP fields associated with our surface cyclone in the lower panels. At this time, our surface cyclone is now forecast to remain just off shore…reducing the threat of heavy snow farther to the west. But our focus is on the storm and the climatic anomalies and not the details of the inherit uncertainty in weather forecasting. We can clearly see that the SREF ensemble mean was able to predict an anomalous surface cyclone along the east coast. A single deterministic model or single SREF member would likely have shown a more anomalous cyclone, but then we could not account for the uncertainty. Still the SREF forecast an anomalous surface cyclone.

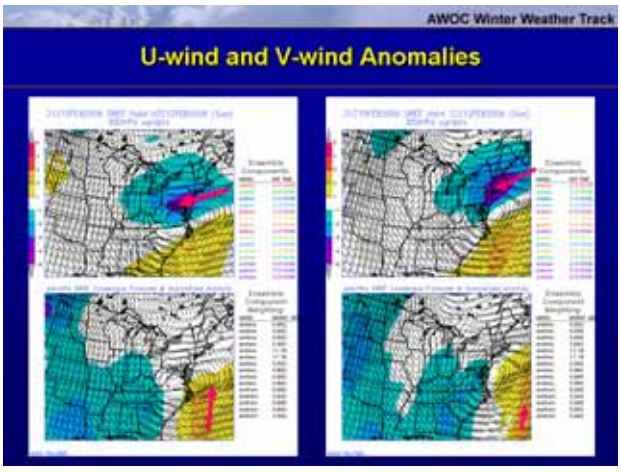
Student Notes:



19. U-Wind and V-Wind Anomalies

Instructor Notes: The data in these images were initialized at the same time as those on the previous slide showing MSLP forecasts. Relative to the previous 850 hPa wind forecasts, the low level jet gets finer and more focused as we get closer to the event time. Thus the anomalies are a bit larger. Smaller differences in EPS members lead to larger and more focused anomalies at shorter forecast ranges. But not as detailed and strong as one might see using a single member or forecast model. We still see the anomalously strong low-level easterly jet north of the cyclone in the area of heaviest snow. We can also see our southerly wind anomalies in the warm sector. These features are associated with nearly all major East Coast Winter storms.

Student Notes:

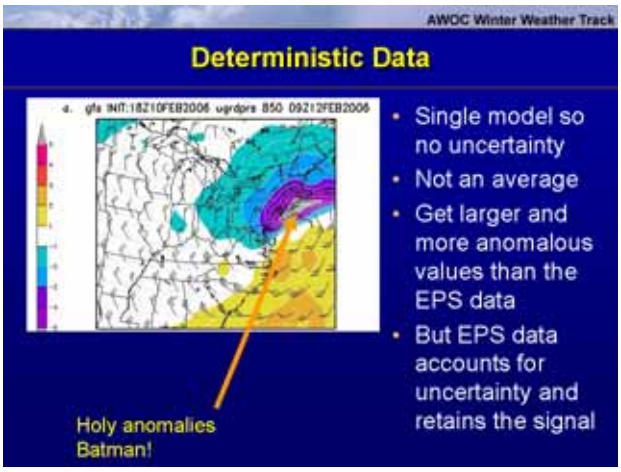


20. Deterministic Data

Instructor Notes: Okay, here is the GFS a single model, so you visualize the much larger u-wind anomalies. All uncertainty is removed, though there is not accounting for model accuracy, and the single forecast shows the strong jet. We could show similar examples of MSLP and 850 hPa temperatures, but the results would be the same. Using

ensemble data you get a slightly reduced signal. A single EPS member or model provides a feel of how strong the real LLJ may be, but a false sense of exactly where it may be!

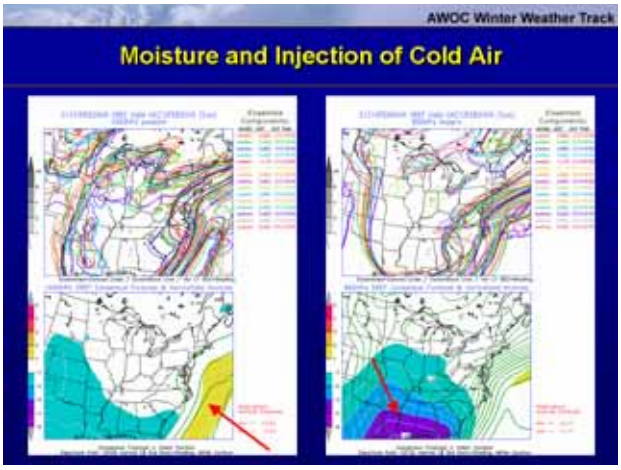
Student Notes:



21. Moisture and Injection of Cold Air

Instructor Notes: MSLP anomalies and U and V wind anomalies are not the only anomalies of value in forecasting winter storms. Other key fields include moisture which we will show using precipitable water (PWAT). We can see the moisture anomaly with our storm over the western Atlantic in the lower left hand panel. This is in close proximity to our low-level southerly jet. Thermal anomalies are also important. An intrusion of cold air is typically observed to the west of our surface cyclone and is important in the cyclongenesis. In this case, we can see the intrusion of very cold air into the central Gulf States as forecast by the SREF. The case lacked the strong positive thermal anomaly often observed in the warm sector of many major and significant East Coast Winter Storms.

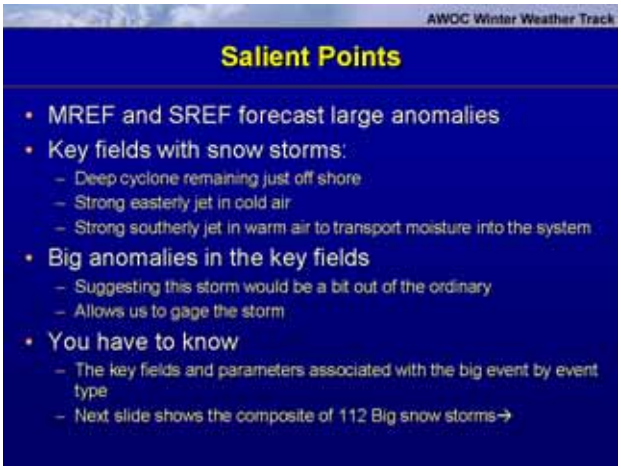
Student Notes:



22. Salient Points

Instructor Notes: MREF and SREF forecast large anomalies. Key fields with snow storms: Deep cyclone remaining just off shore, strong easterly jet in cold air, strong southerly jet in warm air to transport moisture into the system, big anomalies in the key fields, suggesting this storm would be a bit out of the ordinary and allows us to gage the storm. You have to know the key fields and parameters associated with the big event by event type. Next slide shows the composite of 112 big snow storms.

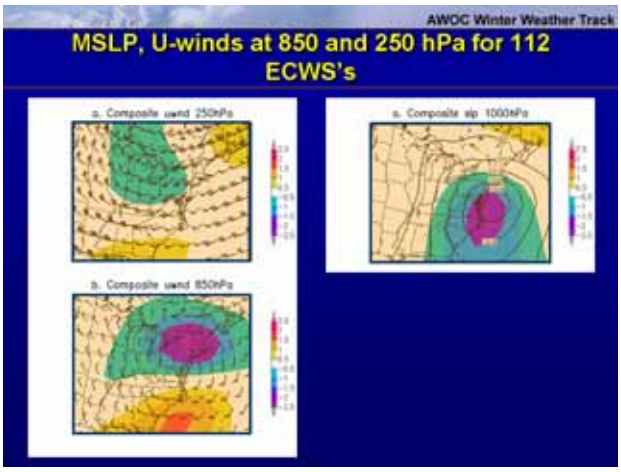
Student Notes:



23. MSLP, U-Winds at 850 and 250 hPa for 112 ECWS's

Instructor Notes: These images show some of the key features with major ECWS's. We found about 112 cases and composited them. The data showed a deep cyclone just off shore and a strong easterly wind north of the low at 850 hPa. The 250 hPa winds shown suggest weaker than normal westerlies in the upper level jet…its an entrance region. Other features are not shown but many parameters leave a strong signal including that intrusion of low-level cold air at 850 hPa and lower levels.

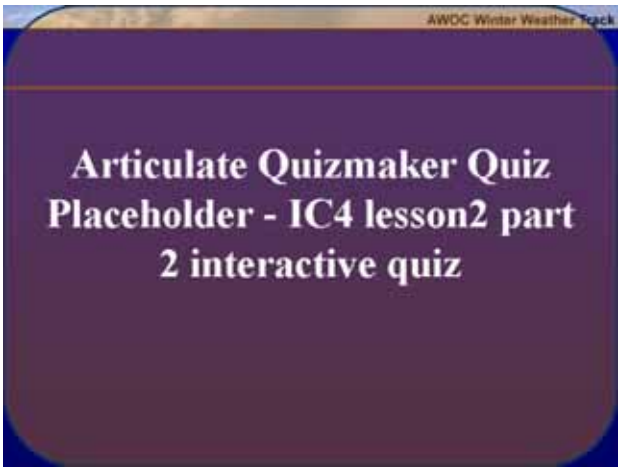
Student Notes:



24. Winds and Winter Storms and Anomalies

Instructor Notes: Take a few moments to complete this interactive quiz.

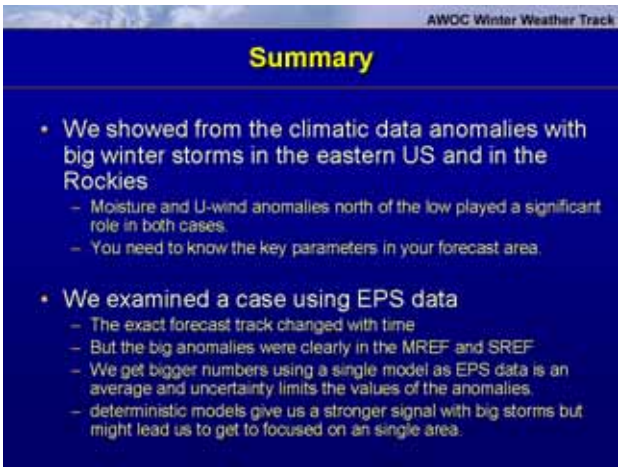
Student Notes:



25. Summary

Instructor Notes: We showed from the climatic data anomalies with big winter storms in the eastern US and in the Rockies. Moisture and U-wind anomalies north of the low played a significant role in both cases. You need to know the key parameters in your forecast area. We examined a case using EPS data. The exact forecast track changed with time, but the big anomalies were clearly in the MREF and SREF. We get bigger numbers using a single model as EPS data is an average and uncertainty limits the values of the anomalies. Deterministic models give us a stronger signal with big storms but might lead us to get to focused on an single area.

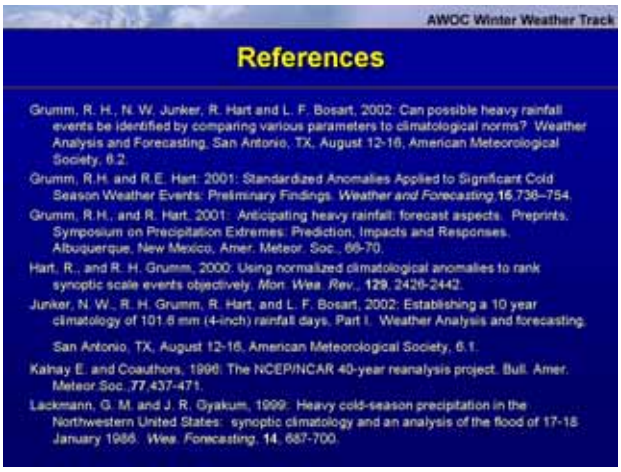
Student Notes:



26. References

Instructor Notes: A few notable references.

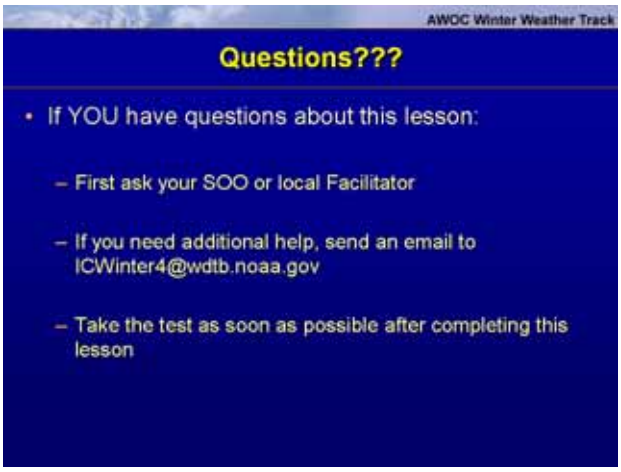
Student Notes:



27. Questions???

Instructor Notes: If you have any questions about this lesson, first ask your local AWOC facilitator. If you need additional help, send an E-mail to the address provided. When we answer, we will CC your local facilitator and may consider your question for our FAQ page. We strongly recommend that you take the exam as soon as possible after completing Lesson 3.

Student Notes:



1. IC4.3: Microclimates: Interaction of Synoptic Patterns with Local Terrain

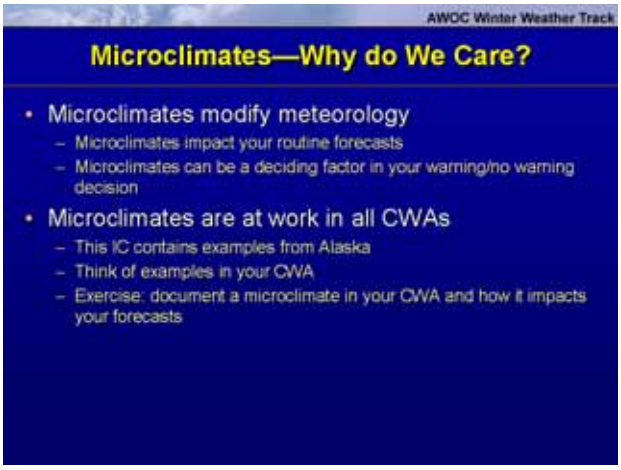
Instructor Notes: Welcome to IC 4, Lesson 3, “Microclimates” or “How Synoptic Patterns Interact with Local Terrain to Impact Winter Weather.”

Student Notes:

2. Microclimates—Why do We Care?

Instructor Notes: You may ask why microclimates are important. After all, we are meteorologists, not climatologists. The reason microclimates are worth your time is that microclimates modify the meteorology in your CWA. Microclimates are a constant consideration—they impact your routine day-to-day forecasts, and they can be a deciding factor in your warning/no warning decision. This IC contains descriptions of the broad categories of microclimates. Then to illustrate how these microclimates really impact our jobs on the forecast desk, some examples of microclimates in action will be presented. Microclimates are highly localized phenomena, and the specific examples presented in this lesson will come from Alaska, since I am most familiar with that area. Please don’t take the message that microclimates are only important in Alaska—they are not, microclimates impact the weather all across the country. These are just some examples from Alaska. As we go through this lesson, think of how these concepts might apply to your forecast issues in your CWA. At the end of this lesson there will be an exercise to document a microclimate in your CWA.

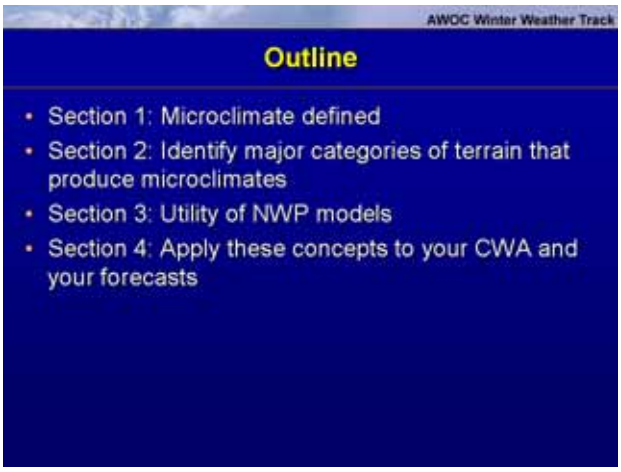
Student Notes:



3. Outline

Instructor Notes: This will be a very qualitative IC. We will present these concepts broadly and briefly. Section 1: Microclimate defined. Section 2: Identify major categories of terrain that produce microclimates. Section 3: Utility of NWP Models. Section 4: Apply these concepts to your CWA and your forecasts. This last point is the real point—learning more about microclimates in our CWAs and applying this knowledge to our forecasts.

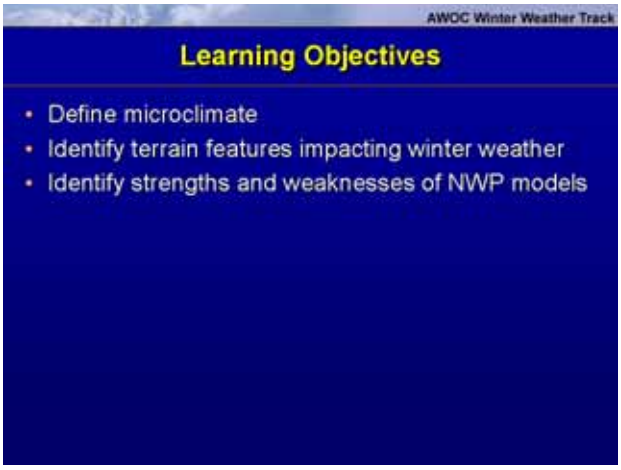
Student Notes:



4. Learning Objectives

Instructor Notes: By the end of this lesson you will be able to… Define microclimate; Identify terrain features impacting winter weather; Identify strengths and weaknesses of NWP models.

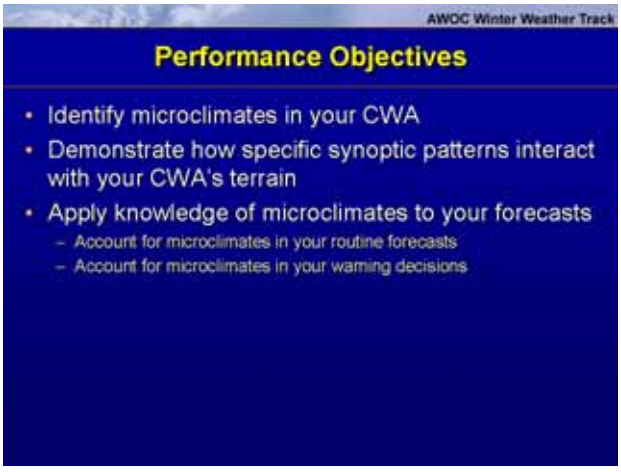
Student Notes:



5. Performance Objectives

Instructor Notes: We have three performance objectives with this IC. Identify microclimates in your CWA. Demonstrate how specific synoptic patterns interact with your CWA's terrain. Apply knowledge of microclimates to your forecasts, both routine day-to-day forecasts as well as warning decisions. Again, note the emphasis on YOUR CWA and your forecasts. This IC presents general concepts and a few examples from Alaska, but the performance objective we are all hoping for is in reference to your CWA and your forecasts.

Student Notes:

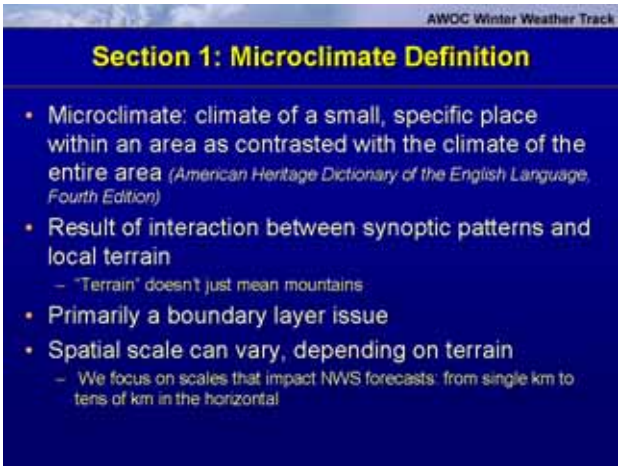


6. Section 1: Microclimate Definition

Instructor Notes: That is all for section 1, the definition of microclimate Here is the definition from American Heritage Dictionary of the English Language, Fourth Edition. …Online. This American Heritage definition is useful to consider. Building on that definition, the idea I have kept in mind while developing this IC is that a microclimate is the result of interaction between the synoptic pattern and local terrain, with the outcome being sensible weather on the local scale that may at first glace appear to be unex-

pected. But upon further study, we see that such localized weather occurs regularly under certain synoptic regimes and is actually a micro climate. For the purposes of our discussion here, we will not limit the term “terrain” to mean only mountains. The Rocky Mountains certainly are a terrain feature, but we also need to consider bodies of water as terrain features which impact microclimates. Your soil type can be a factor, the degree of vegetation can be a factor. Terrain here is anything underneath the sky. Microclimates are primarily a boundary layer issue. For example, under a quiet high pressure scenario, the 500mb height field and 850mb temperature field may be nearly devoid of gradients over your CWA, but nighttime temperatures down at the surface, where the people are, may vary considerably over hilly or mountainous terrain due to the development of shallow surface-based radiation inversions. The spatial scale of a microclimate can vary widely, depending on terrain. For the purposes of this IC we will limit our focus to the spatial scales which impact NWS forecasts. Now in the digital age, the spatial resolution of IFPS is a consideration. We’ll focus on scales of single kilometers to tens of kilometers in the horizontal. This upper end of such scales may be encroaching into the mesoscale, but for the sake of our quick discussion here we will refer to all these terrain-driven modifications of weather as microclimates. One could also argue that there are microclimates of very small scales—for example, different climates immediately to the north or south sides of a single building. But we will not consider those fine-scale influences as important to this discussion. That is all for section 1, the definition of microclimate

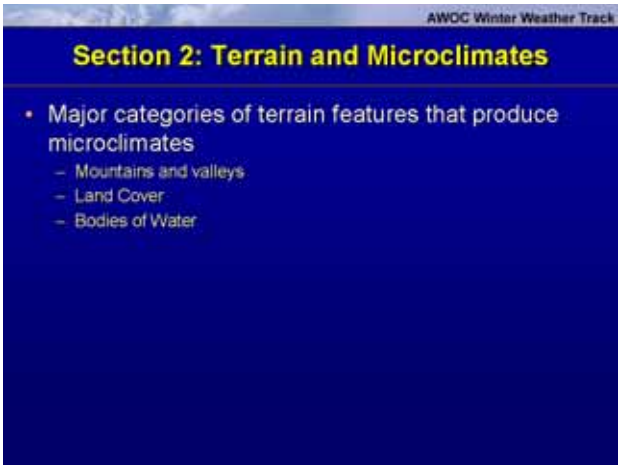
Student Notes:



7. Section 2: Terrain and Microclimates

Instructor Notes: Here is section 2 of the IC, the kinds of terrain that can interact with the synoptic pattern and produce microclimates. For the purposes of our discussion here, “terrain” doesn’t just mean mountains. Terrain does include mountains, but also forests, farm fields, lakes, basically anything under the sky. Here are the three major categories of terrain features that produce microclimate: Mountains and valleys; Land cover: trees, soil types, etc.; Bodies of water, lakes and oceans. Now we will look at each of these categories more closely and see some examples of how these terrain features affect day-to-day weather and even watch/warning decisions.

Student Notes:



8. Mountains and Valleys

Instructor Notes: The first of the three major types of terrain features that produce microclimates is mountains and valleys. Mountains and valleys impact the wind. --Wind speeds can be accelerated. Examples include gap flow and Chinook winds. --Winds can be steered down a valley. One could also loosely define “valley” enough to include narrow marine channels where winds blowing either up channel or down channel are favored. --Sometimes the terrain prevents much wind of any kind from being realized at a location. For example, the bottom of a valley that is frequently under a radiation inversion and is effectively decoupled from the flow above the inversion. Mountains and valleys also impact precipitation. This is the old rule of enhanced precipitation on the windward, upslope side of a mountain barrier, and a downslope precipitation shadow on the lee side of the barrier. This topic is covered in more depth elsewhere in AWOC Winter Weather track. Temperatures are also affected, and not simply because it’s colder on a 15,000 ft. mountain top than it is at sea level. Even with much less extreme relief than that, radiation inversions will develop in valleys and lead to sometimes striking stratification of temperatures in the vertical, even down in the inhabited elevations. A mountain barrier can also constrain the movement of air masses in the horizontal, particularly a cold surface-based air mass. One classic example of this effect is when a topographic barriers constrains the advection of cold air at the lower levels and produces a cold air damming event.

Student Notes:

9. Vertical Temperature Stratification

Instructor Notes: Here's an example of how rough terrain, be it mountains and valleys or less extreme terrain like rolling hilly country, can produce significant temperature variations near the surface. In Alaska's interior, strong surface-based temperature inversions are common in the winter. This example is extreme, but it is fun to look at because it so dramatically illustrates the issue. Through the bottom 150 ft. of the atmosphere temperature rises 37F. The surface-based inversion is established as long-wave radiation escapes during the long clear nights, and density currents then allow the coldest air to pool down in the valley bottoms. Once established, the inversion can be tough to remove if the surrounding higher terrain hinders the ability of a new airmass to scour out the cold air down in the valleys. Not to say that the inversion will NEVER leave. If clouds move in, the radiative balance will change, and surface temperatures can rise substantially. Also, if a puff of wind comes along, a sharp but shallow inversion like the one in this sounding will be mixed out and surface temperatures can rise substantially. Since these inversions develop down in the inhabited elevations, they are an important forecast issue. Such inversions occur many times during a winter season, and they contribute to the microclimate where valley bottoms are much colder than the surrounding higher terrain—this is a variation on the "thermal belt" theme associated with fire weather forecasting.

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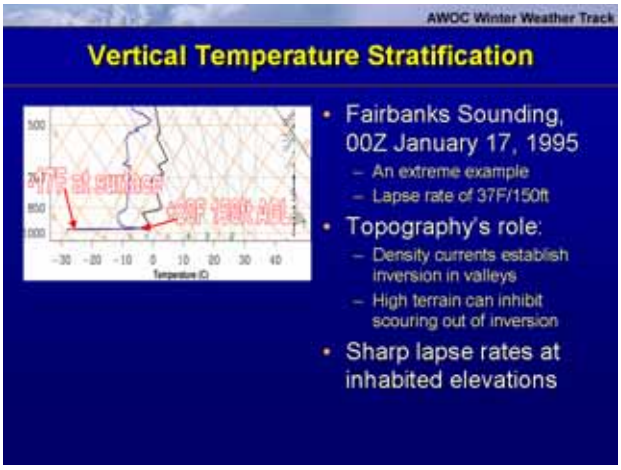

10. Vertical Temperature Stratification

Instructor Notes: Having looked at an extreme example of this effect on a single point basis, let's switch to a more routine example, but this time in the plan view. Here are two images of Alaska's interior: on the left is a topographic map where low elevations are green and high elevations progress from yellow to brown. On the right is a polar orbiter IR image from a clear day in February 2005. Since skies were totally clear when this picture was taken, all we are seeing here is surface temperatures. The images are labeled, because at first glance it is difficult to tell them apart—that's how strong the relationship is between temperature and height in this case. In this case, temperatures down at inhabited elevations, where the towns and roads are, range from 50 below to near zero Fahrenheit, with the coldest temperatures down in the valley bottoms. This type of temperature distribution is common in Alaska's interior when skies are clear during the winter—this is no once-a-decade extreme example, this is a routine microclimate. Note that cold temperatures have pooled in the broad, roughly bowl-shaped Upper Yukon Valley. Cold air settles in broad valleys and in narrow valleys alike. Note the narrow valleys draining out of the Brooks Range near the top of these images—the cold air settles into the narrow valleys here just as easily as it does in the broad Upper Yukon Valley. This example comes from Alaska, but the concepts apply everywhere: colder air will settle into valley bottoms. Most CWAs don't have large mountains, but there can still be river valleys where this kind of microclimate may play a role. Even slightly rolling terrain can be impacted. As part of this IC you will do an exercise in which you document a microclimate in your CWA. Is there a vertical stratification of temperature in your CWA that you could document?

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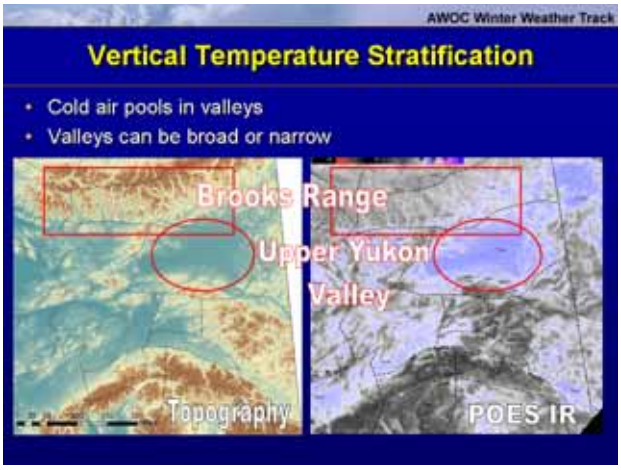

11. Vertical Temperature Stratification

Instructor Notes: As the size of the area under consideration increases, the relative nature of elevation becomes evident. That is, no single elevation above mean sea level separates the cold air in the valleys from the milder air in the hills across this entire domain. For example the Yukon Tanana Uplands in Alaska's southeastern interior could generally be described as elevated terrain. In this area, an elevation of 1500 ft. mean sea level is in the valley bottoms and thus is in the bitterly cold air, as we see in the satellite picture. But in the greater Fairbanks area, within the circle, the same absolute elevation 1500 ft. MSL is up in the hills with the milder air. So the lesson here is that cold air settles into valleys, but valleys are relative to the local surrounding terrain--you can't simply query elevation in the GFE to assign cold air across the entire domain below a single elevation MSL.

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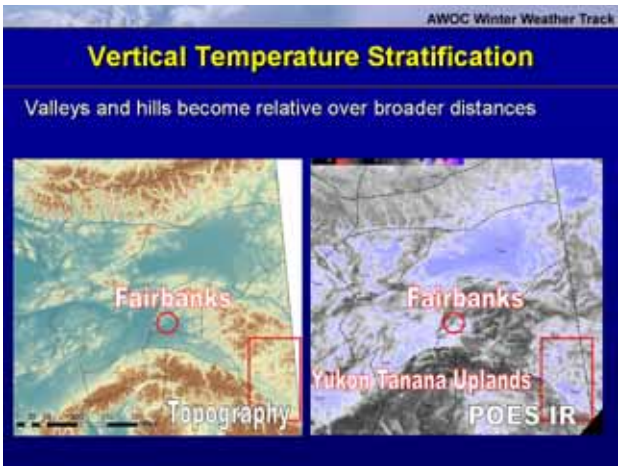

12. Vertical Temperature Stratification

Instructor Notes: As we saw in the sounding on slide 9, the depth of the surface-based inversion can be quite shallow. Wind can mix the boundary layer and eliminate the sharp

stratification of temperature in the vertical. There is an example of this wind-induced mixing phenomenon at work in this same case we have been looking at over the last couple of slides. On the topographic map note how the Tanana River flows down the Tanana Valley from the southeast to the northwest. A down-valley wind known as the “Tanana Valley Jet” is common here and can mix away the surface-based inversion. Note the more smeared-out homogenized look to the temperatures in the windy area on the IR image. This satellite image allows us to make only a binary qualitative assessment of the wind speed here: in areas where there is at least “some” wind the IR imagery shows milder temperatures, even down in the valley bottoms. In areas where there is little or no wind the highly detailed dendritic pattern is evident in the IR temperatures as the cold air quietly settles into the lower elevations. In the windy areas we can’t correlate specific temperatures to specific wind speeds, rather we simply know that the wind speeds in these warmer homogeneous areas are non-zero. We will return to the Tanana Valley Jet later in this IC during our discussion of NWP models and their strengths and weaknesses in accounting for microclimates.

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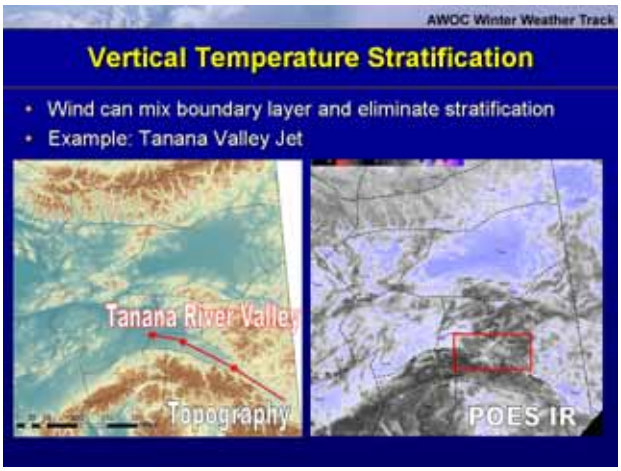

13. IC 4.3 Interactive Quiz

Instructor Notes:

Student Notes:

14. Downslope Flow

Instructor Notes: Now we're going to look at how mountains and valleys produce downslope flow which makes hazardous weather less likely at one location. On this simple cartoon we see a surface low with an occlusion stretching to the southeast. On the synoptic scale, the villages of Nome and Unalakleet appear to be in the same situation: these villages are about 150 miles apart, but both are coastal villages ahead of an approaching occlusion, and they both can expect gusty easterly winds and some snow. Blowing snow may reduce visibility down to blizzard levels. This is a common winter storm pattern for Alaska's west coast. However, it turns out that under this kind of scenario Unalakleet actually verifies blizzard conditions only about half as often as Nome does. And if Unalakleet does have a blizzard, the blizzard is often comparatively brief, while Nome may have many hours of blizzard conditions. Why the difference?

Student Notes:

15. Downslope Flow

Instructor Notes: We zoom in to look at the topography around Nome and Unalakleet. Again, these villages are about 150 miles apart. Notice how the village of Unalakleet is at the western end of a river valley that cuts through higher terrain. When a winter occlusion is approaching from the south, the flow at Unalakleet is out of the east, down the river valley, and is a downslope flow out of the higher terrain. Up at Nome an easterly flow is roughly parallel to the coastline where there is no downslope component. The downslope flow at Unalakleet makes precipitation associated with the approaching occlusion less likely than at Nome where there is no downslope. This is not to say that blizzards cannot happen at Unalakleet when an occlusion is approaching from the south…the blizzards are just less likely than at other communities in the area such as Nome. As the occlusion passes directly over Unalakleet the synoptic scale dynamic forcing can overcome the downslope and produce some snow and possible blizzard conditions…but this blizzard is not usually very long-lived. Nome is not protected by downslope and can begin getting blizzard conditions while the occlusion is still comparatively far to the south. So this is an example of how the terrain produces a microclimate that actually makes

severe winter weather less likely at a location. Microclimates can just as easily protect an area from severe winter weather as make an area more vulnerable. This kind of information can be useful in our WSWs, since it may allow us to specify locations where conditions are likely to be more or less severe during a winter weather event. This is the end of our discussion of the first category of terrain that produces microclimates, mountains and valleys.

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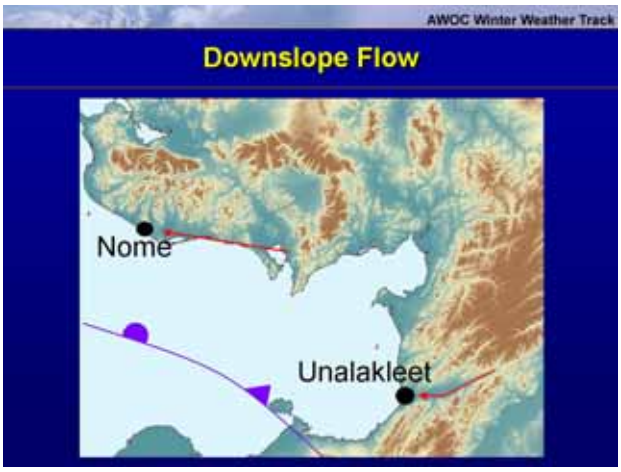

16. Land Cover

Instructor Notes: The second of the three major types of terrain features that produce microclimates is land cover: trees, stubble in a plowed field, bare rocks, a built-up urban area, snow, etc. The land cover effects radiation from and into the surface. A great example of this is the impact of an insulating cover of fresh snow. All other things being equal, newly snow-covered ground will radiate much more effectively under clear skies at night than snow-free ground. Snow-covered ground will also reflect incoming short-wave raditaion during the daytime and limit the diurnal rise in temperatures. It is important to keep in mind that snow's albedo and radiative properties can change as the snow pack ages-the snow can compact over time, become "dirty," etc. Different types of soil, such as sand, dirt, or rocks-all have their own radiative properties and albedos which can impact your temperature forecast, both at night and during the day. The degree of urbanization can produce a "urban heat island" and alter the local radiative properties of the landscape as compared to rural areas. Land cover will impact the magnitude of the wind, and consequently the potential for blowing snow. It's very difficult to achieve a zero-visibility white-out due exclusively to blowing snow in the middle of a thick forest. Even less prominent land cover, such as a farm field of corn or sunflowers, can diminish the magnitude of the wind, compared to wind blowing over a field that has been harvested and is bare except for ankle-high stubble. Again the age and condition of the snow cover can be an issue here. A fresh fluffy snowpack is more available to being picked up by the wind and reducing visibility as blowing snow than is an older snowpack which may already be wind-sculpted or crusted over from previous thaw/freeze episodes. Compared to mountains and valleys, land cover is very changeable in time. Snow cover comes and goes, forests may be cut down or replanted, forests can also

burn down and regrow over time. Advancing urban sprawl can mean the urban heat island will have an increasing effect in an area.

Student Notes:

17. Land Cover

Instructor Notes: Here's an example of how ground cover can influence the likelihood of blowing snow events. In the area around Fairbanks, there is a "tree line" at about 2000 ft. mean sea level, with trees below this elevation and much shorter types of vegetation above. This map shows the road system around Fairbanks. You can drive from Fairbanks, at 450 ft. MSL, up to Eagle Summit, at 3500 ft. MSL. In the high terrain northeast of Fairbanks there is extensive area above tree line. When the wind kicks up, blowing snow can reduce visibility throughout these uplands, even to the point of blizzard conditions. Down at elevations below tree line, some locations can become very windy—like the wind down the Tanana River Valley we saw earlier—but the territory surrounding these low-elevation windy locations is usually covered by trees, so less blowing snow is produced and blizzard conditions are almost unheard of. So in the northern Alaska CWA, you can't simply use the GFE query tool to select all grid boxes for winds greater than some value and then assign a visibility restriction due to blowing snow. Instead you might need to query for wind speed and then also query for elevations above tree line. Only in areas where there is both sufficient wind speed and also sufficient surface area devoid of trees can enough blowing snow be kicked up to introduce a treat of legitimate blizzard conditions. This is an Alaskan example. Can this concept be applied to your CWA? Are there differences in land cover across your CWA that could impact the likelihood of blowing snow? Are some areas thickly wooded and other areas which are more open? Again, keeping in mind your exercise to document a microclimate in your CWA as part of this IC, are there any land cover issues which impact forecasts in your CWA?

Student Notes:

18. Bodies of Water

Instructor Notes: The third of the three major type of terrain features which produce microclimates is bodies of water, where the body of water in question can be large, like an ocean or one of the Great Lakes, or even smaller, but still significant lakes and major rivers. The classic impact here is lake effect snow, as shown in this visible satellite image of the upper Great Lakes. LES is covered in more detail in Winter Weather AWOC IC5 Lesson 7. Also, temperatures can be impacted along a coast within the marine layer, and the degree of inland penetration of the marine layer can be somewhat variable. Impacts will include temperature, dewpoint, cloud cover, precipitation. Coastal flooding isn't just for tropical storms. Wintertime extratropical cyclones can also ravage a coastline, both with pounding waves and with a storm surge. As in the case with tropical storms, different coastal communities have differing degrees of vulnerability to coastal flooding depending on the immediate terrain. This picture is from the coastal community of Nome, on Alaska's west coast, during the great storm of October 2004. That's ocean water flooding the village. The storm surge during this event was eight to ten feet high. As in the case with land cover, the impact from bodies of water can change over relatively short periods of time. For example, LES in the lee of the Great Lakes will become less of a factor if the lake ices over. In northern Alaska, the coastal flood season effectively ends as the ocean ices over. That is it for Section 2 of this IC, identifying the three major categories of terrain features that produce microclimates: Mountains and Valleys, Land Cover, and Bodies of Water.

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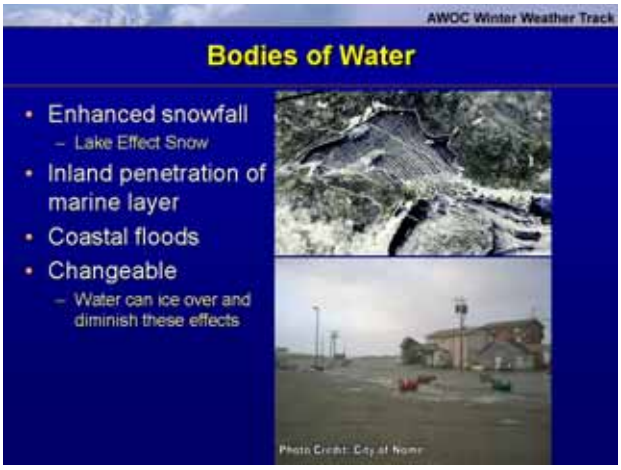

19. Utility of NWP Models: Gridded Fields

Instructor Notes: Now on to Section 3, NWP models and their strengths and limitations when it comes to depicting microclimates. We're going to look at both the gridded NWP output as well as MOS. We will look at an example of how two different models depict 2-meter temperatures, in a case where temperatures are highly influenced by topography, per our discussions earlier in this IC. Here's another map of topography over northern Alaska. Note the Brooks Range, an east-west oriented mountain chain extending across northern Alaska. Elevation decreases sharply to the north of the crest. Here again is the roughly triangle-shaped bowl of the Upper Yukon Valley. With ever increasing computer power, the spatial resolution of NWP models is constantly becoming finer and finer. A model with finer resolution can depict finer-scale features. Here's a picture of the DGEX model 2-meter temperatures. The DGEX, which is basically a tight-domain version of the 12km eta forced by the GFS for the boundary conditions, is able to show a fair amount of topographically forced detail in the temperature field. For example, note the sharp temperature gradient the DGEX depicts from the crest of the Brooks Range down to the purple puddle of cold air on the flats to the north. This is the vertical stratification of temperature in complex terrain microclimate at work again, and the DGEX depiction is conceptually very reasonable. The DGEX also has a less pronounced cold pool here in the Upper Yukon Valley. Now here is the DGEX's parent the GFS with a depiction for the same time, 12z March 5th, 2004. The GFS is a much coarser model than the DGEX, so it's depiction looks very different from the DGEX. The GFS' 2-meter temperature field has the same idea in putting a cold pool on the flats north of the Brooks Range, but is not able to resolve the sharp temperature gradients along the crest of the mountains as well, and in this case does not have as extreme a minima on the flats either. The GFS also has a local cool spot in the Upper Yukon Valley, but again differences appear between the models regarding the sharpness of the temperature gradients and in the magnitude of the extrema. So we see here that finer resolution models can depict finer features. Now we just need a 1 km model that goes out seven days and IFPS can take care of itself and everything will be perfect. Or maybe not. Keep in mind that fine resolution doesn't necessarily mean the forecast is more accurate. Remember that microclimates are the result of synoptic patterns interacting with local terrain. If the model's long wave

synoptic-scale forecast is wrong, then no degree of fine resolution of terrain will be enough by itself to yield an accurate solution. In this sense, relying on a model simply because of its fine resolution can be like watching an outrageous daytime talk show on high-definition television-it looks sharp, but the underlying substance may be questionable and the overall result may be garbage. There are still plenty of other pitfalls for any model aside from the issue of resolution, such as accounting for radiation processes and proper depiction of snow cover, etc, but, in general, if a model's synoptic-scale solution is good, and if the model has a very fine resolution, then it **should** provide a better depiction of these kinds of terrain-influenced microclimate effects than that of a coarser model, all other things being equal.

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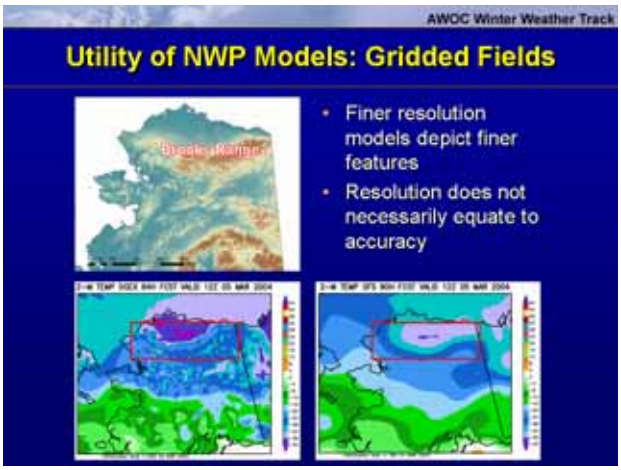

20. Utility of NWP Models: MOS

Instructor Notes: Now we'll take a look at how MOS, even if its parent NWP model is comparatively coarse, has the potential to account for microclimates on a point by point basis. To illustrate this point we'll look at part of the Tanana Valley in Alaska's interior, and at a microclimate called the "Tanana Valley Jet." Fist we set the stage on the synoptic scale. On the right is NCEP's sea level pressure analysis at 06Z November 28, 2003, a typical Tanana Valley Jet scenario. A 1016mb high is centered over northwestern Canada and is centered north of the arctic front. Surface temperatures in northwest Canada and over the eastern half of Alaska's interior associated with this high range from about 35 below zero up to the single digits above zero. The low near on Alaska's west coast has a central pressure of 975mb, so the sea level pressure gradient across mainland Alaska is around 40mb. Under these conditions, the pressure gradient force will produce the Tanana Valley Jet, but the winds will not be realized everywhere. Some locations become very windy, and other locations have little or no wind at all. We are going to consider the portion of the Tanana Valley from Northway downriver to Fairbanks, which we've zoomed into on the topographic map. Just to get you oriented, here is, roughly speaking, this same section of the Tanana Valley on the broader NCEP analysis. On the topographic map of the Tanana Valley the road system in red, and we see the communities of Fairbanks, Delta Junction, and Northway are all located down in the valley bottom. When the Tanana Valley Jet develops, high pressure is to the southeast, and the wind

accelerates due to pressure gradient force. But the wind doesn't develop in the uppermost reach of the valley. It starts between Northway and Delta Junction where the Tanana Valley begins to widen. The wind then follows the valley northwestward and eventually spreads out and weakens over the broader valley to the south of Fairbanks. The Tanana Valley Jet is a routine event at Delta, and it almost never is realized at Fairbanks or Northway—these wind regimes occur several times a year and are microclimates. Roughly speaking, when the SLP contrast from Northway to Delta exceeds 10mb, peak wind gusts up to 50 m.p.h. at Delta are possible, all while winds are calm or light and variable at Northway and Fairbanks. So, how did the numerical weather prediction models handle this event? As we will see in this example, the gridded output from the GFS model, and the MAV MOS from the GFS model account for this wind microclimate very differently.

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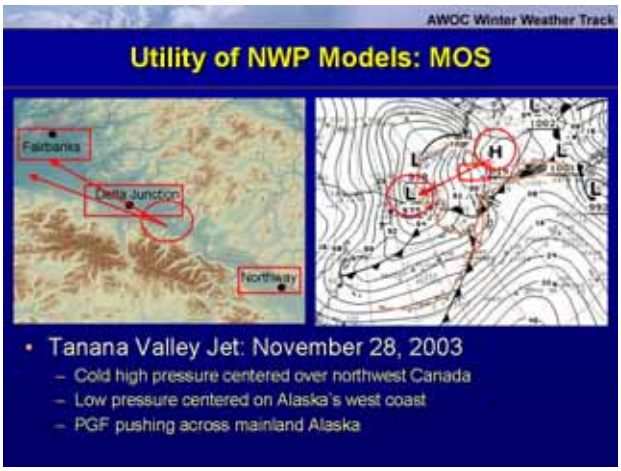

21. Utility of NWP Models: MOS

Instructor Notes: Here's an AWIPS D2D screen capture zoomed into the southeastern part of mainland Alaska. The image is the "hi res topo image," and overlayed on this image is the GFS forecast of sea level pressure in white, the GFS surface winds in blue, and the actual METARs in green, all valid at 06z November 28, 2003. These fields are from the 06z run of the GFS, so it is the initialization of the model. To get you oriented, Northway is here, Delta Junction is here, and Fairbanks is here. The low valley bottom of the Tanana Valley runs from southeast to northwest here, so we can see that the pressure gradient force is pointed straight down the valley. The lower terrain is purple and pale pink. The mountains are blue, green, and yellow and red. At this time the wind at Northway is 12006kt, wind at Delta is 10022g30kt (with temperatures of -6F), and wind at Fairbanks is calm. So how does the GFS wind field compare to the METARs in the Tanana Valley? To the GFS' credit, it depicts a maximum of wind speed near Delta Junction, although the direction is off by almost 90 degrees. If we look around this image, we can see that in locations where the METAR shows at least some wind, that is, no calm or light and variable, the magnitude of the GFS wind is within the ballpark, although the direction often is not. So one of the GFS grid's big weaknesses here is wind direction. Also, the grids fail to depict calm winds at Fairbanks—the GFS has winds at Fairbanks in

the 15 to 20 kt range. In general, the GFS's coarse depiction fails to capture the discontinuities in the wind field that are associated with these microclimates. The GFS's solution may be accurate with regard to the synoptic-scale features, but the resolution of the model is simply too coarse for it to identify these microclimates or even to identify the terrain that helps produce the microclimates. The lesson here is not that we should never use the GFS model. Rather, we just need to consider that the model is not designed to depict microclimates. The GFS' long wave synoptic-scale solution may be of very high quality, and it should be used in a way that maximizes this strength. But if we are going to produce a highly detailed forecast for specific points that are influenced by microclimates, the GFS grids alone will not be sufficient. The GFS grids may be an adequate starting point, but additional details would have to be introduced to account for microclimates.

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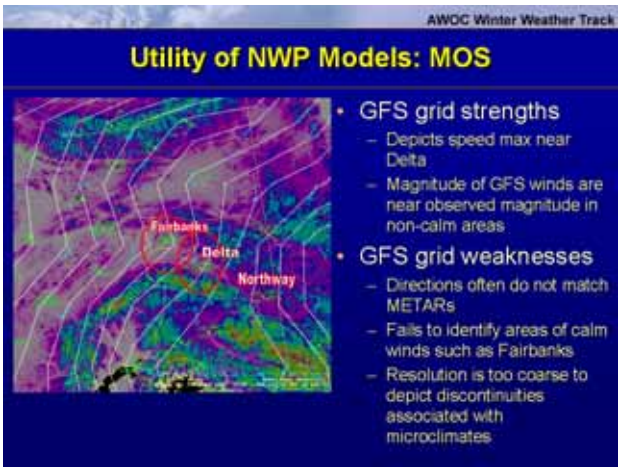

22. Utility of NWP Models: MOS

Instructor Notes: Here is a table showing the actual winds from the METARs at Northway, Delta Junction, and Fairbanks, as well as the MAV MOS forecast, at 18 hour projection, and the initialized winds from the GFS initialization. One caveat here, is that the GFS grid winds are estimated, since the GFS didn't have data points exactly at the sites we are interested in, some subjective interpolation has been done. So what are the results? We see here that the MAV MOS wind forecast is closer to the METAR winds than the GFS grid winds are. This is especially true with regard to wind direction at Northway and Delta Junction—see that the GFS grids show southerly flow while the MAV MOS improves on the grids by nudging the wind direction to the southeast. The MOS also did very well with the wind speed at Fairbanks, where the MOS correctly identifies that winds will basically be calm. Again, the GFS grids did a good job with the wind speed at Delta Junction, and so did the MAV MOS. This example illustrates how the MAV MOS can account for microclimate effects on a point-by-point basis that its parent model, the coarse GFS, cannot identify. The MOS doesn't physically model these microclimates, but it has "learned" in a statistical sense that each of these locations have their own distinct wind microclimates, and so the MOS is able to account for the microclimates in its forecasts. One weakness of MOS is that it is not complete in space—there is only MOS

guidance for specific points. Fortunately, these points are where most of the people live, but in the digital age we have to produce grids that are complete in space. At the time this IC was recorded, there was work ongoing to develop a viable gridded MOS that could be use in IFPS. One last note…remember a few slides ago when discussed ground cover, and the impact of being above or below tree line with regard to blowing snow? Here at Delta Junction winds of 30kt or greater occur several times a winter--this climatologically normal. But blizzard conditions almost never occur at Delta despite having snow on the ground and very windy conditions. Delta Junction is down in the Tanana Valley, well below tree line. So while the immediate Delta Junction area is commonly very windy, most of the surrounding terrain is forest, so there isn't much square mileage of highly exposed snow for a significant blowing snow event to get going. Above tree line there is widespread bare terrain, and it is those areas which are much more prone to significant visibility reduction from blowing snow.

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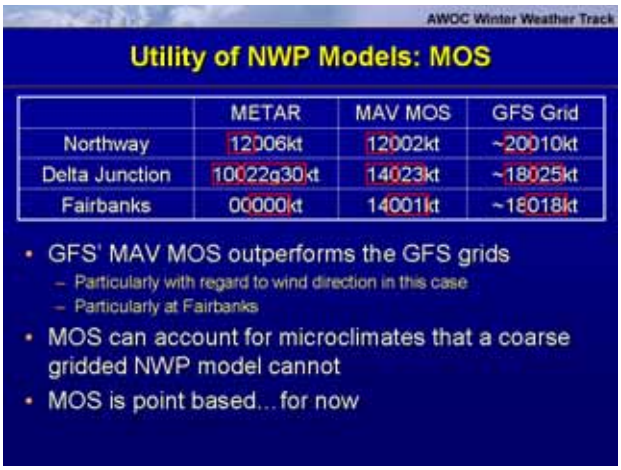
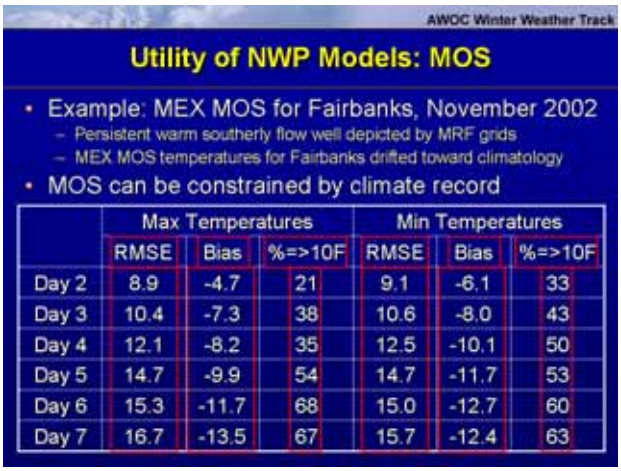


23. Utility of NWP Models: MOS

Instructor Notes: There is no single tool that works best in all situations, and that same caveat applies to MOS. MOS's ability to incorporate the climate record into its forecasts can become a weakness during an unusual event, especially further out in time. To illustrate this point we can consider the great Alaskan high-amplitude meridional flow event of November 2002. During this event a very persistent southerly flow brought unusually mild temperatures to much of Alaska, including Fairbanks, through almost the entire month of November. The MRF grids (as it was known in those days, today the GFS) did a fairly good job with the longwave forecast—that is, the MRF grids usually kept the strong southerly flow in place over Alaska out through days 4 to 7. The temperatures from the corresponding MEX MOS runs for Fairbanks, however, routinely cooled down toward climatology out at days 4 to 7. This kind of divergence between the grids and the MOS happened run after run, basically through the entire month of November. It turns out that the grids were right and the MOS was wrong. This table shows the dismal verification scores for the MEX MOS at Fairbanks during the entire month of November, 2002. Again, this verification if for the entire month, not just for one bad run. The vertical axis is time, going out to day 7. The horizontal axis contains verification statistics

for both the max and min temperatures: There is the RMSE, or “root mean square error,” and the ideal number here is zero. Bias is the measure of skewedness in the distribution, and again the ideal number here is zero. A negative bias means the MOS forecast is too cold. A positive bias means the MOS forecast is too warm. All of these values are degrees Fahrenheit. We can see that for both the max and min temperatures the root mean square error increases as we go further out in time, up to around 17 degrees by day 7. Error increases with time, which is not surprising, but the magnitude of this error is unusually high. Bias also gets worse with time, so that the bias is around 13 degrees too cold by day 7. Again, the ideal bias is zero, so the MOS is forecasting way too cold. Max and min temps were off by 10 degrees or more two thirds of the time out at days 6 and 7. Despite the persistent mild southerly flow depicted by the MRF grids, which turned out to be a pretty good forecast, each run of the MOS advertised a cooling trend with time, a trend toward climatology. The result was a very rough month for the mid-range MOS. I think we can attribute the MOS’s poor performance to its being constrained by the climate record, or more precisely the microclimate record in Fairbanks. In effect, the MOS was saying, “This is November in Fairbanks--it should be cold, I don’t care what the long wave pattern is.” Again, this has been an Alaskan example used to illustrate the broader point. In your CWA, are there situations in which the NWP gridded data and/or MOS routinely perform particularly well or particularly poorly? Does the MOS identify microclimate effects on a point basis that the gridded fields fail to depict? What role would microclimate play a role in such situations?

Student Notes:



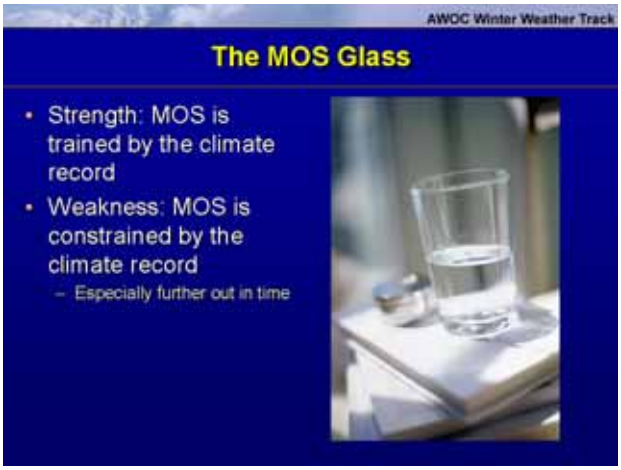
	Max Temperatures			Min Temperatures		
	RMSE	Bias	%=>10F	RMSE	Bias	%=>10F
Day 2	8.9	-4.7	21	9.1	-6.1	33
Day 3	10.4	-7.3	38	10.6	-8.0	43
Day 4	12.1	-8.2	35	12.5	-10.1	50
Day 5	14.7	-9.9	54	14.7	-11.7	53
Day 6	15.3	-11.7	68	15.0	-12.7	60
Day 7	16.7	-13.5	67	15.7	-12.4	63

24. The MOS Glass

Instructor Notes: This leads us to our final NWP slide: the MOS Glass. One of MOS’s greatest strengths is that it learns from the past and thereby can account for microclimatic effects. As we saw in this example at Delta Junction, Alaska, MOS, on a point basis, can replicate local weather that is produced by microclimatic mechanisms, in this case it is the unique wind microclimate at Delta. These are local weather effects that a coarse NWP model cannot explicitly depict. But this influence of the climate record on MOS is also a weakness for MOS. MOS can have difficulty depicting a radical event, such as record-breaking temperature that is several standard deviations away from “nor-

mal." This tendency is especially prominent at the further time projections, such as days four to seven. This is the problem we saw illustrated on the last slide, when the MEX MOS numbers consistently cooled down toward climate normals at Fairbanks, despite the parent MRF model's depiction a persistent warm pattern. So MOS is both trained and constrained by the climate record, specifically the microclimate record for specific points. The MOS glass is either half full or half empty, or both, depending on the weather scenario at hand. We have come to the end of section 3, the utility of NWP models, both gridded data and MOS, in accounting for microclimates.

Student Notes:



25. IC4.3 Interactive Quiz

Instructor Notes:

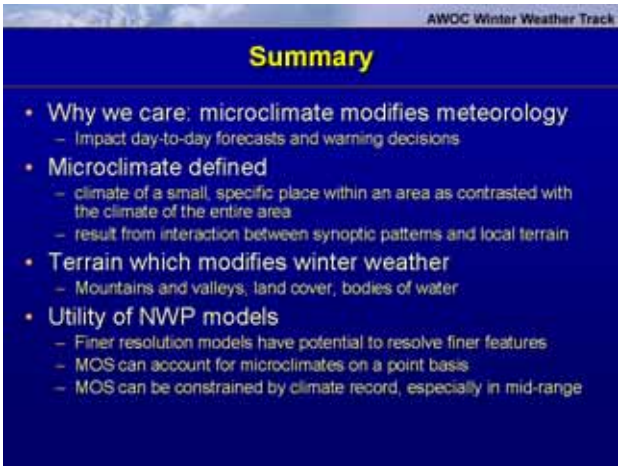
Student Notes:

26. Summary

Instructor Notes: Let's step back and do a brief summary of the IC to this point. We have described the basic concepts of microclimates and have seen some specific examples of how microclimates impact a forecast. These examples came from Alaska, but the underlying concepts are potentially applicable across the NWS. Why we care: We are meteorologists, not climatologists. We care because microclimates modify the meteorology. Microclimates are a frequent consideration. Microclimates can play a role in your routine day-to-day forecasts as well as during a the "storm of the decade." Microclimate defined. The major categories of terrain features which modify synoptic scale winter weather, again grouped together very roughly Mountains and valleys, which modify winds, modify precipitation through upslope enhancement and downslope shadowing, and modify temperatures through stratification in the vertical as well as affecting the flow of airmasses in the horizontal. Land cover. The ground's cover can impact temperatures due to radiative properties and albedo. Land cover also helps determine the wind and blowing snow regime at specific locations. Unlike mountains and valleys, some kinds of

land cover, such as the presence or absence or condition of a snow pack, can change on time scales we care about. Bodies of water. Can produce LES. The marine layer will influence a number of parameters as far inland as it penetrates. Coastal flooding due to extratropical cyclones is also an issue. The Utility of NWP models There is more to a good model than fine spatial resolution, but a fine-resolution model at least has the **potential**, all other things being equal, to depict a microclimatic phenomenon, such as terrain channeled winds. MOS can account for microclimates on a point basis, even when the MOS' parent model has a spatial resolution too coarse to explicitly resolve the phenomena in question. However, keep in mind that MOS can also be constrained by the climate record, and can have difficulty portraying unusual events—this is especially true further out in time, such as in the days four to seven range.

Student Notes:

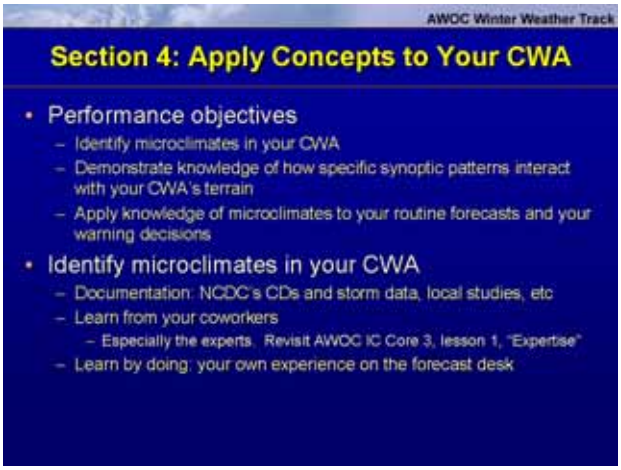


27. Section 4: Apply Concepts to Your CWA

Instructor Notes: Now on to section 4, the most important, and most difficult, part: applying these concepts to your CWA and your forecasts. Here again are the "performance objectives" mentioned earlier in this IC: Identify the microclimates in your CWA. Demonstrate knowledge of how specific synoptic patterns interact with your CWA's terrain. Apply knowledge of microclimates to your routine forecasts and your warning decisions. Here are some ways you can meet the first performance objective, identifying microclimates in your CWA. You can consult existing documentation, such as NCDC's climate data and storm data. There may also be local studies done at your WFO, perhaps your station duty manual or focal point manuals addresses your CWA's microclimates. Secondly, you can consult the "human capital" of your WFO. Some of the most important knowledge about microclimates in your CWA may not even be written down, but could rather be part of the shared knowledge of the forecast staff. You can learn a lot about microclimates in your CWA by asking other forecasters to share their thoughts and experiences. It is likely we can learn something from everyone. The veteran forecasters have the advantage of years of experience to draw on. Newer forecasters bring a fresh perspective and may notice things no one else has considered yet. You can also zero in on the forecasters in your office who are the true "experts" and try to absorb as much knowledge from them as you can. Consider revisiting AWOC IC Core 3,

lesson 1, “Expertise” for more information on “experts.” Lastly, you can learn by doing, by working the forecast desk, and in so doing you become one of your WFOs experts with regard to microclimates. Increased knowledge does not come automatically from working the forecast desk, however. There is a difference between someone who has 20 years of experience and someone else who has one year of experience repeated 20 times. To truly gain expertise we need to be able to learn from our successes and failures and apply this learning to our forecasts in the future. This IC, like all ICs in Winter Weather AWOC, has a quick on-line quiz to test your learning of the basic concepts. But since these performance objectives deal specifically with your CWA, and there is no way a single quiz can account for this across the entire NWS, there is also a quick exercise to help you meet the second and third performance objectives.

Student Notes:

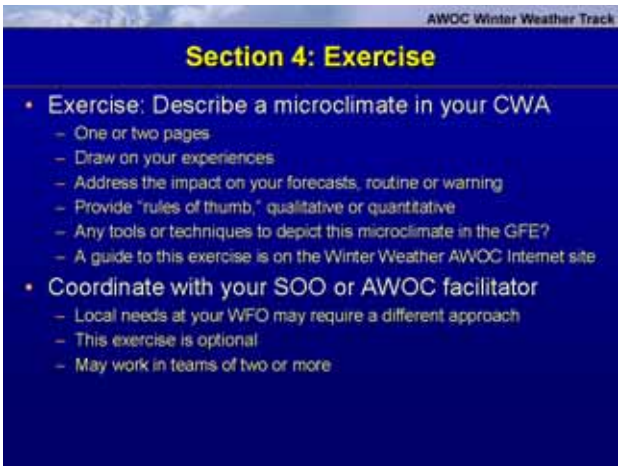


28. Section 4: Exercise

Instructor Notes: The exercise is for you to produce a one or two page document that describes a microclimate in your CWA. This is not a graduate school dissertation. Keep it short and simple, just one or two pages. It should take just an hour or so to complete--this is nothing overly formal or thorough. Ground breaking research is not required here. Ideally, you can draw on things you have learned about a microclimate in your CWA but have never had the opportunity to document before. Consider the basic categories of microclimates described in this IC as a template of how to identify a microclimate. Then draw upon your own experience on the forecast desk at your WFO. Focus on a microclimate that impacts your forecasts. Perhaps the phenomenon in question is an issue for your routine forecasts, or maybe it has an impact on your warnings. Include any helpful hints or rules of thumb that will help a forecaster make the right decision when dealing with this microclimate. How do the numerical models and MOS handle this microclimate? You may also want to consider the GFE—are there any SmartTools or grid editing techniques that make depicting the effects of this microclimate in the GFE easier? A more complete guide to doing this exercise, including examples from the northern Alaska CWA, are on the Winter Weather AWOC Internet site. Each WFO has unique microclimates and unique circumstances. Your SOO or AWOC facilitator will be in the best position to help shape your WFO’s approach to this exercise. This exercise is optional—you

will still be able to meet the national requirements for passing Winter Weather AWOC without doing the exercise. Individual WFOs may place different amounts of emphasis on this exercise—the upshot is to coordinate with your SOO or AWOC facilitator for the exact approach to be used at your WFO. Individual WFOs may offer unique approaches to this exercise to better meet their unique circumstances. Perhaps you will be asked to work in teams of two or more, or to model your exercise after a specific template or even as a PowerPoint slide show.

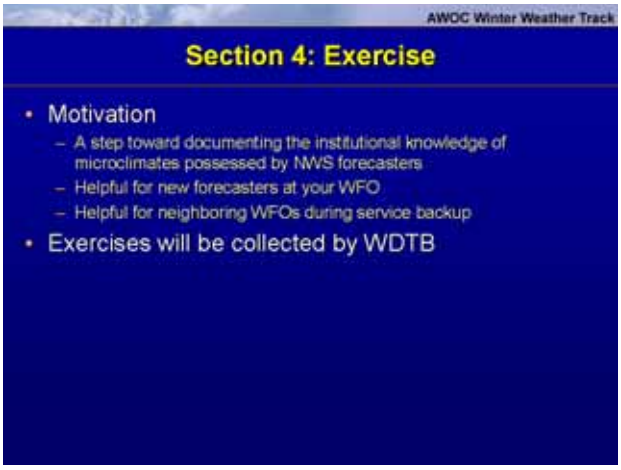
Student Notes:



29. Section 4: Exercise

Instructor Notes: There are three motives in doing this exercise. As forecasters across the NWS complete this exercise, we as an agency will take a step toward documenting the institutional knowledge of microclimates that may until now have only been held in people's heads. Such documentation will be helpful for new forecasters who come to your WFO in the coming years. Also, the sharing of expertise could help neighboring WFOs make better forecasts for your CWA during service backup. Assume that your exercise will be read by a meteorologist who is a good forecaster but who is simply not yet familiar with the specific microclimates unique to your CWA. Consulting your exercise should help this person get a quick and practical introduction to how this microclimate impacts forecasts in your CWA. These exercises will be collected by Winter Weather AWOC Headquarters at the Warning Decision Training Branch so that they can be made readily available to new forecasters and to neighboring WFOs.

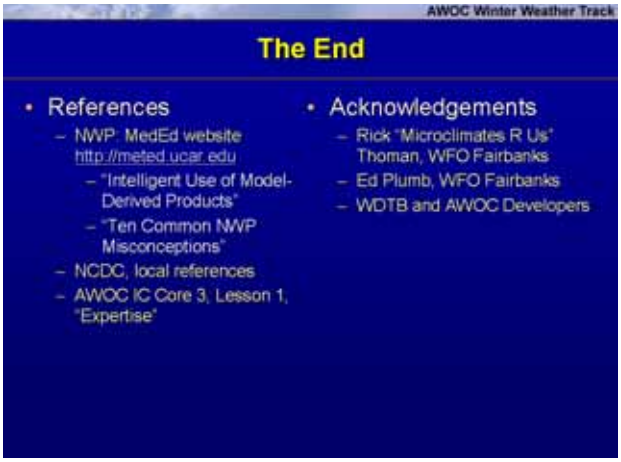
Student Notes:



30. The End

Instructor Notes: This is the end of Winter Weather AWOC IC4.3, Microclimates: the interaction between synoptic patterns and local terrain. Regarding references, there aren't many generalized references on microclimates. There is considerable literature concerning specific microclimates, such as lake effect snow regimes and wind regimes in complex terrain, however. Concerning NWP models and their strengths and limitations, please consider these two MetEd modules… Concerning microclimates at your own CWA…per the earlier slide there may be some documentation produced by NCDC, or produces locally at your WFO. AWOC IC Core 3, lesson 1, "Expertise" deals with how we can acquire new expertise about microclimates from our coworkers and from our own experiences on the forecast desks. A number of people provided vital assistance in the development of this lesson and should be acknowledged. Rick Thoman, lead forecaster at WFO Fairbanks, is a microclimate expert and supplied frequent guidance throughout the construction of this lesson. Ed Plumb, Service Hydrologist at WFO Fairbanks and former NOAA Employee of the Month, used his GIS skills to produce the topographic maps used in this lesson. And of course all the team at the Warning Development Training Branch and the AWOC developers across the Weather Service helped build this lesson.

Student Notes:



IC4.3: Microclimates Exercise Guide

Overview: You have the opportunity to write a quick (one or two page) description of a microclimate in your CWA and describe why this microclimate is important to your forecasts. This will be a “quick and dirty” write-up. If you spend more than an hour or two on this exercise, your scope may be too broad or too detailed. You don't need to do original ground-breaking research--just document what you have already learned from your experience in dealing with the weather in your CWA. You may learn that your subject has been documented in the literature, if so, reference the literature in standard AMS style format. Likewise, you may have a smart tool that you use to forecast the occurrence of the microclimate oriented weather event. Be sure to document your smart tool as well. Should you choose to document a microclimate, you may choose to work as sole author, or include your colleagues as multiple authors. As an example, a brief write-up of the Tanana Valley Jet microclimate in the WFO Fairbanks CWA is included at the end of these instructions.

Motive: Our motive is to document some of the extensive informal knowledge learned on the job concerning microclimates that impact our forecasts—knowledge which until now may not be well known by you or your neighboring offices. Consider as your audience an operational meteorologist who is capable and intelligent, but is simply unfamiliar with the microclimate in question. Consider the point of view of a forecaster who is new to your CWA or perhaps a forecaster at a neighboring WFO who will need to know about your microclimate to back up your forecasts.

Your documented microclimate, upon permission from your AWOC facilitator, will be included in an online site at WDTB for all NWS staff to view. You will be credited for going above and beyond the requirements for finishing the winter AWOC course.

Topic: Coordinate with your AWOC facilitator on your choice of topic. The collective effort at each WFO should be spread out to cover as many topics as possible. To increase the number of possible topics, your SOO or AWOC facilitator may include any phenomena that may require you to issue a warning, especially those that occur in the cool season.

Format: Your AWOC facilitator may require your exercise to conform to a certain format. Aside from any local instructions, the specific format of your document is up to you. In general, some things you may want to include in your document are…

1. A description of the synoptic-scale pattern which “activates” the microclimate.
2. An outline of the impact this microclimate has on your forecasts.
3. Any qualitative “rules of thumb” or quantitative formulas to use in forecasting the sensible weather associated with this microclimate. You should briefly document any smart tools that your office uses.
4. A description of any strengths and weaknesses the NWP models, including MOS, have with regard to this microclimate.

Please don't feel that you have to follow the exact form of the Tanana Valley Jet example--do what you think is best for your topic. Your write-up could be primarily narrative, or could rely on tables or a bulleted outline. You can include hand-drawn sketches or AWIPS D2D screen captures if you like. In addition to the example Tanana Valley Jet, you may peruse other examples from this lesson page.

Once you have written up a microclimate, ask your facilitator to review it and then e-mail the document to icwinter4@wdtb.noaa.gov and put a subject as IC4 microclimate “Your topic title” and your office ID.

IC4.3: Microclimates Exercise Example: The Tanana Valley Jet

Overview: The Tanana Valley Jet (TVJ) is a winter season wind phenomenon that commonly occurs in zone 223, with particular impact on the community of Delta Junction. The TVJ is a cold katabatic wind blowing down the Tanana Valley from southeast to northwest. The pressure gradient force down the valley is the primary driver of the TVJ.

The TVJ does not occur in the very upper reaches of the Tanana Valley where the valley is quite narrow. The wind only begins once the valley widens out, roughly half way between Northway and Delta. The area covered by the TVJ then extends westward down the valley until the wind dissipates over the Tanana Flats south of Fairbanks and Nenana. The TVJ can sometimes wonder out of the boundary of zone 223 to affect Eielson AFB and Nenana, and but it never impacts Fairbanks. Even if the TVJ does affect Eielson or Nenana, wind speeds in these locations will be less than at Delta. The boundary of zone 223 was drawn with the TVJ in mind. See figure 1 to look at the topography of this area. Figure 2 shows a TVJ event in progress, as evidenced by smeared out appearance of the IR imagery in the windy area, which is contained within AKZ223.

Wind magnitudes of as little as 15 m.p.h. and as much as 60 m.p.h. are possible at Delta with the TVJ, depending on the strength of the PGF, and the wind direction at Delta during a TVJ event is approximately 110 degrees, which is the down-valley direction. Unlike the Chinook wind, which blows into Delta from 180 degrees and brings moderate temperatures, the TVJ is a cold katabatic wind, so wind chills will need to be considered. The synoptic-scale pattern that produces the TVJ is a dry pattern, so the wind with the TVJ is not accompanied by falling snow, and blizzard conditions at Delta will be very unlikely even during a strong TVJ event. A TVJ event can last from a few hours to as long as a few days, depending on the evolution of the synoptic-scale regime.

Synoptic-scale Ingredients: A cold surface high over northwest Canada and/or along the Alcan border is required, along with a surface low somewhere along Alaska's west coast. The idea is to produce a sea level pressure gradient push down the Tanana Valley, with a dome of arctic air over northwest Canada and the eastern interior of Alaska. As long as these conditions persist, the TVJ can persist.

Diagnosis and Prognosis: Experience suggests that a sea level pressure push of around 10mb from Northway to Delta Junction is sufficient to produce gusts of 40 to 50 m.p.h. at Delta.

Unfortunately, there is not a simple one-to-one relationship between the SLP gradient and wind speeds at Delta. It seems that a relatively high SLP gradient is needed to "turn on" the TVJ, but then once the TVJ is established, the SLP gradient can drop below that value at which the event began and yet winds of a similar magnitude will continue. Once the TVJ event has been established, the SLP difference between Northway and Delta may have to drop well below 10mb before occasional gusts of 40 to 50 m.p.h. will cease.

The GFS model: MAV MOS can often do a passable job forecasting the sustained wind speed at Delta during a TVJ event, although you may need to add 10 to 15 m.p.h. to

account for the higher gusts. The MAV grids are too rough to depict the TVJ itself, but these grids can do a good job of depicting the synoptic-scale regime which activates the TVJ.

Figure 1. The Tanana Valley from Northway to Fairbanks

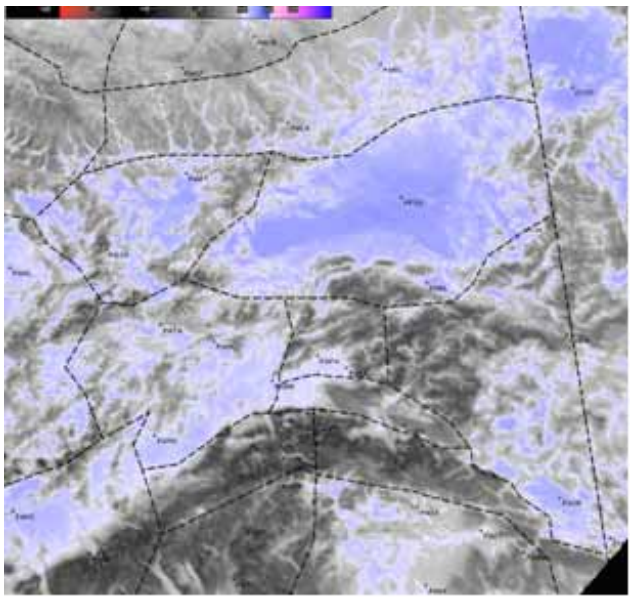


Figure 2. The TVJ mixing the inversion in zone 223

IC4: References

Web sites Used in Lesson 1 Part 1:

http://www.cpc.noaa.gov/products/precip/CWlink/MJO/enso.shtml#references

http://www.cpc.noaa.gov/

http://www.nasa.gov

http://www.cdc.noaa.gov

Web sites Used in Lesson 1 Part 2:

http://www.cpc.ncep.noaa.gov/products/precip/CWlink/MJO/new.mjo3.shtml#forecast

http://www.cdc.noaa.gov/MJO/Forecasts/climate_discussions.html

http://www.cpc.ncep.noaa.gov/products/people/wd51hd/mjo_olr.html

http://www.cdc.noaa.gov/MJO/Current/

http://www.bom.gov.au/bmrc/clfor/cfstaff/matw/maproom/index.htm

http://www.bom.gov.au/bmrc/clfor/cfstaff/matw/maproom/RMM/phase.Last90days.gif

http://www.bom.gov.au/bmrc/clfor/cfstaff/matw/maproom/RMM/index.htm

Lesson 1 Part 3:

Barnston, A. G., and R. E. Livezey, 1987: Classification, seasonality and persistence of low-frequency atmospheric circulation patterns. Mon. Wea. Rev., 115, 1083-1126.

Chen, W. Y., and H. van den Dool, 2003: Sensitivity of Teleconnection Patterns to the Sign of Their Primary Action Center, Mon. Wea. Rev., 131, 2885-2899.

van den Dool, H. M., S. Saha, and Å. Johansson, 2000: Empirical Orthogonal Teleconnections. J. Climate, 13, 1421-1435.

Lesson 1 Part 4:

http://www.cpc.ncep.noaa.gov/index.html

http://www.cdc.noaa.gov/

http://www.cpc.ncep.noaa.gov/products/partnerships/

http://iri.ldeo.columbia.edu/

Lesson 2:

Grumm, R. H., N. W. Junker, R. Hart and L. F. Bosart, 2002: Can possible heavy rainfall events be identified by comparing various parameters to climatological norms? Weather Analysis and Forecasting, San Antonio, TX, August 12-16, American Meteorological Society, 6.2.

Grumm, R.H. and R.E. Hart: 2001: Standardized Anomalies Applied to Significant Cold Season Weather Events: Preliminary Findings. Weather and Forecasting,16,736–754.

Grumm, R.H., and R. Hart, 2001: Anticipating heavy rainfall: forecast aspects. Preprints, Symposium on Precipitation Extremes: Prediction, Impacts and Responses. Albuquerque, New Mexico, Amer. Meteor. Soc., 66-70.

Hart, R., and R. H. Grumm, 2000: Using normalized climatological anomalies to rank synoptic scale events objectively. Mon. Wea. Rev., 129, 2426-2442.

Junker, N. W., R. H. Grumm, R. Hart, and L. F. Bosart, 2002: Establishing a 10 year climatology of 101.6 mm (4-inch) rainfall days, Part I. Weather Analysis and forecasting, San Antonio, TX, August 12-16, American Meteorological Society, 6.1.

Kalnay E. and Coauthors, 1996: The NCEP/NCAR 40-year reanalysis project. Bull. Amer. Meteor.Soc.,77,437-471.

Lackmann, G. M. and J. R. Gyakum, 1999: Heavy cold-season precipitation in the Northwestern United States: synoptic climatology and an analysis of the flood of 17-18 January 1986. Wea. Forecasting, 14, 687-700.

Lesson 3:

http://meted.ucar.edu

http://www.ncdc.noaa.gov/oa/ncdc.html

IC Winter 5: Precipitation Forcing Mechanisms and Associated Diagnosis of Winter Weather Systems

1. IC5.1: Diagnosing Synoptic Scale Internal Forcing: A Review of QG Theory and Potential Vorticity

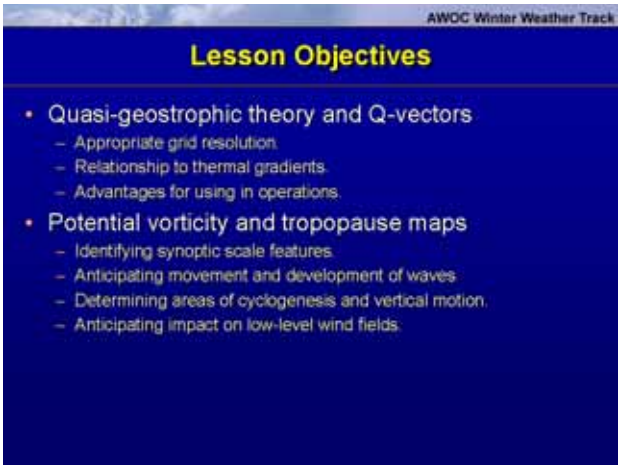
Instructor Notes: Welcome to the AWOC Winter Track Instructional Component 5, Lesson 1. Phillip Schumacher and Pat Market are the presenters for this presentation, entitled Diagnosing Synoptic Scale Internal Forcing: A Review of QG Theory and Potential Vorticity, which should last approximately 35 to 40 minutes.

Student Notes:

2. Lesson Objectives

Instructor Notes: By the end of this lesson, you should understand the following topics of quasi-geostrophic theory and Q-vectors: appropriate grid resolution, the relationship to thermal gradients, and advantages for using in operations. You should also be able to address the following issues with potential vorticity and tropopause maps: identifying synoptic scale features, anticipating movement and development of waves, determining areas of cyclogenesis and vertical motion, and anticipating impacts on low-level wind fields.

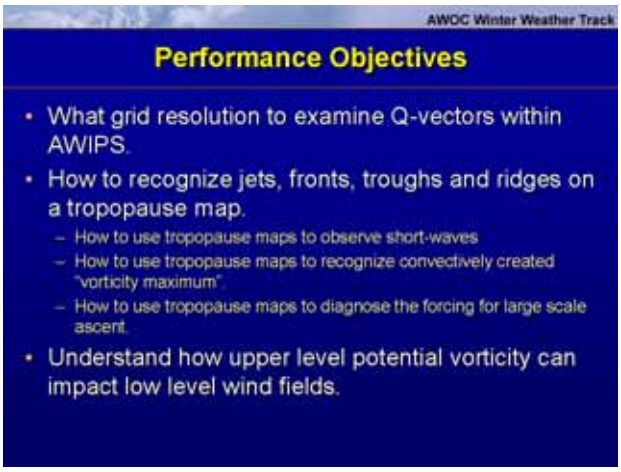
Student Notes:



3. Performance Objectives

Instructor Notes: There are several performance objectives for this lesson. After completing this lesson, you should be able to demonstrate the following: the proper grid resolution to examine Q-vectors within AWIPS; how to recognize jets, fronts, troughs, and ridges on a tropopause map (including how to use tropopause maps to observe short-waves, recognize convectively created “vorticity maximum”, and diagnosing the forcing for large scale ascent); and understanding how upper level potential vorticity can impact low-level wind fields.

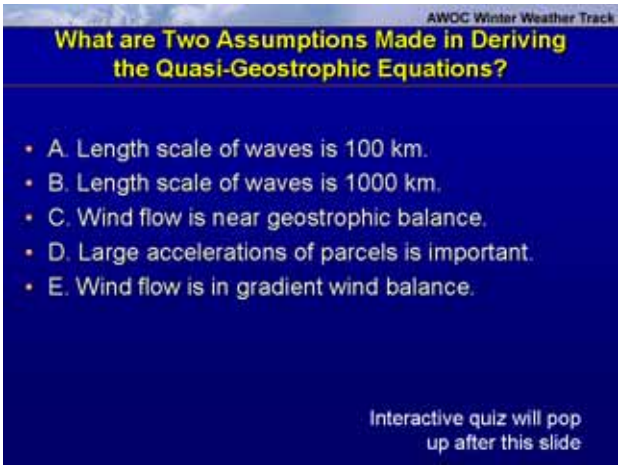
Student Notes:



4. What Are Two Assumptions Made in Deriving the Quasi-Geostrophic Equations?

Instructor Notes: We realize that many of you have seen QG-theory somewhere before. Therefore, we will not spend a lot of time on the details of QG-theory and how to apply it operationally. Rather, this lesson will discuss how to best apply QG-theory to mesoscale forecasts of winter weather. To achieve this, we will ask you a series of questions. If you get the question correct, you will be given the option to hear an explanation of the correct answer. If you answer incorrectly, you will automatically be taken to an explanation of the correct answer. Here is your first question. What are two assumptions made in deriving the quasi-geostrophic equations?

Student Notes:



5. Assumptions in QG Forcing

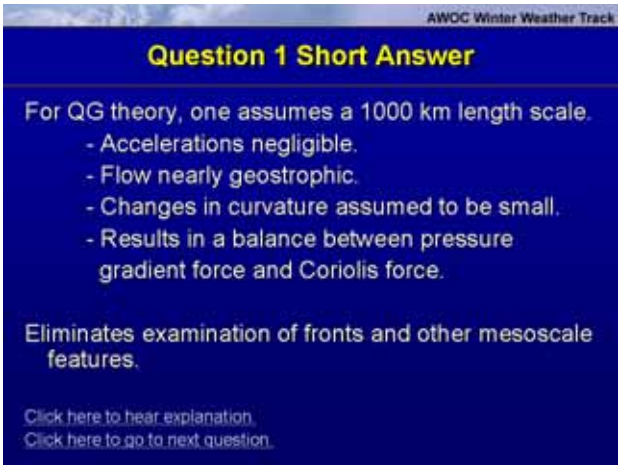
Instructor Notes: Interactive quiz question

Student Notes:

6. Answer to Quiz Question #1

Instructor Notes: When the quasi-geostrophic equations are developed, several assumptions need to be made. One assumption is that the horizontal length scale of any disturbance is around 1000 km. Two other assumptions are then made: that the mean geostrophic wind speed is 10 m/s and the mean ageostrophic wind speed is 1 m/s. When this is done, then one can scale the primitive equations to remove parcel acceleration and the ageostrophic wind. Then through a lot of mathematical manipulation we can get the quasi-geostrophic omega and height tendency equations. However, by using these assumptions we have eliminated an examination of all mesoscale features such as fronts as well as highly curved flows where the role of ageostrophic flow is large. Therefore QG theory and the QG equations only apply for synoptic scale features.

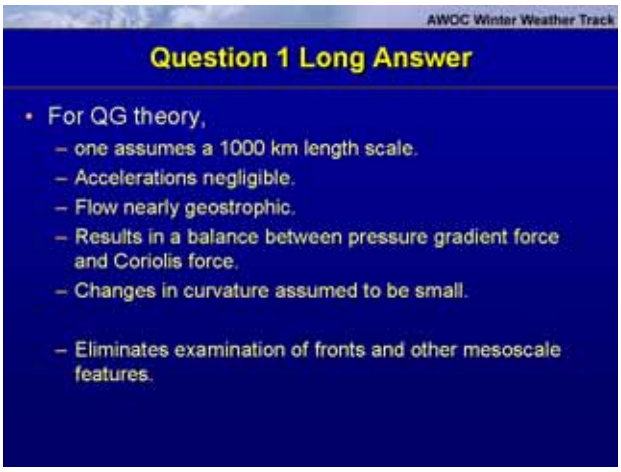
Student Notes:



7. Long Answer to Quiz Question #1

Instructor Notes: The instructor provides a more detailed explanation for the answer to the quiz question in the presentation.

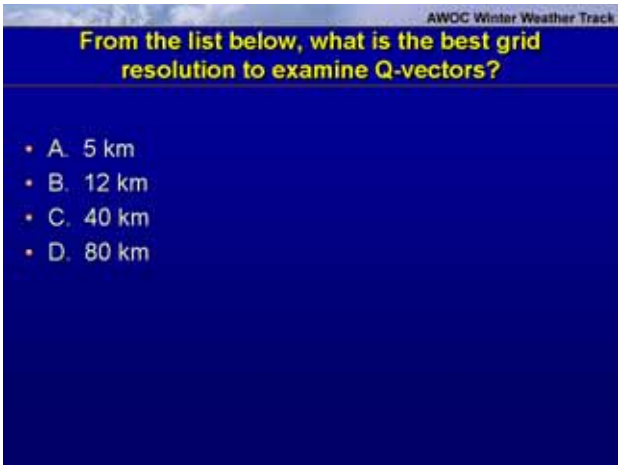
Student Notes:



8. From the List Below, What is the Best Grid Resolution to Examine Q-Vectors?

Instructor Notes: Here's your second question. From the list below, what is the best grid resolution to examine Q-vectors?

Student Notes:



9. Best Grid Resolution for QG

Instructor Notes: Interactive quiz question.

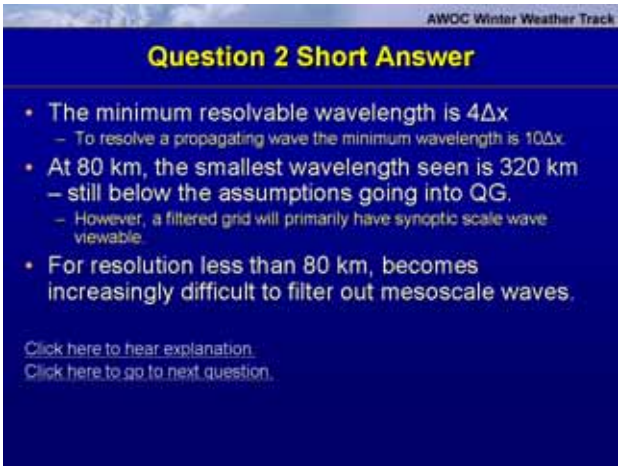
Student Notes:

10. Answer to Quiz Question #2

Instructor Notes: The correct answer is D. A standing wave can be resolved to 4 times the grid spacing. However, to capture a propagating wave, the smallest resolvable wave would need to be 10 times the grids spacing. So, looking at the answers provided, in a 5 km grid the smallest resolvable wave would be between 20 and 50 km, for a 10 km grid between 40 and 100 km, for a 40 km grid between 160 and 400 km and for an 80 km grid between 320 km and 800 km. Both the 5 and 10 km grid resolve wavelengths well below the assumptions used to derive the QG omega equation. Even a 40 km grid will resolve waves which are more mesoscale than synoptic scale. Since we only want to use Q-vectors on a grid scale which is consistent with the assumption made to derive the equation, then one needs to have a 80 km grid. Other mesoscale grids will include energy from waves on the mesoscale and therefore not provide information on the synoptic-scale forcing for ascent. In fact, even an 80 km grid is on the low end for calculating Q-vectors.

Barnes et al. (1996) showed that noise in the height field of these models can feed back into calculations of the geostrophic wind and QG theory. Barnes developed a filter to use on these type of grids which can remove much of the mesoscale energy but retain the synoptic-scale wave energy. This filter is generally applied to an 80 km grid to remove these small scale waves. This filter cannot be applied successfully on smaller grids such as 40 km, however. The filter would need to be applied several times to remove mesoscale energy. Barnes has shown that when applied numerous times, it will also remove a significant amount of energy for synoptic-scale waves.

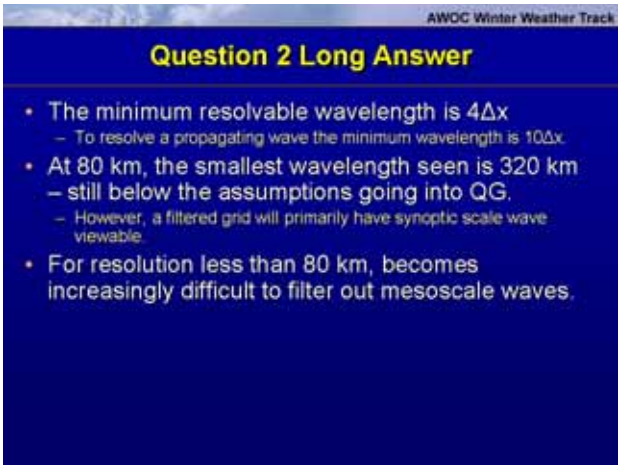
Student Notes:



11. Long Answer to Quiz Question #2

Instructor Notes: The instructor provides a more detailed explanation for the answer to the quiz question in the presentation.

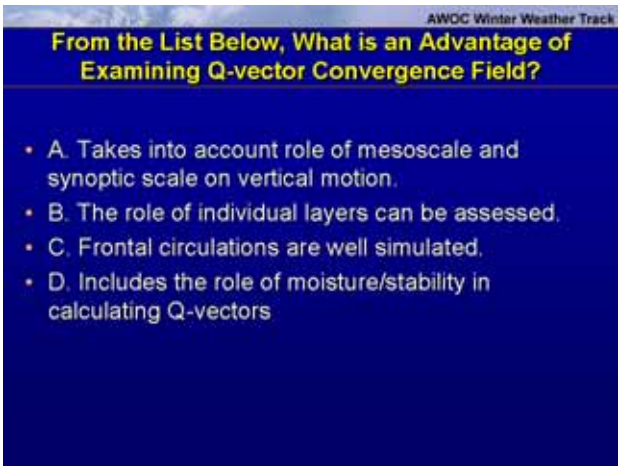
Student Notes:



12. From the List Below, What is an Advantage of Examining Q-Vector Convergence Field?

Instructor Notes: Question #3. From the list below, what is an advantage of examining the Q-vector convergence field?

Student Notes:



13. Advantage of Q-Vector Convergence

Instructor Notes: Interactive quiz question.

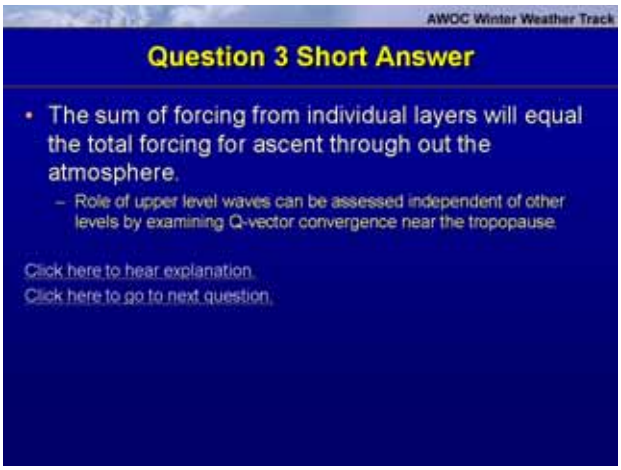
Student Notes:

14. Answer to Quiz Question #3

Instructor Notes: The correct answer is B. The sum of the forcing at individual layers will equal the total forcing through the entire troposphere. A is not correct because Q-vectors can only be used to assess synoptic-scale forcing. The assumptions used to derive the equations do not allow for examination of mesoscale waves. C is not correct because the cross-front circulation is a mesoscale phenomenon. While not shown in this

talk, the QG frontal circulation is not realistic. D is not correct because Q-vectors themselves do not include spatial variations, stability, and moisture. However, were one to solve the QG omega equation, stability does play a role. When you examine Q-vectors and its convergence you are only examining the ageostrophic response to geostrophic advection. B is correct. You can examine an individual layer and determine that layer's influence on the overall QG-vertical motion. Therefore, one can look at a layer near the tropopause and determine its influence on the overall synoptic scale forcing for vertical motion. This does not say there will be ascent or subsidence. Rather it tells you that were this layer acting alone there would be ascent through the troposphere. As we will discuss later in this lesson, this can also be done with potential vorticity – however, the local WFO lacks the computer power or time to do this type of calculation. In Lesson 2, we will discuss how this property of Q-vectors can be used to determine coupling between the upper-level wave and low- or midlevel frontal circulation.

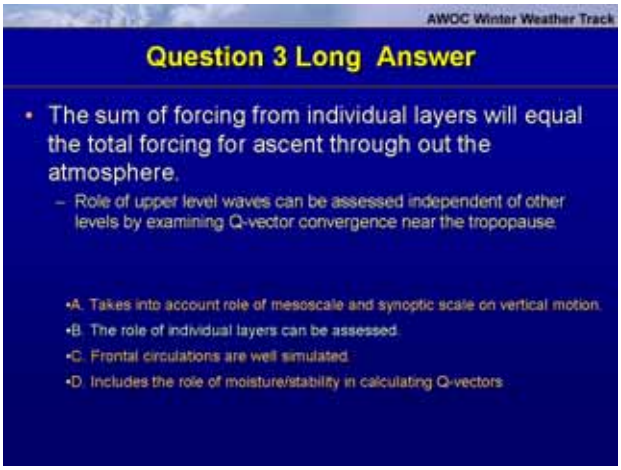
Student Notes:



15. Long Answer to Quiz Question #3

Instructor Notes: The instructor provides a more detailed explanation for the answer to the quiz question in the presentation.

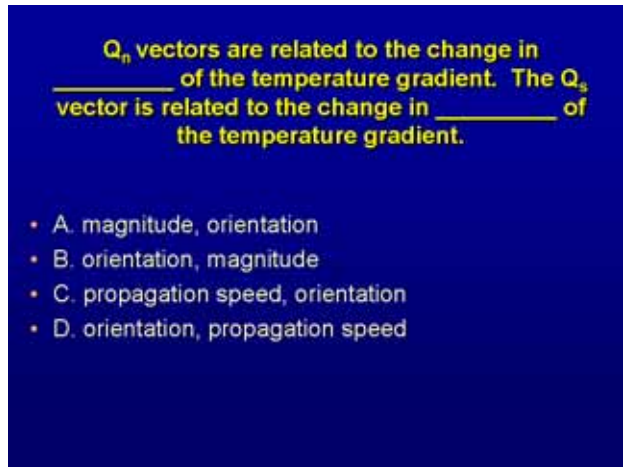
Student Notes:



16. Q_n and Q_s Vectors Question

Instructor Notes: And finally, here's your last question. Q_n vectors are related to the change in "blank" of the temperature gradient. The Q_s vector is related to the change in "blank" of the temperature gradient.

Student Notes:



17. Q-Vectors & Temperature Gradients

Instructor Notes: Interactive quiz question.

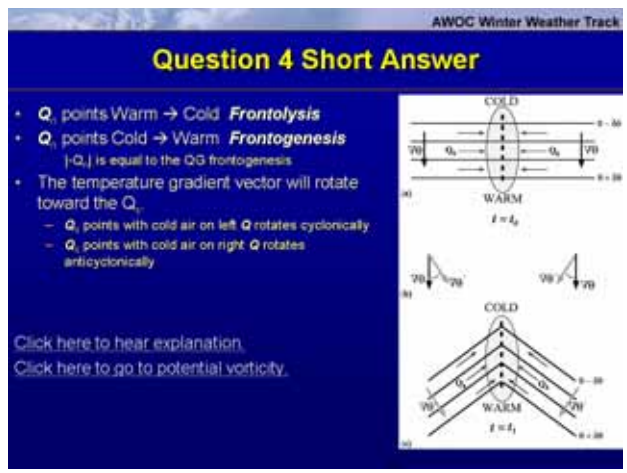
Student Notes:

18. Answer to Quiz Question 4

Instructor Notes: A is the correct answer. Q_n and Q_s do not tell you anything about the movement of a frontal boundary. However, they do provide information on whether a thermal gradient is frontogenetic or frontolytic and which way the isotherms are rotating. In most cases, forecasters are concerned with Q_n and whether a thermal gradient is frontogenetic. When the Q-vector points from warm air to cold air then the gradient is fron-

tolytic. When pointing from cold air to warm air, then it is frontogenetic. In addition, the magnitude of the Q_n vector is equal to the geostrophic frontogenesis. We'll discuss geostrophic frontogenesis in more detail in Lesson 2. The Q_s vector is showing changes in orientation to the thermal gradient. While used less often in operational forecasting, the diagram from Martin (1999) shows that the Q_s forcing plays a role in reorienting isotherms to produce a trowal structure within the occlusion of a cyclone. This will be discussed in lesson 5. What is also seen is that, when Q_s is convergent along a thermal gradient, it will act to rotate the isotherms in such way that a thermal ridge will develop on a front where the convergence is maximized. When Q_s is divergent along a thermal gradient, the geostrophic wind is acting to rotate the isotherms so that a thermal trough will develop on the front. The thermal trough will develop where the divergence is maximized along the gradient.

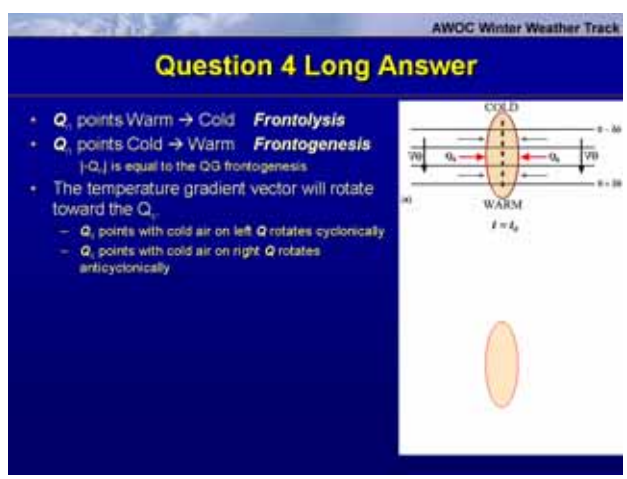
Student Notes:



19. Long Answer to Quiz Question 4

Instructor Notes: The instructor provides a more detailed explanation for the answer to the quiz question in the presentation.

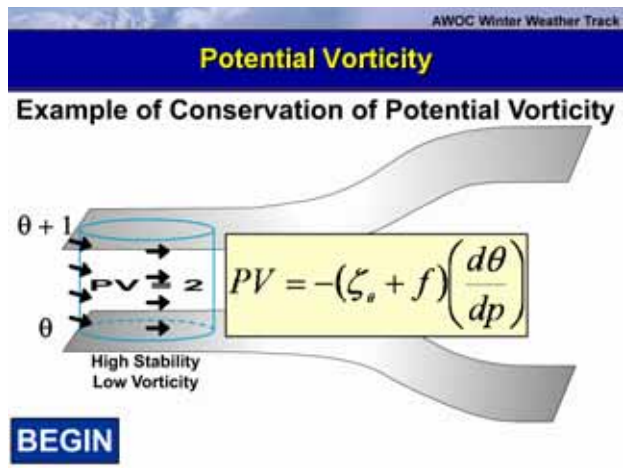
Student Notes:



20. Potential Vorticity

Instructor Notes: Potential vorticity (PV) is the product of the absolute vorticity and the static stability. Typically potential vorticity is calculated on an isentropic surface since PV is conserved in motions along an isentropic surface. PV will be positive in an inertially stable and dry statically stable atmosphere. Except for brief periods of time over small areas, this is true. Because PV is conserved in motions along isentropic surfaces we can anticipate changes in the vorticity if we examine the advection of potential vorticity in a fluid. In the animation above, we start with a parcel in a stable environment. As the parcel moves to a less stable environment, there is no change in PV which means that the vorticity must increase. By the time, it reaches a weakly stable environment, the vorticity has increased markedly and one can imagine the development of a strong cyclonic circulation.

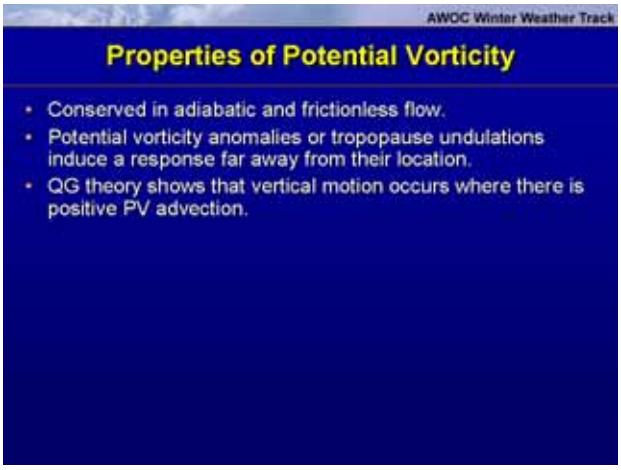
Student Notes:



21. Properties of Potential Vorticity

Instructor Notes: Potential vorticity is of interest to forecasters for two reasons. First, potential vorticity is a conserved quantity in adiabatic and frictionless flow. This makes it easier to follow short-waves, which have high values of PV, as they move through troughs and ridges. One can also picture how wave will be advected and distorted in a particular wind field. Second, potential vorticity anomalies (i.e. troughs or ridges) induce a response in the wind field away from the anomaly. While this fact has been known for a while, one can mathematically show how these anomalies affect the wind and temperature field. This relationship has made it easier to develop conceptual models which allow forecasters to anticipate how the wind field may adjust to an approaching wave. We can picture how an approaching wave may affect the low-level wind field and also where the lift or cyclogenesis is most likely to occur. Later in this lesson as well as in Lesson 2, we will use PV inversion to help understand how upper-level waves can impact low level frontal circulations.

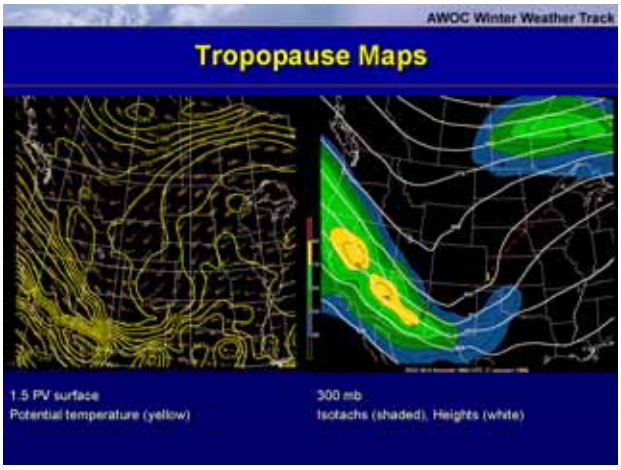
Student Notes:



22. Tropopause Maps

Instructor Notes: The biggest benefit to potential vorticity in operations is the ability to look at the dynamic tropopause on a tropopause map. Above is a comparison of a tropopause map with potential temperature and wind and the 300 mb surface with isotachs and height. The concept of a tropopause map is similar to that of a isentropic map. However, instead of plotting variables onto a constant potential temperature surface, we plot variables (wind, temperature, etc.) onto a constant potential vorticity surface. While there are occasions where potential vorticity can have the same value at different heights, in practice, the lowest pressure where that value occurs is usually plotted. These plots are called tropopause maps because the 1.5 or 2.0 PVU surface is used which is typically defined as the dynamic tropopause. Above 2.0 PVU it is assumed the air is of stratospheric origin. So why use tropopause maps? The reason is that many features can be observed quickly. Like PV on an isentropic surface, potential temperature on a PV surface is conserved. While pressure is not conserved, it can also be plotted on tropopause maps and there are advantages to doing so. The biggest advantage is being able to see how low into the atmosphere a particular short-wave, or PV anomaly, descends into the troposphere. As we will discuss in Lesson 3, this observation has an influence on how well an upper wave can interact with a low-level front. Further, since the tropopause varies with height, one can usually see both the polar and subtropical jets on the same map. This relationship is generally not true on either isentropic or constant pressure maps. Other features of tropopause maps include: high pressure (cold potential temperature) which indicates positive PV anomalies, tight pressure (thermal) gradients are indicative of jet streaks, positive pressure (negative potential temperature) advection can indicate wave/jet movement, and positive pressure (negative potential temperature) advection is associated with large scale forcing for lift. Finally, because potential temperature is conserved on PV surfaces in the absence of convection, it is possible to follow individual PV anomalies and to anticipate their future movement based upon the wind field on the tropopause.

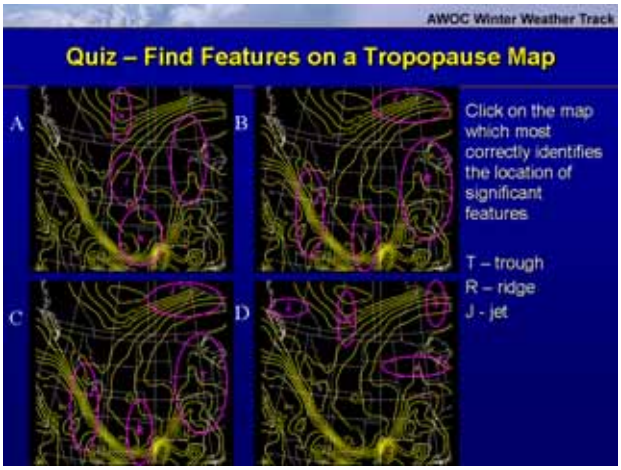
Student Notes:



23. Quiz – Find Features on a Tropopause Map

Instructor Notes: Let's test your interpretation of tropopause maps. There are 4 tropopause maps shown with several ellipses. Each ellipse has a letter in it indicating it is circling a jet (J), ridge (R), or trough (T). Click on the image in which the jet, trough and ridge are labeled correctly.

Student Notes:



24. Potential Temperature Question

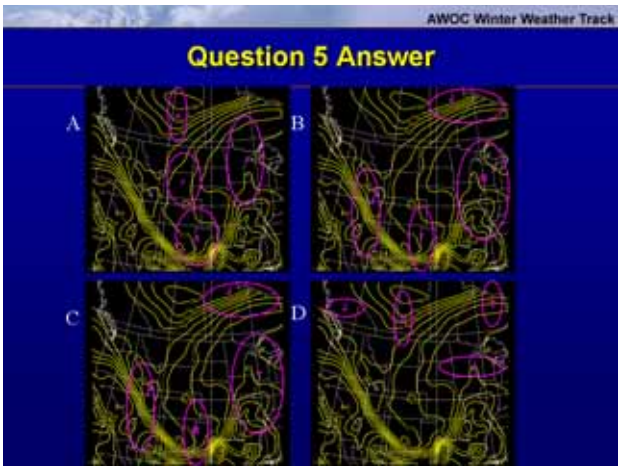
Instructor Notes: Interactive quiz question.

Student Notes:

25. Answer to Quiz Question #5

Instructor Notes: The jets are located where the potential temperature gradients are largest: one over the western United States from Oregon to New Mexico and the second over southern Canada from Manitoba to Hudson Bay. The trough is located where there is a relative minimum in potential temperature. The most pronounced trough is over western Texas, although there is a second trough located along the Alberta and Saskatchewan border. Finally, the ridge is located where there is a relative maximum in potential temperature (along the Mississippi River Valley). Note that there is also likely a ridge off the west coast of the United States.

Student Notes:



26. Examining the Movement of Jet Streaks

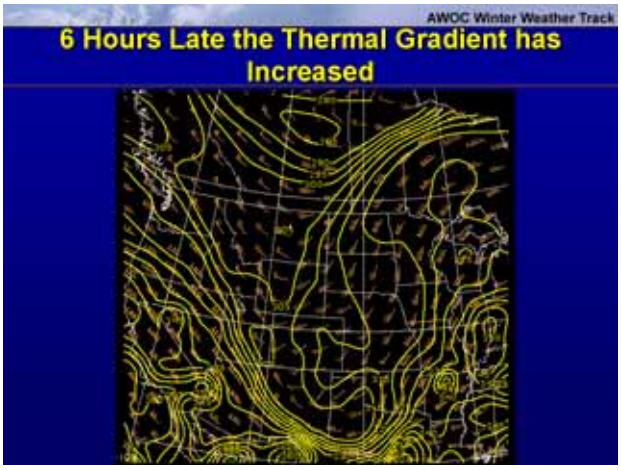
Instructor Notes: With tropopause maps, we can also examine if jets will propagate or remain nearly stationary. Let's examine the jet streak across southern Canada which is indicated by the tight potential temperature gradient extending from southwest Saskatchewan into Ontario. Notice that northwest of the thermal gradient there is cold advection while to the south of the gradient there is neutral or even weak warm advection. Since this is winter, we will assume that convection is not significant and potential temperature is conserved. Since potential temperature is conserved this would imply that the thermal gradient should intensify across Manitoba which would hold the entrance region of the jet in place.

Student Notes:

27. 6 Hours Later the Thermal Gradient has Increased

Instructor Notes: Six hours later we can see that, in fact, the thermal gradient on the tropopause has tightened and remained nearly stationary across southern Manitoba and the jet streak has progressed very little downstream over the six hours. In fact, the entire long wave system has amplified as the southern storm trough has moved into western Oklahoma. A couple of observations examining jet streaks on tropopause maps: Recall that we can imply large-scale forcing for ascent when there is cold (positive pressure) advection on the tropopause. As discussed earlier, there are two jet streaks on the map above. We have already discussed the northern jet streak. Notice that, when using a contour interval of 5 K, that the cold advection is not readily apparent within the entrance region over the Dakotas and Minnesota – especially 00Z 18 January (previous slide). However, with the southern jet streak, extending from Utah into Texas, we can see a tight gradient in the left exit region of the jet streak. Both areas are a focus for lift. In fact, there was a significant blizzard and ice storm over the northern plains and Great Lakes. Yet, the advection within the entrance region of the northern jet appears less significant. Displaying contours of wind speed with wind and pressure (or potential temperature) on the tropopause can help one recognize areas where advections on the tropopause may be more subtle, especially with jet streaks. Also, as we will discuss in Lesson 2 and 3, fronts and stability can play a large role in determining the impact of a PV anomaly on vertical motion. Typically, the anticyclonic shear side (south side) of a jet streak is an area with lower stability.

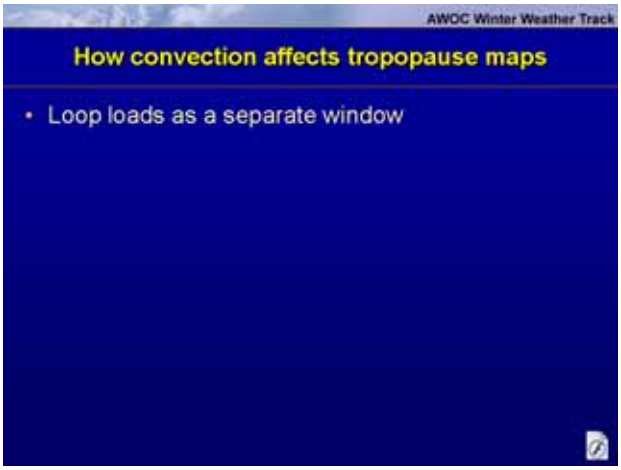
Student Notes:



28. How Convection Affects Tropopause Maps

Instructor Notes: While this course in not about convection, tropopause maps can also be used to determine whether a vorticity maximum seen at 500 mb is convectively produced or part of a baroclinic wave. We will examine two loops. The first will show 3-hour QPF and 500 mb vorticity for the first 15 hours of the Eta forecast beginning at 0000 UTC 24 June 2003. As you look at this loop, notice that the vorticity rapidly increases just ahead of where the QPF is maximized. After you finish examining that loop, click on the toggle and examine the same loop with tropopause pressure and wind with 3-hour QPF. Notice that where the 500 mb vorticity maximum was, the tropopause pressure decreases rapidly. This is not a result of advection as there is no lower pressure on the tropopause upstream. Instead, the pressures are decreasing where the QPF is maximized. This is a result of non-conservation. The latent heat release associated with convection “destroys” potential vorticity. This results in raising the tropopause locally. Then this area of lower pressure is advected downstream resulting in the development of a mesoscale ridge aloft. Notice the development of this ridge is where the 500 mb vorticity is maximized. By overlaying tropopause pressure with 500 mb vorticity, one can determine whether a particular vorticity maximum is baroclinic or convectively induced.

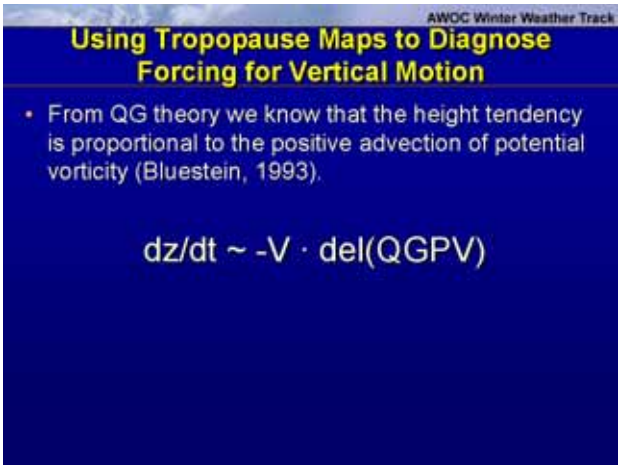
Student Notes:



29. Using Tropopause Maps to Diagnose Forcing for Vertical Motion

Instructor Notes: We have seen how we can diagnose the movements of troughs and ridges as well as jets using tropopause maps. But the question we want to answer when forecasting is how can you use tropopause maps to diagnose forcing for vertical motion. Unlike QG theory, there is no equation that explicitly relates potential vorticity advection to vertical motion. However, one can develop an equation that relates the height tendency to potential vorticity advection. Specifically, height falls are proportional to the amount of positive vorticity advection in the atmosphere. As we discussed earlier, positive vorticity advection at a level (such as 300 mb) similar to positive pressure advection (or negative potential temperature advection) on a tropopause maps. Therefore an area where there is higher pressure being advected on a tropopause map will be an area we would expect height falls. In a couple of slides we will see an example of this with respect to cyclogenesis. Because of the forcing for height rises and falls, a secondary circulation must develop. From the isallobaric equation we know areas of height falls (rises) will be areas where the isallobaric wind will produces convergence (divergence). If this process was the only forcing for vertical motion in the troposphere, then one would produce ascent (descent) where the positive (negative) pressure advection on the tropopause. Let's look at an image.

Student Notes:

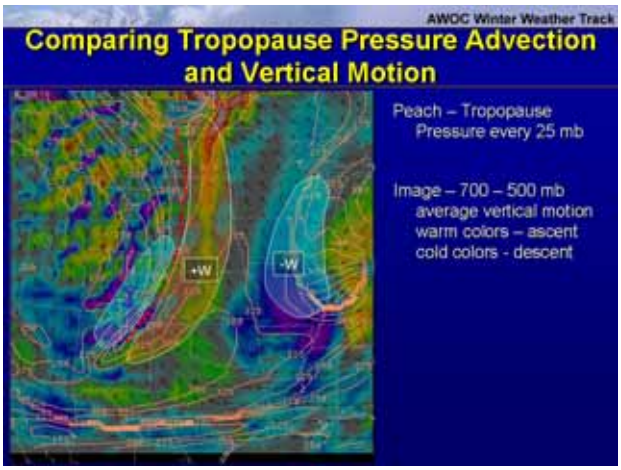


30. Comparing Tropopause Pressure Advection and Vertical Motion

Instructor Notes: Let's look at an example. The first graphic shows two waves. A stronger wave, with the tropopause pressure greater than 500 mb, is located over Indiana and Illinois with negative pressure advection implied across Wisconsin and Illinois. A weaker wave, with tropopause pressures down to 375 mb, extends from North Dakota into New Mexico. The implied positive pressure advection extends across the eastern Dakotas to the Texas panhandle. There is neutral or weakly negative pressure advection over east-

ern Colorado into western New Mexico. Now examine the mean 700-500 mb omega at the same time. We have kept tropopause pressure and wind overlaid to provide context. Looking over the Mississippi River Valley, we see there is generally subsidence over the entire region where there is negative pressure advection. Over the plains, we generally see ascent over the area from the eastern Dakotas into western Texas. However, over the Rockies, there is much less correlation as the influence of terrain overwhelms the influence of the upper level wave. The impact of terrain will be discussed in later lessons. While the correlation is not perfect between the pressure advection on the tropopause and vertical motion, one can say in general that ascent (descent) is associated with areas of positive (negative) pressure advection on the tropopause. As will be discussed in Lessons 2 and 3, the strength of this vertical motion, or how heavy the snow, is determined by mesoscale features, stability, and the degree of interaction between the low-level front and upper-level PV anomaly.

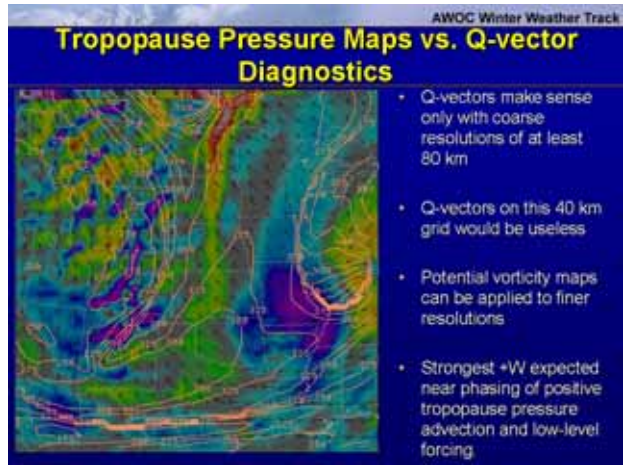
Student Notes:



31. Tropopause Pressure Maps vs. Q-Vector Diagnostics

Instructor Notes: So how is this different from what we already examine, particularly Q-vectors? As noted earlier, we need to use a grid resolution of 80 km or higher. With tropopause maps and PV, there are no such restrictions. We can examine pressure advection on a high resolution grid and determine the large-scale forcing for ascent. This provides a particular advantage when using AWIPS since the higher resolution data has higher time resolution. So we can examine when synoptic-scale forcing for ascent deduced from a tropopause map is collocated with an area with low-level frontogenesis and low stability. In the operational environment, we can use the lower resolution (> 80 km) data to explicitly examine Q-vector convergence for forcing for synoptic-scale ascent and then use pressure advection on tropopause maps on higher resolution (< 80 km) grids when examining mesoscale forcing associated with fronts and the potential interaction between the upper- and lower-level features.

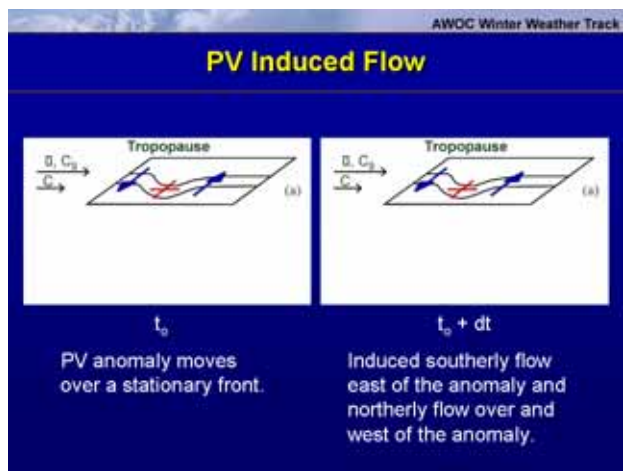
Student Notes:



32. PV Induced Flow

Instructor Notes: As noted earlier, a potential vorticity anomaly can induce flow at low levels. The above illustration shows a tropopause anomaly moving over a stationary front. The PV anomaly itself is associated with a cyclonic rotation. Meanwhile, at the surface, we have no thermal advection with directional shear across the front. However, if the front remains in place, a cyclonic circulation will develop along the surface boundary and a thermal ridge will develop at the surface. Eventually, a cyclone would develop along the front. Notice the cyclonic circulation is displaced downstream from the upper-level PV anomaly.

Student Notes:

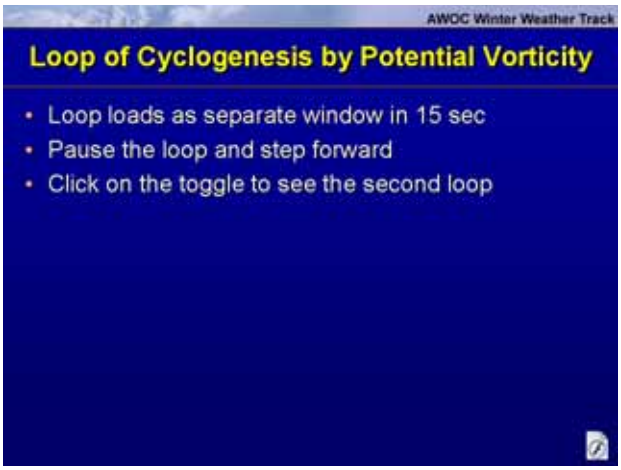


33. Loop of Cyclogenesis by Potential Vorticity

Instructor Notes: Above are two loops showing cyclogenesis from a potential vorticity perspective. In the first loop, above, we examine tropopause pressure, mean sea level pressure, and equivalent potential temperature. Focus on the equivalent potential temperature gradient which extends from western Kansas into Tennessee (and then along the East Coast). An area with higher pressure on the tropopause will move from the

northern Rockies into western Kansas. As the pressure gradient moves over the thermal gradient, a cyclone develops across western Kansas. This cyclone remains in the pressure gradient as it moves across the Mississippi River into Tennessee. However, as the low approaches the Appalachians, a new cyclone develops off the East Coast. Both cyclones move northeast, with the western cyclone weakening and the eastern cyclone strengthening. This occurs despite the fact that the pressure gradient ahead of the western wave is stronger than the gradient and pressure advection to the east. To explain what is happening, we need to examine stability. The second loop shows potential temperature on the tropopause, mean sea level pressure, and the difference between the boundary equivalent potential temperature and potential temperature on the tropopause, which is shaded. The latter is a simple way to assess the stability in the troposphere. When the two are nearly equal (yellow to red shading) then the atmosphere is nearly unstable and the influence of the PV anomaly can more easily reach the surface. As you examine this loop, notice that there is lower stability across western Kansas where the cyclone initially develops. The stability decreases across Tennessee and, as the wave approaches that area, the central pressure does decrease 3-5 mb. However, notice the persistent area of low stability off the southeast coast of the United States. This area of low stability occurs because of the presence of the Gulf Stream results in higher boundary layer equivalent potential temperature. A weak PV anomaly moves from the Gulf of Mexico over this area, just when cyclogenesis commences off the Carolina coast. As the cyclone develops off the coast, the stability increases near the Appalachians and the primary cyclone fills as it moves west of the Appalachians.

Student Notes:

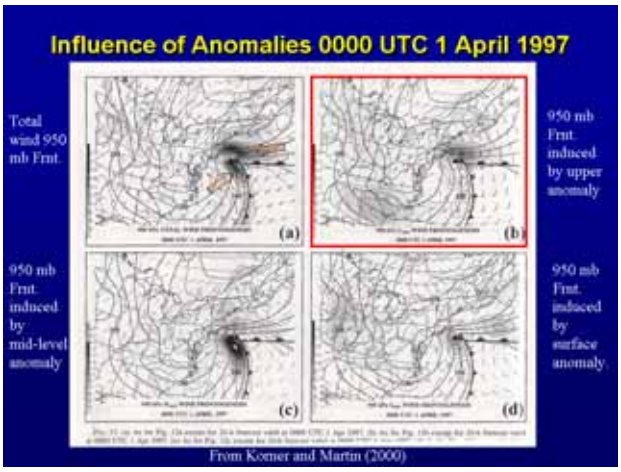


34. Influence of Anomalies: 0000 UTC 1 April 1997

Instructor Notes: Another way to examine the influence of an upper-level wave is to explicitly calculate the low-level wind field induced by the upper-level PV anomaly. Like with Q-vectors, one can partition PV into layers and calculate what the wind field looks like due to that anomaly. Korner and Martin (2000) did so and even calculated frontogenesis from the induced winds. In the upper-left corner is the total frontogenesis. In the upper-right corner, frontogenesis calculated from the 950 mb wind field induced from the upper-level anomaly. What is evident is that a large portion of the frontogenesis along the

warm front is the result of winds induced by the upper-level wave. Being aware of how the upper level wave can influence the winds, such as by increasing deformation, can help forecasters anticipate frontal evolution and circulations.

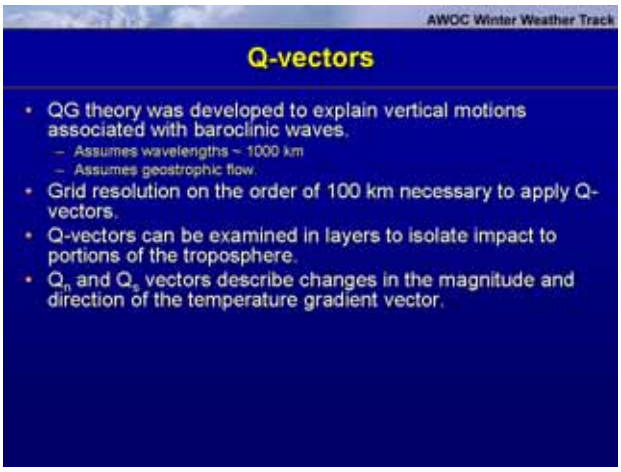
Student Notes:



35. Q-Vectors

Instructor Notes: Listed on the slide is a summary of the topics that were discussed about Q-vectors.

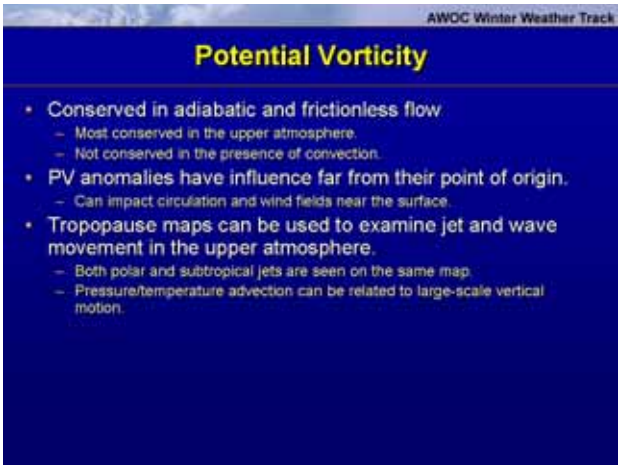
Student Notes:



36. Potential Vorticity

Instructor Notes: Listed on the slide is a summary of the topics covered on the subject of Potential Vorticity and tropopause maps.

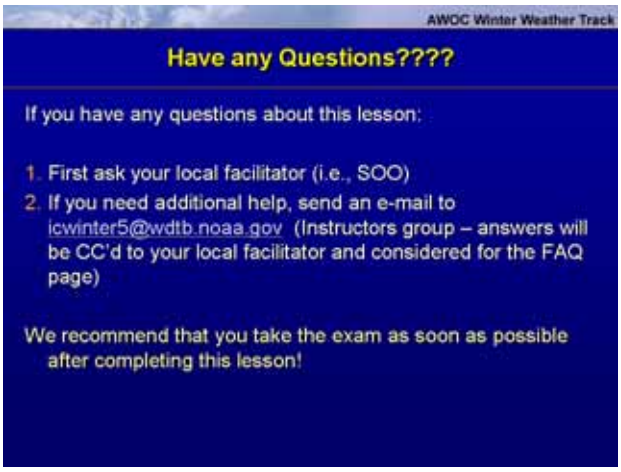
Student Notes:



37. Have any Questions????

Instructor Notes: If you have any questions about this lesson, first ask your local AWOC facilitator. If you need additional help, send an e-mail to the address provided. When we answer, we will CC your local facilitator and may consider your question for our FAQ page. We strongly recommend that you take the exam as soon as possible after completing this lesson.

Student Notes:



IC5.1: Optional Job Sheet

A Review of QG Theory and Potential Vorticity

Objective: Apply the knowledge gained from the winter weather AWOC IC 5 Lesson 1 training module to a case study.

Data: 15 March 2004 winter storm event in the Midwest. You will be using your WES machine in case review mode.

Instructions:
On your WES machine, load the 15 March 2004 case, DMX localization, and set the clock to 15 March 2004, 13:00 UTC.
On the regional map scale, load NAM 80 500mb Height, geostrophic wind, and ageostrophic wind
Where are the QG assumptions valid and invalid? (location detail such as "northern Missouri" would suffice) Explain why.

On the regional map scale, load a NAM 80 tropopause map (use "trop" under the misc. planes menu in the volume browser) with wind vectors, potential temperature and pressure at 3 layers: 700-500 mb, 500-400 mb, and 400-300 mb. Answer the following questions.
Focusing on each layer, where is the upward forcing located? If there is no upward forcing, answer "None".

700-500 mb layer forcing:_____

500-400 mb layer forcing:_____

400-300 mb layer forcing:_____

In which layer does the Q_S pattern favor the development of a thermal ridge?

On the regional map scale, load a NAM 80 1.5 PV map (tropopause map) with wind vectors, θ_e, and pressure.

Where are the jets, trough, ridge?

Jets located:_____

Trough located:_____

Ridge located:_____

Where is air of stratospheric origin being lowered into to the mid-troposphere?

Stratospheric Air: _____

Will the trough **strengthen** or **weaken?** (circle one) Explain your answer.

Will the jet **progress east** or **remain nearly stationary** over the next 6 hours? (circle one)

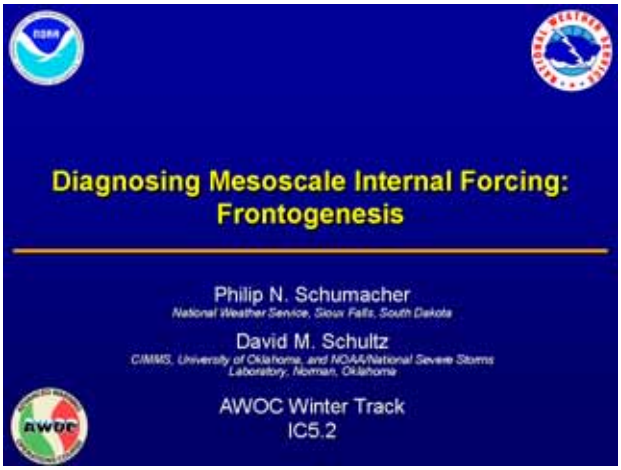
Are there any areas where a low-level front (or frontogenesis) could be enhanced due to the influence of the PV anomaly? (You'll have to load a pane displaying low-level thermal gradients to answer this one)

An answer key is available for this job sheet. Please see your local AWOC Winter Weather facilitator to obtain a copy.

1. IC5.2: Diagnosing Mesoscale Internal Forcing: Frontogenesis

Instructor Notes: This is Lesson 2 in the precipitation forcing Instructional Component. You'll be listening to Phil Schumacher, the SOO at Sioux Falls, SD and Dave Schultz at NSSL. It is 29 slides long and should take 30-35 minutes to complete.

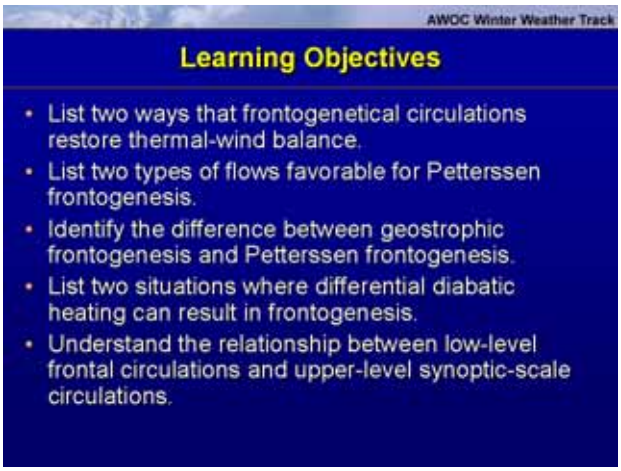
Student Notes:



2. Learning Objectives

Instructor Notes: There are five learning objectives for this lesson. List two ways that frontogenetical circulations restore thermal-wind balance. List two types of flows favorable for Petterssen frontogenesis. Identify the difference between geostrophic frontogenesis and Petterssen frontogenesis. List two situations where differential diabatic heating can result in frontogenesis. Understand the relationship between low-level frontal circulations and upper-level synoptic-scale circulations.

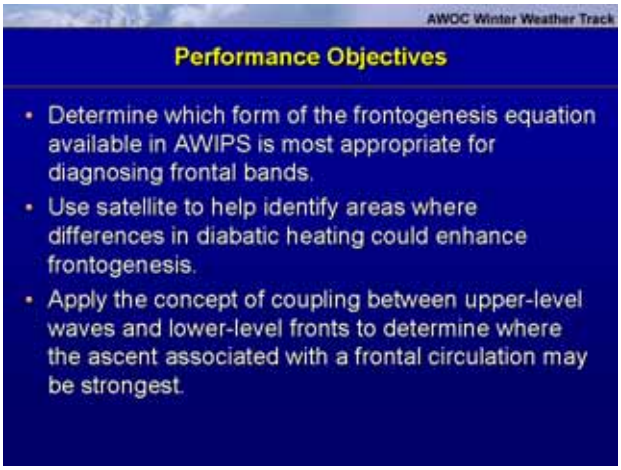
Student Notes:



3. Performance Objectives

Instructor Notes: There are three performance objectives for this lesson. Determine which form of the frontogenesis equation available in AWIPS is most appropriate for diagnosing frontal bands. Use satellite to help identify areas where differences in diabatic heating could enhance frontogenesis. Apply the concept of coupling between upper-level waves and lower-level fronts to determine where the ascent associated with a frontal circulation may be strongest.

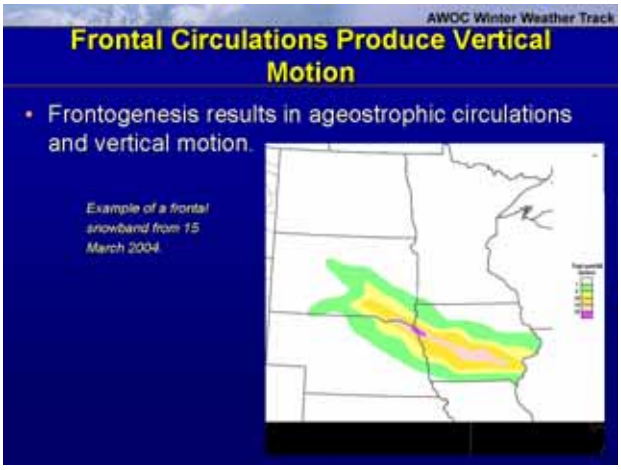
Student Notes:



4. Frontal Circulations Produce Vertical Motion

Instructor Notes: The role of frontogenesis is to produce a direct circulation which will offset the effects of frontogenesis. The result is ascent on the warm side of the front which can produce heavy snow or rain. In some cases, very narrow and intense bands of snow (or rain) can develop. In the above case, notice that the snowband shown on radar is nearly coincident with the 700 mb frontogenesis at the same time. This snowband remained nearly stationary across South Dakota and northwest Iowa but did move north into central Iowa during the morning before becoming stationary. As a result there was a narrow band of 10 to 20 inches of snow from southeast South Dakota into east central Iowa.

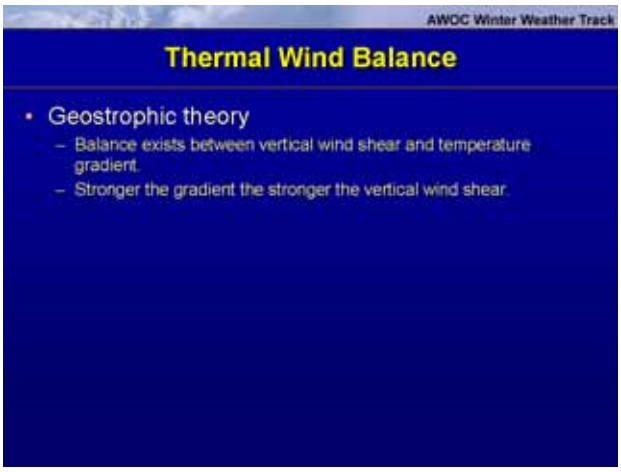
Student Notes:



5. Thermal wind balance

Instructor Notes: Geostrophic theory shows that a balance exists between the vertical wind shear and the horizontal temperature gradient. The result is that the stronger the temperature gradient, the stronger the vertical wind shear must be to balance. Any forcing which disrupts this balance will produce an ageostrophic circulation which will try to restore the balance.

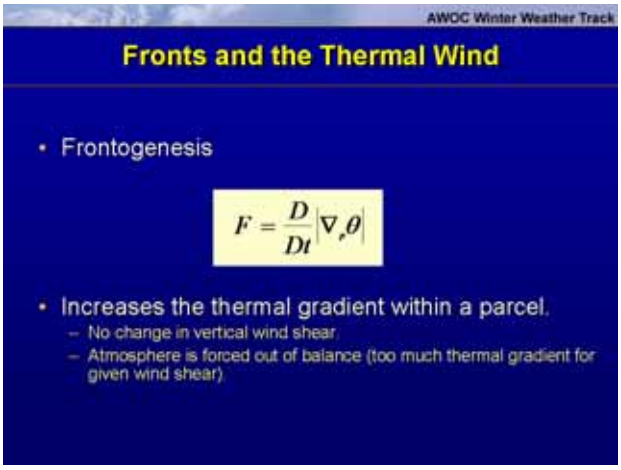
Student Notes:



6. Fronts and the Thermal Wind

Instructor Notes: Frontogenesis examines the time rate of change of the magnitude of the temperature gradient within a parcel. An area that is frontogenetic does not necessarily mean that the thermal gradient associated within a front is necessarily strengthening. In fact, there are times when the local temperature gradient may be weakening even where there is frontogenesis. Frontogenesis only acts on the temperature gradient (i.e., there is no change in vertical wind shear). This process will produce an imbalance in the atmosphere and an ageostrophic circulation will develop.

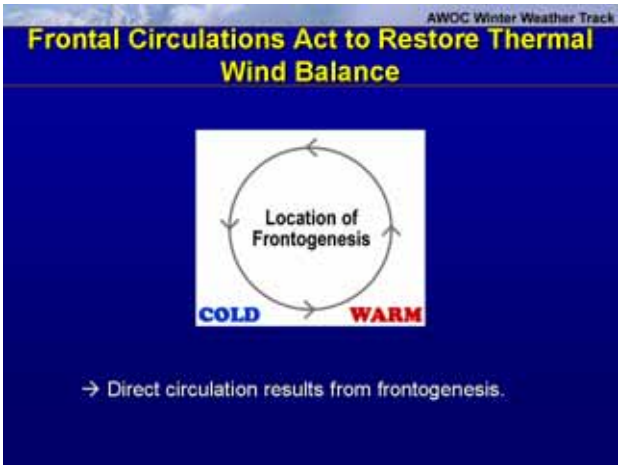
Student Notes:



7. Frontal Circulations Act to Restore Thermal Wind Balance

Instructor Notes: A direct circulation develops which tries to restore thermal wind balance, which was disrupted by frontogenesis. The vertical portion of the circulation results in ascent in warm air and subsidence in cold air which reduces the temperature gradient. The horizontal ageostrophic flow increases the vertical wind shear. This results because the change in the geostrophic wind is directly proportional to the ageostrophic wind speed. So assuming this is an east-west front with cold air to the north, the upper branch of the circulation, which will produce ageostrophic southerly flow, increases the westerly geostrophic flow aloft. The lower branch of the horizontal circulation will produce ageostrophic northerly flow, increasing the easterly geostrophic flow at the surface.

Student Notes:



8. Interactive Quiz #1

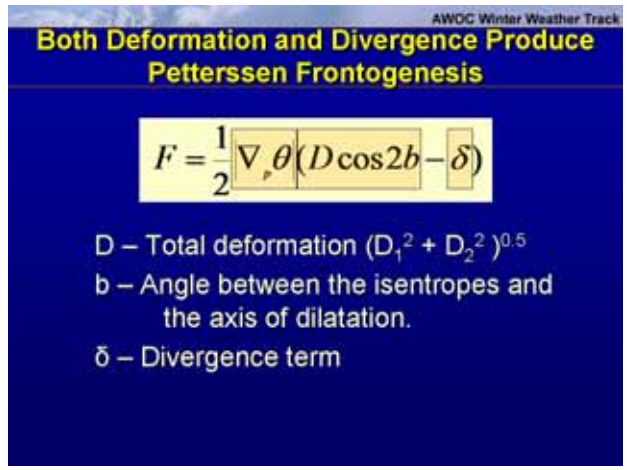
Instructor Notes: Take a moment to complete this interactive quiz.

Student Notes:

9. Both Deformation and Divergence Produce Petterssen Frontogenesis

Instructor Notes: Let's look specifically at frontogenesis and what produces changes in the temperature gradient. Note that frontogenesis is directly proportional to the magnitude of the temperature gradient. The temperature gradient is then multiplied by a quantity which is the sum of two terms. Both terms are related to the kinematics of the wind field. We'll examine each term separately in the next two slides.

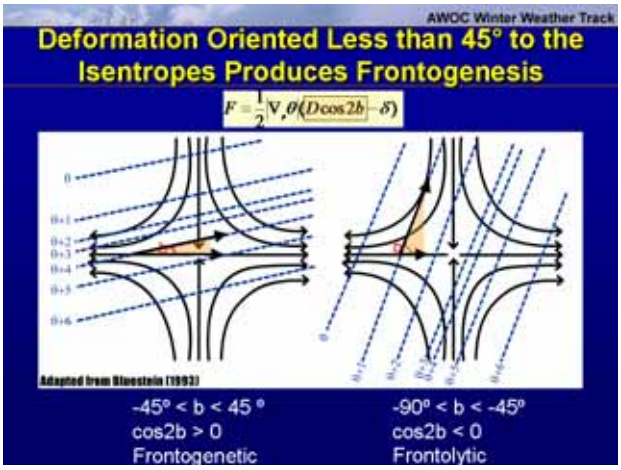
Student Notes:



10. Deformation Oriented Less Than 45° to the Isentropes Produces Frontogenesis

Instructor Notes: Whether deformation is frontogenetic depends upon the orientation of the axis of dilatation with respect to the isotherms. In the diagram shown, the axis of dilatation is parallel to the x-axis. If the axis of dilatation lies within 45 degrees of the isotherms, then deformation will act frontogenetically. If the axis of dilatation is oriented more than 45 degrees from the isotherms, then deformation acts frontolytically. It should be noted that deformation is usually acting to rotate isotherms along the axis of dilatation increasing the frontogenetic forcing due to deformation.

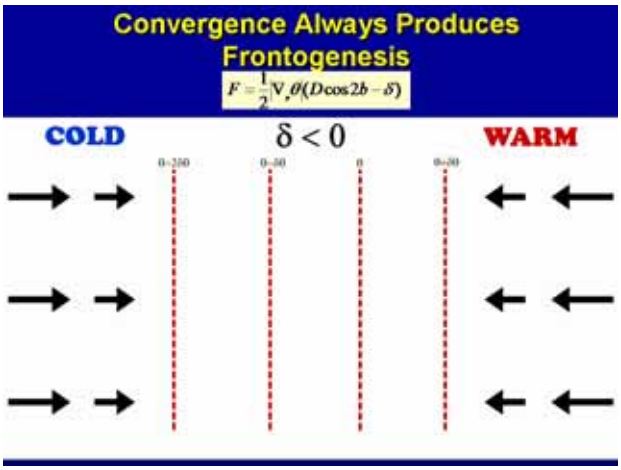
Student Notes:



11. Convergence Always Produces Frontogenesis

Instructor Notes: Convergence will always produce frontogenesis. In the example shown, we see that convergence will act to bring isotherms together and therefore increase the temperature gradient.

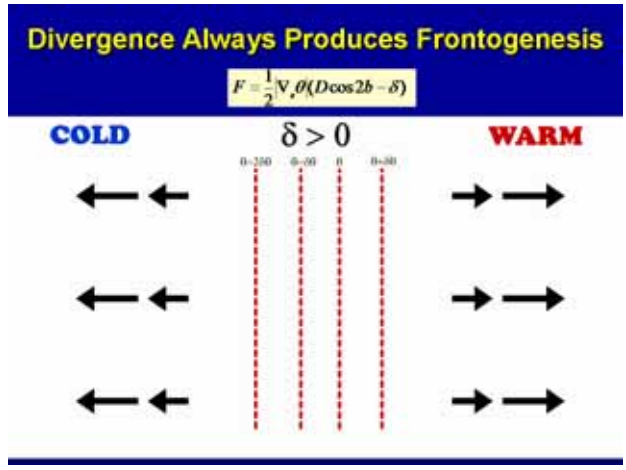
Student Notes:



12. Divergence Always Produces Frontogenesis

Instructor Notes: On the other hand, divergence always acts frontolytically. In the above example we see that divergence is acting to weaken the frontal gradient.

Student Notes:



13. Fronts Form Through a Two-Step Process

Instructor Notes: Our conceptual model of how fronts are formed is that large-scale geostrophic deformation leads to frontogenesis. The vertical component of the ageostrophic secondary circulation then acts to oppose frontogenesis and weaken the temperature gradient. Meanwhile, the horizontal branch of the secondary circulation acts frontogenetically since it results in an increase in low-level convergence. In the middle of the atmosphere, the vertical branch of the circulation can offset the role of convergence while near the surface the vertical branch has little influence.

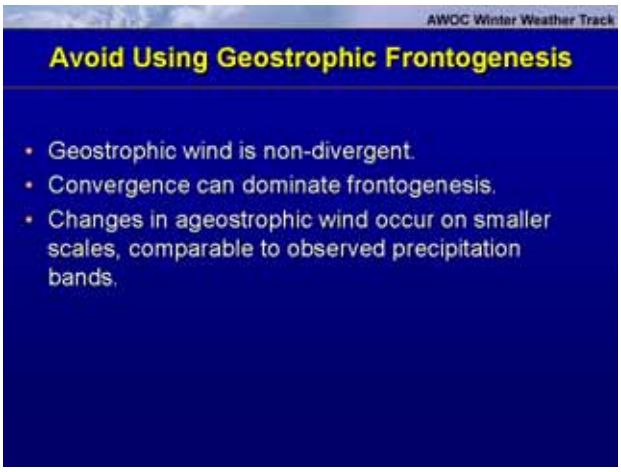
Student Notes:

14. Avoid Using Geostrophic Frontogenesis

Instructor Notes: Although geostrophic frontogenesis is available in AWIPS, it should not be used to diagnose frontal bands. Geostrophic frontogenesis uses only the geostrophic wind, which is non-divergent. This means that divergence is not included in QG frontogenesis. Using geostrophic frontogenesis in operations ignores convergence which contributes a significant portion of the total frontogenesis especially away from cyclones. In addition, semi-geostrophic theory shows the presence of an ageostrophic cross-front

wind is critical to the development of realistic looking fronts. By ignoring convergence, one misses an important ingredient to frontogenesis. We will explore this difference in the next two slides.

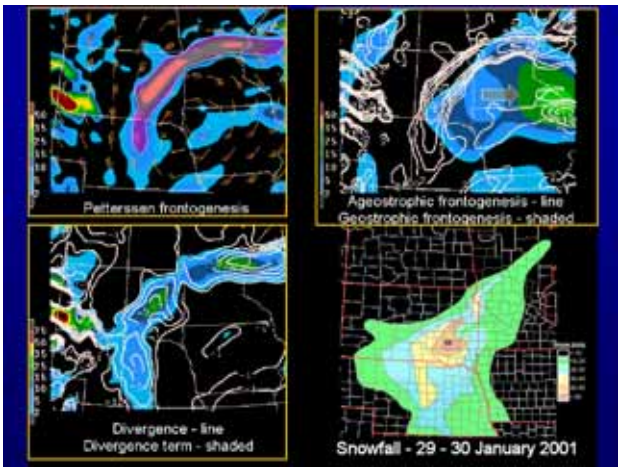
Student Notes:



15. Comparing Total, Geostrophic Frontogenesis

Instructor Notes: The above example shows a case where the total and geostrophic frontogenesis are not coincident. The geostrophic frontogenesis is maximized over southeast Minnesota while the total frontogenesis is maximized over eastern South Dakota. Notice that this maximum is collocated with the maximum in convergence. In this case, the divergence term of the frontogenesis equation is dominant.

Student Notes:

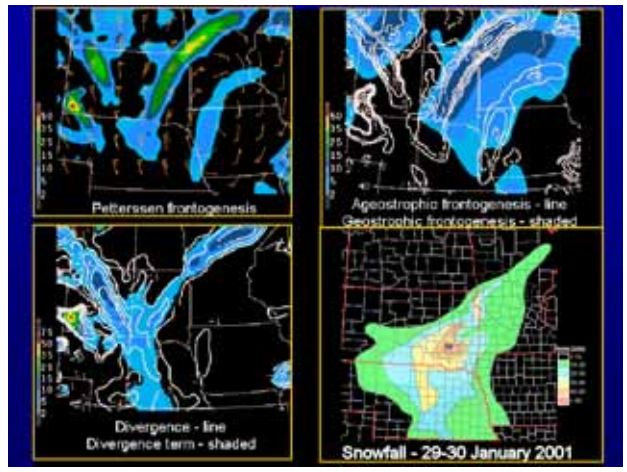


16. Geostrophic vs. Total Wind

Instructor Notes: As the front continues to develop, the total frontogenesis and QG frontogenesis are nearly coincident in eastern South Dakota. However, the total frontogenesis is much stronger and more narrow due to the frontogenesis of the ageostrophic wind. While frontogenesis has developed in the western Dakotas, it was not associated

with significant precipitation. The heaviest snowfall, up to 2 feet, was coincident with the location of the Petterssen frontogenesis. Much of this snow fell before the QG frontogenesis was maximized across eastern South Dakota and central Nebraska. Using geostrophic frontogenesis would have resulted in missing potential for a significant snowfall event over Nebraska, South Dakota and Minnesota and anticipating the sharp gradient on the northwest side of the low.

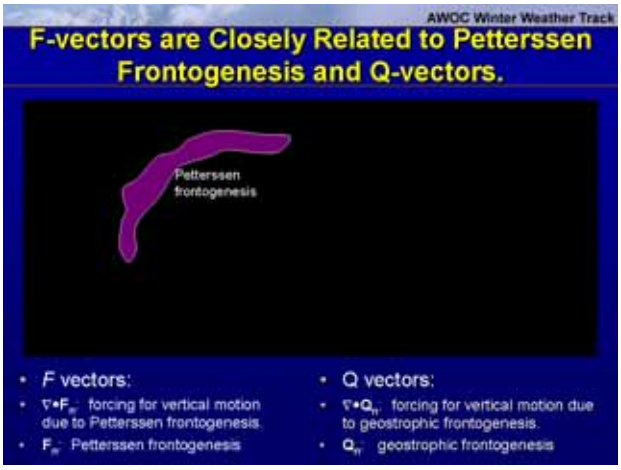
Student Notes:



17. F-Vectors Are Closely Related to Petterssen Frontogenesis and Q-Vectors.

Instructor Notes: You may be familiar with Q-vectors. Q-vectors calculate the effect that the geostrophic wind is having on the flow. Specifically, the orientation of Q points in the same direction as the low-level branch of the secondary circulation, and the magnitude of Q is proportional to the magnitude of this branch. Through the QG omega equation, the divergence of Q can be used to diagnose the forcing for vertical motion. One partitioning of the Q-vector yields Q_n and Q_s. Q_n is the component of the Q-vector normal to the local orientation of the isentropes. Q_s is the component of the Q-vector parallel to the local orientation of the isentropes. Thus, Q_n represents the frontogenesis due to the geostrophic wind alone. As we previously argued, this is generally inappropriate for ascertaining frontal circulations. In AWIPS, you may find some functions called F-vectors. F-vectors have two components: F_n and A_s. F-vectors are the total-wind generalization of Q-vectors and the magnitude of F_n is the same as Petterssen frontogenesis. While no similar expression relating F-vectors to forcing for vertical motion (as in the Q-vectors in QG theory), the divergence of F-vectors can be used to diagnose the forcing for vertical motion due to the total wind. Thus, F_n and its divergence are the preferred methods for diagnosing frontal circulations, not Q_n and its divergence. Because F uses the total wind, the convergence field is much noisier than seen with Q-vector convergence. Therefore forecasters should look for temporal continuity in the divergence of F_n and overlay frontogenesis in order to help identify areas where there is persistent forcing for ascent.

Student Notes:



18. Interactive Quiz #2

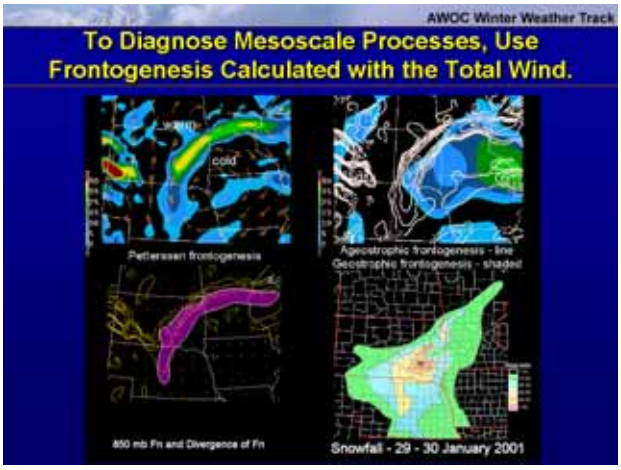
Instructor Notes: Take a moment to take this interactive quiz.

Student Notes:

19. To Diagnose Mesoscale Processes, Use Frontogenesis Calculated with the Total Wind.

Instructor Notes: In this example, the warm air is located to the north and west of the 850 mb frontogenesis. The F_n vector convergence is located to the warm side of the frontogenesis maximum and along the gradient in frontogenesis. So at 850 mb, the largest lift would be extending from central South Dakota into central Minnesota. As one goes higher into the atmosphere, the ascent would slope to the southeast. Therefore, because of the sloped ascent of a frontal circulation, it is critical to determine what level is most appropriate to examine frontogenesis when determining where the heaviest precipitation will be located. We will discuss selection of levels to examine frontogenesis later in this lesson and also in Lesson 3.

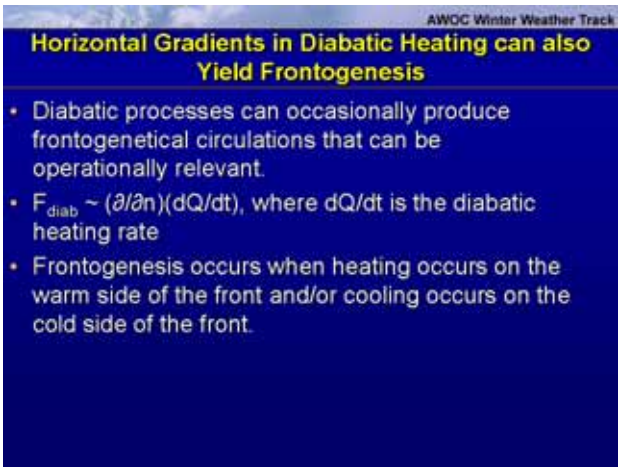
Student Notes:



20. Horizontal Gradients in Diabatic Heating Can Also Yield Frontogenesis

Instructor Notes: Note that n is in the cross-front direction. We can produce a conceptual graphic.

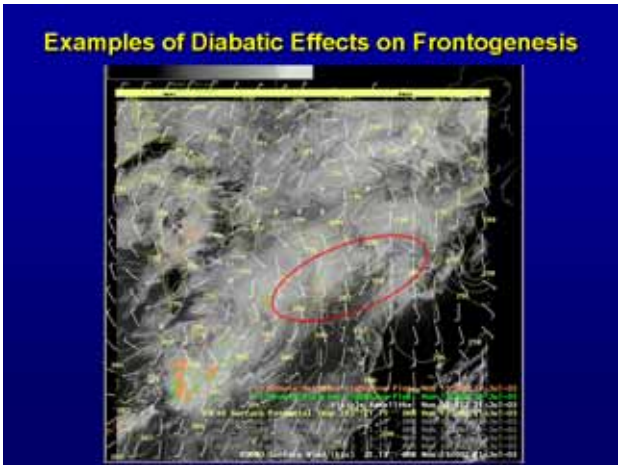
Student Notes:



21. Examples of Diabatic Effects on Frontogenesis

Instructor Notes: The sensible heating from the water on the warm side of the Gulf Stream can enhance fronts moving offshore. The low clouds behind cold fronts can reduce the diurnal temperature range, and clear skies ahead of the front can increase the diurnal temperature range. In this situation, vertical motion along the front can be enhanced during the daytime when the front is increasing in intensity and minimized during the night when the front is decreasing in intensity. As shown by Markowski et al. (1998), cloud boundaries can be another region where frontogenesis can occur.

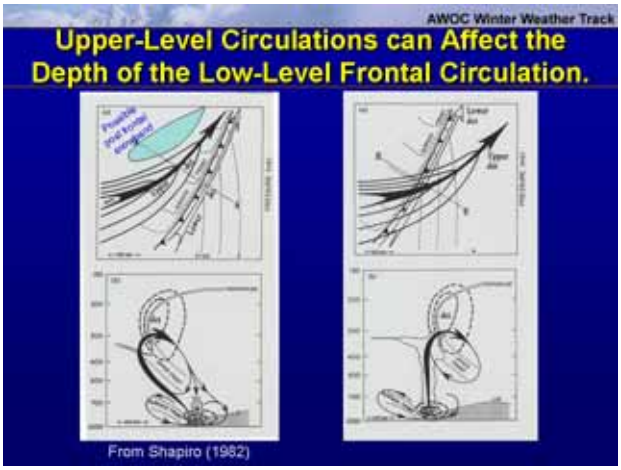
Student Notes:



22. Upper-Level Circulations Can Affect the Depth of the Low-Level Frontal Circulation.

Instructor Notes: In 1982, Shapiro used a conceptual model to show that the location of an upper-level jet relative to a low-level frontal circulation can play a critical role on whether a deep tropospheric circulation develops or not. In the example on the left, the exit region of the jet crosses over the surface front. The result is that the ascending branch of the indirect circulation of the jet is coincident with the ascending branch of the direct circulation associated with the front. This coincidence produces deep convection over the surface front. On the right side, the jet does not cross the surface front. As a result the descending branch of the indirect circulation is located over the ascending brand of the direct circulation of the front near the surface boundary. This suppresses convection and one is left with shallow lift along the surface boundary. However, notice that as one continues to the left and deeper into the cold air the ascending branch of the indirect jet circulation is collocated with the ascending branch of the frontal circulation. This does produce deep lift well behind the surface front and, were this winter, one could imagine a band of heavy snow developing in that area.

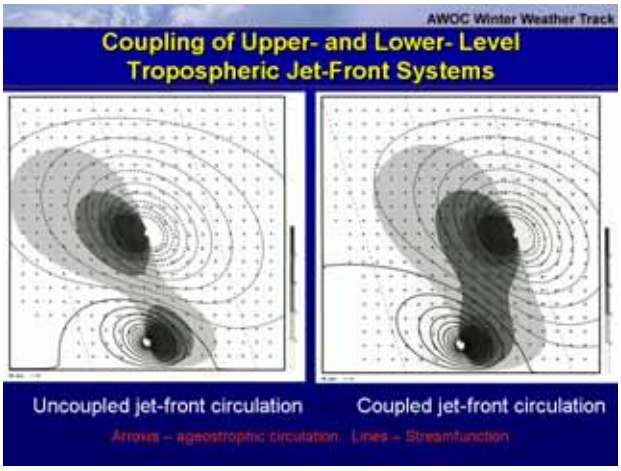
Student Notes:



23. Coupling of Upper- and Lower-Level Tropospheric Jet-Front Systems

Instructor Notes: Hakim and Keyser (2002) ran a theoretical model to test this conceptual model of Shapiro (1982). To simplify the problem, Hakim and Keyser have frontogenesis located near the surface and frontolysis (to represent the exit region of a jet) aloft. This condition does not produce a realistic frontal circulation that extends well behind the front. What it does show is that the location of the forcing with respect to each other is critical. In the uncoupled case, we see that the ascending branches are separate and the low-level frontal circulation remains shallow, while in the coupled case both ascending branches are coincident and a much deeper ascent is observed. This illustrates how critical the location of the upper wave can be to development of intense frontal circulations.

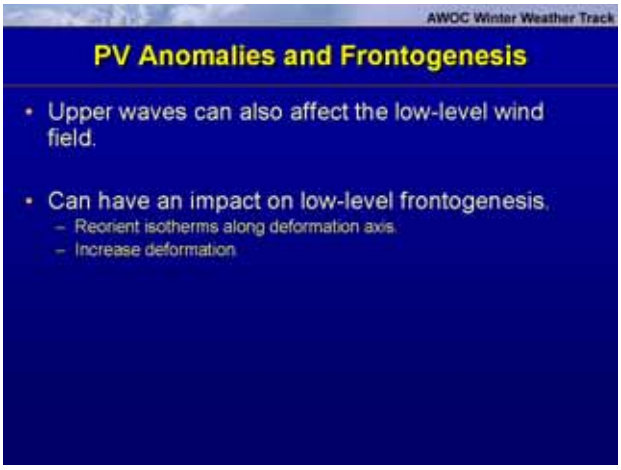
Student Notes:



24. PV Anomalies and Frontogenesis

Instructor Notes: Upper waves also impact low-level wind field and thermal field. Recall from Lesson 1 that potential vorticity anomalies act like magnetic fields, their impact extends well beyond the level where they are located. This can increase the deformation and divergence in the presence of a front. One way to examine this impact is to invert potential vorticity to look at the wind field due only to an anomaly located near the tropopause. While the exact details of this process are beyond this talk, realize that when one inverts you only recover the non-divergent portion of the wind field. The role of convergence in frontogenesis will be missed.

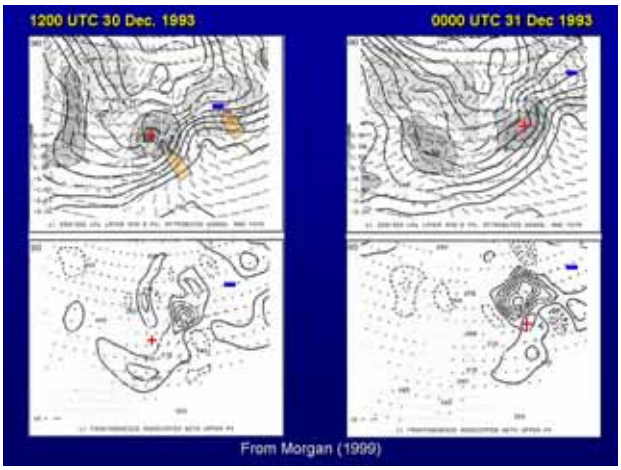
Student Notes:



25. 1200 UTC 30 Dec. 1993 - 0000 UTC 31 Dec. 1993

Instructor Notes: Morgan (1999) split PV anomalies between upper-level, midlevel (diabatically produced), and surface anomalies (coincident with cold and warm temperature anomalies). We will examine the role of the upper anomaly. The graphic on this slide examines a deepening cyclone over New England. In the 250 to 500 mb layer (top) one can see a positive PV anomaly over New York and a negative anomaly over the Canadian maritimes. Both anomalies translate northeast in 12 hours. The resultant thermal and wind field (bottom) induced by these two anomalies shows that there is enhanced frontogenesis near the thermal ridge over New England which extends south along the cold front. The impact on frontogenesis increases 12 hours later over the Canadian maritimes. In this case the interaction of the two PV anomalies results in frontogenesis develop within a trowal and enhances snowfall in eastern New England and the maritimes.

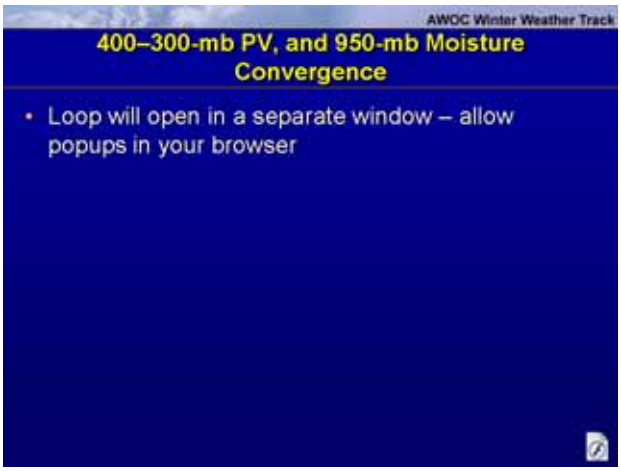
Student Notes:



26. 400–300 mb PV, and 950-mb Moisture Convergence

Instructor Notes: On April 30, 2001, a small area of severe convection developed from northeast Nebraska into southeast Minnesota. This resulted from an interaction between a PV anomaly moving across South Dakota and a surface convergence boundary over northwest Iowa. The shaded image shows the PV anomaly as a darkening area over South Dakota. Also overlaid is the wind convergence at 950 mb. As the upper wave approaches eastern South Dakota, the convergence increases and narrows across eastern Nebraska, western Iowa, and southern Minnesota.

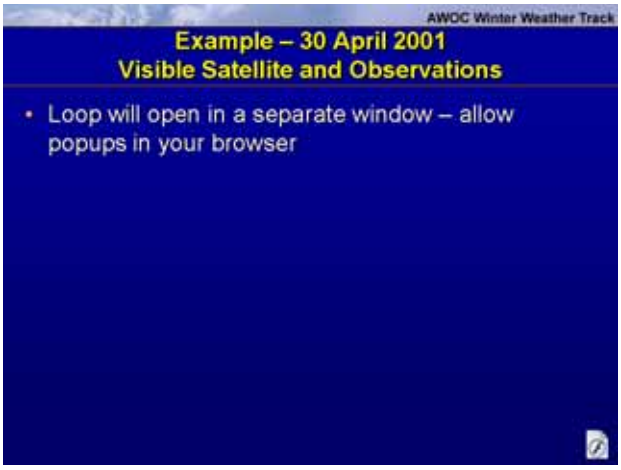
Student Notes:



27. Example: 30 April 2001 Visible Satellite and Observations

Instructor Notes: This loop (which shows up in a separate window...**make sure your popup blocker is turned Off**) shows the visible satellite imagery and observations from 30 April 2001. The orange X is the approximate location of the center of the PV anomaly and the dashed red line is the convergence boundary. Notice that as the PV anomaly approaches, the convergence line slowly progresses to the northwest. The winds in portions of northwestern Iowa shift to the southeast and accelerate to 10 to 15 knots. Across southeast South Dakota, the winds became northwest and increased over 10 kts as well. The result was increased surface convergence and with the low surface stability severe surface-based convection developed over northwest Iowa. We believe that the approach of the PV anomaly not only induced lift near the surface boundary but may have induced more convergence flow near the boundary.

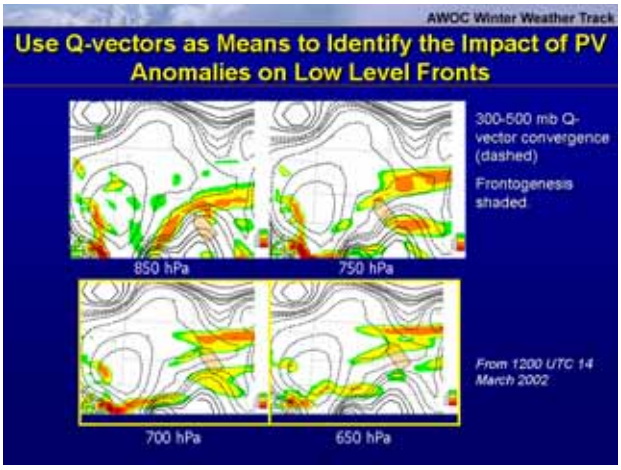
Student Notes:



28. Use Q-Vectors as Means to Identify the Impact of PV Anomalies on Low-Level Fronts

Instructor Notes: One of the most difficult decisions for a forecaster is to determine what level to examine frontogenesis. We saw from Hakim and Keyser (2002) that the location of the upper-level anomaly with respect to the low-level anomaly was critical to determine whether a coupled circulation will develop. To apply this idea, overlay the upper-level Q-vector convergence, which examines the role of the synoptic-scale upper-level wave and then frontogenesis at different levels. Noting where the frontogenesis is generally collocated with the Q-vector convergence can help you decide what level to examine. In most cases, there will be a 50 – 100 mb layer that may apply. While the example only shows a snap shot from one time, one would generally want to examine the Q-vector convergence and frontogenesis through the entire event to see how both evolve. Note that the 850 mb frontogenesis is located well south of the axis of Q-vector convergence. At the same time both 700 mb and 650 mb are nearly located along the axis of Q-vector convergence. They remain nearly coincident with the strong Q-vector convergence through the event and either level would be a good choice. This process will still not tell you how broad or narrow the frontal band will be. This topic will be examined in Lesson 3. In addition, Lesson 4 will provide more examples of the role of the upper level wave in enhancing frontal circulations and IC 6 will discuss a methodology for determining the potential for frontal bands.

Student Notes:



29. Interactive Quiz #3

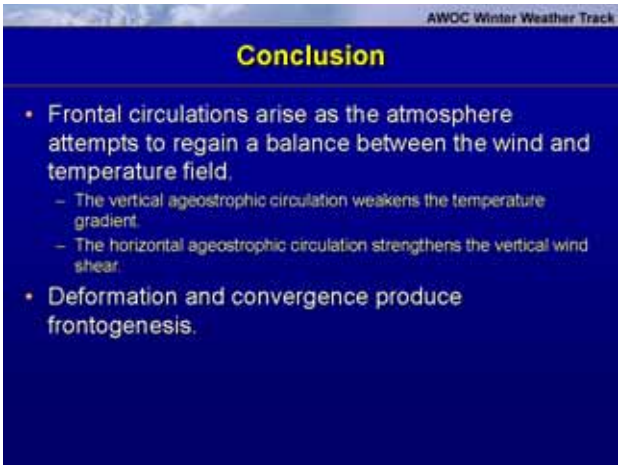
Instructor Notes: Take a moment to complete this quiz.

Student Notes:

30. Conclusion

Instructor Notes: In conclusion, frontal circulations arise as the atmosphere attempts to restore thermal wind balance. Frontogenesis acts to increase the thermal gradient while not changing the vertical wind shear. Therefore an ageostrophic circulation will develop. The horizontal portion of the circulation will act to increase the vertical wind shear while the vertical portion of the circulation will act to weaken the thermal gradient. When calculating horizontal frontogenesis, deformation and convergence both can act to increase the thermal gradient within a parcel.

Student Notes:



31. More Conclusions

Instructor Notes: While both Petterssen and geostrophic frontogenesis are available in AWIPS, it is critical the Petterssen frontogenesis is used. The geostrophic form of frontogenesis does not include convergence since the geostrophic wind is non-divergent. This will result in a calculation which is broader and weaker than using the total wind. Differences in diabatic heating, such as land vs. water surface or clear vs. cloudy skies, can also result in frontogenesis and, given time, produce a frontal circulation. Finally, upper-level PV anomalies can have large effect on frontal circulations. First, PV anomalies are also associated with ageostrophic circulations. These circulation can act to enhance or inhibit the updraft associated with a frontal circulation. Therefore being aware where superposition of frontal circulation and synoptic-scale wave circulations can help identify locations where frontal bands are most likely to develop. Second, PV anomalies can influence the low-level wind field. This can mean increased or decreased deformation along a thermal gradient which can impact frontogenesis. By changing the deformation near a boundary, a PV anomaly may also change the strength of a frontal circulation.

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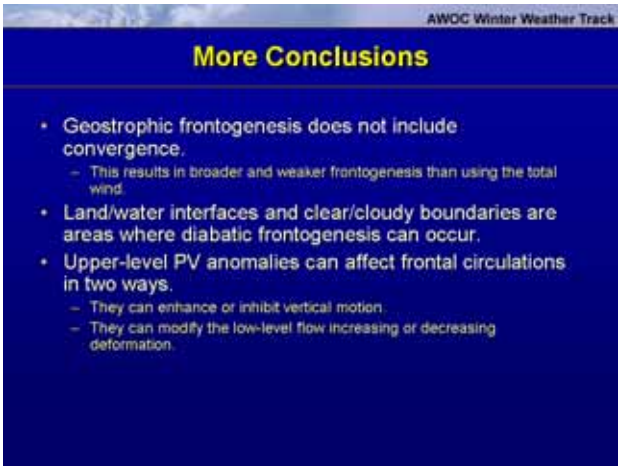
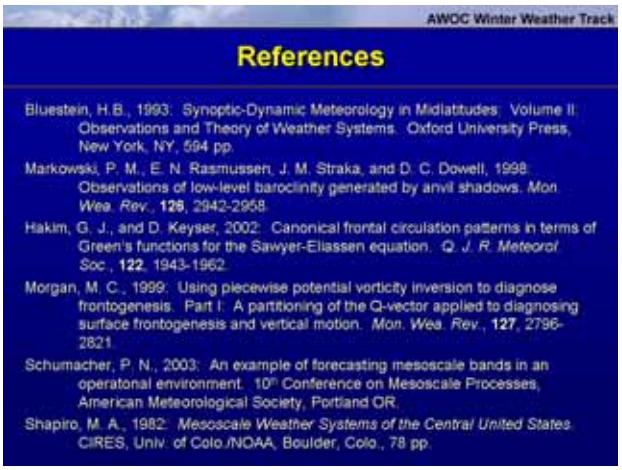


32. References

Instructor Notes: This slide contains a list of references mentioned during this presentation.

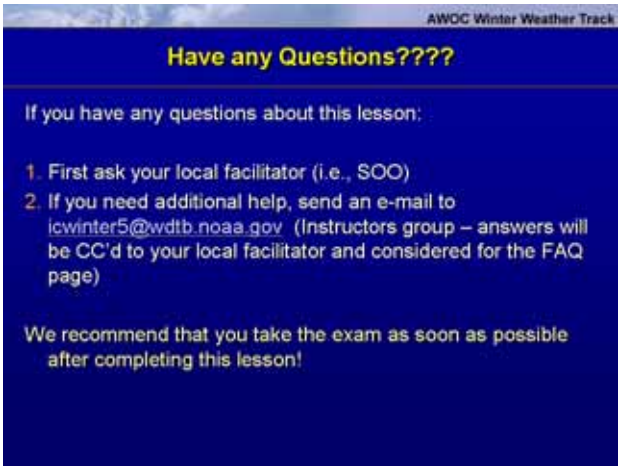
Student Notes:



33. Have any Questions????

Instructor Notes: If you have any questions about this lesson, first ask your local AWOC facilitator. If you need additional help, send an E-mail to the address provided. When we answer, we will CC your local facilitator and may consider your question for our FAQ page. We strongly recommend that you take the exam as soon as possible after completing this lesson.

Student Notes:



IC5.2: Optional Job Sheet

Diagnosing Mesoscale Internal Forcing—Frontogenesis

Objective: Examine a winter weather event and apply frontogenesis concepts discussed in the IC 5 Lesson 2 training module.

Data: 15 March 2004 winter storm event in the Midwest. You will be using your WES machine in case review mode.

Instructions:
On your WES machine, load the 15 March 2004 case, DMX localization, and set the clock to 15 March 2004, 13:00 UTC.
Take a vertical cross section perpendicular through the low-level thermal gradient from MN south to MO and load NAM 80 $_e$, omega, wind vectors, 2-D frontogenesis, and Div Q.

Where would you expect to find a secondary ageostrophic circulation?

Is there any sign of such a circulation, and if so, where is it located?

What do you think is causing the vertical motion over southern Iowa?

Where are the upper- and lower-level circulations coupled? (list a vertical layer and a general geographic location)

In a plan view pane and regional scale, load NAM80 750mb wind divergence, wind, total deformation and $_e$.
Does this appear to be **frontogenetic** or **frontolytic**? (circle one)

Where is the convergence maximized?

At any scale of your choosing, load a satellite image over surface obs and NAM 80 850mb 2-D frontogenesis.
Do you expect any enhanced frontogenesis from diabatic effects?

At the regional scale, load NAM80 500-300mb PV and overlay 700mb frontogenesis.
Where and at what forecasted time might the PV anomaly strengthen and/or couple with the frontogenesis?

Load a 4 panel plan view of NAM 80 Div-Q from 700-500 mb, with 2-D Frontogenesis at 4 different heights making up the 4 panels.
At what height are frontogenesis and Div-Q coupled to produce maximum forcing?
Where geographically is this coupling located?

An answer key is available for this job sheet. Please see your local AWOC Winter Weather facilitator to obtain a copy.

1. IC5.3: The Effect of Stability on the Response to Internal Forcing in the Atmosphere

Instructor Notes: Welcome to the winter AWOC IC 5 on precipitation forcing. This is Lesson 3 – The Effects of Stability on the Response to Internal Forcing in the Atmosphere. This lesson is presented to you by Phil Schumacher and David M Schultz. This lesson is 30 slides and should take you 30 minutes to complete.

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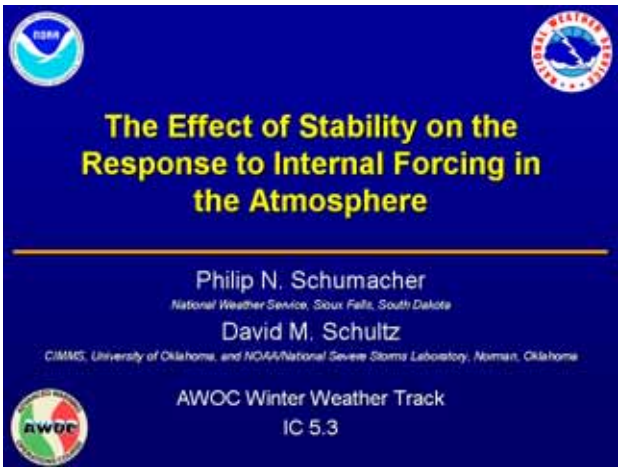
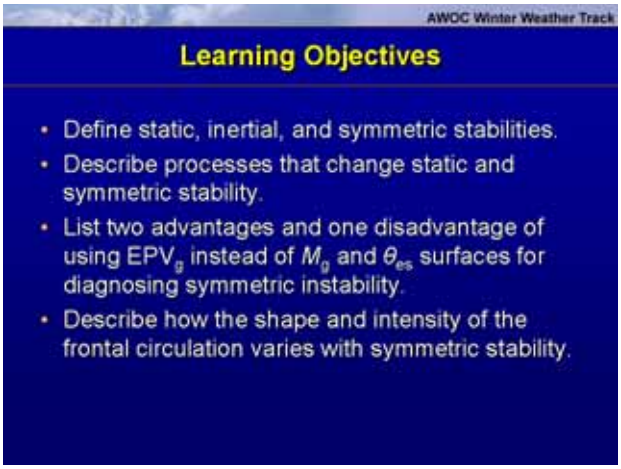


2. Learning Objectives

Instructor Notes: This lesson has four learning objectives. First, you should be able to define static, intertial, and symmetric stabilities. Next, you should be able to describe the processes that change static and symmetric stabilities. Third, you should be able to identify two advantages and one disadvantage to using EPV instead of M and saturated equivalent potential temperature surfaces for diagnosing symmetric instability. Lastly, describe how the shape and intensity of the frontal circulation varies with symmetric stability.

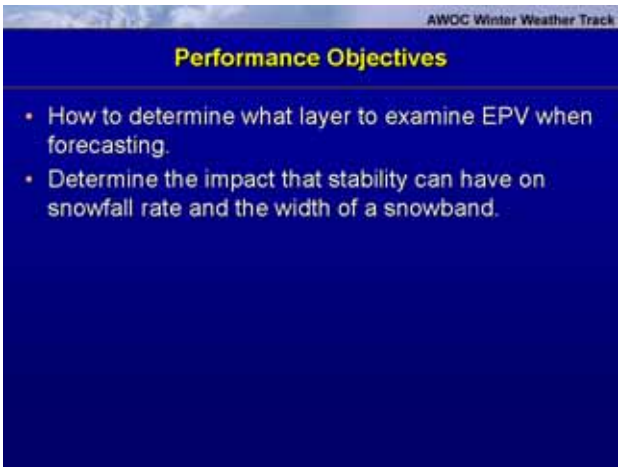
Student Notes:



3. Performance Objectives

Instructor Notes: There are two performance objectives for this lesson. You should be able to determine what layer to examine EPV when forecasting. Secondly, you should be able to determine the impact that stability can have on snowfall rate and the width of a snowband.

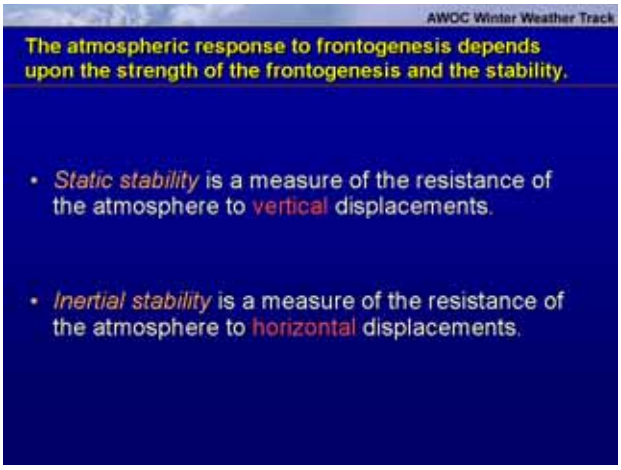
Student Notes:



4. The Atmospheric Response to Frontogenesis Depends Upon the Strength of the Frontogenesis and the Stability

Instructor Notes: In Lesson 2, we learned about frontogenesis. When frontogenesis occurs, a secondary ageostrophic circulation results that attempts to restore thermal wind balance. Specifically, in the presence of frontogenesis, a thermally direct circulation results. The strength and depth of a secondary ageostrophic circulation is dependent upon the strength of the frontogenetical forcing and on the stability. In Lesson 2, we saw that all things being equal, stronger frontogenesis leads to greater vertical motion. Later in this presentation, we will be more precise in what we mean by stability. In the meantime, let's consider two types of stability: static stability and inertial stability. Static stability is a measure of the resistance of the atmosphere to vertical displacements. Inertial stability is a measure of the resistance of the atmosphere to horizontal displacements.

Student Notes:



5. Perturbations Placed in an Unstable Environment Grow Larger

Instructor Notes: The definition of an unstable environment is one in which perturbations placed in that environment grow larger. It doesn't matter what kind of environment we're talking about. A pencil standing on its pointed end on a table is unstable. Any perturbations to the pencil will result in the perturbation growing and the pencil falling over. The atmosphere can be unstable to vertical or horizontal displacements. One type of instability to vertical displacements is called static instability. You should be familiar with the concepts of static stability. The condition for static instability is that the environmental lapse rate is between the dry and the moist adiabatic lapse rate, or equivalently the saturated equivalent potential temperature decreases with height. The saturated equivalent potential temperature is the equivalent potential temperature an air parcel would have if it were brought to saturation at the same temperature and pressure by evaporating water into the parcel. Conditionally unstable environments may eventually undergo vertical motions in the form of deep moist convection that overturn the unstable layer and release the instability. You may be less familiar with inertial instability. Inertial instability is not common in the free atmosphere, but may be found on the anticyclonic-shear side of jets where the absolute geostrophic vorticity is less than zero. Inertially unstable environments can develop a form of "horizontal" convection in which ageostrophic circulations develop to restore balance. In this regard, the release of inertial instability is analogous to the release of static instability to form deep moist convection. Thus, for static stability, the greater the saturated equivalent potential temperature decreases with height, the more statically unstable the air is. The smaller the absolute geostrophic vorticity is, the lower the inertial stability.

Student Notes:

6. The Rate of Adiabatic Cooling Depends on the Static Stability of the Environment

Instructor Notes: For example, let's consider how the static stability can affect the vertical response to frontogenesis. One can define stability as the difference between the environmental and the dry (or moist) adiabatic lapse rate. For a given amount of forcing (i.e. frontogenesis), when stability is large [a large difference between the environmental lapse rate and dry (moist) adiabatic lapse rate] then the vertical motion is most likely going to be small. On the other hand, when stability is small, then there will be a lot of vertical motion. Also, note that whether a parcel is saturated or not can have a large effect on the stability since the moist adiabatic lapse rate is smaller than the dry adiabatic lapse rate (9.8 degrees C/km vs. ~6.5 degrees C/km). What can be a stable environment when the atmosphere is unsaturated, can become much less stable when the atmosphere becomes saturated. This would mean a large increase in vertical motion once the atmosphere is saturated.

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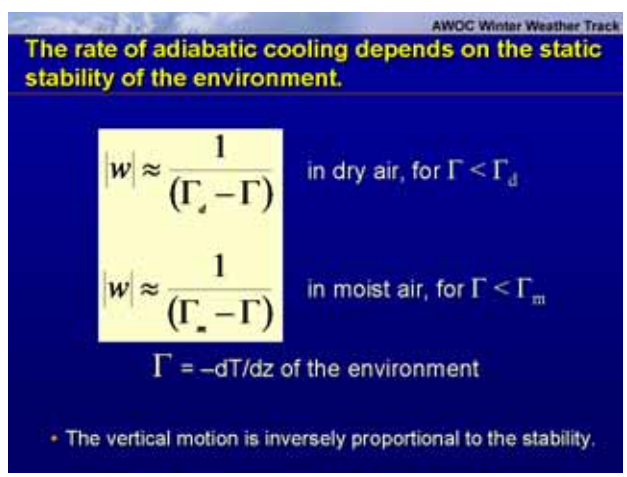
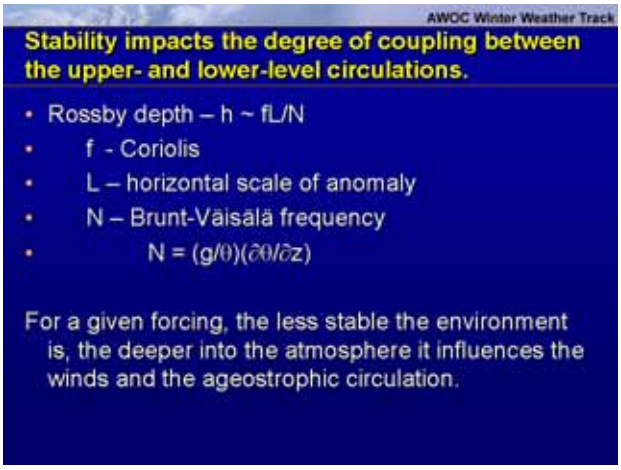


7. Stability Impacts the Degree of Coupling Between the Upper- and Lower-Level Circulations

Instructor Notes: Recall from Lesson 1 that potential vorticity anomalies will induce winds at levels far removed from where the anomaly is located. The Rossby depth determines how deep into the atmosphere the influence of a particular wave will be. While the horizontal extent of the wave is one factor, stability plays a large role in determining the ability of an upper level PV anomaly to “communicate” with a low-level front. This relationship is best illustrated by comparing summer and winter. In winter, strong PV anomalies that move over cold anticyclones will result in little vertical motion or surface response because of the high stability within the air mass. In summer, smaller and weaker waves can produce a large response because the stability is generally near moist adiabatic. Therefore, knowledge of the stability between a low-level front and upper-level wave is critical to understanding the strength of a coupled jet/front circulation.

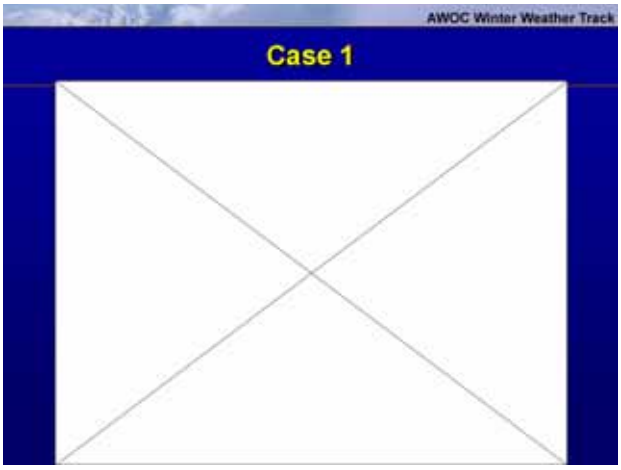
Student Notes:



8. Case 1

Instructor Notes: As we saw from the relationship between stability and vertical motion, high static stability means weak vertical motion. So, the vertical component of the circulation will be shallow and weak. At the same time, low inertial stability means that air parcels will accelerate far away from their initial horizontal position. Thus, the horizontal component of the circulation will be large and strong. Therefore, we would see a broad but shallow circulation in the event of high stability and low inertial stability.

Student Notes:



9. Case 2

Instructor Notes: The other extreme would be weak static stability and high inertial stability. With low static stability, the vertical component of the secondary circulation will be large and deep. With high inertial stability, the horizontal component of the secondary circulation will be small. Thus, the circulation is narrow in the horizontal but extends much more deeply in the vertical.

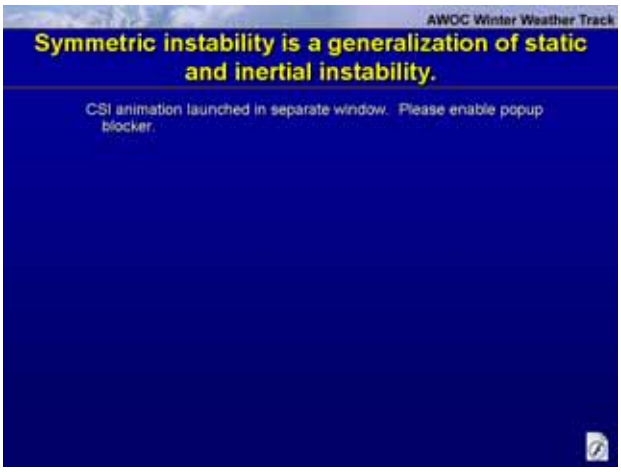
Student Notes:

10. Symmetric Instability is a Generalization of Static and Inertial Instability

Instructor Notes: Instability in the atmosphere can be viewed more generally. Specifically, the instability resulting from vertical displacements and the instability resulting from horizontal displacements can be generalized into instability resulting from slantwise displacements. Symmetric stability is a measure of the resistance to slantwise ascent by parcels. The atmosphere can be symmetrically unstable but inertially and statically stable. Symmetric stability plays a large role in determining the strength and width of the

ageostrophic frontal circulation. When there is small symmetric stability, the result will be an intense and narrow updraft. When symmetric stability is large, a broad and weak updraft.

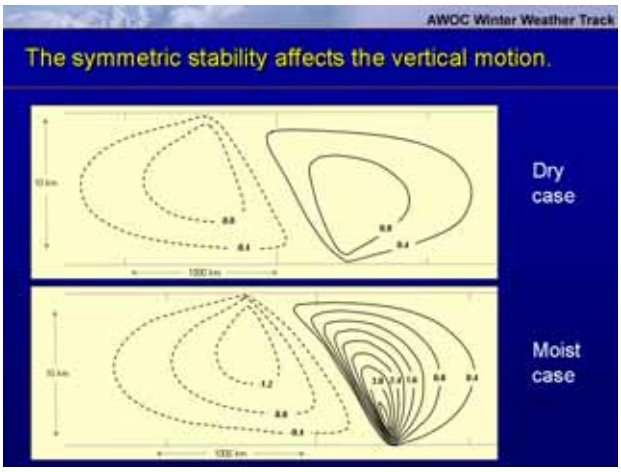
Student Notes:



11. The Symmetric Stability Affects the Vertical Motion

Instructor Notes: Thorpe and Emanuel (1985) ran two simulations of a 2-D semi-geostrophic model with same frontogenetic forcing. The only difference they made was to change the symmetric stability in the warm air (through the moist or equivalent potential vorticity, to be discussed later). In the first run, the entire domain had large, dry potential vorticity. We will call this the dry case. In the second run, the potential vorticity was set to near zero on the warm side of the front. This is equivalent to the weakly stable case. The result in the vertical motion is dramatic. While both areas of ascent are slantwise into the cold air, the dry case shows very broad and weak vertical motion. In the “moist” case, the ascent is unbalanced with very strong and narrow ascent on the warm side of the boundary. While the subsidence on the cold side of the front is stronger than the dry case, the higher stability behind the front still means rather broad area of subsidence.

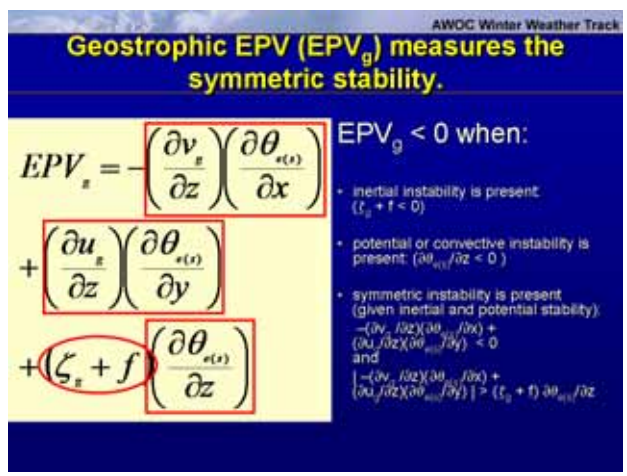
Student Notes:



12. Geostrophic EPV (EPV_g) Measures the Symmetric Stability

Instructor Notes: We can calculate the stability of parcels to moist slantwise ascent by calculating Equivalent Potential Vorticity (EPV_g). The equation is similar to dry potential vorticity (PV) except that the full three-dimensional geostrophic vorticity is used, and theta-E (or theta-es) is used instead of potential temperature. The EPV_g equation above has 3 terms. Terms 1 and 2 are vertical wind shear and horizontal temperature gradient, respectively. Near a strong front the horizontal temperature gradient will be large as well the vertical wind shear. Both terms combined will usually be negative (assuming colder air to the north and west in the Northern Hemisphere). Term 3 is absolute geostrophic vorticity and static stability. This term is positive when the atmosphere is inertially and statically stable. There are three conditions when EPV_g is negative: inertial instability, potential (convectively) instability, and symmetric (CONDITIONAL) instability. While inertial instability is rare, to be potentially or conditionally unstable is relatively common, especially in summer. In these cases, the atmosphere is susceptible to upright convection and not slantwise ascent. However, in cases with weak inertial stability and weak upright stability, then the first two terms can force EPV_g to be negative. These are the situations where there can be strong slantwise ascent and even slantwise convection.

Student Notes:

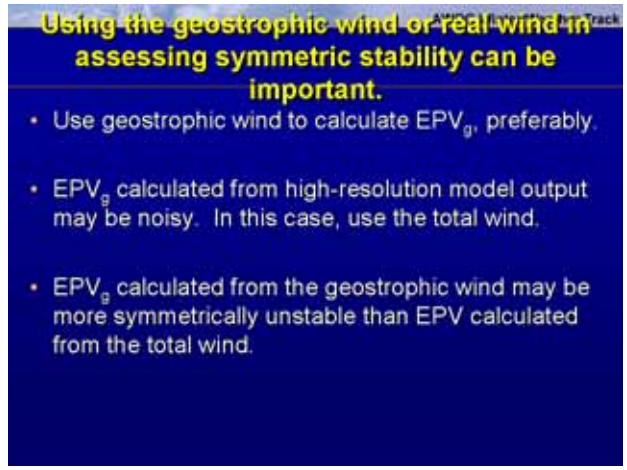


13. Using the Geostrophic Wind or Real Wind in Assessing Symmetric Stability Can Be Important

Instructor Notes: Strictly speaking, evaluating the symmetric stability requires use of the geostrophic wind in the calculation of EPV_g. In high-resolution numerical model output, the geopotential height (and by extension the geostrophic wind) may be noisy, making determining the symmetric stability difficult. In this case, using the total wind may be preferable. In cases where the horizontal and vertical gradients of the geostrophic wind and total wind are similar, the EPV calculated either way will be nearly the same. When

large differences occur, the EPV calculated from the geostrophic wind may be found to be more symmetrically unstable.

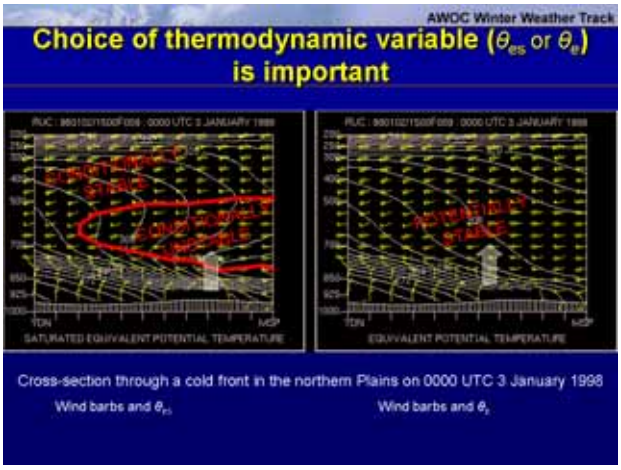
Student Notes:



14. Choice of Thermodynamic Variable (θes or θe) is Important

Instructor Notes: As noted in the previous slide, EPV_g can be calculated using θ_e or θ_{es}. The figures show that there can be large differences between the two calculations for the same case. On the left, saturated theta-e is used and, for a large portion of the cross-section above the frontal inversion, saturated theta–e decreases with height, implying convective instability. Therefore the atmosphere would be susceptible to upright convection assuming a saturated atmosphere. On the right, theta–e increases with height through the entire cross-section, implying potential stability throughout. Using saturated theta-e or theta–e when calculating EPV_g can have affect how one would interpret the atmospheric response. Using saturated theta-e, locations where there is conditional instability would be negative and imply the possibility of upright convection. For the cross-section on the right, the entire area is potentially stable. So if one used theta-e to calculate EPV_g, then negative EPV_g would imply potential symmetric instability (PSI) along the entire cross-section. No study has been done to determine which form of EPV is operationally better so forecasters need to be aware of the differences especially if the atmosphere is not saturated.

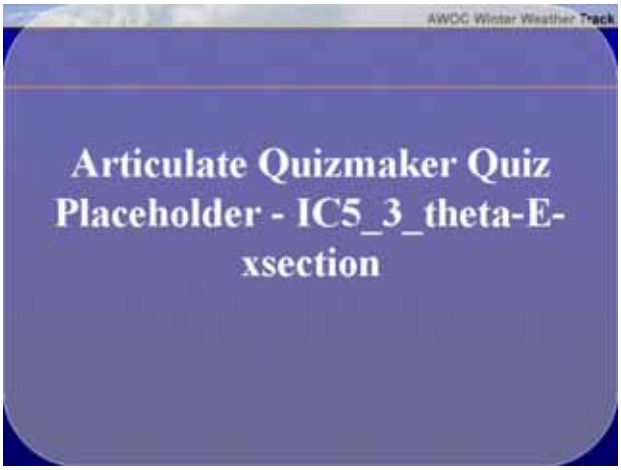
Student Notes:



15. Interactive Quiz #1

Instructor Notes: Take a few moments to complete this quiz.

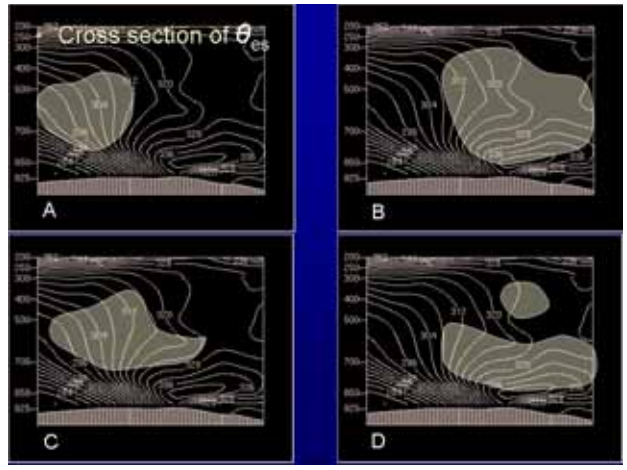
Student Notes:



16. Interactive Quiz #1 Review

Instructor Notes: The best answer to the question is the analysis in D where q_e decreases with height. The shaded area in all other choices include some region where q_e actually increases with height.

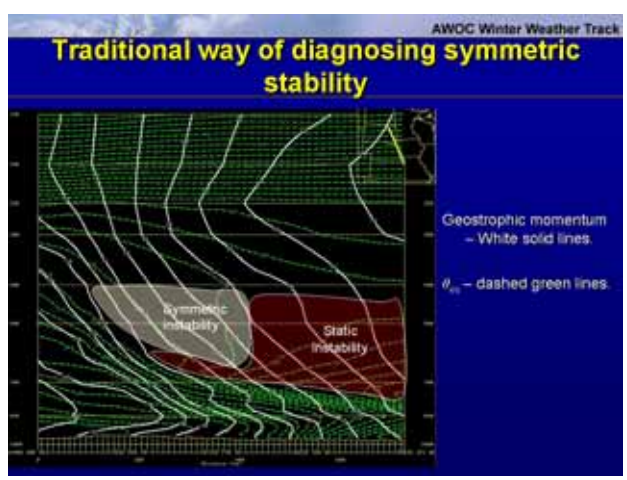
Student Notes:



17. Traditional Way of Diagnosing Symmetric Stability

Instructor Notes: We will compare the M_g–q_{es} technique for identifying areas with symmetric stability to that using EPV. The above figure shows the M_g–q_{es} surfaces. The traditional way that symmetric instability has been taught was to compare the slope of Mg surfaces to those of qes surfaces in a cross section constructed perpendicular to the thermal wind (called the M_g–q_{es} relationship). If the slope of the M_g surfaces is less than that of the q_{es} surfaces, then symmetric instability is present. There are two disadvantages of this approach. First, cross-sections can only tell part of the story. Forecasters need to know the horizontal distribution of instability in order to determine how the frontal band will evolve over. The duration of frontogenesis and low stability over an area is critical for knowledge of how much snow may fall over a location. Second, the validity of the M_g–q_{es} relationship requires the flow is not curved since M is calculated only from the normal component of the wind. Significant direction shear will result in large changes in M that are not the result of speed shear but changes in direction.

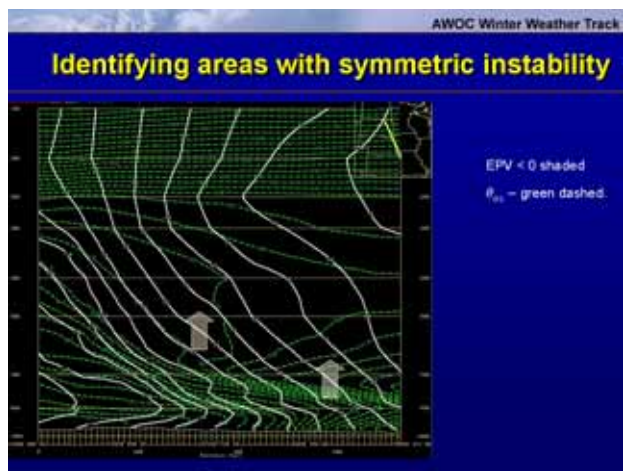
Student Notes:



18. Identifying Areas with Symmetric Instability

Instructor Notes: Fortunately, there is a better approach. Negative saturated equivalent geostrophic potential vorticity (MPV_g*) is equivalent to the M_g–q_{es} relationship and does not face those above limitations. Unfortunately, distinguishing conditional symmetric instability from conditional instability is not possible without examining the vertical profile of q_{es} to confirm that it decreases with height. A useful diagnostic approach is to overlay frontogenesis, MPV_g*, and RH in a horizontal map or in a cross-section. Above is the same cross-section as for the M-θ_{es} cross-section above. Notice that the layer which is symmetrically unstably (or weakly stable) is obvious in this cross-section when an image is used to highlight EPV near or below zero. By overlaying θ_{es} we can also easily identify regions of conditional instability and symmetric instability. Notices that regions of conditional instability generally have much lower values (more negative) of EPV than areas that are conditionally unstable. While not shown in this case, one may also want to overlay relative humidity. As with conditional instability, only when parcels are saturated will the instability be realized. As we will see later, while the EPV is very negative on the right (south) side of the cross-section, it is also very dry and coincident with the dry slot. Therefore, this instability will not result in enhanced vertical motion until parcels reach saturation.

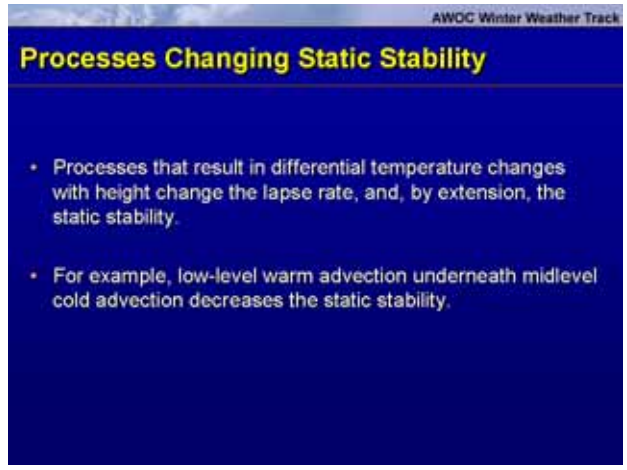
Student Notes:



19. Processes Changing Static Stability

Instructor Notes: Situations that are statically stable can be made statically unstable by changing the lapse rate, or producing differential temperature changes with height. For example, one way to produce a different rate of change of temperature between two levels is by having low-level warm advection underneath midlevel cold advection. The combined effect of these two processes will result in a lowering of static stability.

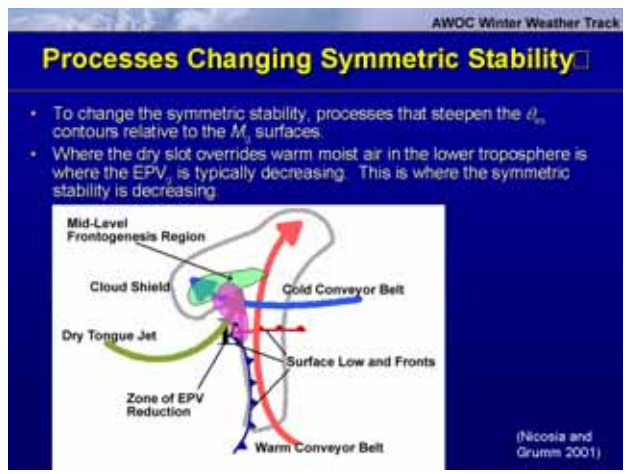
Student Notes:



20. Processes Changing Symmetric Stability

Instructor Notes: Similarly, changes in symmetric stability can be viewed as processes that steepen the θ_{es} contours relative to the M_g surfaces. This will produce a reduction in EPV_g. One location where the θ_{es} contours tend to overturn is the dry slot region of an extratropical cyclone. It is at the leading edge of the dry slot as it rides over the warm front where you can sometimes find heavier precipitation due to the reduction in stability.

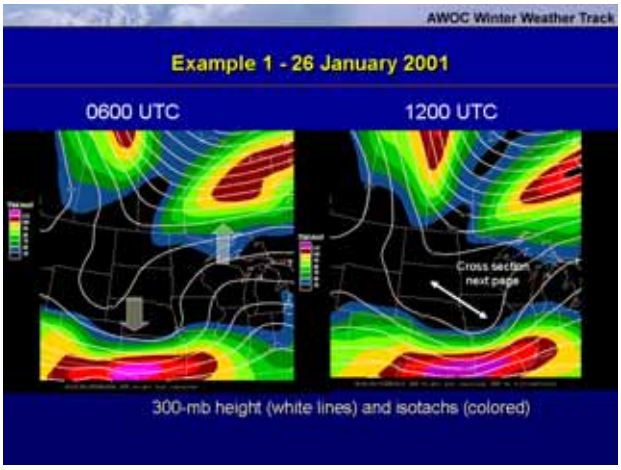
Student Notes:



21. Example 1 - 26 January 2001

Instructor Notes: We will now look at two examples which have frontogenesis and an upper-wave but differences in stability. Our first example is from 26 January 2001. The above plots show 300 mb isotachs (shaded) and heights (white lines). This example was a split flow regime with two waves moving across the region: the first moving along the U.S. and Canadian border and the second moving across southern Nebraska and southern Iowa. Both waves are associated with jet streaks where winds were in excess of 100 kts.

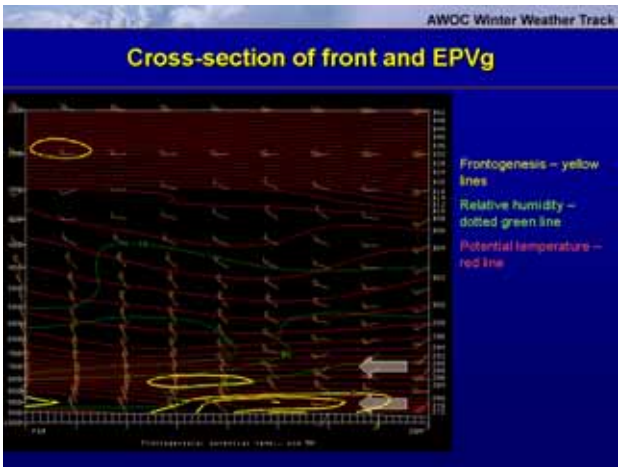
Student Notes:



22. Cross-Section of Front and EPV_g

Instructor Notes: The cross-section above shows potential temperature, relative humidity and frontogenesis. This cross-section is taken perpendicular to the low-level front. Notice that the frontogenesis is confined below 850 mb and that above the level frontogenesis is a very stable layer. Were this an unstable environment then the fact that this is a shallow front would not matter: a frontogenetical circulation would develop resulting in precipitation. However, even though it is saturated, the stability is very high above the front. This will limit the strength of the frontal circulation and the ability of the upper wave to couple with the low level front to produce precipitation.

Student Notes:

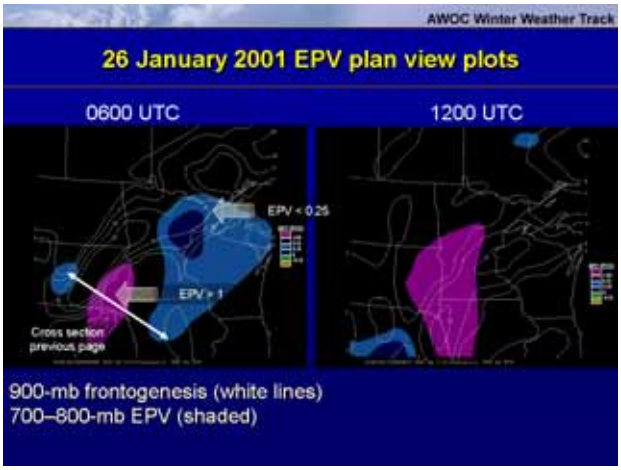


23. 26 January 2001 EPV Plan View Plots

Instructor Notes: These figures shows frontogenesis (thin white lines) and 700 to 800 mb EPV (shaded). What we saw in the cross-section is confirmed when we calculate EPV. Over southeast South Dakota, an area of EPV greater than 1 PVU is situated over the frontogenetic region at 900 mb. As we saw earlier, high stability can act to suppress frontal circulations and therefore one would expect little precipitation across eastern

South Dakota into western Iowa. Across northeast Minnesota, where the stability is lower, the potential for more significant precipitation would be higher.

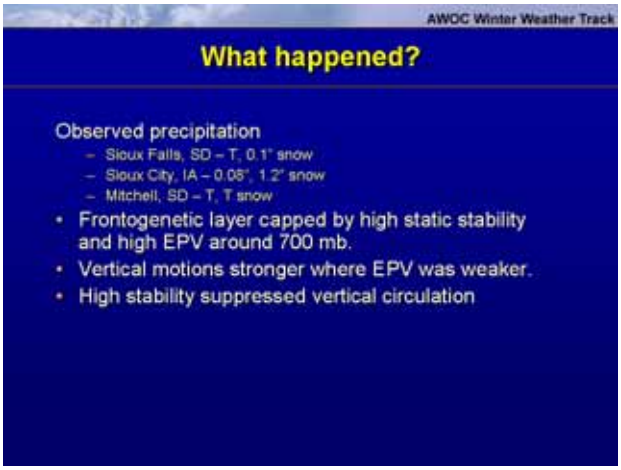
Student Notes:



24. What Happened?

Instructor Notes: As a result of the high stability, there was little observed precipitation associated with the front as it moved across. Despite the presence of an upper level wave and low-level frontogenesis, the frontal circulation remained suppressed due to the presence of high stability above the frontal surface.

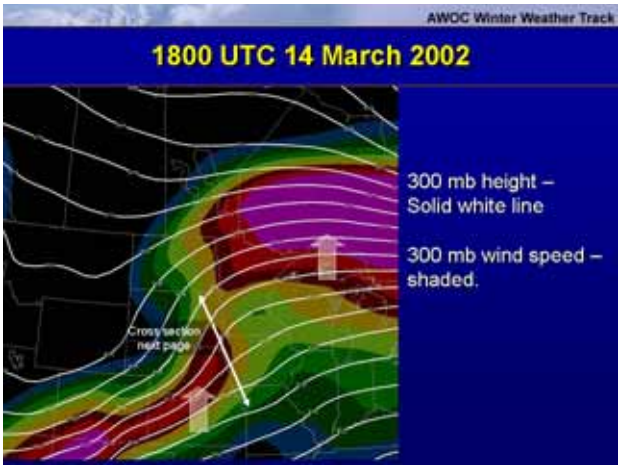
Student Notes:



25. 1800 UTC 14 March 2002

Instructor Notes: The second example is from 14 March 2002 and displayed is 300 mb winds and height. We see two jet streaks. The first is located along the U.S.–Canadian border placing eastern South Dakota and southern Minnesota within the right entrance region of the jet. A second jet streak is located behind an upper-level shortwave moving into Nebraska. From a large-scale perspective the eastern Plains have synoptic-scale support for vertical motion.

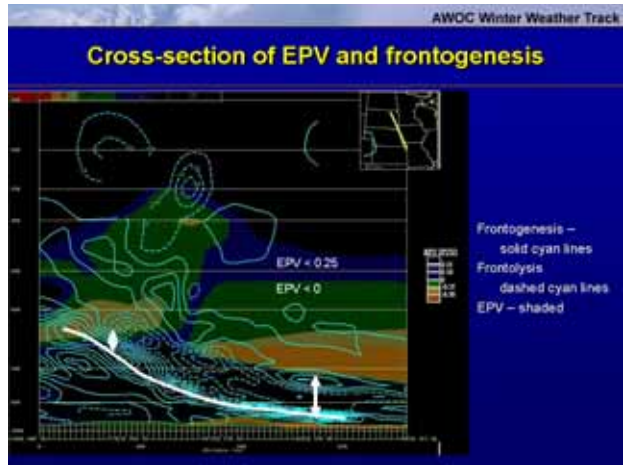
Student Notes:



26. Cross-Section of EPV and Frontogenesis

Instructor Notes: Now let's look at a cross-section perpendicular to the front across eastern South Dakota and western Iowa. In Lesson 2, we discuss how one can examine where the frontogenesis with respect to the Q-vector convergence in a layer near the tropopause. Where the two (nearly) overlay is the level (or layer) where one can get a coupled circulation between the upper-level wave and low-level front. However, there are cases where the upper-level wave moves along or even south of the surface front. In those cases, there can be a 200 mb thick layer (or larger) where the best Q-vector convergence and frontogenesis are coincident. This can extend across a couple hundred miles. In those cases, one needs to examine a cross-section of frontogenesis and EPV to see where the frontal layer is nearly coincident with the least stable layer. This is best done prior to the development of precipitation in the model, which can impact the location of both frontogenesis and instability due to diabatic effects. On the right side of the cross-section, which is farthest south, the unstable layer is approximately 150 mb above the frontogenetic layer. However, toward the middle of the cross-section, the difference is less than 100 mb. This would suggest that 700 mb or 650 mb may be the best level to examine the frontogenesis and then look at EPV from 650–550 mb. This is because the decreased stability above the frontal surface would allow the frontal ascent to narrow and accelerate compared to farther south.

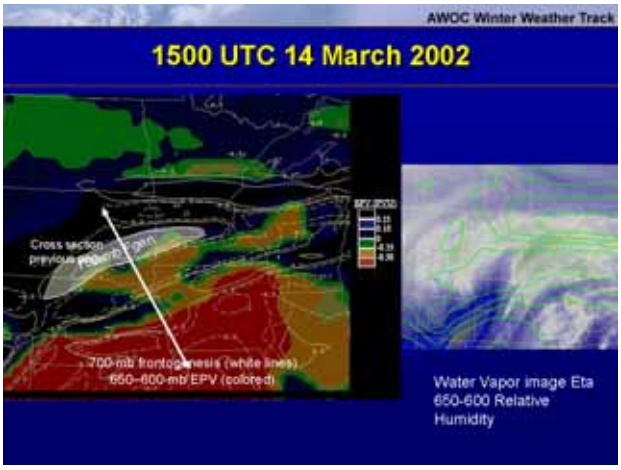
Student Notes:



27. 1500 UTC 14 March 2002

Instructor Notes: Once you identify the level(s) to examine frontogenesis and the layer to examine EPV, you can display a horizontal plot with both overlayed in order to see how both evolve over time. The first graphic shows 700 mb frontogenesis in the white lines and EPV_g in the 650 to 600 mb layer in color. Dashed white lines represent frontolysis and solid white lines represent frontogenesis. One can also examine the F_n divergence as discussed in Lesson 2. So we have also displayed 650 mb F_n divergence in the white lines and EPV, both from 1500 UTC 14 March. The convergence of F_n can be associated with upward vertical motion so either frontogenesis or convergence of F_n can be used to examine where the lift due to frontogenetic forcing will be located. When we look at frontogenesis, we are examining the ascent above the level of frontogenesis. Therefore, we examine EPV in the 650 to 600 mb layer which is where the ascending branch of the frontal circulation would be located. If F_n convergence is used, we are assuming that ascent is occurring at that level (650 mb) and so we examine EPV in a layer that includes the level we are displaying F_n convergence. Notice that in this case the 650 F_n convergence is co-located with the maximum of 700-mb frontogenesis. The diagnosis is the same in both figures – it is symmetrically unstable above the frontal boundary which would mean the potential an intense and narrow frontal band developing. Notice is it also very unstable across southern Nebraska and southern Iowa. However, as seen in the water vapor image, this is an area where the relative humidity is below 80 percent and where the dry slot is located. In fact, in many cases with frontal bands, the snow band will be at the northern edge of the dry slot where there is symmetric (and sometime conditional) instability and moisture. This region is not the most unstable area but it is the area where moisture, lift and instability combine to produce a heavy snowband.

Student Notes:



28. Snowfall 14 March 2002

Instructor Notes: On the left is a radar picture which shows a band of heavy snow from the morning of 14 March. Snowfall in excess of one inch per hour was occurring at this time. The result was snowfall in excess of one foot (30 cm) across east central South Dakota and southwest Minnesota. Note the large gradient in snowfall between MML (Marshall, MN) and OTG (Worthington MN). These two cities are only separated by 60 miles but snowfall varied by over 12 inches. In this case the co-location of strong frontogenesis, low stability (or even instability) and a strong upper-level wave set the conditions for intense narrow band of snowfall.

Student Notes:

29. Interactive Quiz #2

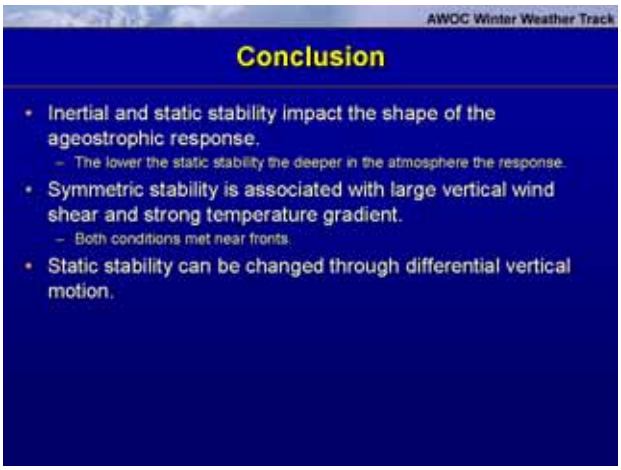
Instructor Notes: Take a few moments to complete this quiz.

Student Notes:

30. Conclusion

Instructor Notes: This is the first slide that discusses all the concepts covered in this presentation.

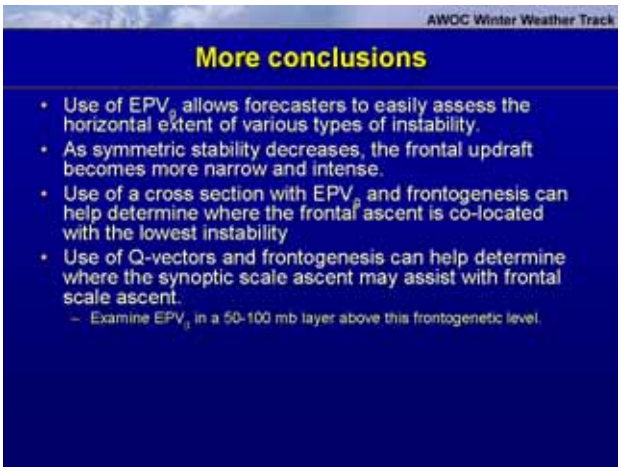
Student Notes:



31. More Conclusions

Instructor Notes: This is the second slide that summarized the content of this lesson.

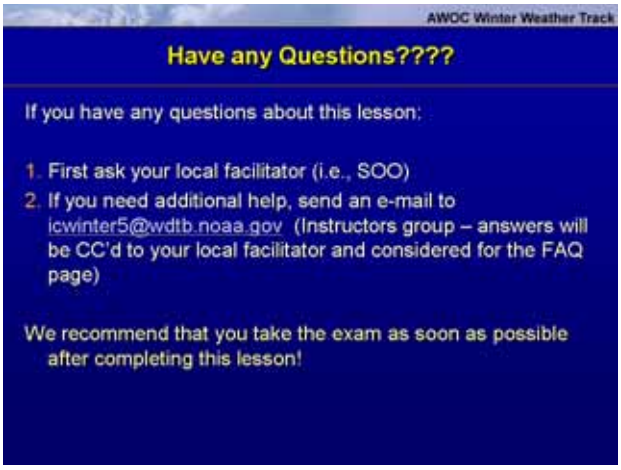
Student Notes:



32. Have any Questions????

Instructor Notes: If you have any questions about this lesson, first ask your local AWOC facilitator. If you need additional help, send an E-mail to the address provided. When we answer, we will CC your local facilitator and may consider your question for our FAQ page. We strongly recommend that you take the exam as soon as possible after completing this lesson.

Student Notes:



IC5.3: Optional Job Sheet

The Effect of Stability on the Response to Internal Forcing in the Atmosphere

Objective: Demonstrate how to assess Equivalent Potential Vorticity (EPV) fields and their effect on winter weather precipitation through a case study.

Data: You will examine 2 different cases to show how EPV or lack of EPV affects the scale and magnitude of the precipitation. As with job sheets for IC 5 Lessons 1 and 2, you will first re-examine the 15 March 2004 winter storm event in the Midwest, then a contrasting event from 4 November 2003, also across the Midwest. You will be using your WES machine in case review mode.

Instructions:

Case #1

On your WES machine, load the 15 March 2004 case, DMX localization, and set the clock to 15 March 2004, 13:00 UTC.

Load surface metars and RUC or NAM40 surface θ_e.

Take a cross section northeast to southwest from southeast Minnesota to eastern Kansas, normal to the surface front across southern Iowa. Load NAM 80 wind vectors, and ageostrophic vertical circulation streamlines. Focus on the NAM analysis at 12 UTC 15 March 2004.

Based on the shape of the circulation and pattern of the vertical motion streamlines, what would you infer about the static stability and inertial stability?

Overlay geostrophic momentum and θ_{es}. Does this agree with model's assessment in #1 of the vertical circulation and thus the inertial and static stability? Why or why not?

Next, overlay Saturated EPV_g (MPV_g). How does this compare with what you saw with momentum surfaces and θ_{es} regarding static stability?

Where is the strongest conditional or symmetric instability in this cross section? Is it deep?

Along the same cross section but in a different window, load NAM80 θ_{es}, saturated equivalent geostrophic potential vorticity (MPV_g), and RH. Shade only the PV values less than +0.25 PV units. Focus on the NAM analysis valid 12 UTC 15 March 2004. What is the likely cause of the MPV_g minimum in the 700-300 mb layer across the southern end of the cross section?

Overlay 2-D frontogenesis. Where is the smallest vertical separation between the maximum in frontogenesis and MPV_g minimum located?

Where would the north and south extents of the heavy snow band likely occur? (Hint, examine the horizontal distance from the maximum frontogenesis at 600 mb to the northeast and at 900 mb to the southwest)

Based on your analysis of the NAM analysis valid 12 UTC 15 March 2004, load a plan view 2-D frontogensis near the level of maximum frontogenesis over Iowa, and overlay MPV_g in the layer 100 mb above the front you discovered in the cross sections. Where, if anywhere, is the MPV_g minimized above the frontogenesis?

Based on your answer to the above, where do you expect the heaviest snowfall to occur and what is the primary forcing mechanism in that region?

Overlay Div-Fn vectors in the same layer you displayed MPV_g. How do the Fn convergence fields compare to the stability above the frontal zone? Is this surprising? Why/Why not?

Case #2—A different perspective

If you have extra time and want to examine a case with different stability and frontogenesis coupling, give this event a try. Load the 04 November 2003 case, FSD localization, and set the clock to 04 Nov 2003, 07:00 UTC.

Determine the location of the surface front at 6 UTC on 4 November 2003.

Take a cross section normal to the surface front across southern North Dakota to southeast Kansas (essentially normal to the thermal wind) and load NAM80 wind vectors, and ageostrophic vertical circulation streamlines. Focus on the NAM analysis at 06 UTC 04 November 2003.

Based on the shape of the circulation and pattern of the vertical motion streamlines, what would you infer about the static stability and inertial stability?

Overlay geostrophic momentum and $_{es}$. Does this agree with model's assessment in #11 of the vertical circulation and thus the inertial and static stability? Why or why not?

Next, overlay MPV_g. How does this compare with what you saw with momentum surfaces and $_{es}$ regarding static stability?

Where is the strongest conditional or symmetric instability in this cross section? Is it deep?

Along the same cross section but in a different window, load NAM80 saturated equivalent potential temperature, MPV_g, and RH. Focus on the NAM analysis valid 06 UTC 04 November 2003.
Where do you see the potential for deep convection to develop?

Overlay 2-D frontogenesis. Where is the smallest vertical separation between the maximum in frontogenesis and MPV_g minimum located?

Where would the north and south extents of the precipitation band likely occur?

Based on your analysis of the NAM analysis valid 06 UTC 04 November 2003, next load a plan view 2-D frontogensis near the level of maximum frontogenesis over southern Nebraska/central Kansas, and overlay MPV_g in the layer 100-150 mb above the front you discovered in the cross sections.
Where, if anywhere, is the MPV_g minimized above the frontogenesis?

Based on your answer to the above, where do you expect the heaviest precipitation to occur and what is the primary forcing mechanism in that region?

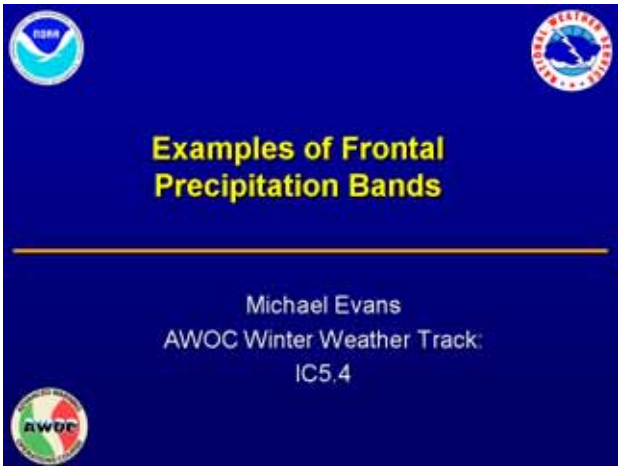
Overlay Div-Fn vectors in the same layer you displayed EPV_g. How do the Fn convergence fields compare to the stability above the frontal zone? Is this surprising? Why/Why not?

An answer key is available for this job sheet. Please see your local AWOC Winter Weather facilitator to obtain a copy.

1. IC5.4: Examples of Frontal Precipitation Bands

Instructor Notes: Welcome to IC 5, Lesson 4. My name is Mike Evans and I will be presenting this lesson, Examples of Frontal Precipitation Bands. This lesson should take approximately 25-30 minutes.

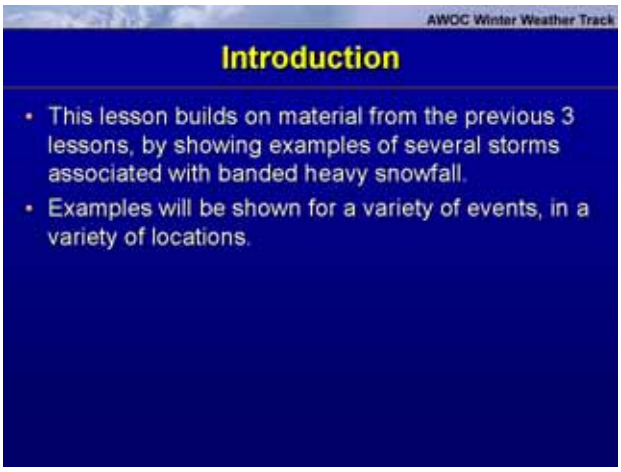
Student Notes:



2. Introduction

Instructor Notes: This lesson builds on the material from the previous three lessons in IC 5, by showing examples of several storms associated with banded heavy snowfall. Examples will be shown for a variety of events, in a variety of locations.

Student Notes:

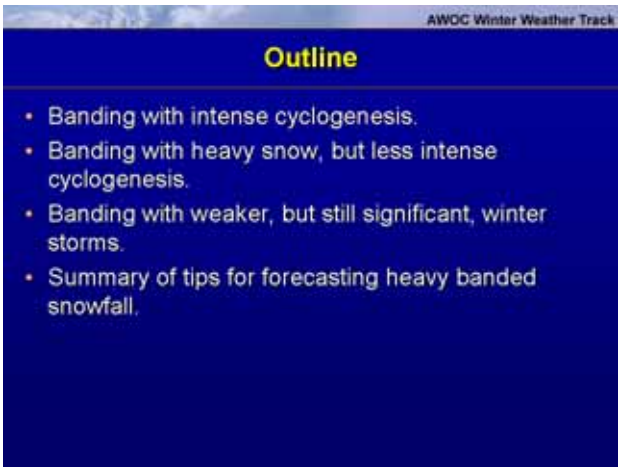


3. Outline

Instructor Notes: In order to demonstrate how forecasters can use the material from Lessons 1 to 3 to forecast banded snowfall in a variety of synoptic- and mesoscale situations, several examples will be shown. The first example shows diagnostics and obser-

vations associated with intense banding that occurred with a major east coast cyclogenesis event. In the second and third examples, diagnostics and observations will be shown from 2 major snow events that produced intense bands, yet were not associated with a rapidly deepening cyclone. Next, an example will then be shown of less intense, but still significant, banding. The lesson ends with a summary of tips for forecasting banded snowfall.

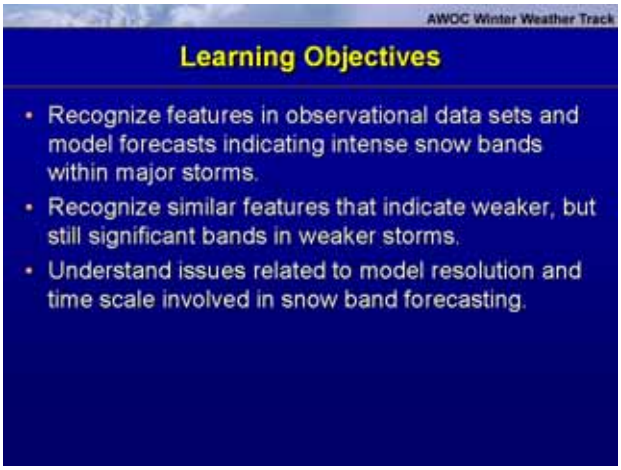
Student Notes:



4. Learning Objectives

Instructor Notes: This lesson has three learning objectives. First, you should be able to recognize features in observational data sets and model forecasts indicating intense snow bands within major storms. Next, you should be able to recognize similar features that indicate weaker, but still significant bands in weaker storms. Lastly, you will understand issues related to model resolution and time scale involved in snow band forecasting.

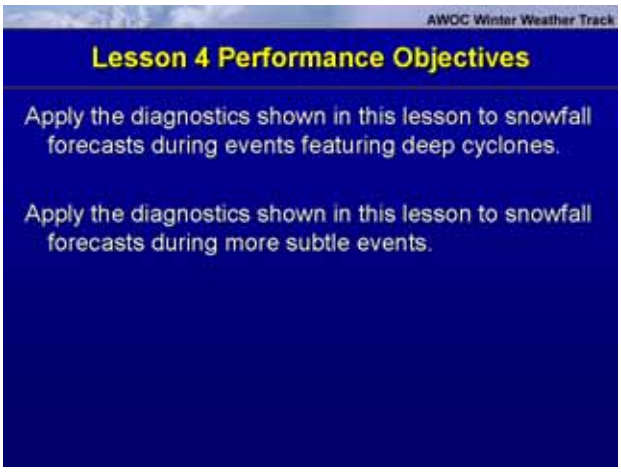
Student Notes:



5. Lesson 4 Performance Objectives

Instructor Notes: There are two performance objectives for this lesson. First, you will apply the diagnostics shown in this lesson to snowfall forecasts during events featuring deep cyclones. Second, you will be able to apply the diagnostics shown in this lesson to snowfall forecasts during more subtle events.

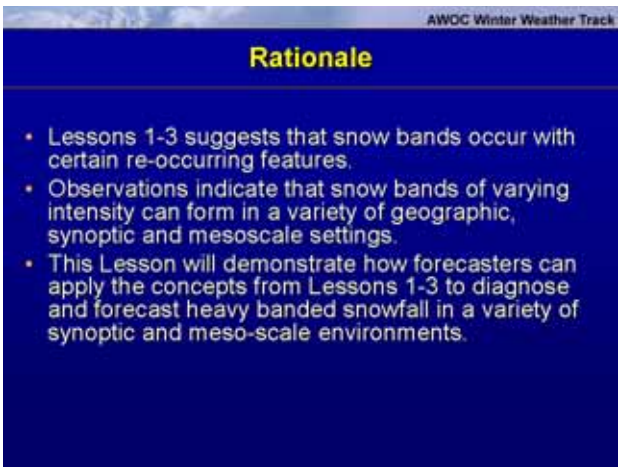
Student Notes:



6. Rationale

Instructor Notes: The theory described in Lessons 1-3 suggests that snow bands occur with certain re-occurring features – namely significant large-scale forcing, frontogenesis and reduced or negative stability to slantwise motion in a near saturated environment. However, observations indicated that snowbands of varying intensity can form in a variety of synoptic- and mesoscale settings. This lesson will demonstrate how forecasters can apply the concepts from Lessons 1-3 to diagnose and forecast heavy banded snowfall in a variety of synoptic- and mesoscale environments.

Student Notes:



7. Review Conceptual Models

Instructor Notes: To start, lets briefly review some conceptual models. The images on this slide are based on collaborative research between the NWS and SUNY Albany. The first image on the slide shows a plan view map of a synoptic pattern that typically is associated with heavy snow and banding. Key features are a closed circulation at 500 mb with its associated mid-tropospheric zone of deformation and frontogenesis. The surface low is located just east of the closed circulation, and a dry slot is shown sweeping over the south edge of the cyclone from the southwest. Banding, as indicated by black, dashed lines is shown to the north and northwest of the cyclone, within the midlevel deformation zone. The second image shows a cross-section taken from southeast to northwest across the cyclone shown in the first image. A steeply sloping, southeast to northwest frontal zone is indicated by the red shaded frontogenesis. Upward vertical motion is indicated by the thick, black arrow, on the warm side of the frontogenesis. Equivalent potential temperature is shown by the thin black contours. Note that these contours are packed close together in the frontal zone. Meanwhile, southeast of the frontal zone they are nearly vertical, indicating potential instability to slantwise vertical displacements. Banding would be expected underneath the area where the strongest upward motion is co-located with this potential symmetric instability zone.

Student Notes:

8. Christmas 2002 Storm – Satellite Imagery

Instructor Notes: The first example shown in this lesson is the Christmas day, 2002 storm that brought heavy snow to much of the northeast United States. The satellite imagery on this slide shows how a disorganized cloud pattern at 12 UTC on the 25th evolved into a classic comma-shaped pattern by 00 UTC on the 26th as the surface cyclone deepened rapidly off of the New Jersey coastline.

Student Notes:

9. The Christmas Day 2002 Storm – Basic Maps

Instructor Notes: This slide shows some forecast data from the NAM model run at 12 UTC on the 25th. The first and second images show a 500 mb closed low forecast to develop over New Jersey. The 3rd and 4th images show the associated surface low forecast to deepen rapidly south of Long Island – down to 982 mb. Subsequent observations indicated that the surface low would actually deepen to below 980 mb by 00 UTC on the 26th.

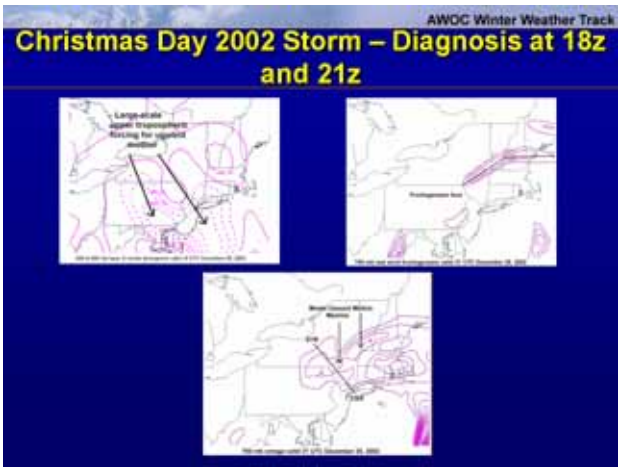
Student Notes:

10. Christmas Day 2002 Storm – Diagnosis at 18z and 21z

Instructor Notes: The relationship between the large-scale forcing, frontal scale forcing and model forecast upward vertical motion for this event is summarized by the NAM forecast data on this slide. The data at the upper left is a 6-hour forecast of 500 to 500 mb layer divergence of Q, displayed on an 80 km grid, and valid at 18 UTC on the 25th. This was the time when intense banding was just starting to develop over eastern and central

New York state. A maximum of convergence is shown extending from Pennsylvania to New Jersey. This indicates where the large-scale forcing associated with the middle to upper-tropospheric wave was being maximized. The slide on the upper right shows a 40 km 21z analysis of 700 mb real-wind frontogenesis extending from New England toward northeast Pennsylvania. This can be considered an indication of the mid-tropospheric frontal scale forcing for upward motion. A 40 km resolution NAM analysis of upward vertical motion, which is a function of all of the forcings, at all scales that the model is able to resolve, is shown at the bottom of the slide. The maximum of upward vertical motion is indicated over western New England and southeast New York, and appears to correlate more closely with the frontogenesis than with the upper-level large-scale forcing. The next slide will show cross-sectional forecast data along the line shown in the figure at the bottom, from Laguardia, NY (LGA) to Syracuse, NY (SYR).

Student Notes:

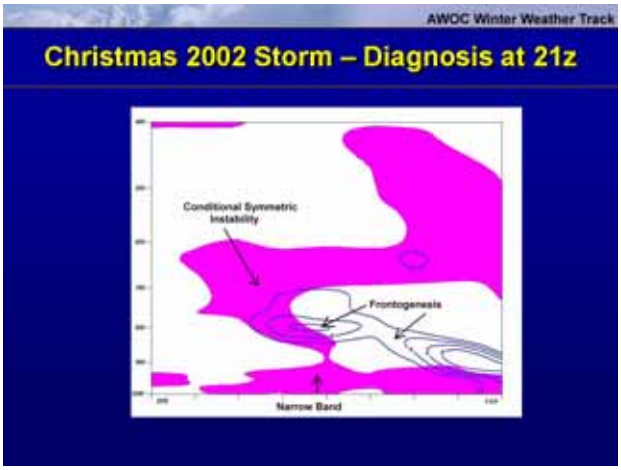


11. Christmas 2002 Storm – Diagnosis at 21z

Instructor Notes: The relationship between the upward vertical motion and mid-tropospheric real-wind frontogenesis is shown by the first image on this slide. The data is an NAM analysis of frontogenesis and model vertical motion, taken along a cross-section from LGA to SYR and valid at 21 UTC on the 25th. Note that the maximum of upward vertical motion is located above and just to the southeast of the maximum of mid-tropospheric frontogenesis. These data indicates that a strong, thermally direct circulation was forecast to develop in association with the frontogenesis, with upward motion on the warm side of the frontogenesis, and sinking motion on the cold side. Note also that the upward vertical motion shown on this slide is deep, extending upward through 400 mb. This indicates significant coupling between the upward motion associated with the lower to midlevel front, and the upward motion associated with the upper-level support. The next image shows the real-wind frontogenesis, contoured in blue, along the same LGA-SYR cross-section, along with negative EPV shaded purple. The EPV was calculated using the geostrophic wind and saturated equivalent potential temperature. Relative humidity (not shown) throughout this area was forecast to be greater than 80 percent. Note the large area of negative EPV located above the frontogenesis, in the area where the upward motion, shown on in the previous image, was maximized. The data on this

slide indicate a favorable condition for conditional symmetric instability, which would be favorable for the development of intense snow bands. The heavy snow band at 21z, marked by the arrow on this image, was located directly beneath the area where the strong upward motion, strong midlevel frontogenesis and negative EPV were all co-located.

Student Notes:



12. Christmas 2002 Storm – Radar Images

Instructor Notes: The radar loop from the KENX WSR-88D shown on this slide shows that narrow, heavy snow bands did develop within a large area of light to moderate snow over central and eastern New York. Snowfall rates within the heaviest of these bands ranged from 3 to 5 inches per hour.

Student Notes:

13. Christmas 2002 Storm - Total Snowfall

Instructor Notes: This image (courtesy of the Northeast Regional Climate Center) shows that a large area of heavy snow fell across the northeast U.S. on the 25th. The

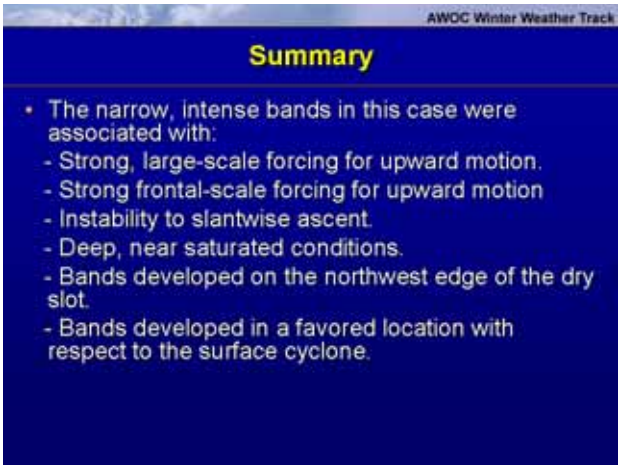
heaviest snow, in excess of 24 inches, fell in association with the narrow, intense bands shown on the previous slide.

Student Notes:

14. Summary

Instructor Notes: The narrow, intense bands in this case were associated with strong large-scale forcing for upward motion and strong frontal scale forcing for upward motion. Coupling between these two forcing mechanisms resulted in a deep plume of upward vertical motion over central and eastern New York. Instability to slantwise motions was indicated by negative EPV, and deep saturation was associated with the deep plume of upward vertical motion. The favorable co-location between strong forcing for upward motion and midlevel instability occurred at the northwest quadrant of the cyclone, near the northwest edge of the dry slot of the storm.

Student Notes:

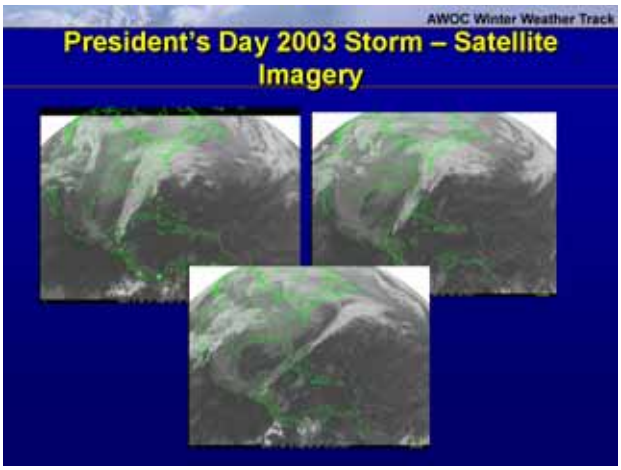


15. President's Day 2003 Storm – Satellite Imagery

Instructor Notes: Our next example will be the President's Day 2003 snowstorm. The President's Day 2003 storm was another major snowstorm for the northeast and mid-

Atlantic states. This series of satellite images shows an elongated north-south cloud band, associated with the warm conveyor belt of the storm, moving east off the east coast. Meanwhile, the head of the developing comma cloud can be seen organizing over the mid-Atlantic and northeastern states.

Student Notes:



16. President's Day Storm – Basic Maps

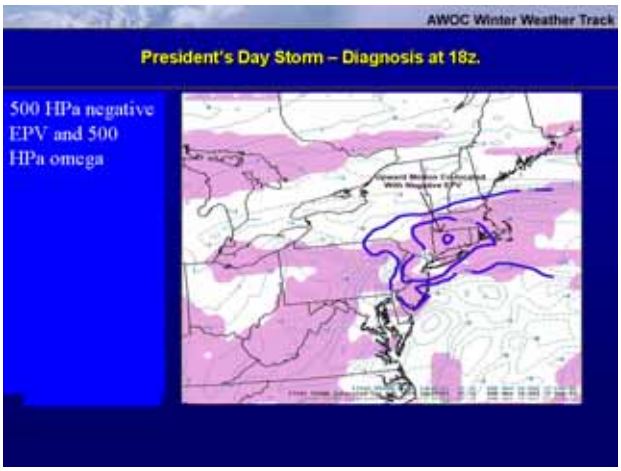
Instructor Notes: The data on the next few slides are forecasts from the NAM model run at 12 UTC on February 17, 2003. This first two slides show a closed low at 500 mb over the eastern Ohio Valley, while the next two images show a surface low forecast to move slowly northeast along the eastern seaboard. Unlike the Christmas Day storm, neither the 500 mb or the surface low was forecast to deepen much during this period, with the surface low pressure center forecast to deepen from 1009 mb to 1007 mb between 12 UTC on the 17th and 00 UTC on the 18th. A strong high pressure system northeast of New England was resulting in a strong easterly pressure gradient over New England.

Student Notes:

17. President's Day Storm – Diagnosis at 18Z.

Instructor Notes: The images on this slide show the large-scale and frontal-scale forcing for upward vertical motion in this case, valid at 18 UTC on the 17th. The first image shows the 500 to 300 mb Q vector divergence valid at 18 UTC on the 17th and displayed on an 80 km grid. A large, oval-shaped maxima can be seen over the northern mid-Atlantic area, just downstream from the deep upper trough over the Ohio Valley. The next 3 images are shown to illustrate smaller, frontal-scale forcings for this event, and are displayed on a 40 km grid. The second image shows that viewing frontogenesis on a 40 km can be a bit noisy. However, an elongated maxima of 600 mb frontogenesis can be seen, extending from New England west toward eastern New York, indicating the potential for strong frontal-scale forcing for upward motion near or just to the south of that area. As was the case with the Christmas storm, the close proximity between the large-scale forcing associated with the upper wave and forcing associated with the lower-tropospheric front indicated the potential for coupling between the two forcings, and a deep plume of upward vertical motion. The third image shows the model forecast upward vertical motion, maximizing just south of the mid-tropospheric frontogenesis, over southern New England westward toward southern New York. Finally, the fourth image shows the co-location between the elongated maximum of 600 mb upward motion (contoured in blue), and an area of negative 500-400 mb EPV (calculated using the geostrophic wind and saturated equivalent potential temperature and shaded purple) over southern New England. The presence of deep saturation over southern New England (not shown), in combination with the factors outlined previously, indicated the potential for intense snow banding over southern New England at 18 UTC on the 17th.

Student Notes:



18. President's Day 2003 Storm (Loop)

Instructor Notes: The data on this slide show a loop of WSR-88D reflectivity from 16 UTC through 21 UTC on the 17th. We'll stop the loop at 18z to point out a few key features. There appears to be a broad band of moderate to heavy snow covering the entire area from southern New England to western New York. Note also that there appears to

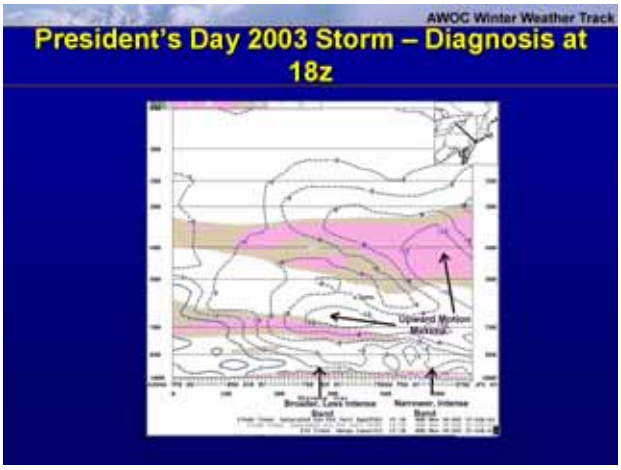
be a more narrow, intense band embedded within the broader band, over southern New England. The precipitation over southern New England at this time was all snow, therefore the strong returns indicated on these images were probably not associated with brightbanding.

Student Notes:

19. President's Day 2003 Storm – Diagnosis at 18z

Instructor Notes: The data on this slide are shown to try to understand the character of the banding observed in the radar imagery in the last slide. The first image is a NAM 40 km analysis of real-wind frontogenesis, taken along a southeast-northwest cross-section from south of Long Island to near Lake Ontario. Two maxima can be seen, one representing the midlevel front over south central New York, and one representing the low-level front near New York City. The next image shows the upward vertical motion maxima associated with the frontogenesis. Note the deep plume of upward vertical motion, indicating coupling between the upper-tropospheric forcing and forcing associated with the lower-tropospheric front. The final image shows the upward vertical motion overlayed with negative EPV (shaded pink) and weakly positive EPV (shaded light brown). The key point here is that the area where the narrow, intense banding was observed was characterized by co-location of a deep layer of negative EPV and a large area of strong upward motion, while the area where the band was broad and only moderately intense was characterized by a smaller area of strong, upward motion and only a narrow layer of negative EPV. In this case, one could conclude that reduced stability narrowed and intensified the frontal circulation throughout the area from New England to New York state, leading to an enhanced upward branch of the circulation across the area from southern New England to southern New York. The result was a broad band of moderate to heavy snow located across that entire area. Slant-wise instability may have been released in the area of co-location between deep negative EPV and deep, strong upward vertical motion, over southern New England, which led to a further narrowing and intensification of the band in that area.

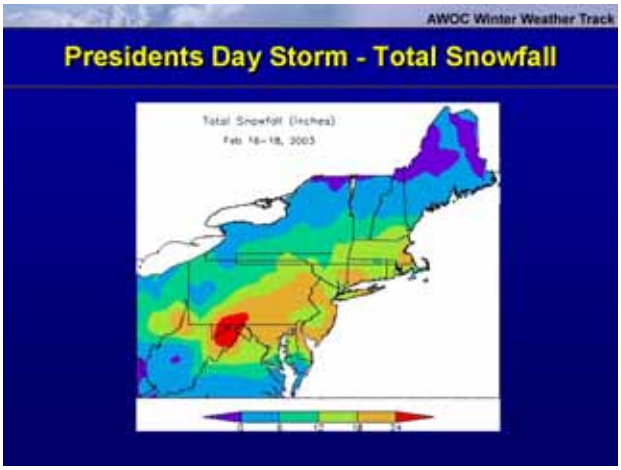
Student Notes:



20. Presidents Day Storm - Total Snowfall

Instructor Notes: This image of total snowfall (courtesy of Northeast Climate Data Center), shows that snowfall totals of 18 to 24 inches were observed within the intense bands over southern New England. Meanwhile, totals of around 12 inches were common farther to the west, underneath the broader, less intense band.

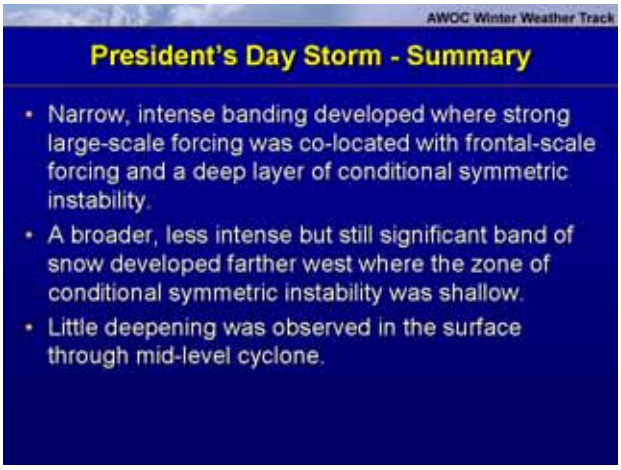
Student Notes:



21. President's Day Storm - Summary

Instructor Notes:

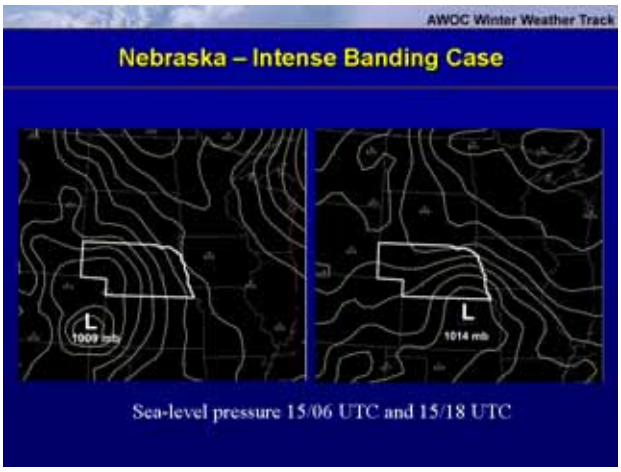
Student Notes:



22. Nebraska – Intense Banding Case

Instructor Notes: The next example in this lesson shows data from another event that produced significant bands of heavy snow, despite a lack of strong surface cyclogenesis. The sea-level pressure maps shown on this slide are from March 15, 2004. Low pressure developed to the lee of the central Rockies by 06 UTC on the 15th, then moved northeast to south central Nebraska by 18 UTC. No deepening was occurring during this time.

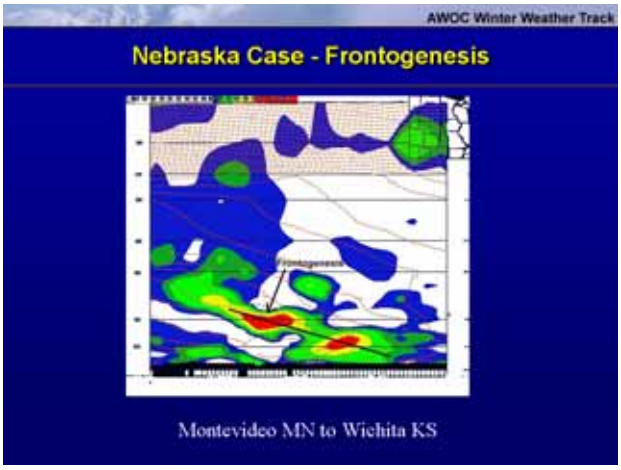
Student Notes:



23. Nebraska Case - Frontogenesis

Instructor Notes: This cross-section shows the sloping front associated with this system, located from Kansas at low levels north to eastern South Dakota at midlevels. A maxima of midlevel frontogenesis is indicated at around 700 mb across eastern Nebraska.

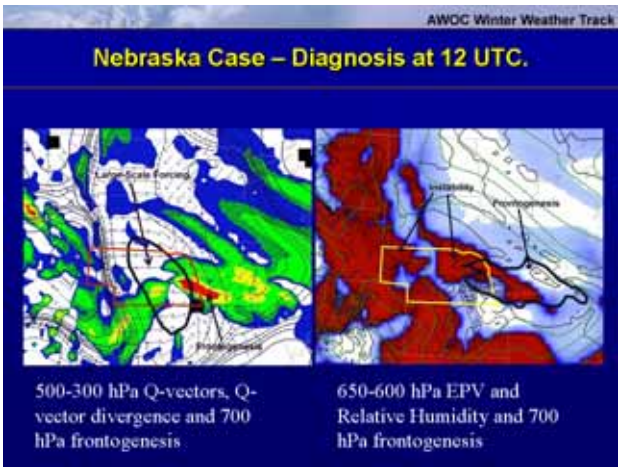
Student Notes:



24. Nebraska Case – Diagnosis at 12 UTC

Instructor Notes: The data on this slide shows how the large-scale and frontal-scale forcing were co-located with instability in this event. The image on the left shows large-scale forcing associated with the upper wave, as shown by the black-contoured 500-300 mb Q-vector divergence, centered over Nebraska at 12 UTC. Meanwhile, the midlevel frontal-scale forcing, as indicated by the yellow to red-shaded 700 mb frontogenesis, was located along an east-west axis from Iowa to Nebraska. The image on the right shows the instability, as indicated by red-shaded negative 650-600 mb EPV, co-located with the black-contoured frontogenesis maxima over Iowa and Nebraska.

Student Notes:



25. Nebraska Case – NAM QPF

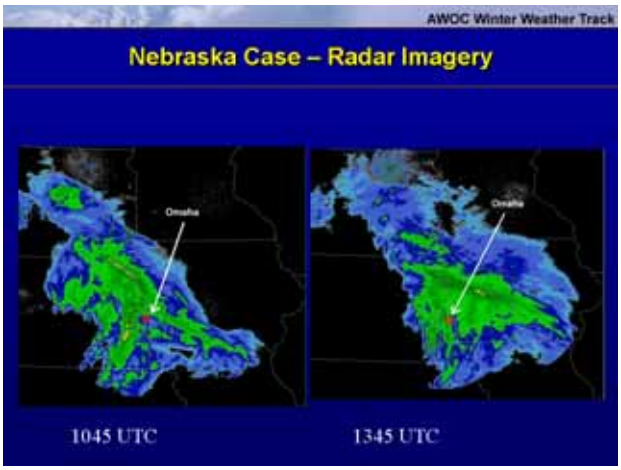
Instructor Notes: The NAM 27-hour QPF was indicating a narrow band of heavy precipitation stretching from southern Iowa to eastern Nebraska for this event. This forecast implied a heavy snow event centered over Omaha.

Student Notes:

26. Nebraska Case – Radar Imagery

Instructor Notes: Radar data around the time of the diagnostics shown in the previous slides show that bands of heavy snow did develop over eastern Nebraska and western Iowa.

Student Notes:



27. Nebraska Case – Observed Snowfall

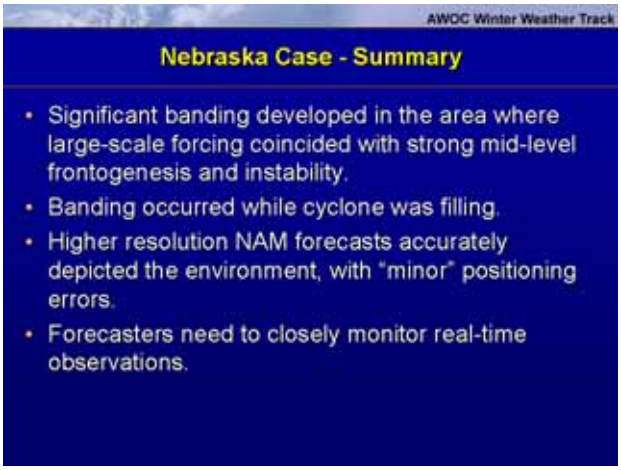
Instructor Notes: This slide shows that the observed heavy snowfall with this case did fall in roughly the same location as was indicated by the NAM. However, the devil was in the details. Note that the heavy snow actually fell just to the north of Omaha, into extreme southeast South Dakota and eastward to western Iowa. So, one could conclude from this case that while the NAM model was giving the forecaster important clues on the potential for a band of heavy snow, forecasters would still need to closely monitor observational clues in order to pinpoint the actual location of the heavy snow.

Student Notes:

28. Nebraska Case - Summary

Instructor Notes: Here is a summary of the Nebraska case.

Student Notes:



29. Choices

Instructor Notes: Take a few moments to complete this question.

Student Notes:

30. Snowbands with Moderate Accumulations - Upstate New York

Instructor Notes: For our next case – March 1st – 2nd, 2005 - we return to upstate New York. The first image shows a 6-hour NAM forecast of 500 mb heights and sea-level pressure forecast valid at 00 UTC on the 2nd. These data shows that upstate New York was in an area of north to northwest cyclonic flow on the backside of a major cyclone located over New England. The next image shows that the strongest upper-level large-scale forcing for upward motion, as indicated by the 500 to 300 mb Q-vector convergence, was located over the Canadian Maritimes, with weaker upper-level forcing indicated over upstate New York. This type of large-scale setup is typically associated with a large area of light snow or snow showers across upstate New York, and may be associated with significant lake effect snow under certain conditions. The next image shows a surface plot over New York and Pennsylvania at 00 UTC on March 2nd. An east-west surface trough is indicated over southern New York, embedded within the northwest flow. Strong convergence is evident along the surface trough between Elmira (ELM) and Ithaca (ITH). Moderate to heavy snow was developing along and ahead of the trough at this time.

Student Notes:

31. Upstate New York

Instructor Notes: The series of images on this slide shows the NAM forecast development of low-level frontogenesis associated with this surface trough as it moved south across upstate New York. At 18 UTC, the frontogenesis was not significant. By 21 UTC, a strengthening area of frontogenesis is indicated below 850 mb. An area of negative geostrophic EPV is also indicated below 850 mb. The bottom image shows a strong maxima of frontogenesis, confined to the area below 850 mb, and co-located with an area of negative EPV. Ageostrophic vertical circulation vectors are included to illustrated the shallow nature of the circulation (confined mainly below 700 mb). High relative

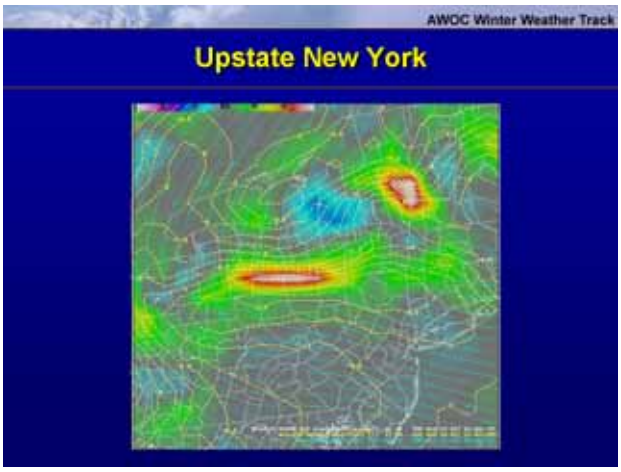
humidity values, not shown on these figures, were also confined to a shallow, surface-based layer.

Student Notes:

32. Upstate New York

Instructor Notes: This slide shows a plan view of 900 mb frontogenesis and temperature valid at 00 UTC on March 2nd. The frontal-scale forcing is clearly evident. Note the strong 900 mb temperature gradient, depicted by the yellow contours, associated with the frontogenesis. The frontogenesis was completely confined to the layer below 850 mb. This case illustrates the importance of not restricting your search for frontogenesis to the usual middle tropospheric levels.

Student Notes:



33. Upstate New York (Loop)

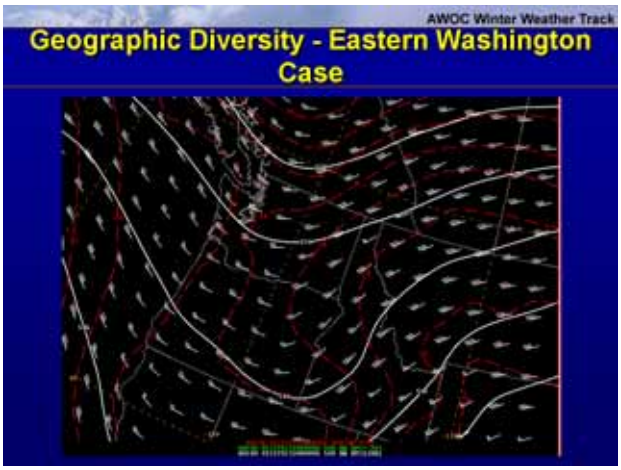
Instructor Notes: This loop shows the development of the associated snowband. The band produced snowfall rates of 1 to 2 inches per hour over the southern tier of New York and northern Pennsylvania. The area defined by the white contour picked up a quick 5 inches of snow in about 5 hours during the evening on March 1st.

Student Notes:

34. Geographic Diversity - Eastern Washington Case

Instructor Notes: While the majority of published case studies of these banding-type events are from the northeast or mid-west, these types of events can occur in other places. For the sake of some geographic diversity, we next take a quick look at a case that occurred over eastern Washington state. This first slide shows a 500 mb trough moving east across the area. Note that there is no midlevel closed circulation associated with this system, just an open wave.

Student Notes:



35. Eastern Washington

Instructor Notes: This next slide shows that a significant band of snow, with snowfall rates of an inch per hour, developed over eastern Washington with this system. The red contoured field is 700 mb frontogenesis. So, as was the case with our other events, the banding developed on the southeast side of the midlevel frontogenesis.

Student Notes:

36. Eastern Washington

Instructor Notes: This slide shows a RUC model forecast sounding at Spokane Washington, valid at the time when banding was occurring across the area. Note the deep layer of saturation and near moist adiabatic lapse rates indicated on the sounding. To briefly summarize this case then: once again banding developed in an area where large-scale and frontal-scale forcing became co-located with saturation and reduced stability.

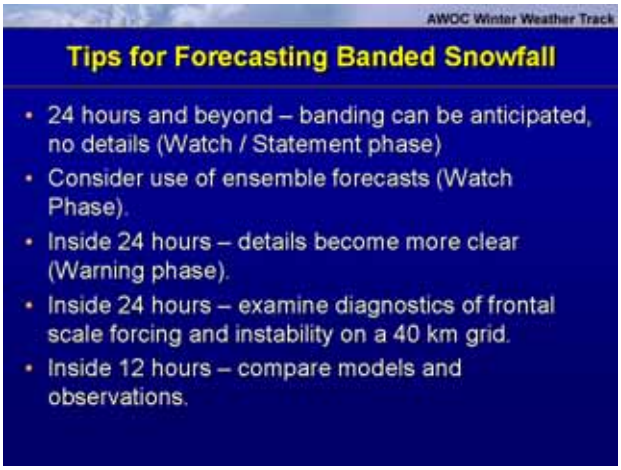
Student Notes:

37. Tips for Forecasting Banded Snowfall

Instructor Notes: So, now let's summarize how we can apply all of this material in a real-time forecasting environment. When you are looking at a potential event that is expected to occur at 24 hours or beyond, you need to be looking primarily at fields that the models do best with at those time scales. That means mostly forecasts of large-scale flow patterns. For example, the potential for major banding events can become apparent at times beyond 24 hours when the models are forecasting that your area of interest will be in the northwest quadrant of a deepening surface cyclone, with diffluent mid-tropospheric flow and associated mid-tropospheric deformation. However, 24 hours or more is

still too early to have much confidence in the details of the placement of the band. This is the time when statements or watches could be issued for large portions of your area. At these extended time periods, forecasters should also consider the use of short range ensemble forecasts. For example, spaghetti and probability charts can be used to help forecasters gauge the uncertainty of the flow evolution, and find areas where favorable conditions for banding are most likely. Inside 24 hours, the details of the potential banding scenario become more certain. By this time, the forecaster should have a situational awareness that banding is likely somewhere in the area – now is the time to try to pinpoint the location and intensity of the bands and to issue warnings. Examination of model forecasts of frontal-scale forcing and instability becomes critical during this period, as the models begin to hone in on the location and intensity of these signatures. Examining these types of diagnostics on a 40 km grid is recommended – a larger grid spacing may "wash-out" some critical signatures, while a smaller grid can sometimes be too noisy. Inside 12 hours, as well as during the event, integration of the model forecasts with observations becomes the main challenge. During this time, model forecasts can be adjusted based on how well the diagnostics and model QPF forecasts are matching the observations.

Student Notes:

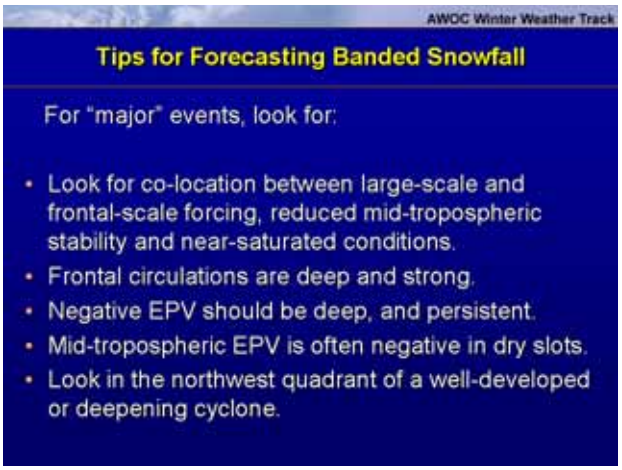


38. Tips for Forecasting Banded Snowfall

Instructor Notes: The information on this slide summarizes some of the characteristics of model forecast diagnostics that you are likely to see prior to and during a "major event", or an event that features intense bands with snowfall rates in excess of an inch per hour, and snowfall totals of greater than 6 inches. For these events, look for co-location between strong mid- to upper-tropospheric large-scale forcing and lower to mid-tropospheric frontogenesis, reduced or negative stability to slantwise displacements, as indicated by EPV, and near saturated conditions. The frontal circulations, or plumes of upward vertical motion, associated with these major events tend to be deep and intense. Likewise, the forecast areas of negative EPV are also usually deep and persistent. For example, some local research here at BGM and SUNY Albany indicates that 40-km grid forecasts of negative EPV for major events are usually at least 50 mb deep and usually persist for at least 3 hours. Keep in mind that EPV is often negative in dry slots, where

moisture decreases with height. Obviously, the dry slot is not a favored location for heavy, banded precipitation. The most common location for heavy snow bands will be at the northwest edge of the dry slot, in the northwest quadrant of the surface to midlevel cyclone.

Student Notes:



39. Tips for Forecasting Banded Snow

Instructor Notes: For "moderate" events, or events that feature snow bands with accumulation rates of an inch per hour or less, and total snow accumulations of less than half a foot, the large-scale forcing may not necessarily be as strong as with "major" events, and may not be as well co-located with the lower-to mid-tropospheric frontal-scale forcing. As a result, the frontal circulations associated with these systems may not as deep as in "major" events. Likewise, research at SUNY Albany and BGM indicates that, while negative EPV is commonly forecast with these types of systems, it is usually not as deep or persistent as in stronger systems. These types of events can still be quite disruptive, especially if they are not forecast with adequate lead times.

Student Notes:

40. Choices

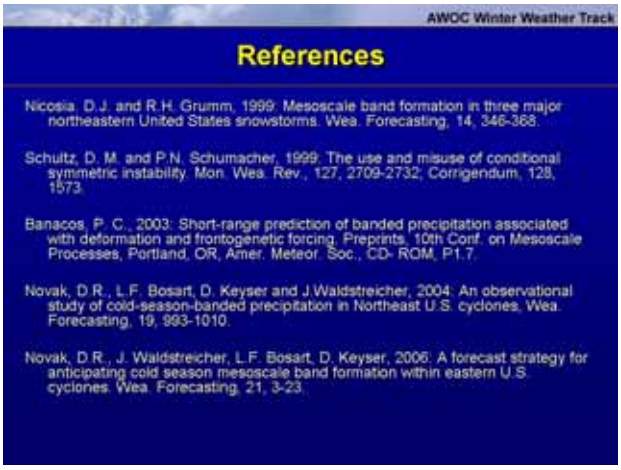
Instructor Notes: Take a few moments to complete this interactive quiz.

Student Notes:

41. References

Instructor Notes: Here are a list of the references cited during this lesson.

Student Notes:



IC5.4: Optional Job Sheet

Examples of Frontal Precipitation Bands

Objective: To apply the diagnostics shown in the IC 5 Lesson 4 training module to a winter weather event.

Data: 24 November 2004 winter storm event in the Midwest. You will be using your WES machine in case review mode.

Instructions:
On your WES machine, load the 24 November 2004 case, ILX localization, and set the clock to 24 November 2004, 01:00 UTC. You will be looking at the 12 hr forecast from the 00Z 24 Nov 2004 run of the NAM 80 across Illinois valid **12Z 24 Nov 2004**.
On the regional scale, load a plan view of NAM 80 400-500mb layer Q vector divergence and Q vectors.
Where is the Q-vector convergence strongest at the 12 hr forecast valid 12 UTC on 24 November?

Step forward 6 hrs to the 18 UTC forecast. At this time where is the upper level forcing strongest?

Load a plan view of NAM 80 700, 850 mb 2-D frontogenesis and 700, 850 mb omega. Where is the low to mid level forcing due to frontogenesis strongest at the forecast valid at 12 UTC? How about the forecast 18 UTC on 24 November?

Is the low- to mid-level forcing collocated with the upper tropospheric forcing at 12 UTC and/or 18 UTC? (Circle the appropriate one(s))
12 UTC 24 November Forecast: **YES/NO**
18 UTC 24 November Forecast: **YES/NO**

Take a cross section perpendicular to the maximum in frontogenesis across Illinois and examine the forecast valid at 18 UTC on 24 Nov 2004. Load NAM 80 omega, 2-D frontogenesis, RH, and saturated geostrophic equivalent potential vorticity.

Do you expect any convection across Illinois, either via conditional instability or slantwise instability?

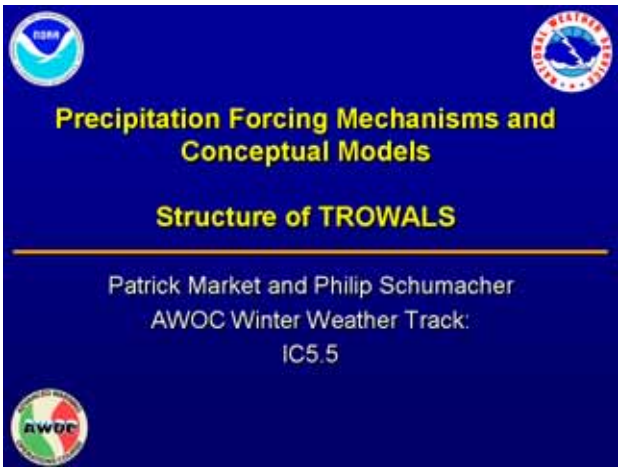
Describe all the different forcing mechanisms that may be in play to result in the > 20 µb/sec rising motion over central Illinois.

An answer key is available for this job sheet. Please see your local AWOC Winter Weather facilitator to obtain a copy.

1. IC5.5: Structure of TROWALS

Instructor Notes: Authors: Dr. Patrick S. Market, Department of Soil, Environmental and Atmospheric Sciences, University of Missouri-Columbia; and Philip N. Schumacher, National Weather Service, Sioux Falls, South Dakota. This presentation should last approximately 25 minutes.

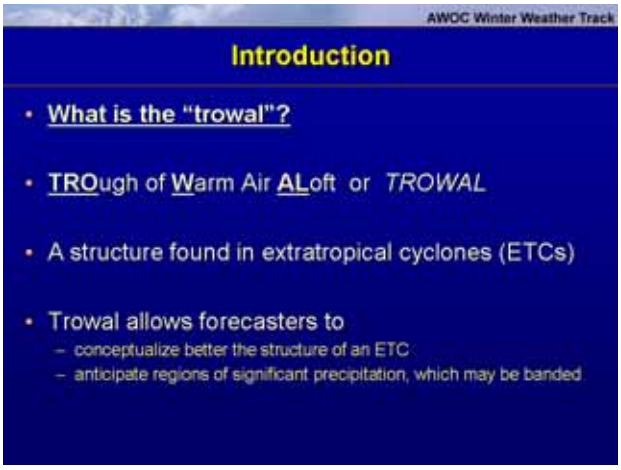
Student Notes:



2. Introduction

Instructor Notes: In this lesson, we will examine the cyclone structure known as the trowal, which is a kind of acronym for “trough of warm air aloft.” The concept of the trowal has been a part of the parlance of operational meteorology for nearly 60 years. Use of the trowal concept is intended to highlight to meteorologists where it is in an extratropical cyclone that precipitation, perhaps banded, may occur over the cold surface air north and west of a cyclone center. When present, an occluded front at the surface is not always the focus of precipitation, low ceilings, and other inclement weather. Also, a trowal-like feature sometimes appears before the surface cyclone may be analyzed as occluded. In either instance, it is often the region of the trowal where significant weather and precipitation occur.

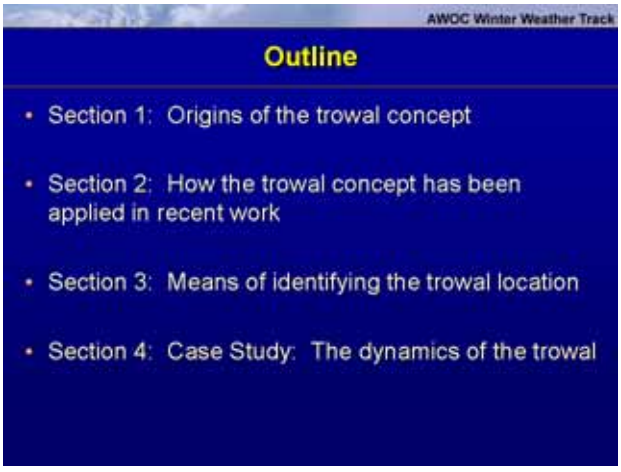
Student Notes:



3. Outline

Instructor Notes: This lesson is broken into four primary components: First, we will examine briefly the origin of the trowal concept in the late 1940s. Next, we will look at Martin's American revival of the phrase in the late 1990s along with the work of some other investigators from about that same time. Third, we will examine different methods for analyzing for and locating the trowal. Finally, we will go about the process of identifying the trowal in an actual case and then looking deeper at the processes that shape and maintain it.

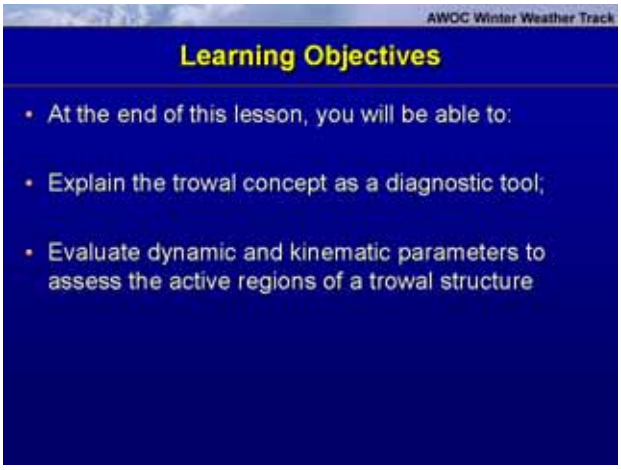
Student Notes:



4. Learning Objectives

Instructor Notes: At the end of this lesson, you will be able to: Explain the trowal concept as a diagnostic tool, evaluate dynamic and kinematic parameters to assess the active regions of a trowal structure, and these learning objectives will be assessed on the final exam (taken on the LMS) for each lesson.

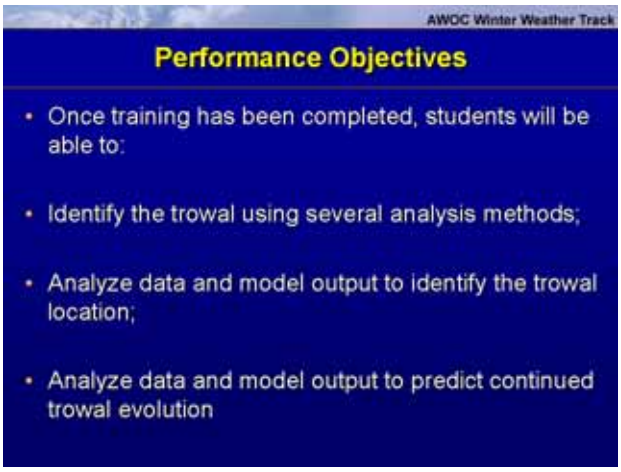
Student Notes:



5. Performance Objectives

Instructor Notes: Once training has been completed, students will be able to: Identify the trowal using several analysis methods, analyze data and model output to identify the trowal location, and analyze data and model output to predict continued trowal evolution. Performance objectives will be evaluated for each student after training is completed, in simulations and on-the-job.

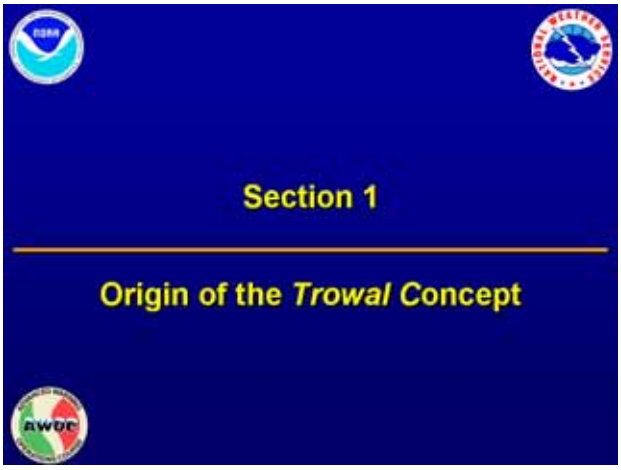
Student Notes:



6. Section 1

Instructor Notes: Now let's start Section 1: Origin of the Trowal Concept.

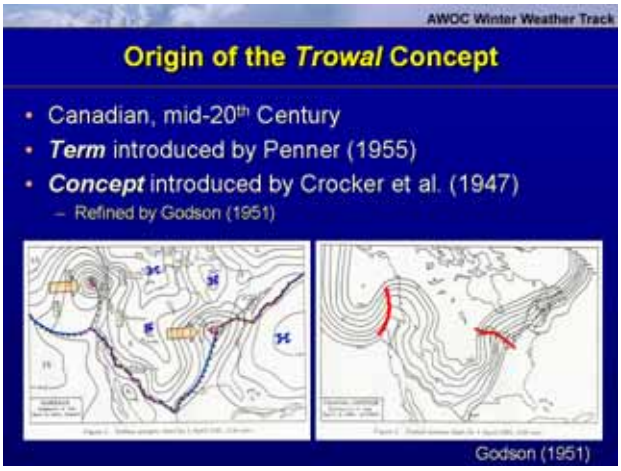
Student Notes:



7. Origin of the Trowal Concept

Instructor Notes: The trowal concept originated in Canada, and the earliest known reference to the feature comes from the paper by Crocker et al. (1947). Throughout each of the referenced studies, the authors were seeking explanations for precipitation and other inclement weather that occurred in the cold air north of a surface cyclone, but away from the analyzed surface occluded front (as often happens). Of the figures shown, the left one is a surface analysis, while the one on the right is a “frontal contour chart.” The latter was meant to depict the location of a front at each successive height in the atmosphere. Simply put, each contour represents the location of the frontal zone on each pressure level. In this instance, the analyst identified a baroclinic zone with vertical integrity through a deep layer (1000-300 mb) spanning an area of several thousand kilometers. The West Coast surface occluded front (left) is accompanied by a trowal axis in red (right). This feature marks the farthest poleward extent of the warm sector air at each higher level. Notice a similar, but less pronounced feature with the pre-occlusion surface low over Lake Huron.

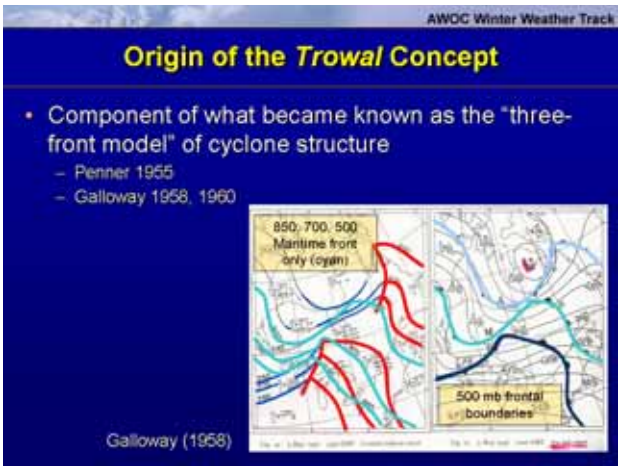
Student Notes:



8. Origin of the Trowal Concept

Instructor Notes: As alluded to previously, finding the trowal was an exercise in first analyzing frontal topography at multiple levels. Sparse data and significant labor in creating such charts likely called the process into question in an age of an improving dynamic understanding of the atmosphere (e.g., the operational emergence of QG theory) and advancing NWP techniques.

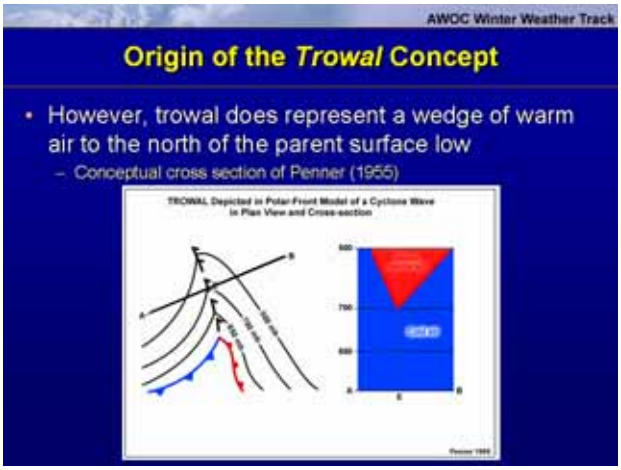
Student Notes:



9. Origin of the Trowal Concept

Instructor Notes: Although the three front approach is cumbersome to use, one artifact remains useful: the trowal. The existence of the warm conveyor belt in an extratropical cyclone ensures the existence of warm air aloft, above much cooler surface air. The sloping axis of that warm sector air is the trowal. The graphic on the screen was captured from a Jim Moore webcast for COMET, based on a presentation by Market (2002).

Student Notes:



10. Interactive Quiz #1

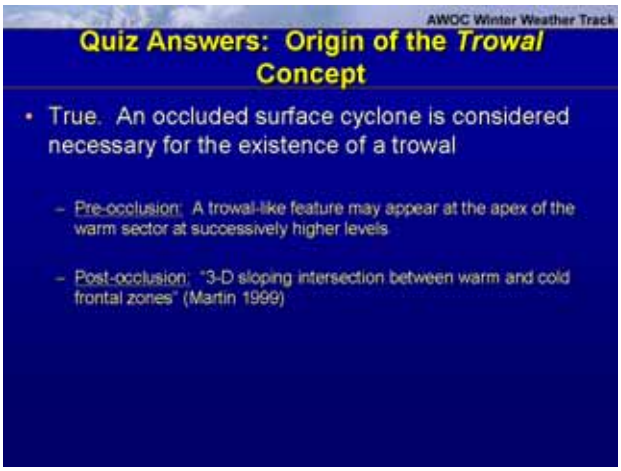
Instructor Notes: Take a few moments to complete the quiz on trowal concepts.

Student Notes:

11. Quiz Answers: Origin of the Trowal Concept

Instructor Notes: This slide explains the correct answer to the first question in interactive quiz #1.

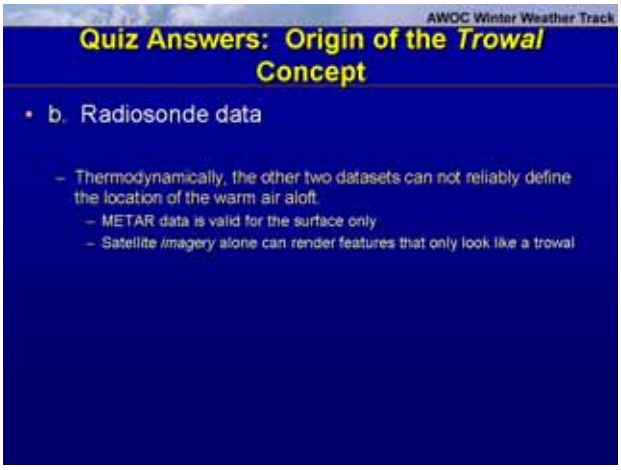
Student Notes:



12. Quiz Answers: Origin of the Trowal Concept

Instructor Notes: This slide explains the answers to the second question in interactive quiz #1.

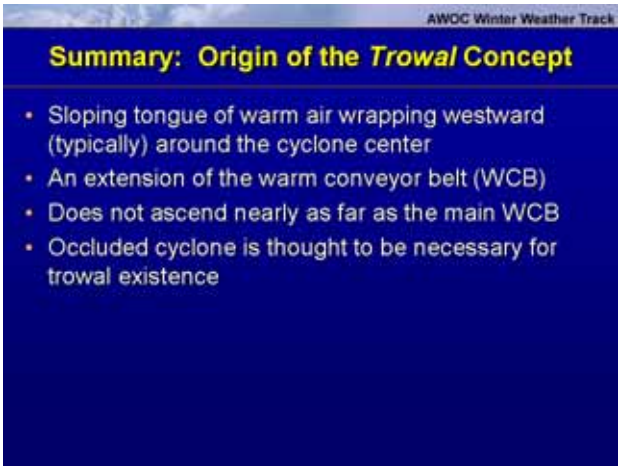
Student Notes:



13. Summary: Origin of the Trowal Concept

Instructor Notes: An excellent VISITView session is available on trowal identification. Although the historical literature suggests that an occluded surface cyclone is necessary for the existence of the trowal (and thus its airstream), recent research has called that view into question.

Student Notes:



14. Summary: Origin of the Trowal Concept

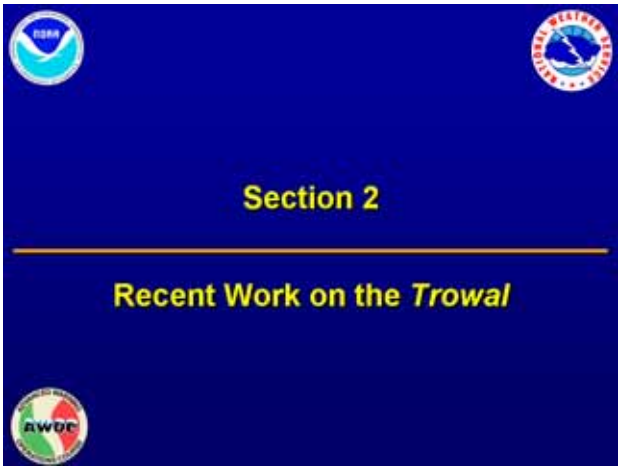
Instructor Notes: Here is a screen shot from one of Jim Moore's COMET webcasts showing the bifurcation in the WCB of a surface cyclone that has not yet occluded. Further work by his group (Moore et al., 2005) has shown similar structures in other weak or non-developing cyclones.

Student Notes:

15. Section 2

Instructor Notes: Now let's look at Section 2: Recent Work on the Trowal.

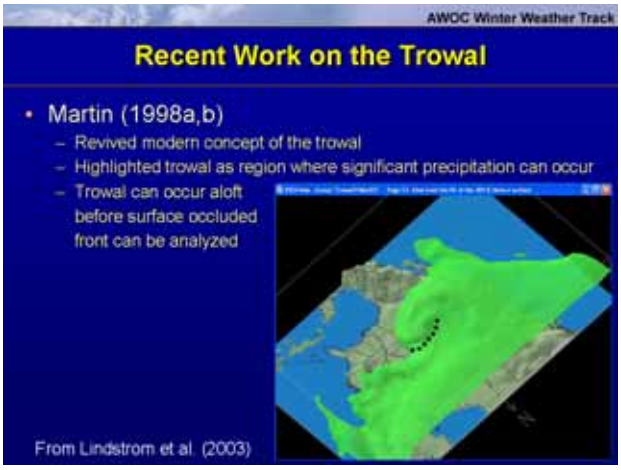
Student Notes:



16. Recent Work on the Trowal

Instructor Notes: Martin's work was the first in recent years to deal directly with the trowal, and its direct influence on banded heavy snowfall. Martin suggested a top-down process for occlusion in this case, wherein the occlusion process occurs aloft before an occluded front can be analyzed at the surface.

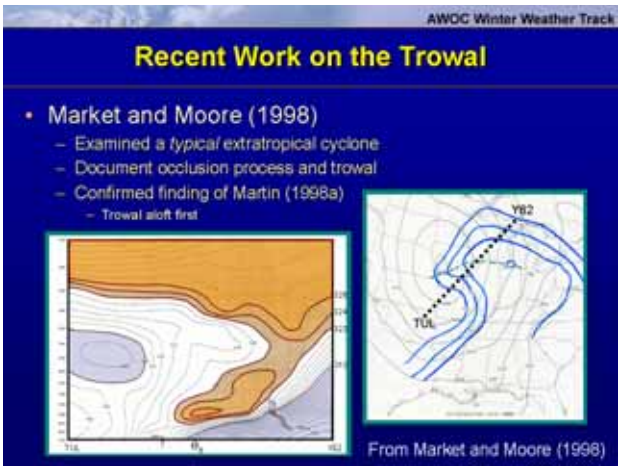
Student Notes:



17. Recent Work on the Trowal

Instructor Notes: The cyclone of Market and Moore generally followed the Norwegian Cyclone Model evolution, with the cyclone occluding first near the surface and thne farther aloft with time (i.e., from the bottom up). The goal was to document the occlusion process in a typical mid-latitude extratropical cyclone. However, a trowal-like feature was present aloft well before a surface occluded front could be analyzed. This feature exhibited cloud and precipitation development.

Student Notes:

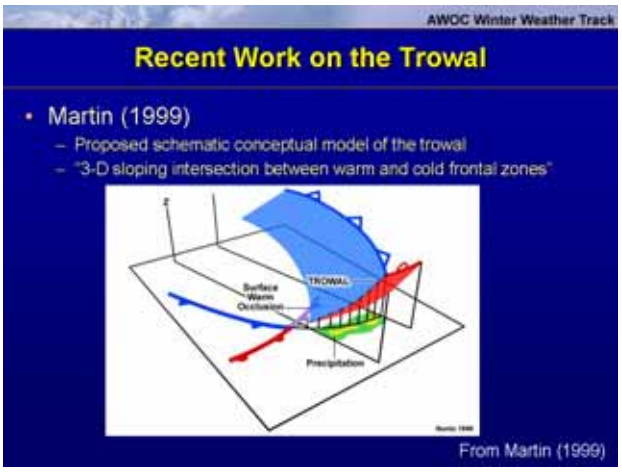


18. Recent Work on the Trowal

Instructor Notes: The seminal work of Martin (1999) detailed for the first time the 3-D structure of the trowal, and its dominant influence over precipitation generation in the region. The model shown here helps forecasters to conceptualize the sloping nature of the trowal, and its strong correlation to the band of precipitation experienced at the surface. Moreover, it highlights the absence of organized precipitation at the surface occluded front as is often the case. Although not unlike the original intent of the Canadian three-front model, Martin's model is a generalized approach which assumes no

elongated frontal boundary with integrity through a deep layer. Instead, this model focuses on the airstream associated with the trowal and its inevitable development within deep extratropical cyclones.

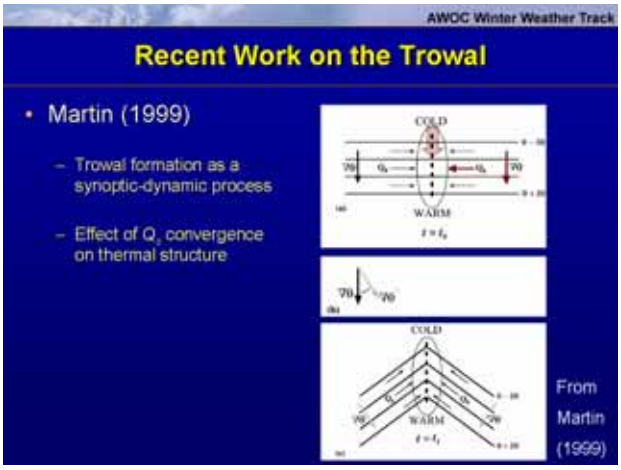
Student Notes:



19. Recent Work on the Trowal

Instructor Notes: Not content to simply conceptualize the trowal structure, Martin sought to explain its evolution. Using the Q-vector and its natural-coordinate, along-stream component, Q_S, Martin set about the task of quantifying the creation of the thermal ridge that is the trowal's signature. We begin with a typical zonal, thermal (potential temperature) gradient with cold air on the poleward side, and the warm air toward the equator (a). The thermal gradient thus points equatorward everywhere on this diagram. Superimposed upon this thermal gradient is a field of Q_S which point toward a common axis in the center of the thermal field. Such an arrangement is common in a young frontal cyclone, where geostrophic motions still dominate the flow. Martin states the following: "The Q vectors located to the left (right) of the Q_S convergence maximum…describe the geostrophic contribution to counterclockwise (clockwise) rotation of the [thermal gradient] vector with time." A known behavior of the Q_S component is its tendency to rotate counterclockwise when cold air exists initially on its left, and a clockwise turn when cold air is on its right. Consequently, the potential temperature gradient vectors rotate toward one another (b). This behavior forces the development of a thermal ridge where the convergence of the Q_S components is maximized (c).

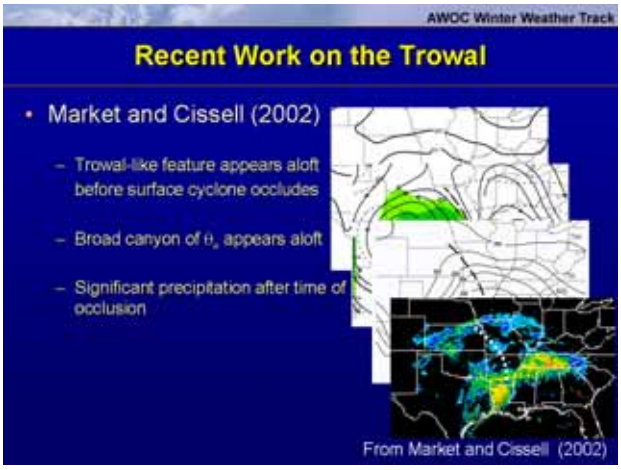
Student Notes:



20. Recent Work on the Trowal

Instructor Notes: Market and Cissell used the trowal concept to help define the axis of greatest precipitation using methods similar to those of Martin. What is of interest in this discussion is the trowal-like feature that emerges before there is evidence of an occluded system at either the surface or in the upper atmosphere. The surface analysis reveals an open wave cyclone with relatively weak centers of circulation near Lake Charles and Shreveport, Louisiana. The analysis of storm-relative winds on the 298K shows a split in the warm conveyor belt (which originates just to the east of the surface lows and follows roughly the Mississippi River), with the westward turning portion originating over Missouri. This airstream also happens to follow the pressure ridge, which in isentropic space, can be shown to be a thermal ridge also. Yet, the equivalent potential temperature gradient fails to show overlapping of surfaces as appeared in Martin's work. Meanwhile the axis of maximum theta-e lies along and just to the west of the pressure ridge depicted in the previous isentropic analysis of 298 K. Nevertheless, significant precipitation fails to appear along this axis at this time. Recall that the original trowal concept was aimed at explaining precipitation bands over cold surface air in a (preferably) occluded system. Although neither of these exist with this system at this time, signatures of what we would call the trowal in occluding cyclones do exist.

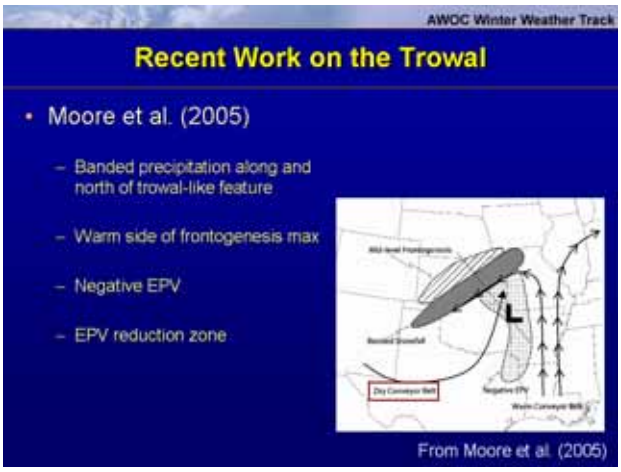
Student Notes:



21. Recent Work on the Trowal

Instructor Notes: Moore and his collaborators examined a weak cyclone that was associated with a band of heavy snowfall over Kansas. Not only was the surface cyclone not analyzed as occluded, but the trough aloft (e.g., 850, 500, 300 mb) was found progressively farther to the west and presenting a positive tilt. A similar cyclone was analyzed by Halcomb and Market (2003). While it is useful to have the trowal and the warm, moist flow that comes along with it, snow totals can be enhanced if the band becomes convective. In that regard, it is ideal for maximum snow totals to produce a layer above the trowal airstream that is potentially colder and/or drier. In this context, Moore et al. (2005) pay particular attention to the presence of the dry conveyor belt which acts to create the comma head of the extratropical cyclone while acting to create instability through Nicosia and Grumm's (1999) concept of EPV reduction.

Student Notes:



22. Section 3

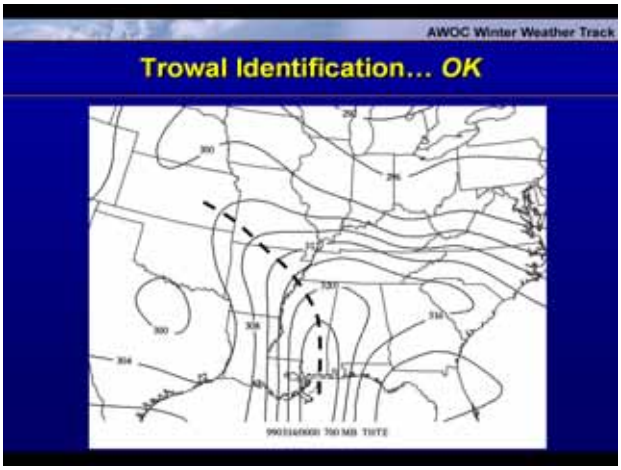
Instructor Notes: Now onto Section 3, which is titled Trowal Identification.

Student Notes:

23. Trowal Identification…OK

Instructor Notes: Equivalent potential temperature on a pressure surface can provide a good first look at the location of the trowal. Plot the equivalent potential temperature on a pressure surface, and assess its pattern. Theta-e is used as it represents parcels with relatively high temperature or humidity or both; more importantly, it is assumed to be largely conserved for both dry and moist processes. 850, 700, and 500 mb are typical levels, with 700 mb being, perhaps, the most common. However, the trowal is a 3-D feature, so confining our analysis to just one level is not the best idea. Moreover, parcels are not bound to pressure surfaces, which also have a much more shallow slope than many equivalent potential temperature surfaces. Even the slope of the dry potential temperature surface is much greater than that of a pressure surface (Moore, 1993).

Student Notes:

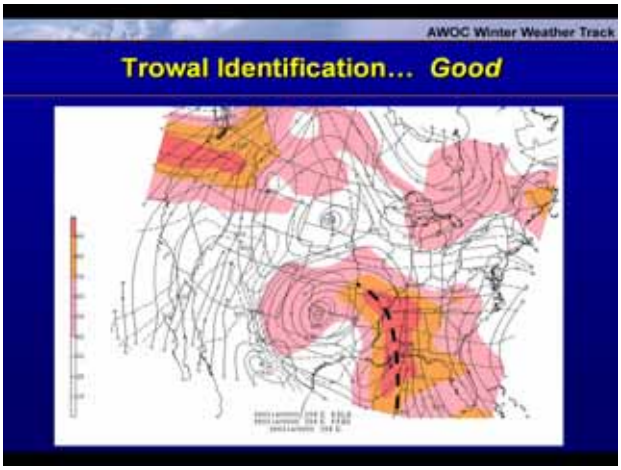


24. Trowal Identification… Good

Instructor Notes: Pressure and storm-relative winds on an isentropic surface. To a first approximation, parcels flow along surfaces of potential temperature. Additionally, surfaces of potential temperature are rarely multi-valued with height; in other words, they

seldom fold over on themselves at higher and higher levels. Thus we have at our disposal surfaces that define, on the synoptic scale, the motion of individual parcels. The following is extra material above what has been mentioned. Through Poisson's equations, we can show that a lower temperature corresponds to a lower pressure on an isentropic surface. Therefore, when we find a pressure ridge, we know that feature is also a thermal ridge with the highest pressures (temperatures) along the axis. Additionally, one may also plot the equivalent potential temperature on a potential temperature surface. The result is often a pattern that is quite similar to that of pressure, but of a parameter that is know to be conserved for moist and dry processes. Given that conveyor belts are system-relative entities, the creation of storm-relative winds is necessary to define any one of the airstreams that comprise an extratropical cyclone. One must first the calculate the storm motion (C), typically the motion of the absolute vorticity maximum over 6 to 12 hours on the surface that is to be examined. This value is then subtracted from the total wind in the observations or the model output as (V-C) in order to get the storm-relative winds. These winds will have their greatest relevance within the radius of the circulation under scrutiny. Moreover, one may think of the resulting streamlines as trajectories, provided the system is translating at a constant pace and in a steady state.

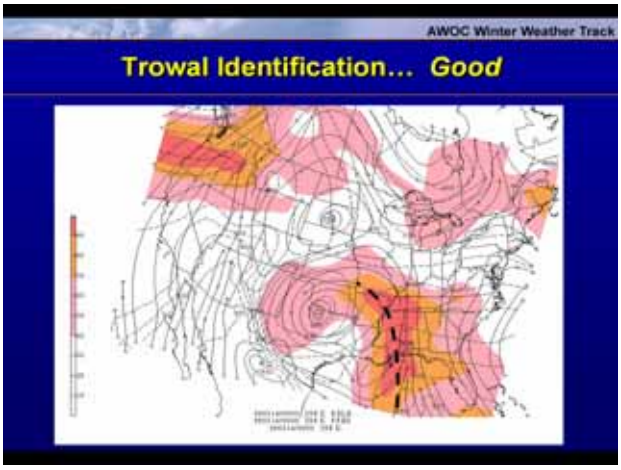
Student Notes:



25. Trowal Identification…Good

Instructor Notes: Pressure and storm-relative winds on an isentropic surface: while valid for synoptic analysis, the traditional isentropic approach begins to break down when applied at too fine a scale. In the instance of the trowal, a region often rich in moisture and ascent, parcels will certainly cease to be purely adiabatic. Consequently, we push the envelope again in order to account for diabatic (primarily latent) heating.

Student Notes:



26. Trowal Identification…Better

Instructor Notes: Topography of the equivalent potential temperature surface: The equivalent potential temperature is assumed to be conserved for unsaturated and pseudo-adiabatic processes. Consequently, their surfaces represent ones on which both dry and moist motions can occur and parcels are still accounted for. Such surfaces are built by plotting only one theta-e contour, say 300 K, at 900, 850, 800, 750, 700 mb, etc. In this instance, the interpretation is the same as it was for the plotting of theta-e on a single pressure surface: that the axis of theta-e ridge represents the axis of the trowal. However, we now use theta-e at multiple levels, and have thus developed a crude theta-e surface.

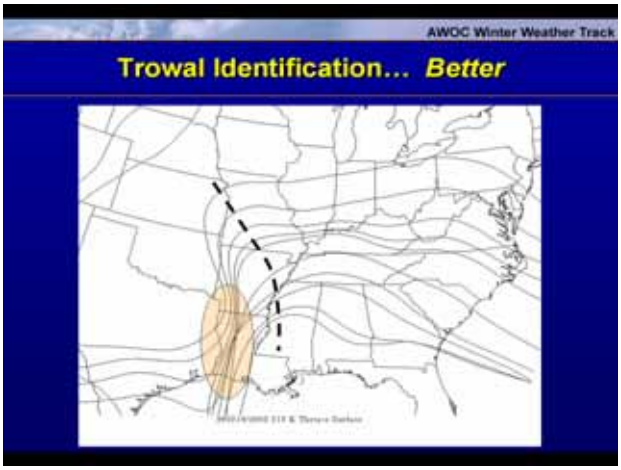
Student Notes:

27. Trowal Identification…Better

Instructor Notes: Once you have plotted the different theta-e contours at different levels, you can draw a line connecting the ridge axis between the different contours. This line will indicate the postion of the trowal. It is important to note that in regions where the contours from different pressure levels overlap are areas of potential instability. An exam-

ple of this occurs in the graphic shown over Louisiana where the all the contours are tangled together.

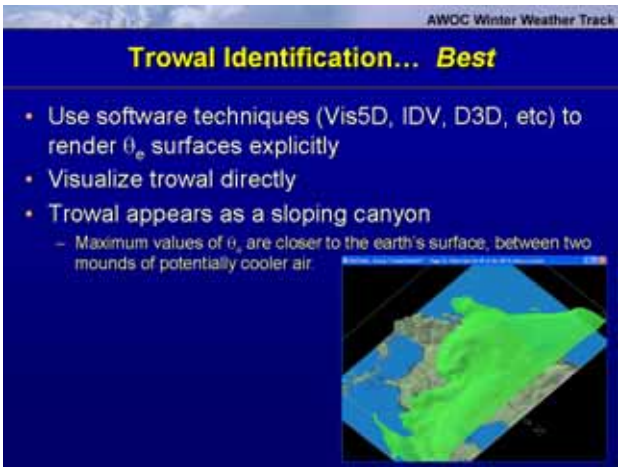
Student Notes:



28. Trowal Identification…Best

Instructor Notes: 3-D visualization of theta-e and trajectories is the best method for identifying the trowal. Expanding on the previous approach leads to the approach of Martin (1999) in visualizing the trowal location. Modern software packages now allow users to interrogate model output to create 3-D surfaces of many kinds. One of these is, of course, the equivalent potential temperature. Additionally, one may also use the model output of u, v, and w wind components to create 3-D trajectories of air parcels through a system as Martin (1999) did with Vis5D. In instances where the computing hardware and software exist to perform this kind of analysis, this may well be the ideal method to examine the trowal and its evolution.

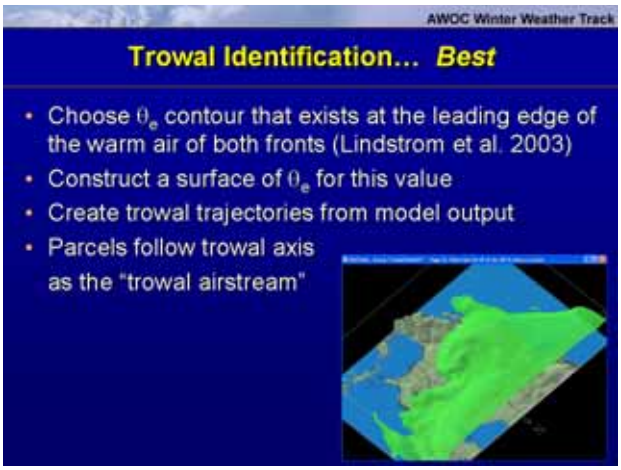
Student Notes:



29. Trowal Identification…Best

Instructor Notes: Further information on this specific approach may be found in the VISITView module on trowal identification.

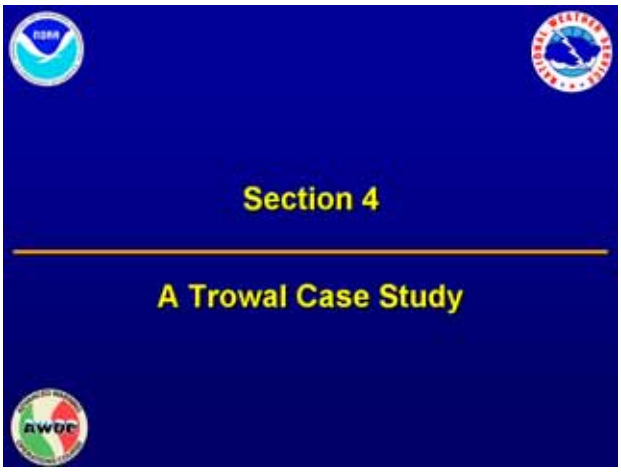
Student Notes:



30. Section 4

Instructor Notes: Now let's move onto Section 4, title A Trowal Cast Study.

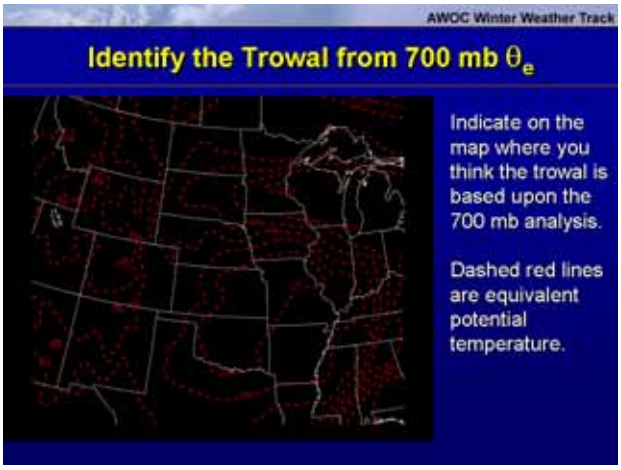
Student Notes:



31. Identify the Trowal from 700 mb θ_e

Instructor Notes: Here is a map of 700 mb theta-E given by the red dashed contours on 03 UTC on the 29th. On the map, indicate where you think the TROWAL would be located. The quiz responder coming in the next slide will allow you to answer this item.

Student Notes:



32. Interactive Quiz #2

Instructor Notes: Please take a moment to complete this interactive quiz question.

Student Notes:

33. The Trowal is Within the θ_e Ridge

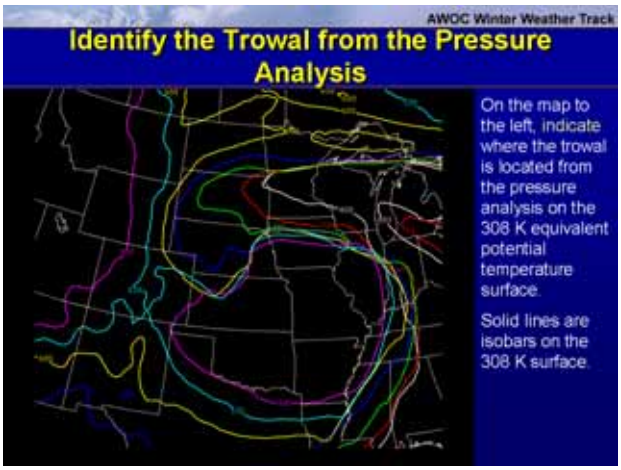
Instructor Notes: As shown earlier, a good first guess for the location of the trowal is the examine equivalent potential temperature on a pressure surface, typically 700 mb although any level from 850 mb to 500 mb would be acceptable. The presence of a thermal ridge indicates that a trowal may be present within the cyclone. In the above diagram the theta-e ridge extends from Wisconsin into western South Dakota.

Student Notes:

34. Identify the Trowal from the Pressure Analysis

Instructor Notes: Take a few moments to look at the analysis on the map shown. Use the contours shown to indicate the location of the trowal. Once you have completed this task, please move to the next slide.

Student Notes:



35. Interactive Quiz #3

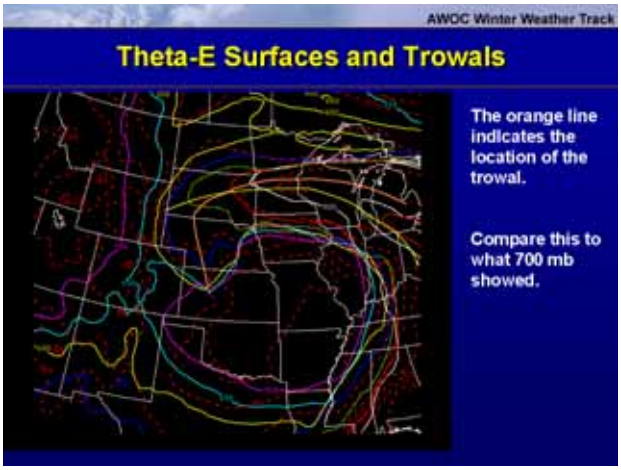
Instructor Notes: Take a moment to complete the interactive quiz on this slide.

Student Notes:

36. Theta-E Surfaces and Trowals

Instructor Notes: Based upon the pressure analysis, the trowal extends from Wisconsin into central South Dakota and then southwest into western Nebraska. The use of isobars on a equivalent potential temperature surface better illustrates the three-dimensional nature of the trowal and provides more insight into where the heaviest snow is likely to be located. When analyzing cyclones in order to determine whether a trowal is present, first use theta-E on a pressure surface as a first guess. If a thermal ridge exists, then examine a theta-E surface. In AWIPS, you can examine the 305, 310 and 315 theta-E surface and plot any variable such as pressure. One can also overlay streamlines and stability to see the flow of moisture and lower stability within the trowal airstream.

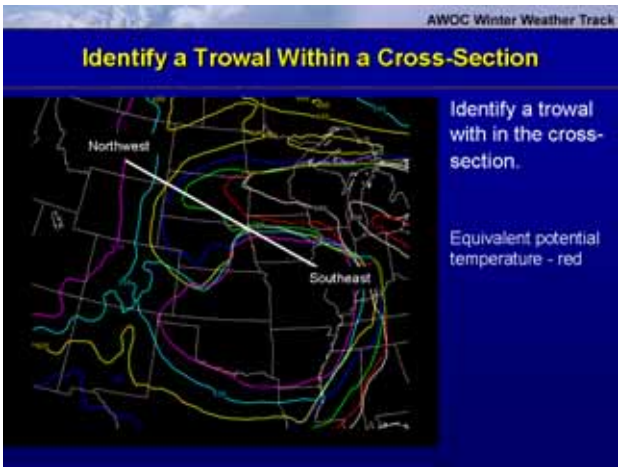
Student Notes:



37. Identify a Trowal Within a Cross-Section

Instructor Notes: We will now use a cross-section (whose endpoint locations are shown on the graphic) to identify the location of a trowal. In the cross-section, the red contours are constant values of equivalent potential temperature.

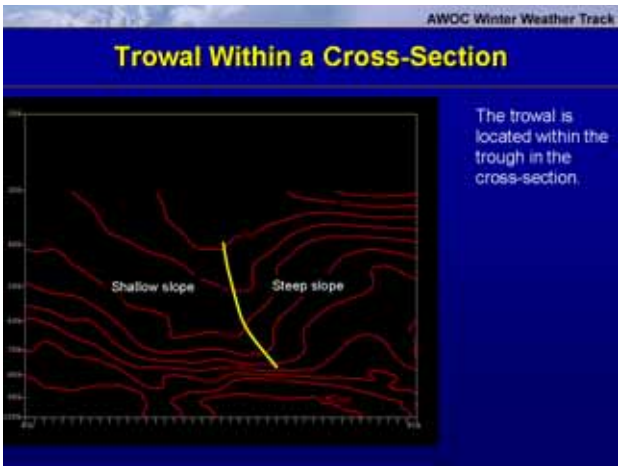
Student Notes:



38. Trowal Within a Cross-Section

Instructor Notes: The trowal is located within the trough in the cross-section. Unlike the case shown earlier, there is not a lot of cold air to the west (or left) of the trowal this makes the trough of warm air appear broader on the west side. On the other hand, much colder air is located to the east of the trowal which makes it easier to identify the eastern edge of the trowal.

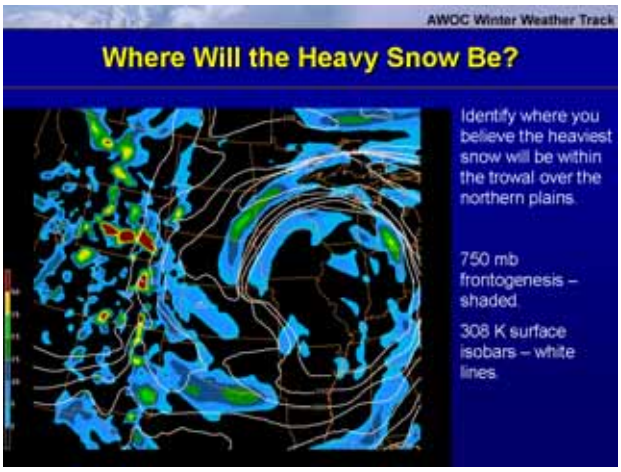
Student Notes:



39. Where Will the Heavy Snow Be?

Instructor Notes: Finally, let's determine where the heavy snow will be over the northern plains. After all, that is why we want to determine the location of the trowal. Use the frontogenesis (shaded contours) and 308 K surface isobars (white contours) to determine where heavy snow will occur.

Student Notes:



40. Interactive Quiz #4

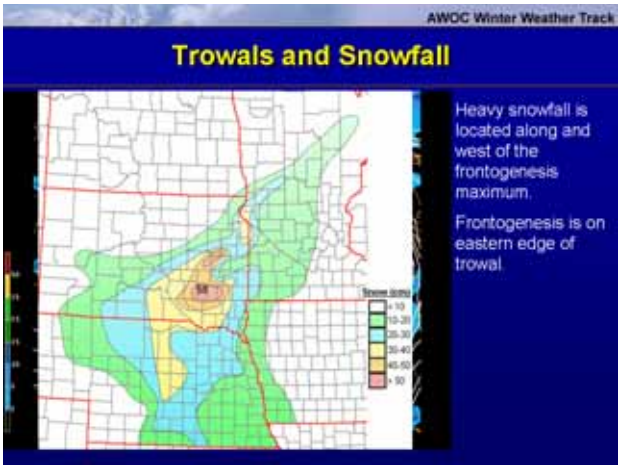
Instructor Notes: Take a moment to complete this interactive quiz on where the location of heavy snow will be.

Student Notes:

41. Trowals and Snowfall

Instructor Notes: Earlier in the talk, it was noted that the heavy snow is on the warm side of the frontogenesis. In most cases in the United States, this will be to the south and east of the maximum frontogenesis and toward the west side of the trowal. However, this case is rather unique. As we noted in the cross-section, the coldest air with the system was to the east of the trowal as one could see the theta-e lines had more vertical slope on the east side of the cross-section. When one looks at the frontogenesis at 750 mb and overlay isobars on the 308 K theta-E surface, the strongest frontogenesis is also along the eastern edge of the trowal. In addition, recall the warm and moist air is located in the trowal axis. This means that the warm side of the frontogenesis maximum is on the north and west side and not to the south and east. When you compare the snowfall map from the event, you can see the heaviest snowfall was coincident with the 750 mb frontogenesis and also closer to the eastern side of the trowal rather than the western side of the trowal.

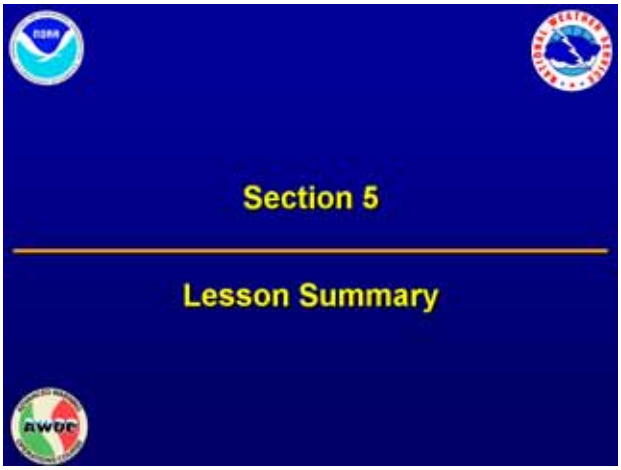
Student Notes:



42. Section 5: Lesson Summary

Instructor Notes: Let's proceed to Section 5: The Lesson Summary.

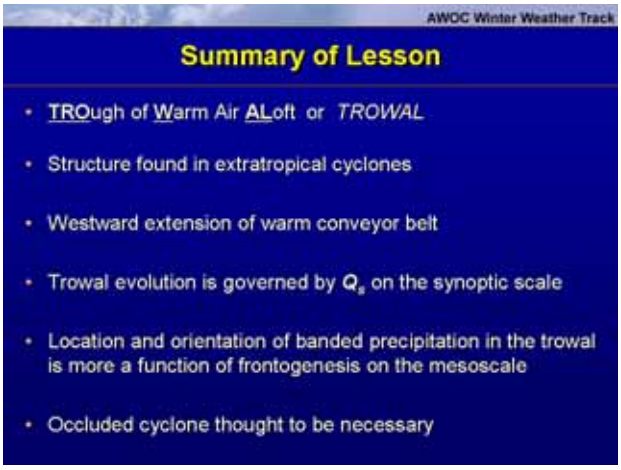
Student Notes:



43. Summary of Lesson

Instructor Notes: This slide provides a brief summary of the material that this lesson covered, including: what a trowal is, what recent research has been conducted on trowals, and what different methods are available to identify the location of a trowal (including which methods are better than others).

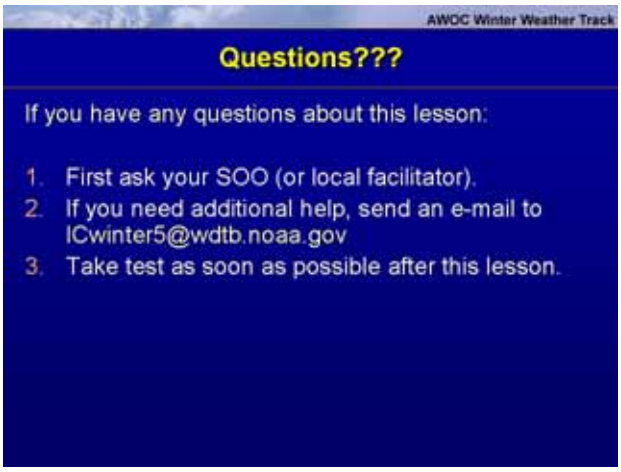
Student Notes:



44. Questions???

Instructor Notes: If you have any questions about this lesson, first ask your local AWOC facilitator. If you need additional help, send an E-mail to the address provided. When we answer, we will CC your local facilitator and may consider your question for our FAQ page. We strongly recommend that you take the exam as soon as possible after completing this lesson.

Student Notes:



IC5.5: Optional Job Sheet

The Structure of TROWALS

Objective: Examine a winter weather case, and using the knowledge gained from the IC 5 Lesson 5 training module, identify a TROWAL and predict its evolution.

Data: 1 March 2004 winter storm event in the High Plains. You will be using your WES machine in case review mode.

Instructions:

On your WES machine, load the 1 March 2004 case, GID localization, and set the clock to 07 UTC March 1, 2004. **You will be examining the NAM 80 06 UTC initialization**. On a plan view at the regional scale, load NAM 80 mslp, surface isotherms, and surface winds, then toggle between overlays of wind vectors and $_e$ at three pressure levels: 925mb, 850mb, and 700mb.
Where is the TROWAL located?

TROWAL Location:_____

Is there a surface occluded front? **YES/NO** (Circle one) If so, where is it located?

Swap panes and load a plan view at the regional scale of NAM 80 pressure on a 305K equivalent potential temperature surface, overlaid with winds and saturated equivalent geostrophic potential vorticity (MPV_g) from 700-500 mb.
Where is the trowel in this image?

TROWAL Location:_____

How are the placement and/or structure of the TROWAL different from what you saw with the constant pressure plot?

Where within the TROWAL is the strongest upward forcing signal, and qualitatively how strong is it?

Is there any instability present in the TROWAL? If so, where?

Cut a cross section through the TROWAL, roughly from E. Nebraska north-northwest into southwest Manitoba. Load NAM 80 $_e$ and 2-D frontogenesis.
Explain what the TROWAL looks like in the cross section. Mention if the $_e$ gradient is larger on one side or the other.

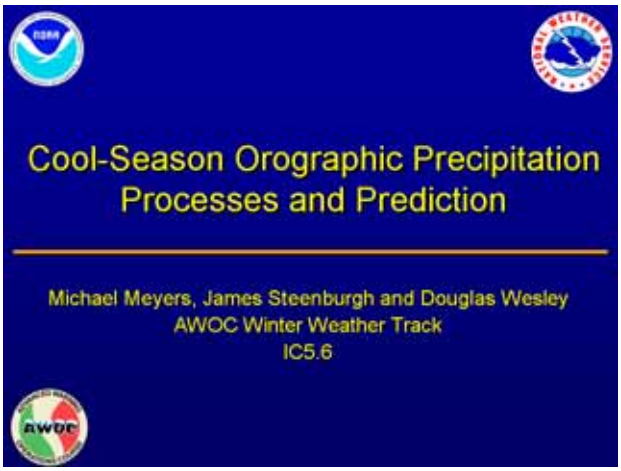
Finally, load a NAM 80 plan view on the regional scale of the 305 equivalent potential temperature surface map with pressure, overlaid with 925 and 850 mb Petterson frontogenesis.
Where would the heaviest snow fall? Explain your reasoning.

An answer key is available for this job sheet. Please see your local AWOC Winter Weather facilitator to obtain a copy.

1. IC5.6: Cool-Season Orographic Precipitation Processes and Prediction

Instructor Notes: Welcome to IC 5, Lesson 6: Cool-Season Orographic Precipitation Processes and Prediction. This lesson was developed by Michael Meyers, James Steenburgh, and Doug Wesley and should take approximately 45-50 minutes to complete.

Student Notes:



2. Lesson Objectives

Instructor Notes: After completing this lesson you will be able to: identify the primary orographic precipitation mechanisms, understand the relationship between the barrier width and the location of the precipitation maximum over a barrier, become familiar with the climatological variations of different mountain ranges in the western US, identify the general storm stage transitions for western US snowstorms, and explain the practical limitations to model accuracy over complex terrain.

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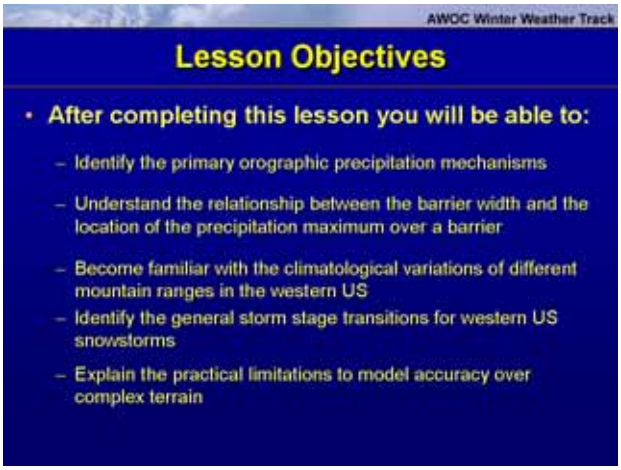

3. Performance objectives

Instructor Notes: By the end of this lesson, you should be able to: describe the major precipitation mechanisms in complex terrain; improve your knowledge of orographic precipitation processes and their geographical, climatological, and storm-to-storm variability for several North American Mountain ranges; and enhance your orographic precipitation forecasting skills based upon climatology, observations and numerical modeling associated with complex terrain.

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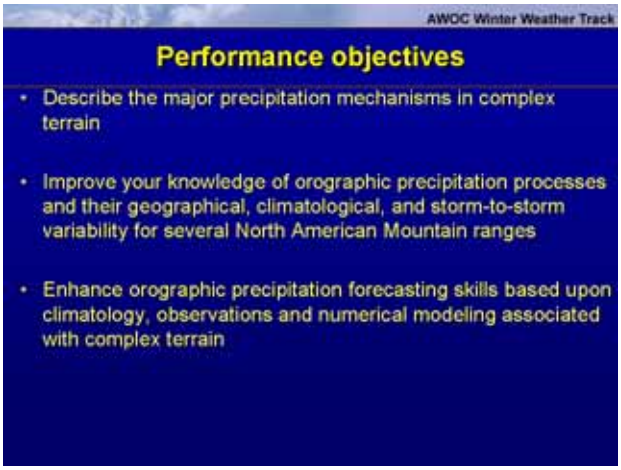

4. Outline

Instructor Notes: We are going to examine the main mechanisms in enhancing precipitation over complex terrain. Next the climatology of orographic precipitation processes in different regimes will be discussed. Finally, forecasting tools and techniques for orographic precipitation will be examined.

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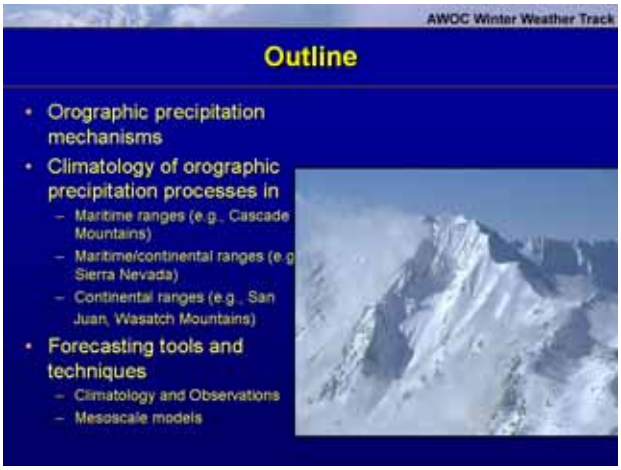


5. Part I: Orographic Precipitation Mechanisms

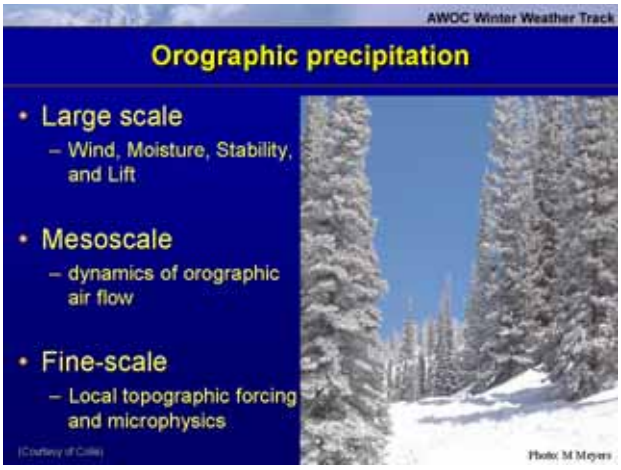
Instructor Notes: Here is a picture of a snow plow operator clearing an avalanche in the San Juan mountains of Colorado.

Student Notes:

6. Orographic Precipitation

Instructor Notes: Forcing of orographic precipitation occurs on the large scale (wind, moisture, stability, lift, the mesoscale-dynamics of orographic air flow) and on the fine scale (local topographic forcing and microphysics).

Student Notes:



7. Primary Orographic Precipitation Mechanisms

Instructor Notes: The primary orographic precipitation mechanisms which we will discuss are: stable upslope processes, the seeder-feeder, sub-cloud evaporation contrasts, precipitation transport on leeward side of barrier, upslope release of potential instability, terrain-driven convergence, cold air damming/barrier jet mechanisms, and precipitation

transport on the leeward side of the barrier. We usually find several of these processes occurring at one time. One topic which we will not discuss is terrain induced-thunderstorms initiation which can occur during all seasons.

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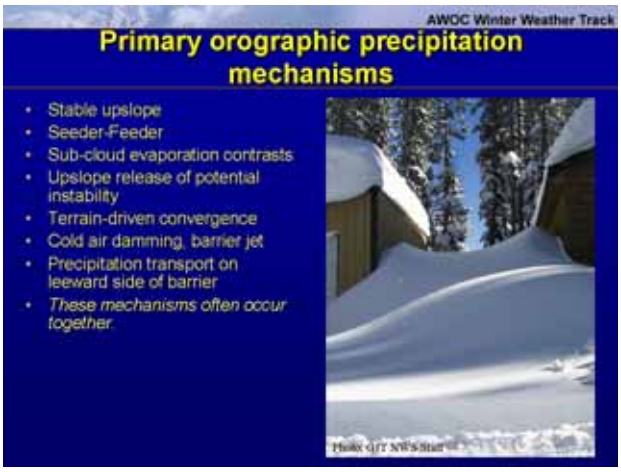

8. Stable Upslope

Instructor Notes: This process is a simple example of orographic precipitation. Here stable ascent is forced by flow over mountain. The parcel will adiabatically cool as it is forced over a mountain range. If the air is sufficiently moist through a deep enough layer, clouds and subsequently, precipitation occurs. Stable upslope flow is an inefficient process for orographic precipitation. In cases, where the layer of upslope ascent is shallow, or not sufficiently moist, non-precipitation clouds may develop.

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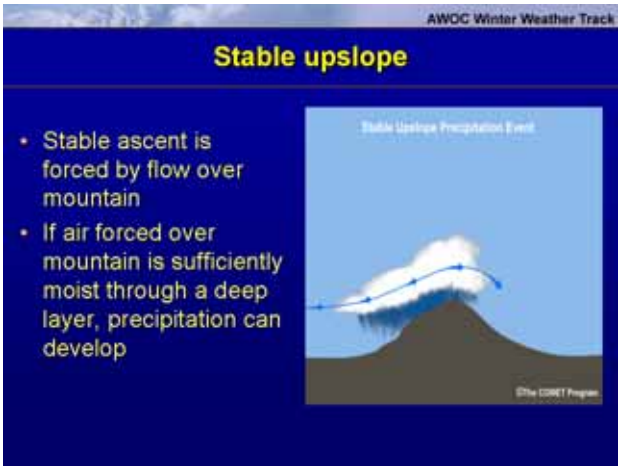

9. Stable Upslope

Instructor Notes: In very shallow upslope events, cold cloud processes may be absent, resulting in freezing drizzle (e.g. Front Range, Appalachians). Results from WISP field project over the Front Range of Colorado (Rasmussen et al. 1995) showed the neces-

sary ingredients for freezing drizzle: supercooled liquid water, low droplet concentrations (a few 10s per cc), spectral broadening of the cloud droplet distribution (including larger cloud droplets), and, finally, an absence of ice.

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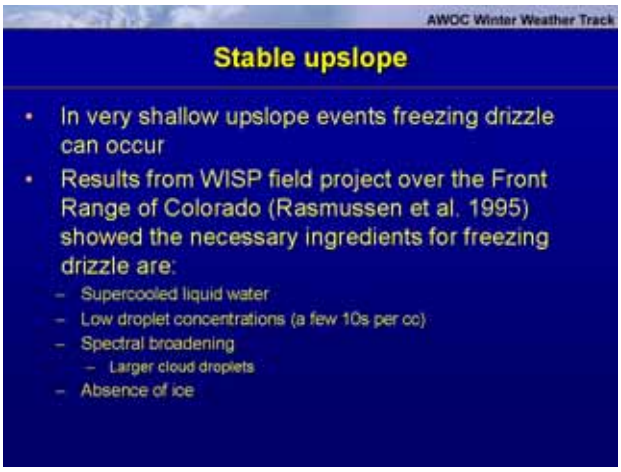

10. Barrier Width Implications

Instructor Notes: With wide barriers (but not so wide Coriolis effects become important), waves are hydrostatic (due to the large horizontal size) and propagate vertically. Wave crests are confined to the area over the terrain and trough/ridge lines slope upstream with height. This mountain wave can be an important source of upward motion in the cloud.

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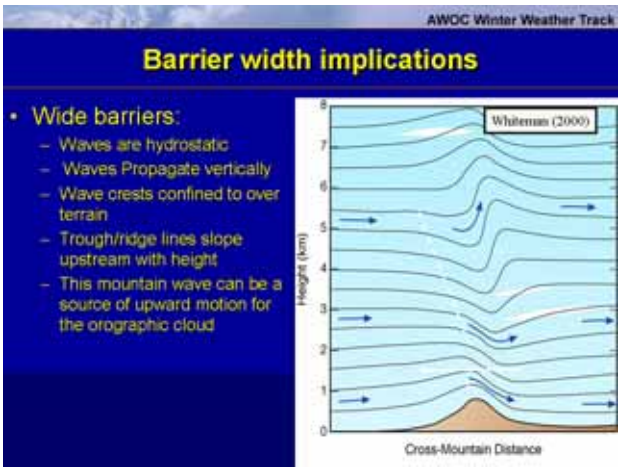

11. Barrier Width Implications

Instructor Notes: Wide barriers: Precipitation maximum is on the windward slope, due in part, to the upward motion resulting from the upstream-tilted mountain wave. A wide barrier allows hydrometeors more time to grow and precipitate over the windward side of the barrier. The effects of blocking and barrier jets can also shift the precipitation maxi-

mum over the windward side of the slopes. Narrower barriers: The precipitation maximum is usually near or along the barrier crest. For narrow barriers, the upstream bias for vertical velocity due to the upstream-tilted mountain wave is approximately offset by downstream bias of fallout location over the crest and to the lee due to the shorter residence time for hydrometeor growth aloft.

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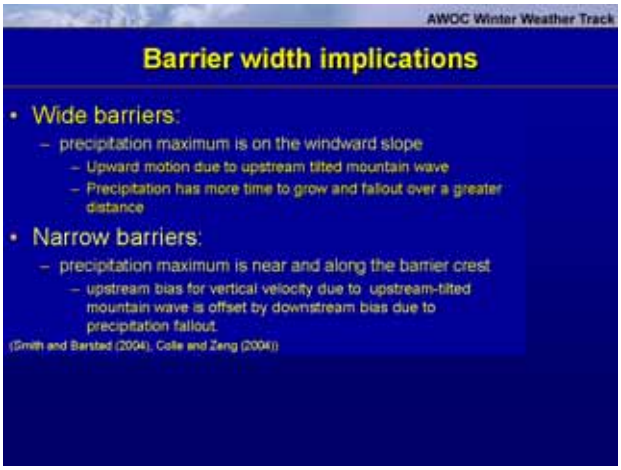

12. Seeder-Feeder

Instructor Notes: In the Seeder-Feeder process, stable ascent occurs producing an orographic cloud, which is then fed by hydrometeors generated by precipitation falling from a higher seeder cloud aloft. This feeder cloud might not precipitate without the precipitation generated in the seeder cloud. A seeder cloud can be frontal, or orographically generated/enhanced. Precipitation in the feeder cloud is enhanced primarily by depositional growth through the Bergeron-Findeisen process, and collision-coalescence in warm rain processes or aggregation in cold cloud process, and by accretion/riming. A feeder cloud may be located to the lee of the mountains (e.g. Front Range). In these situations, higher precipitation rates are found over the mountains than over the lower elevations since this mechanism is not occurring over the lower elevations.

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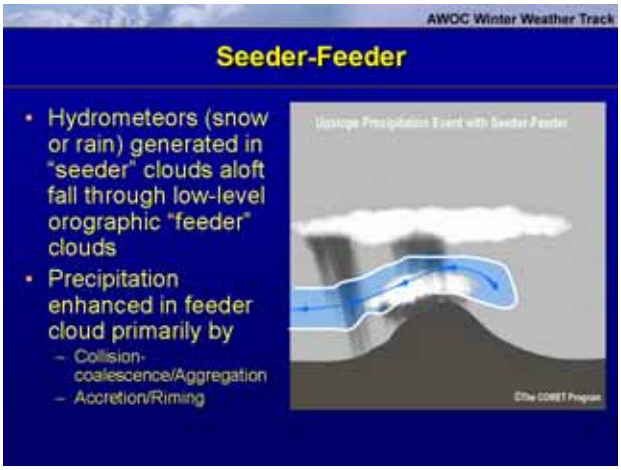

13. Seeder-Feeder

Instructor Notes: The seeder and feeder cloud may not be mutually exclusive and may be more complex than originally thought. A deep frontal cloud (seeder) is often enhanced by vertically propagating gravity wave. Purely orographic cloud (e.g., post-frontal) can often seed itself (Colle and Zeng, 2004). Roe (2005) argues “there is not a clear distinction between upslope ascent and seeder-feeder, and the differences are perhaps somewhat semantic.”

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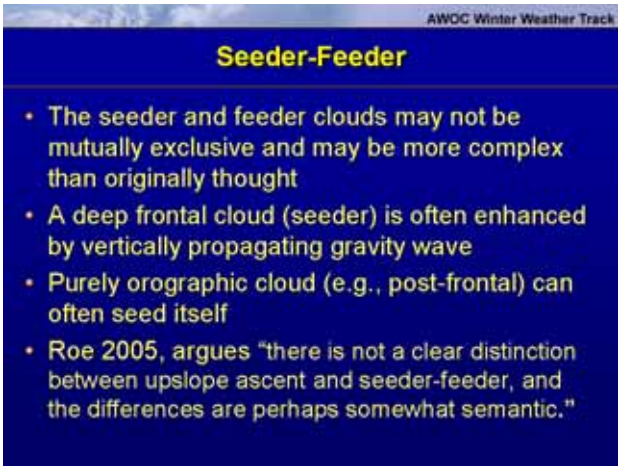

14. Seeder-Feeder

Instructor Notes: Here is an example from the Improve-2 field project over the Oregon Cascades in 2001. In pre-frontal situations, a weak low-level easterly flow often develops off of the Washington Cascades. In these situations, the deep frontal cloud is the main cloud for precipitation. In this 2001 case over the Oregon Cascades, strong cross-barrier westerly flow occurred, which generated an orographic cloud. This high LWC cloud combined with frontal cloud created an optimal structure for a seeder feeder mechanism, where heavily rimed crystals were observed reaching the ground.

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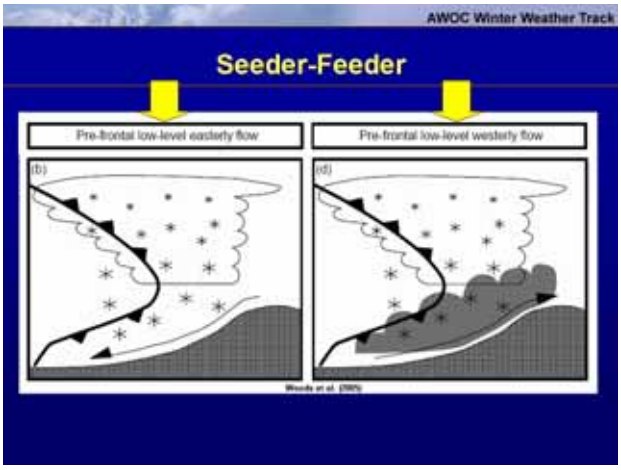

15. Seeder-Feeder

Instructor Notes: The conceptual model (from Houze and Medina, 2005) uses data obtained over the Oregon Cascade Mountains during IMPROVE-2 during 2001 and over the Alps during MAP in 1999. Vertically pointing S-band Doppler radar data suggest that turbulence contributed to the orographic enhancement of the precipitation associated with fronts passing over the mountain barriers. Cells of strong upward air motion (>2 m s^{-1}) occurred in a sheared layer just above the melting layer as the frontal cloud was over the barrier. The flow at the higher levels is strong and is able to cross over the barrier. The low-level layer flow is stable, and it becomes retarded or blocked as it approaches the terrain. The cells develop at this interface between the two flow regimes, likely due to some form of turbulence. The existence of turbulent cells results in the rapid growth and fallout of condensate over the lower windward slopes of the mountains, due to increased accretion growth, riming, and aggregation. Without the turbulent cells, the condensate would more likely be advected farther up and perhaps even over the mountain range, which would shift the precipitation distribution over the mountain. This conceptual model shows that even a stable flow has the capacity to generate cells that will enhance the precipitation processes over the windward slopes of a barrier. Nearly any baroclinic system passing over a mountain range has the capacity to produce cellular overturning over the windward slope regardless of its stability characteristics.

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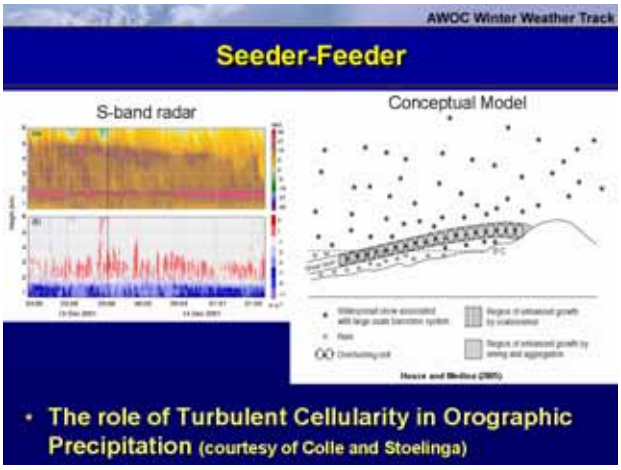

16. Sub-Cloud Sublimation/Evaporation Contrasts

Instructor Notes: Another important mechanism is evaporation/sublimation differences over the mountains and over the lower elevations. This process is very important in the Great Basin region in the western US. In this situation, the deficit between the mountain and valley precipitation is due to the valleys reducing the precipitation. This occurs when you have a dry continental airmass at low levels, and the precipitation will evaporate and sublimate before it reaches the ground. However, over the mountain locations, the precipitation is able to reach the ground since there is less hydrometeor loss due to evaporation/sublimation. In another environment, the airmass that is lifted over the mountains doesn't produce a cloud, but has a higher RH than the airmass over the lower elevations. Similarly, the precipitation rates will be higher over the mountains than the lowlands since the sub-cloud evaporation contrast will be greater over the valleys. This process is very common over the Intermountain West.

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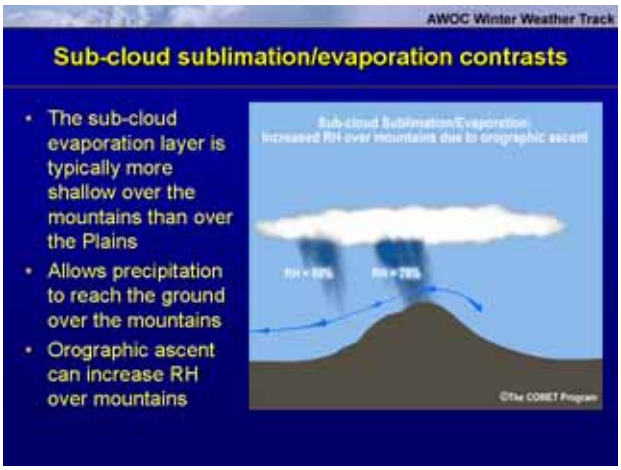

17. Upslope Release of Potential Instability

Instructor Notes: Mechanisms that produce the greatest precipitation rates in orographic storms is the upslope release of potential instability. In these cases, the upstream profile is potentially unstable, q_e is decreasing with height. Convection may not be strong but will enhance precipitation rates. Orographic uplift causes the development and release of convection usually over the windward slopes and crest of the mountains. Convection may be deep or shallow - both can result in substantial precipitation enhancement. From a forecaster's perspective, deep instability is more obvious; shallow convection is more problematic in forecasting when it occurs. Enhanced precipitation rates evident in the form of heavily rimed crystals in shallow convection to graupel in deeper convection.

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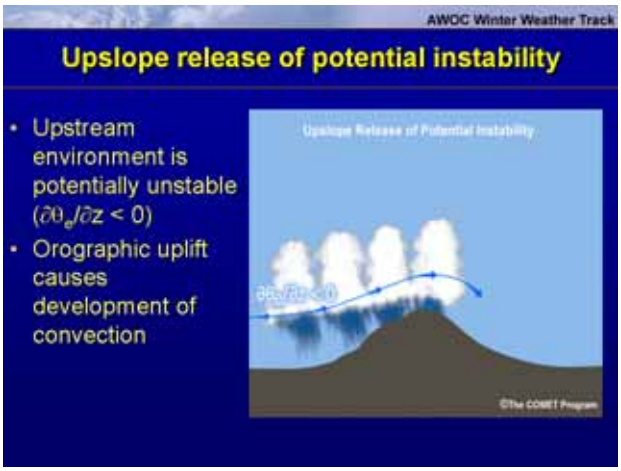

18. Upslope Release of Potential Instability

Instructor Notes: There are preferred synoptic environments in which potential instability will occur. One of the favored areas occurs ahead of a cold front. Here, surges of low q_e aloft ahead of high q_e air ahead of the front. This mechanism is most effective over smaller hills. In big mountains like the Cascades, the mountain induces its own flow pattern, easterly flow at crest level creates subsidence, which dampens out potential instability.

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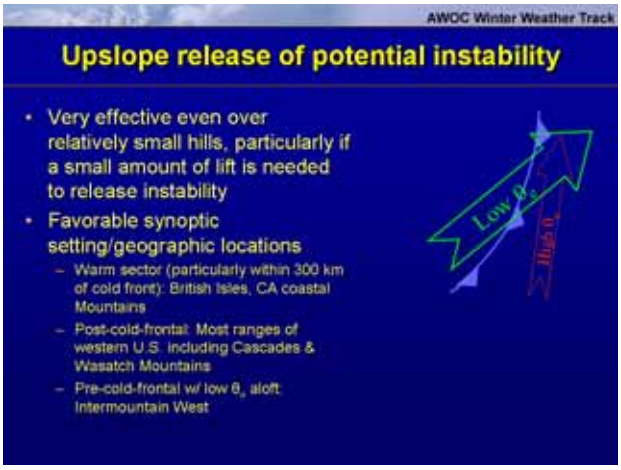

19. Terrain-Driven Convergence (TDC)

Instructor Notes: Terrain-driven convergence (TDC) occurs in many shapes and sizes, depending on the geography of the area. The basic idea is that in low Froude number flow, which is relatively stable flow, the air moves around the barrier. Convergence can occur to the lee of the mountains such as in the Puget Sound, on the windward side of barriers (such as the coastal ranges of North America, Wasatch Mountains, San Juan Mountains, and the Front Range). Many different types of terrain driven convergence can occur which is dependent on the orientation of the topography. The bottom line is that there is a dramatic impact on precipitation due to terrain-driven convergence.

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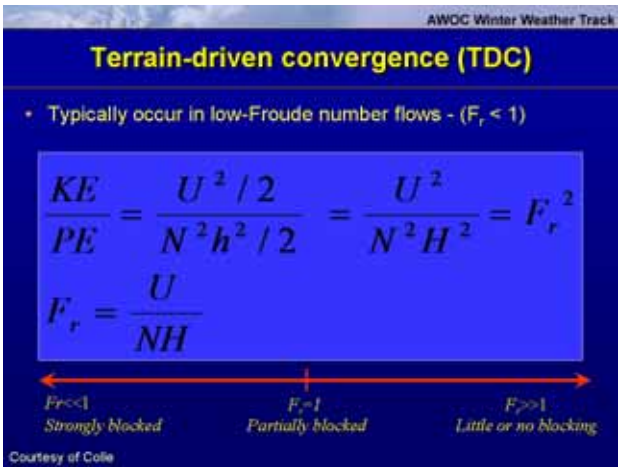

20. Terrain-Driven Convergence (TDC)

Instructor Notes: Examples of convergence windward of the initial slope of a quasi-linear mountain range or ridge are the coastal ranges of North America, Wasatch Mountains, San Juan Mountains, and the Front Range. An example of lee-side convergence is the Puget Sound convergence zone. An example of convergence windward of isolated

obstacles is the Hawaiian cloud bands. Example of other terrain-driven convergence zones are the Snake River convergence zone and the Denver convergence zone.

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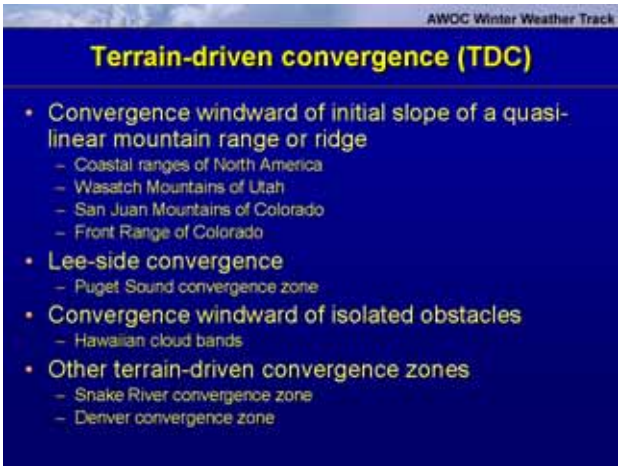

21. Cold Air Damming (CAD)/Barrier Jet

Instructor Notes: As shown in this conceptual model from Bell and Bosart (1988), the approaching upslope flow responds to both the actual terrain and the modified air mass, which creates an effective barrier. This effective barrier influences the approaching flow higher and wider than actual topography and it frequently displaces snowfall maximum well upwind of the steepest slope. The existence and degree of cold air damming (CAD) can also be a dominant factor in precipitation type (e.g. freezing/frozen precipitation in Appalachians and freezing drizzle in Front Range). When trying to diagnose precipitation rates in a blocked flow regime, be sure to use the flow upstream or above the blocked flow, otherwise you would probably underestimate precipitation estimates. (Neiman et al., 2002, used the upslope flow at 1km in the CalJet experiments in the Sierras.)

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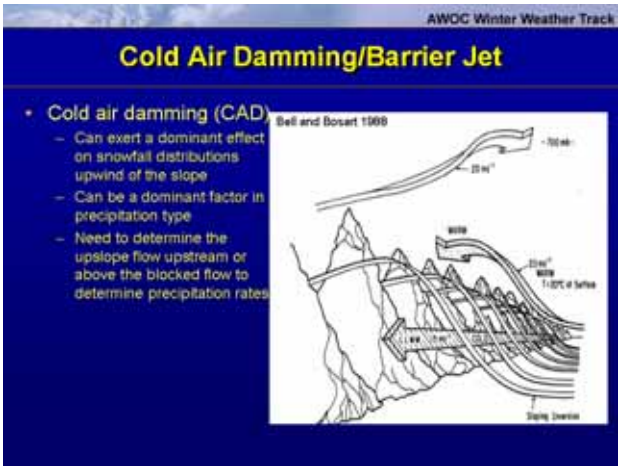

22. Cold Air Damming/Barrier Jet

Instructor Notes: As stable, low-level flow approaches a barrier, it becomes blocked and decelerates. The apparent resultant wind, the barrier jet, develops parallel to the barrier. Barrier jets always blow to the left as they approach a barrier. For instance, a west wind impinging on a N-S barrier will generate a southerly barrier jets. The barrier jets is often associated with CAD. The barrier jet can intensify the degree of blocking-induced overrunning. Barrier jets can impact precipitation type, and modify the spatial precipitation distribution, as is often seen in the Sierras. In such a case, the barrier jet shifts the precipitation distribution to the north. The barrier jet can also be quite strong as indicated by the southerly barrier jet seen in the Sierras as detailed by Parish. The core of the barrier jet reached 25 ms^{-1}. The next example shown is for the Front Range snowstorm 18 March 2003, where an easterly gradient wind is observed well east of the barrier over the Plains with stable flow near the surface. As the flow approaches the barrier, a northeast barrier jet is evident as the topography gradient increases near the foothills of the Rockies.

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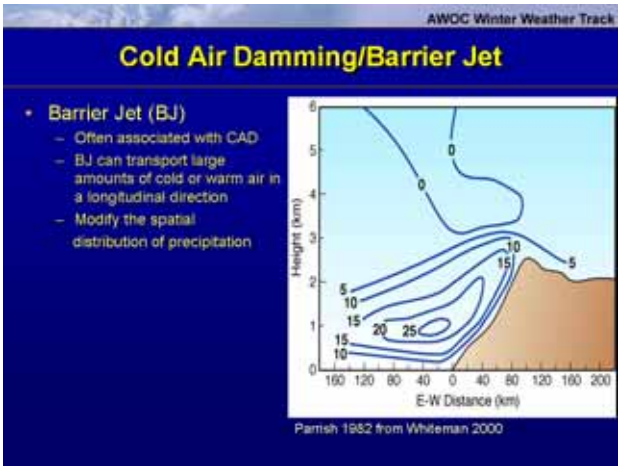

23. Precipitation Transport on Leeward Side of Barrier

Instructor Notes: Typically precipitation amounts rapidly decrease on the leeward side of the mountain crest. In strong downslope situations, precipitation can be transported several miles and produce light accumulations (mainly due to transport of precipitation from the windward side of the crest). However, sometimes there will be significant precipitation transport on the leeward side of the barrier. In the March 16-20 2003 snowstorm over the Front Range of Colorado, precipitation was carried west of the Continental Divide producing ~80” of storm total snowfall at the top of Winter Park Ski area in CO. A stable cloud on the lee side may extend the precipitation much farther downwind of the crest and, typically, there is strong wind shear between the stable cloud and the orographic cloud aloft.

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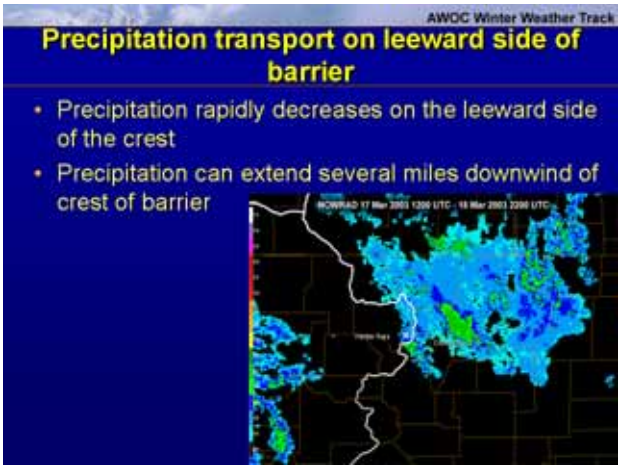


24. Interactive Quiz #1

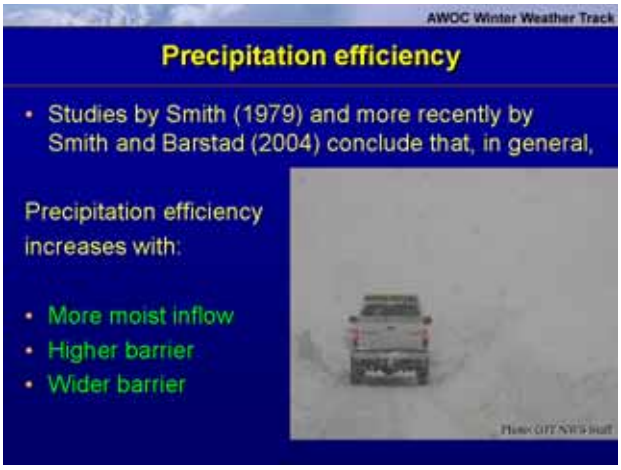
Instructor Notes: Take a few moments to complete this interactive quiz.

Student Notes:

25. Precipitation Efficiency

Instructor Notes: Studies by Smith (1979), and more recently by Smith and Barstad (2004) using a model based on linear mountain wave theory, conclude the following: in general, precipitation efficiency, which is the ratio of the precipitation/total condensate produced by the cloud, increases with more moist inflow, a higher barrier, and a wider barrier.

Student Notes:



26. Summary

Instructor Notes: Several mechanisms contribute to orographic precipitation: stable upslope flow, the seeder-feeder mechanism, sub-cloud evaporation contrasts, precipitation transport on leeward side of barrier, upslope release of potential instability, terrain-driven convergence, and cold air damming/barrier jet. These mechanisms are not mutually exclusive and may occur in concert.

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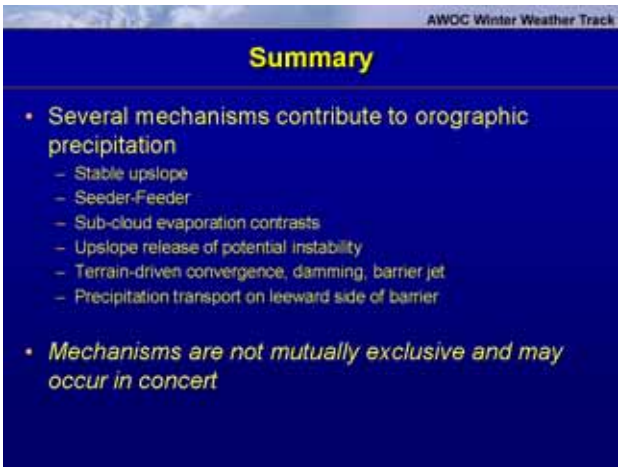
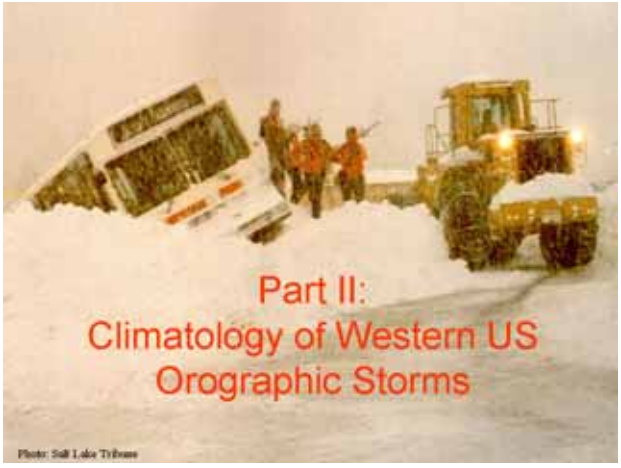


27. Part 2: Climatology of Western U.S. Orographic Storms

Instructor Notes: A winter weather traffic mishap in the Salt Lake City, Utah area. Next we will look at storms for several mountain ranges of the western US.

Student Notes:



28. Cascade Mountains

Instructor Notes: First we will talk about the Cascade range, which has weather similar to the Coast Range of southwestern British Columbia. The Cascades are a quasi-maritime range due to the influx of pollution from Seattle and Vancouver, which tends to make it more continental, at times. The Cascades are approximately 100 km wide. This mountain width affects the orographic storm evolution, which has been detailed by the work of Colle and Zeng (2004). The Cascades separate the Columbia Basin from the Puget Sound lowlands and the Willamette Valley. Some notable passes/gaps include the Columbia River Gorge (MSL), Stampede/Snoqualmie Passes (~1000 m), and Stevens Pass (~1200 m). Some volcanoes in this range include Mt. Rainier, Mt. Adams, Mt. Baker, Mt. St. Helens, and Mt. Bachelor.

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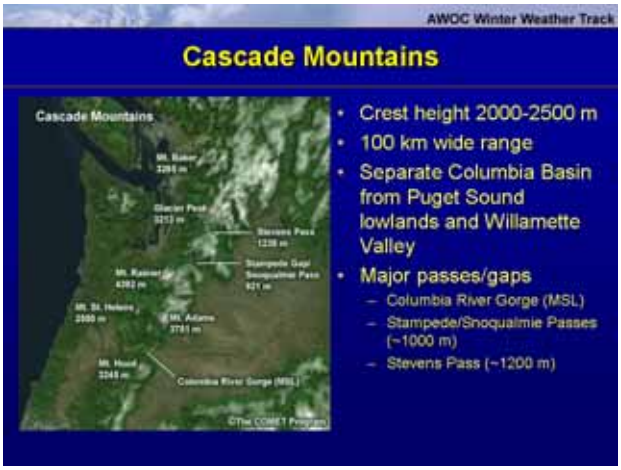

29. Annual Precipitation: Cascade Mountains

Instructor Notes: The precipitation climatology of the Cascades is shown here (the Oregon Climate Service provided the annual precipitation). The heaviest precipitation falls on the windward side of the crest. This feature is typical of broad mountain ranges

like the Cascades, Sierra Nevada Range, and Coast Range of British Columbia. Narrow ranges, like the Wasatch range in Utah, however, exhibit a precipitation maximum near the crest. Wide barriers allow hydrometeors to grow and fallout over the windward slope, while narrow ranges typically have more precipitation falling out over the crest, and spilling over into the lee of the barrier. Washington snow highlights include: 1. Mt. Baker Ski Area (4,300'), 647" annually, 1,224" 1998/99 (world record) and 2. Paradise Ranger Station (5,420'), 633" annually, 1,222.5" 1971/72. Areas observing heavy precipitation in Oregon include: Mt. Hood and Mt. Bachelor/Sisters east of Bend.

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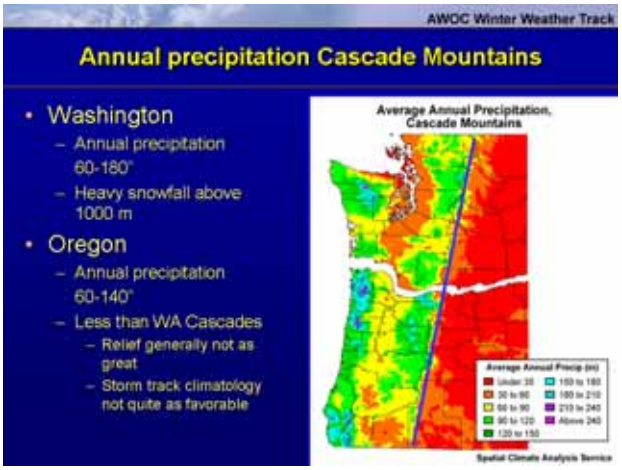
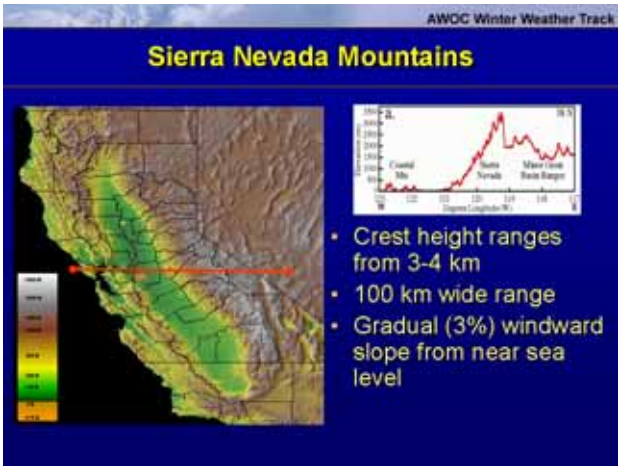


30. Sierra Nevada Mountains

Instructor Notes: Next we will talk about the Sierra Nevada range. It has similar width as the Cascade range (100 km wide), and is oriented slightly NW to SE. The Sierras feature a gradual windward slope 2-3% from near sea level to the crest (the exception being the coastal range, which are relatively small coastal mountains which extend up to ~500 m MSL). The Sierras also feature some dramatic leeward slope in some areas. Mt. Whitney is one example. There are numerous peaks over 3500 m that also have strong leeward slopes.

Student Notes:



31. Sierra Nevada: Annual Precipitation

Instructor Notes: Like the Cascades, the Sierras feature a precipitation peak on the windward side of the barrier rather than at the barrier crest. Typically the precipitation peak is 10-20 km upstream of the barrier crest. Barrier jets that form can be as strong as 25 ms^{-1} and tend to force precipitation to the northern sections. U.S. snowfall records for this region include: a. seasonal snow depth 454”, Tamarack, Mar 1911; b. monthly snowfall 390”, Tamarack, Jan. 1911; c. snowfall from single storm 189”, Mt. Shasta Ski Bowl, 13-19 Feb. 1959; and d. 24-hour snowfall (2nd greatest) 67”, Echo Summit 4-5 Jan. 89. Sierra Nevada records include: the seasonal snowfall 884”, Tamarack, 1906-07.

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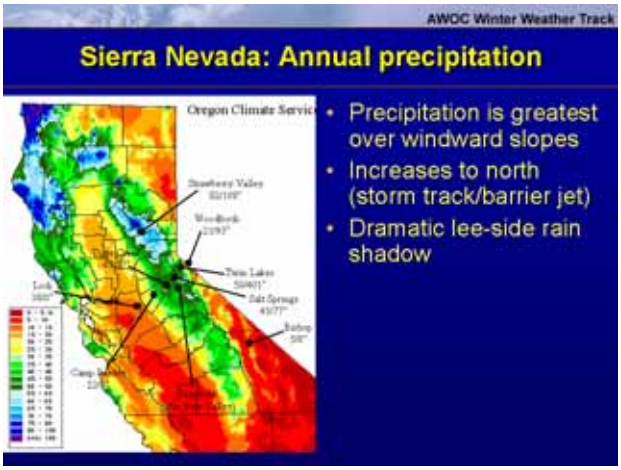
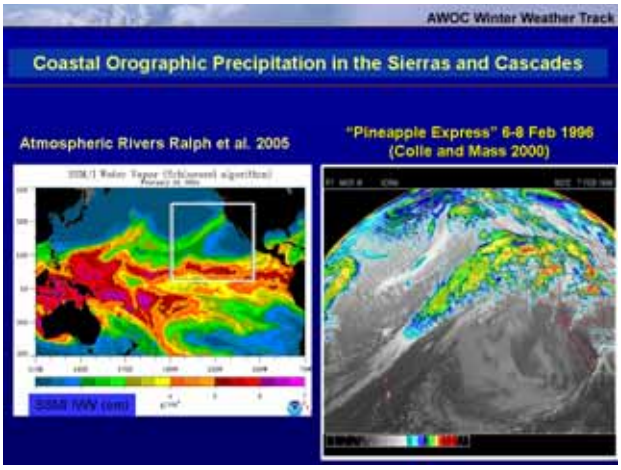


32. Coastal Orographic Precipitation in the Cascades and Sierras

Instructor Notes: Here are two examples in the literature of heavy precipitation producers for the coastal regions of the Sierras and the Cascades. Atmospheric rivers were examined over the coasts of California and Oregon during the CALJET (1998) and PACJET (2001) field projects. Most of the subtropical vapor flux in atmospheric rivers is below 2.5 km, which usually leads to flooding along the coast and in the coastal mountains. Colle and Mass (200) also details the warm moist subtropical southwesterly flow which impacts the coastal regions from California to Washington which often leads to coastal and inland flooding in these locations. The pattern is often dubbed the “Pineapple Express” since the flow often originates near Hawaii.

Student Notes:



33. Cascades and Sierra Nevada Snowstorms

Instructor Notes: This generalization of Cascade and Sierra Nevada snowstorms, does not apply to all storms. However, these storms tend to evolve from prefrontal to transitional to post-frontal conditions. Many of the fronts are associated with deep well-occluded storms in the later stages. The prefrontal regime is usually when the storms are the deepest. However, precipitation rates are steady, but not the greatest. Ice particles, with LWC, dominate over water droplets and, therefore, limit riming. The transitional stage occurs as the occluded front moves through the region. The air becomes increasingly unstable. The upper level cloud shield moves east, reducing the cloud depth (i.e., ice particles become less common). LWC increases to relatively high values, with lowering cloud tops and convection, and riming increases. The precipitation tends to be more showery and heavy, with heavy showers on the western slopes and clearing on the eastern slopes. During the post-frontal regime, unstable conditions will continue and increase. LWC is moderate, with strong updrafts and heavy riming. This riming is very important for the total snow water content of the storm. Precipitation is showery and occasionally heavy.

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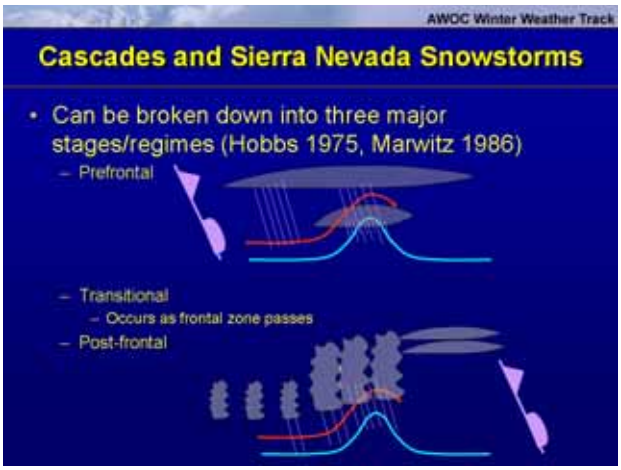

34. San Juan Mountains

Instructor Notes: Next we will look at the San Juan mountains of western Colorado in the interior United States. The San Juans are a crescent-shaped range in southwest Colorado, where crest mean height ranges from 3-4 km. These mountains rise abruptly in last 25 km to the crest (Continental Divide). The Cascades are narrower than the coastal mountains of the west, but not as narrow as the Great Basin ranges of Utah.

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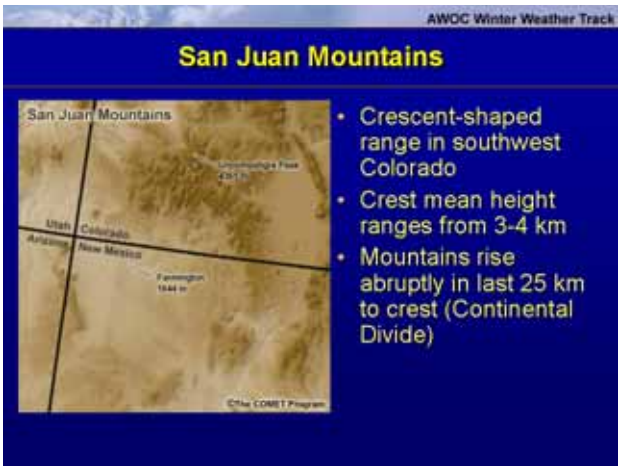

35. San Juan Mountains: Annual Precipitation

Instructor Notes: The greatest precipitation in the San Juans is near and along the crest. Peak precipitation is not shifted to the windward side as in Cascades and Sierras. The contrast between windward and leeward precipitation is not as great as in the Sierras and Cascades. One reason for this feature is that during the storm evolution, the favored upslope flow will shift from typically the south-facing slopes as the storm approaches to the north-facing slopes as the storm moves east of the area. Since it is an interior mountain site, the San Juans have lower annual winter precipitation than Cascades and the Sierras.

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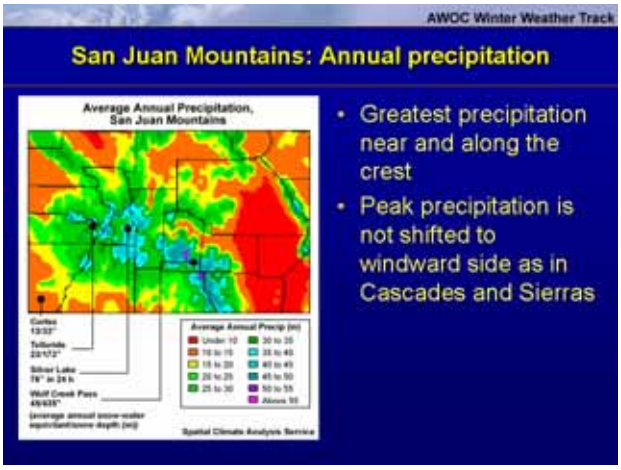

36. San Juan Snowstorms

Instructor Notes: The storm stages for the San Juan storms are similar to those over the Cascade and Sierra Nevada mountains. In the stable regime, there is usually no potential instability. The flow below mountain level is blocked, which reduces the effective height of the barrier. In this environment, orographic ascent is only observed halfway up the barrier to the crest reducing the depth of the orographic ascent. Windward convergence zones are also observed which spatially affect the precipitation distribution. Since there is little liquid water, snow is usually light in the stable regime (where diffusional growth dominates). Precipitation is more focused on the southern facing slopes of the San Juans during this stable regime since the flow is typically from the south/southwest. As it transitions into the neutral stage, many of the storms are associated with closed lows. As a result, the storms have a good baroclinic zone in the midlevels but usually lack a good surface cold front. As the low q_e air aloft moves across the area, neutral or unstable conditions aloft develop. In association with orographic lift, this potential instability can be released. There is also a deepening of the storm during the neutral stage. The strongest snowfall usually occurs over the southern facing slopes of the San Juans with lesser amounts across the north facing slopes due to “snow shadow effect”. Riming increases as liquid water increases. As it finally transitions to the unstable stage, a convergence zone sets up at the base of the mountain. Enhanced precipitation shift to the north facing slopes of the San Juans as flow becomes more northwest as the system moves east of the area. Significant accumulation can occur on these north-facing slopes as the upslope flow shifts to a more northerly direction. Heavily rimed crystals, or graupel, are observed in the unstable stage. This process is similar to the Cascades and Sierra Nevada ranges when a stable regime transitions to unstable regime.

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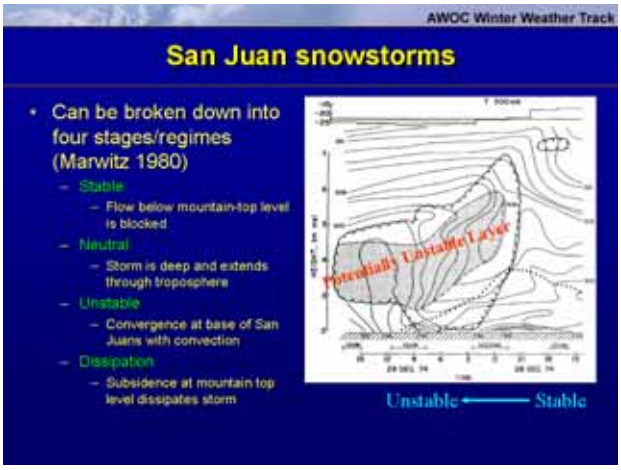


37. San Juan vs. Cascade/Sierra Storms

Instructor Notes: The same general storm stage transitions occur in inland range as they do in a maritime range. Blocking is significant in the Sierras, (i.e., barrier jet), but is less organized in the San Juans (and is even less important in the Cascades). Cloud depth and tops lower in the transition/neutral stages which leads to less ability to nucleate the ice. The Cascade and Sierras are typically warmer than the San Juans.

Student Notes:

38. San Juan vs. Cascade/Sierra Storms

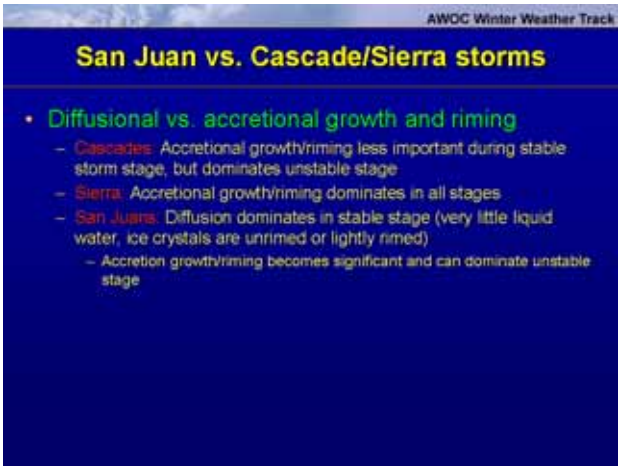
Instructor Notes: More maritime cloud spectra in the Sierras and the Cascades, which leads to better riming. However, the convection in the San Juans compensates for the lack of LWC, and facilitates riming growth processes.

Student Notes:

39. San Juan vs. Cascade/Sierra Storms

Instructor Notes: Depositional growth is more important in the prefrontal/stable stages in each mountain range. However, accretional growth and riming is still important in the Sierras. Accretional growth and riming become more dominant in the transitional/neutral and post frontal/unstable stages.

Student Notes:



40. Wasatch Mountains

Instructor Notes: Next, we will examine the Wasatch Mountains, with Dr. James Steenburgh (from the University of Utah) leading the training.

Student Notes:

41. Wasatch Mountains

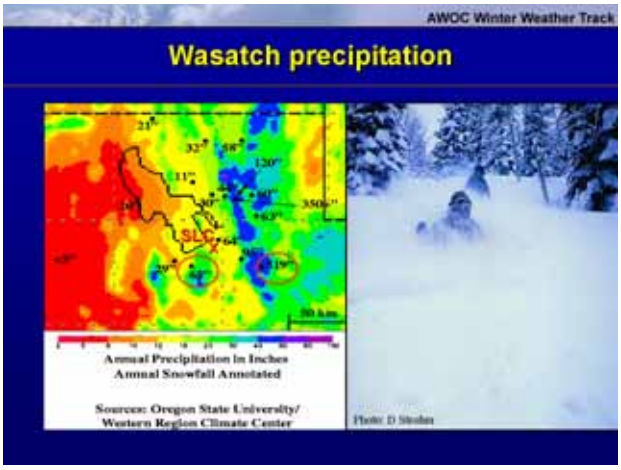
Instructor Notes: The Wasatch are the snowiest mountain range in the interior U.S. The Wasatch is a narrow (10 km wide) range. It rises up 2000 m high over a distance of 5 km on its western slope. The Great Basin has numerous mountain peaks, with broad lowlands in between the peaks. For the Wasatch, the precipitation maximum is over the crest.

Student Notes:

42. Wasatch Precipitation

Instructor Notes: The precipitation maximum is over the crest. Salt Lake City has an annual precipitation of 15” and the mountains to the southwest have an annual precipitation of 65”. This variation occurs over a distance of 15 km or less.

Student Notes:



43. Wasatch Snowstorms

Instructor Notes: Over the Great Basin, we get surges of low θ_e air aloft ahead of an approaching surface cold front. These cold fronts can be associated with intense convection. Immediately behind the cold front stable air will occur, then it will transition back to an unstable air mass. The Great Salt Lake also complicates the forecasts and can impact snowfall. Next will talk about a 100” storm at Alta, UT. This storm features a more complex stability evolution than described by Hobbs (1975) and Marwitz (1980).

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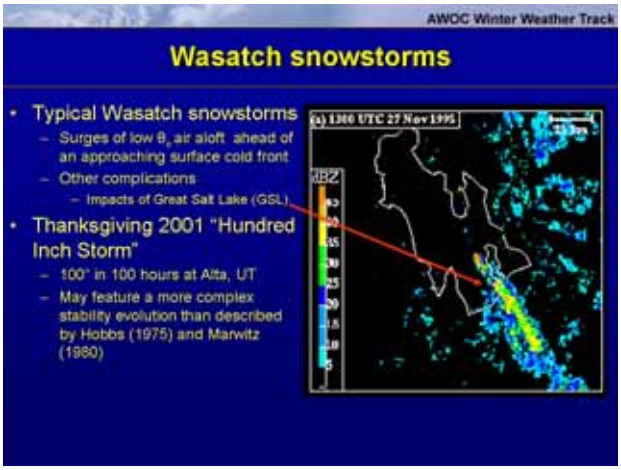

44. 22 November 2001 – Stable Prefrontal Stage

Instructor Notes: In the stable storm stage, we observe mainly stratiform precipitation. Also, we see bright band contamination; as a result, Z-R relationships are poor. In this stage of the storm, there is double the precipitation in Alta as compared to SLC. From the sounding profile, dry conditions in the lower atmosphere lead to subcloud sublimation/ evaporation processes which limited the valley precipitation.

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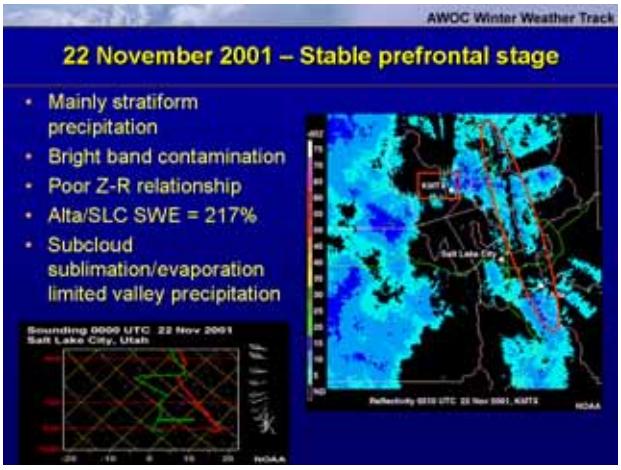

45. 22 November 2001 – Unstable Prefrontal Stage

Instructor Notes: Intrusion of low θ_e aloft led to a potentially unstable environment (and lightning). Convective initiation is not always tied to topography. There was the smallest orographic enhancement of the first storm. This process all occurred ahead of the surface cold front.

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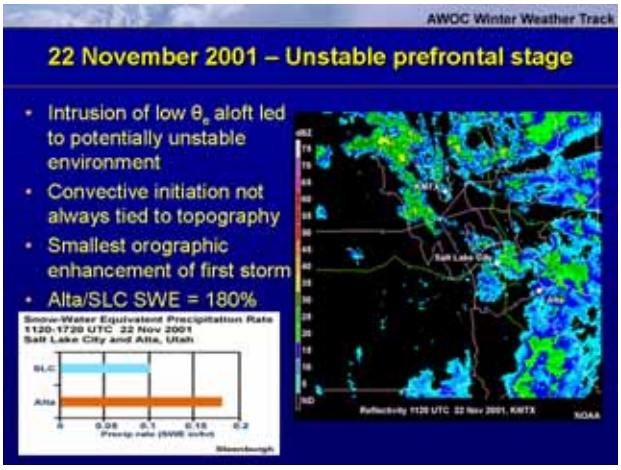
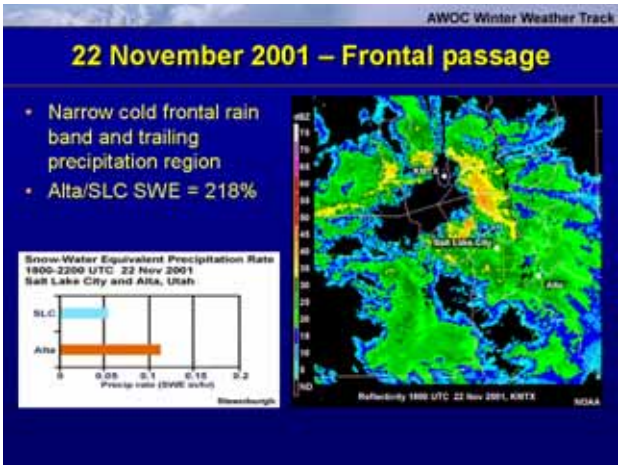


46. 22 November 2001 – Frontal Passage

Instructor Notes: Here you see evidence of the narrow, cold frontal rain band and trailing precipitation region, which is more stratiform. There was a more stable period after the frontal passage.

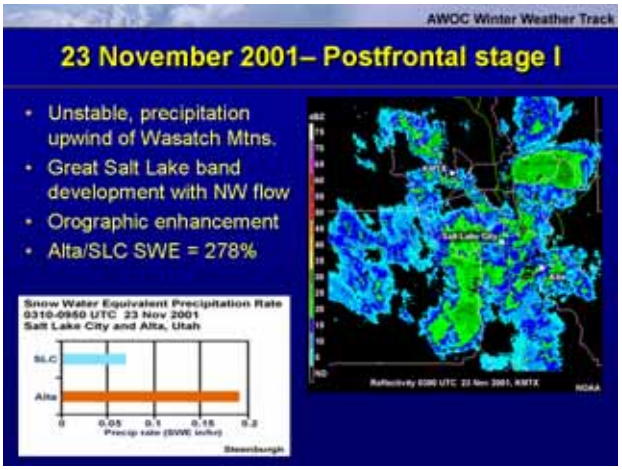
Student Notes:



47. 23 November 2001– Postfrontal Stage 1

Instructor Notes: The atmosphere became more unstable and more post-frontal instability showers developed. Higher reflectivities were seen in the NW flow downwind of the lake. An increase in orographic enhancement was also observed over the Wasatch Mountains.

Student Notes:



48. 23 November 2001 – Mid-Lake Band

Instructor Notes: Here the thermally driven convergence produces a solitary midlake band. Orographic enhancement also occurred in the lake band. Typically, during the biggest events in the lowlands, you can get 20” of snow. 33% of the SWE was produced by the lake effect band and orographic enhancement.

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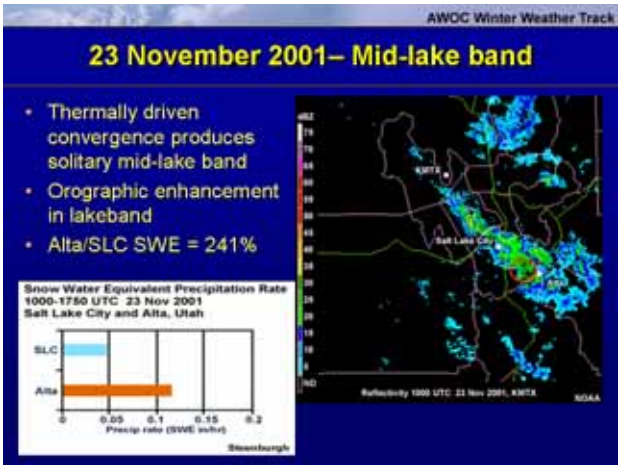
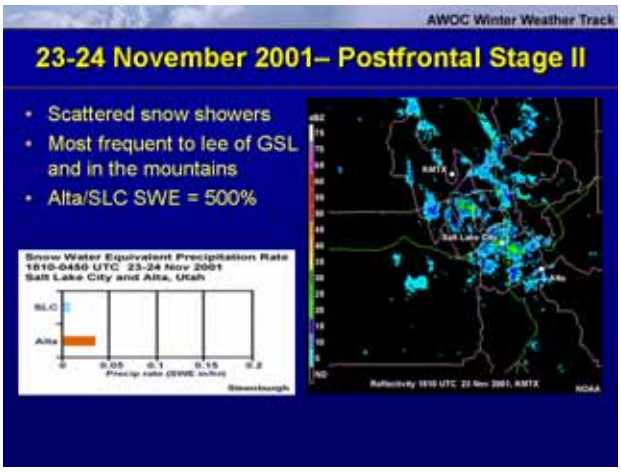


49. 23-24 November 2001– Postfrontal Stage 2

Instructor Notes: Towards the end of the event, the precipitation is mainly over the mountains. Precipitation had become more showery in nature.

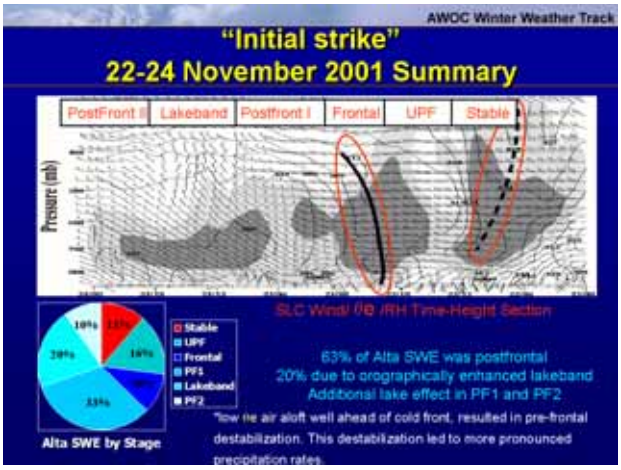
Student Notes:



50. “Initial Strike” 22-24 November 2001 Summary

Instructor Notes: Here is a time-height cross-section for the Alta area during this storm that was created from the RUC analyses. Here you can see the surge of low q_e air aloft well ahead of the surface cold front, resulting in pre-frontal destabilization. This destabilization led to more pronounced precipitation rates.

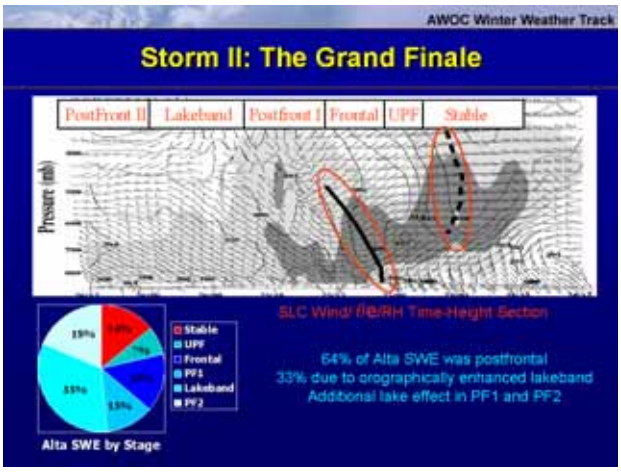
Student Notes:



51. Storm 2: The Grand Finale

Instructor Notes: The next storm, which produced 50" of snow, showed a very similar structure to the first storm.

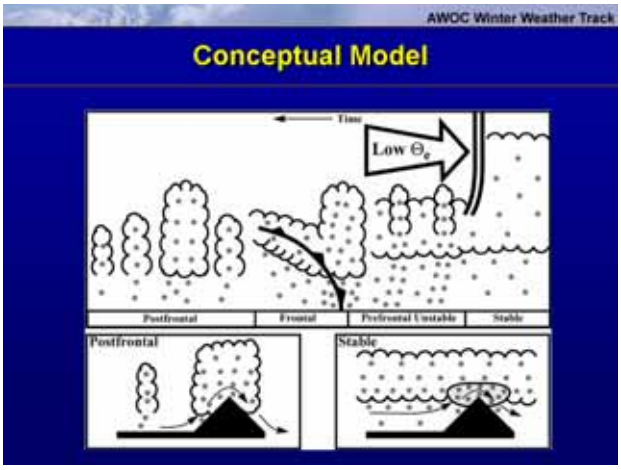
Student Notes:



52. Conceptual Model

Instructor Notes: Based on several cases, this conceptual model applies to some storms which may occur over the interior U.S. Usually, you will see a surge of low q_e air aloft ahead the cold front which leads to destabilization ahead of the front. Using wind profiler data, the troughs tend to be rearward sloping upstream of the Sierras. As they move downstream the upper-level forcing moves ahead of the surface trough position. This may be caused by the upstream topography, plus they are usually old occluded storms that made landfall over the Sierras, where the upper-level cold air may be progressing ahead of the surface cold front.

Student Notes:



53. Interactive Quiz #2

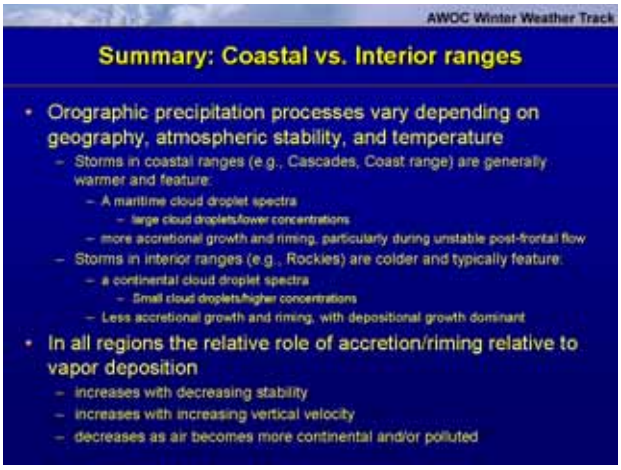
Instructor Notes: Take a moment to complete this quiz.

Student Notes:

54. Summary: Coastal vs. Interior Ranges

Instructor Notes: Orographic precipitation processes vary depending on geography, atmospheric stability, and temperature. Storms in coastal ranges (e.g., Cascades, Coast range) are generally warmer and feature: a maritime cloud droplet spectra, large cloud droplets/lower concentrations, and more accretional growth and riming, particularly during unstable post-frontal flow. Storms in interior ranges (e.g., Rockies) are colder and typically feature: a continental cloud droplet spectra, small cloud droplets/higher concentrations, and less accretional growth and riming, with depositional growth dominant. In all regions, the relative role of accretion/riming relative to vapor deposition increases with decreasing stability, increases with increasing vertical velocity, and decreases as air becomes more continental and/or polluted.

Student Notes:



55. Summary: Coastal vs. Interior Ranges

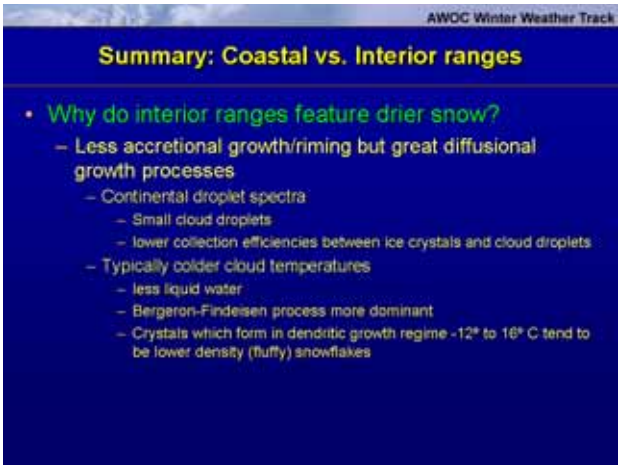
Instructor Notes: Although many orographic storms evolve from stable to unstable stages, some are more complex. Beware of surges of low-θ_e aloft! On the mesoscale, departures from climatological precipitation-elevation relationships can arise from: blocked flow enhancing precipitation upstream of a barrier (e.g., Cold air damming/barrier jets), terrain inducing convergence zones, exposure to synoptic/mesoscale flows, and topographically forced convection.

Student Notes:

56. Summary: Coastal vs. Interior ranges

Instructor Notes: Interior ranges usually have less accretional growth/riming, but great diffusional growth processes, continental droplet spectra, small cloud droplets, and lower collection efficiencies between ice crystals and cloud droplets. They also typically feature colder cloud temperatures with less liquid water. The Bergeron-Findeisen process is more dominant under these conditions and crystals that form in dendritic growth regime (-12º to 16º C) tend to be lower density (i.e., fluffy) snowflakes.

Student Notes:



57. Part 3: Forecasting Tools and Methods

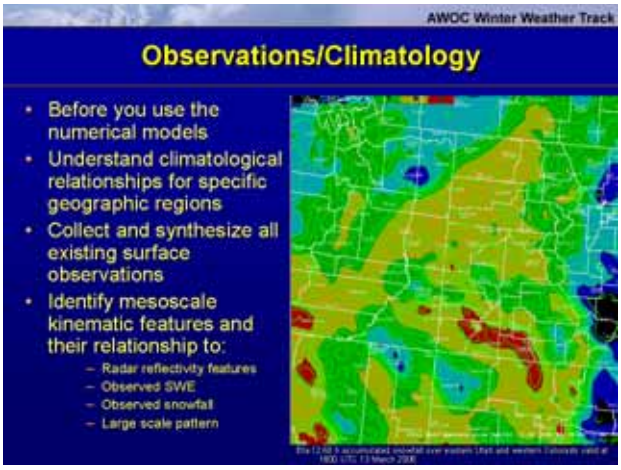
Instructor Notes: The next section of this lesson details forecasting tools and methods for orographic precipitation.

Student Notes:

58. Observations/Climatology

Instructor Notes: Before you use the numerical models, understand that the models produce results that are realistic based upon the specific parameters and physics coded into the model. The problem is that those results may not necessarily be skillful from a forecasting standpoint. It is critical to understand climatological relationships for specific geographic regions. Collect and synthesize all existing surface observations (including both precipitating and non-precipitating features) and radar data to understand physical processes and validate them.

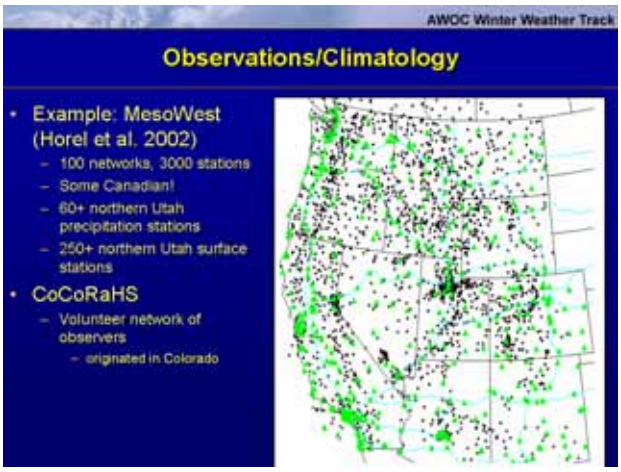
Student Notes:



59. Observations/Climatology

Instructor Notes: Here's an example of an observation system in the west. MesoWest (Horel et al. 2002) utilizes 100 networks with 3000 stations, including some Canadian observations. MesoWest also utilizes 60+ northern Utah precipitation stations and 250+ northern Utah surface stations. The CoCoRaHS Volunteer network of observers, which originated in Colorado, is another example of an important observation system.

Student Notes:



60. Observations/Climatology

Instructor Notes: Another example of these observations systems is the Snotel network. There are approximately 650 Snotel, or snowpack telemetry, sites from the National Resources Conservation Service across 13 states in the western U.S. Each site generates SWE, precipitation, and temperature, with some reporting snow depth. Other sources of information are the NWS Cooperative Observers, observational spotters, and other data such as the DOT observations.

Student Notes:

61. Observations/Climatology

Instructor Notes: Great errors in the snow density measurements can occur during wind events. For instance, undercatch of the precipitation can occur during high winds. Judson and Doesken (2000) noted differences between actual precipitation and catch from an unshielded gauge may exceed 50% for wind speeds of 3 ms^{-1}. This undercatch results in an over assessment of snow-liquid water ratio. In addition to undercatch, settling of snow due to wind and metamorphism can also occur. Lastly, other errors caused by mixed precipitation events or potential melting between observations can also impact observation quality.

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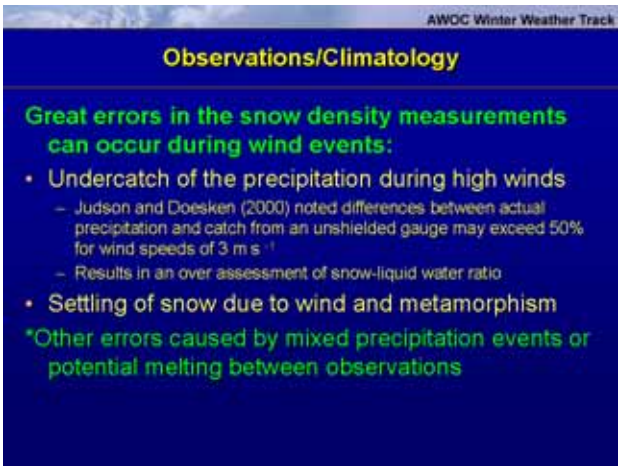
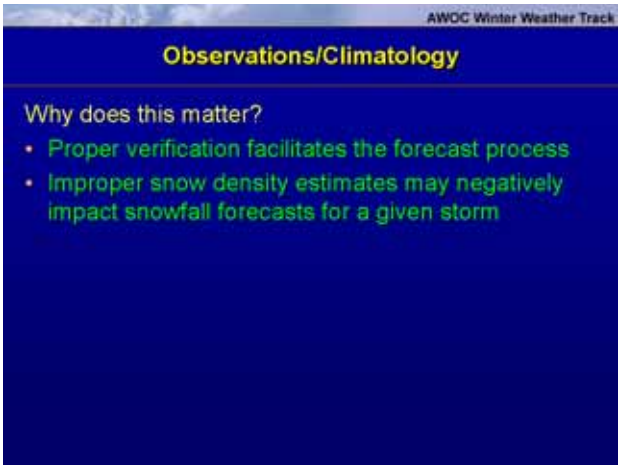


62. Observations/Climatology

Instructor Notes: Why does this matter? Proper verification of snow density facilitates the forecast process for current and future storms. Improper snow density estimates may also negatively impact snowfall forecasts for a given storm.

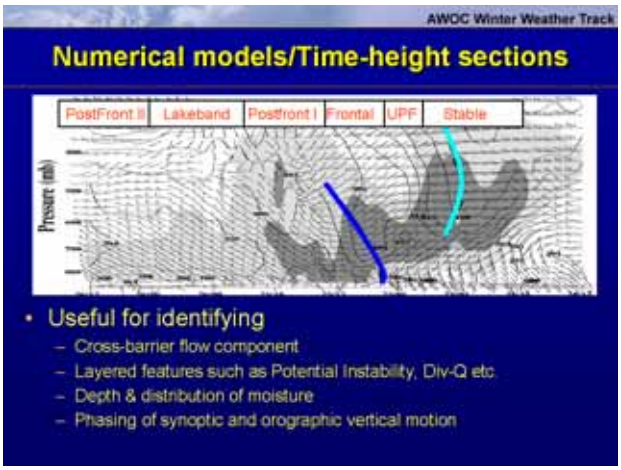
Student Notes:



63. Numerical Models/Time-Height Sections

Instructor Notes: Time-height sections are useful for identifying the cross-barrier flow component, layered features such as Potential Instability, Q-vector divergence, moisture depth and distribution, and phasing of synoptic and orographic vertical motion.

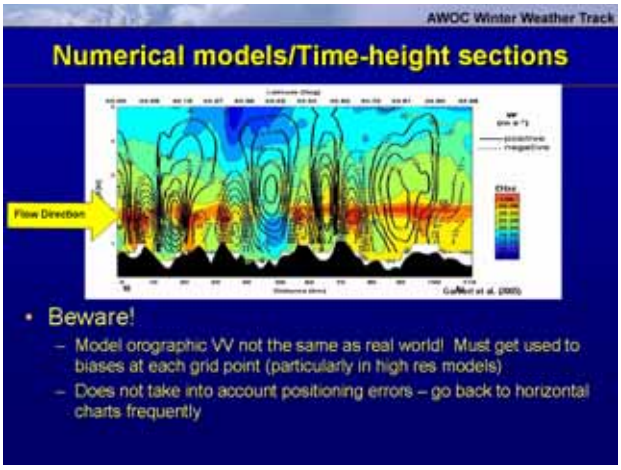
Student Notes:



64. Numerical models/Time-height sections

Instructor Notes: Beware of model produced vertical velocity over significant topography since it may be unrealistic. This diagram shows observed vertical velocities and reflectivity during the IMPROVE 2 field project. Vertical velocity and local precipitation enhancements are being generated by the mountain waves over the terrain. The model depiction for this structure may be quite different. It is important to understand the grid biases. If the topography is not represented well, the location of primary forcing may be altered spatially. Go back to horizontal charts frequently!

Student Notes:



65. Numerical Models/High Resolution Modeling

Instructor Notes: Mountain weather is driven by mesoscale terrain and surface features with extremely diverse geographic structures. High resolution is needed to resolve such local orographic effects. Research simulations produce physically realistic simulations if: the large-scale forecast is accurate. However, this accuracy is not a given. Surface characteristics (e.g., soil temperature, soil moisture, and lake temperature) need to be properly specified, which can be another big if. The validity of the forecasts are also tied to the sophistication of the model physics. Fixed surface forcing of topography should enhance predictability, but there are a few caveats.

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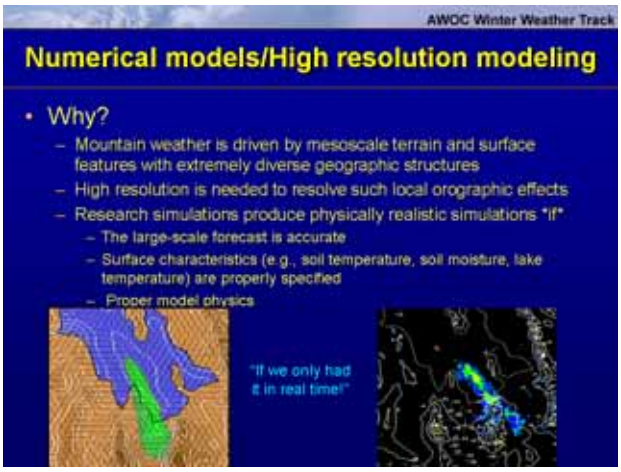
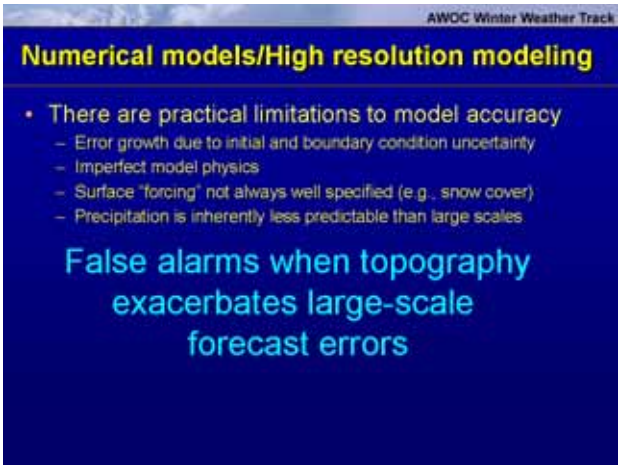


66. Numerical Models/High Resolution Modeling

Instructor Notes: There are practical limitations to model accuracy, such as: error growth (large scale, mesoscale etc.) due to initial and boundary condition uncertainty, imperfect model physics, and surface "forcing" not always being well specified (e.g., snow cover). Precipitation is inherently less predictable than large scales.

Student Notes:



67. Use, Misuse, & Predictability of High Resolution Mesoscale Models

Instructor Notes: Fine-scale representation of topography may enhance predictability of certain flow types, but this debate continues. Mesoscale model forecasts are more sensitive to large-scale forecast errors and specification of surface characteristics. Local orography can enhance large-scale errors, reducing forecast utility. As a result, the false-alarm rate increases with finer grid spacing; in other words, when a model forecast goes bad, it can really go bad!

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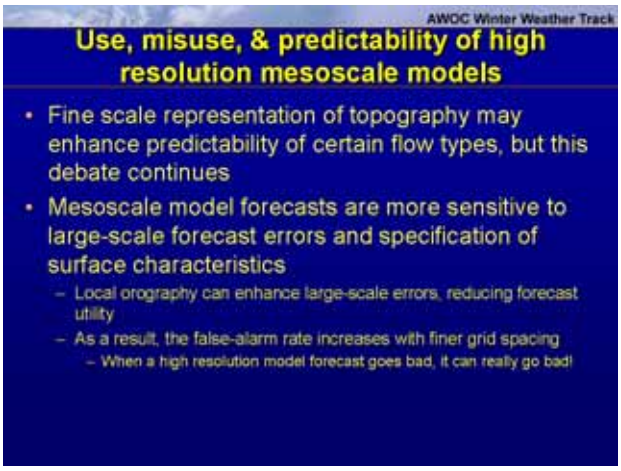
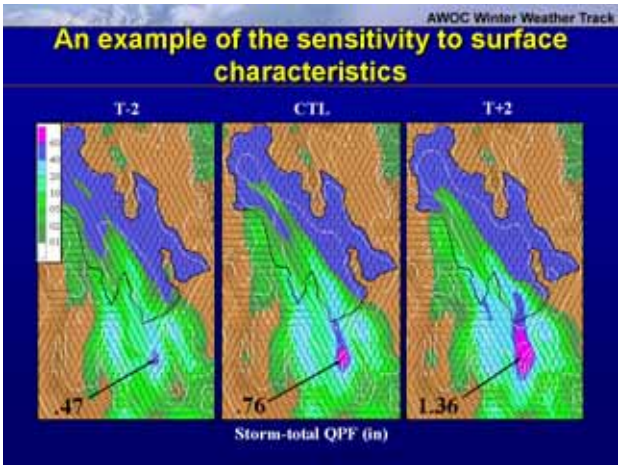


68. An Example of the Sensitivity to Surface Characteristics

Instructor Notes: Here is an example of the model sensitivity to the Great Salt Lake water temperature, which can vary greatly. Just by changing the lake temperature 2 degrees cooler or warmer, the overall QPF model output changed dramatically. It is amazing how a surface condition can have such a profound effect on QPF.

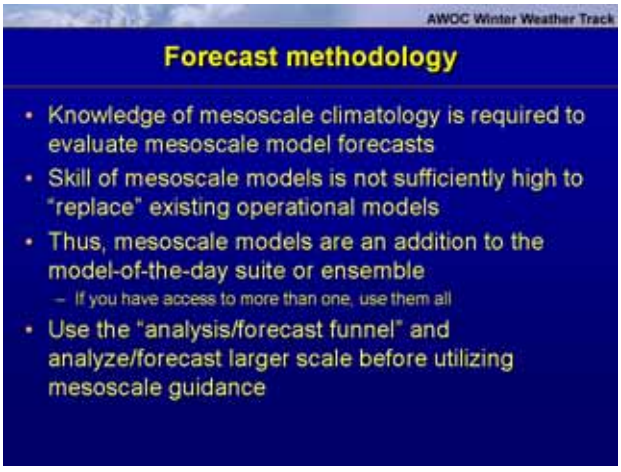
Student Notes:



69. Forecast Methodology

Instructor Notes: Knowledge of mesoscale climatology is required to evaluate mesoscale model forecasts. Skill of mesoscale models is not sufficiently high to “replace” existing operational models. Use them in addition to other operational models to qualitatively create an ensemble of the forecast. Thus, mesoscale models are an addition to the model-of-the-day suite or ensemble. If you have access to more than one, use them all. Use the “analysis/forecast funnel” and analyze/forecast larger scale before utilizing mesoscale guidance.

Student Notes:



70. Analysis/Forecast Funnel

Instructor Notes: Begin at global scale then progress to progressively smaller scales. Evaluate confidence in large-scale forecast by mesoscale model first. Expect limited skill on mesoscale if large-scale is not well forecast. Proceed to the fine-scale detail of the model forecast.

Student Notes:

71. Interactive Quiz #3

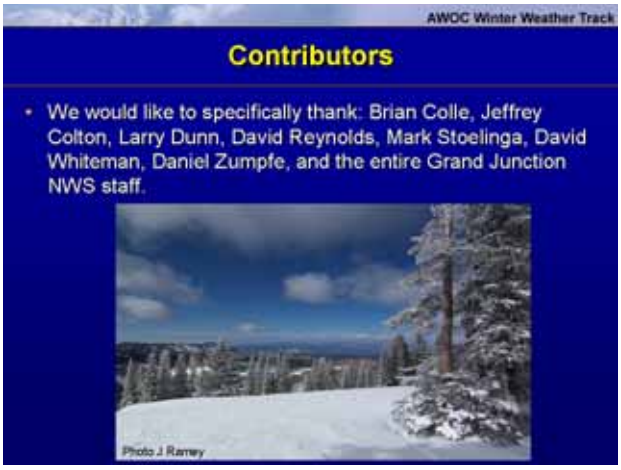
Instructor Notes: Take a few moments to complete this quiz.

Student Notes:

72. Contributors

Instructor Notes: This slide mentions all of the people who helped contribute to this lesson.

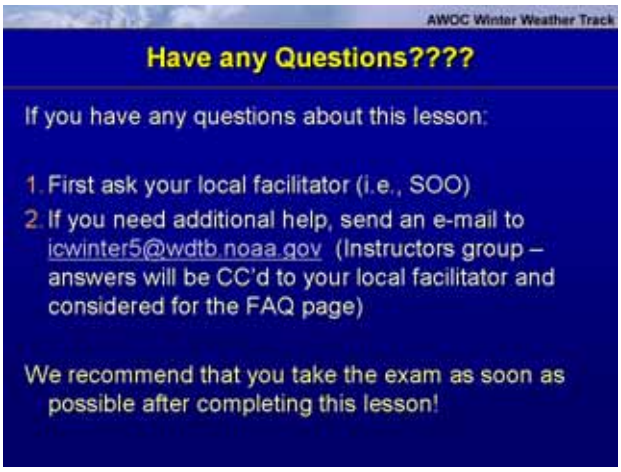
Student Notes:



73. Have Any Questions????

Instructor Notes: If you have any questions about this lesson, first ask your local AWOC facilitator. If you need additional help, send an E-mail to the address provided. When we answer, we will CC your local facilitator and may consider your question for our FAQ page. We strongly recommend that you take the exam as soon as possible after completing this lesson.

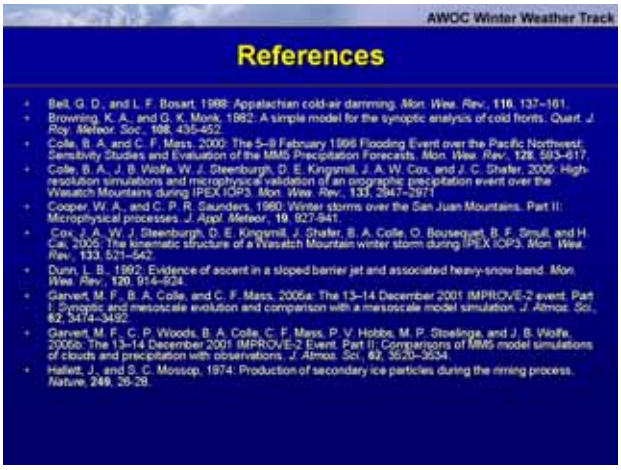
Student Notes:



74. References

Instructor Notes: This slide is the first of six slides that contain a list of all the references in this presentation.

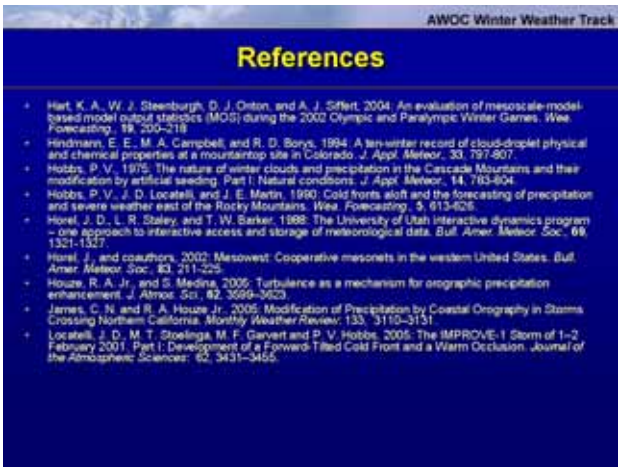
Student Notes:



75. References

Instructor Notes: This slide is the second of six slides that contain a list of all the references in this presentation.

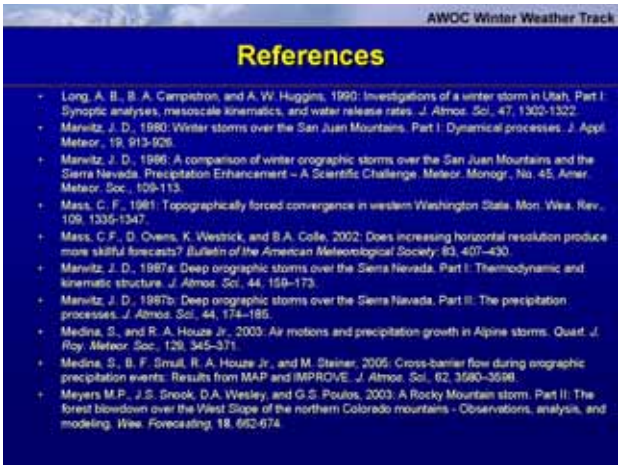
Student Notes:



76. References

Instructor Notes: This slide is the third of six slides that contain a list of all the references in this presentation.

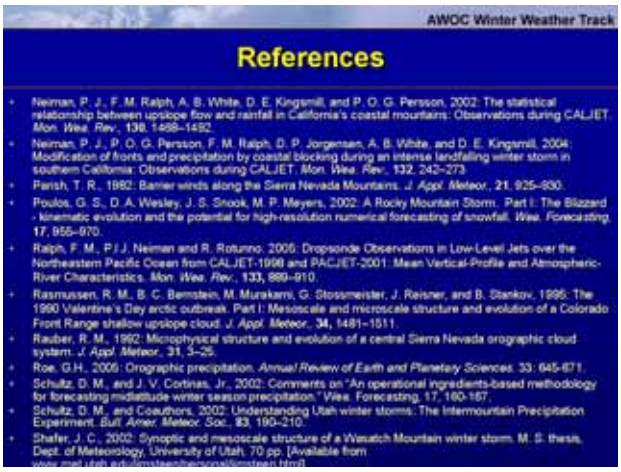
Student Notes:



77. References

Instructor Notes: This slide is the fourth of six slides that contain a list of all the references in this presentation.

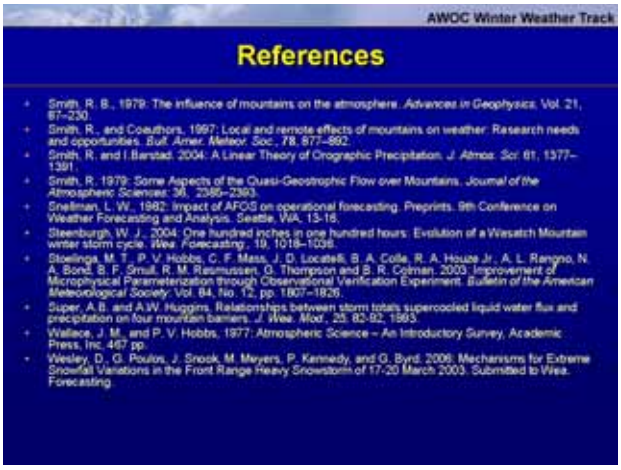
Student Notes:



78. References

Instructor Notes: This slide is the fifth of six slides that contain a list of all the references in this presentation.

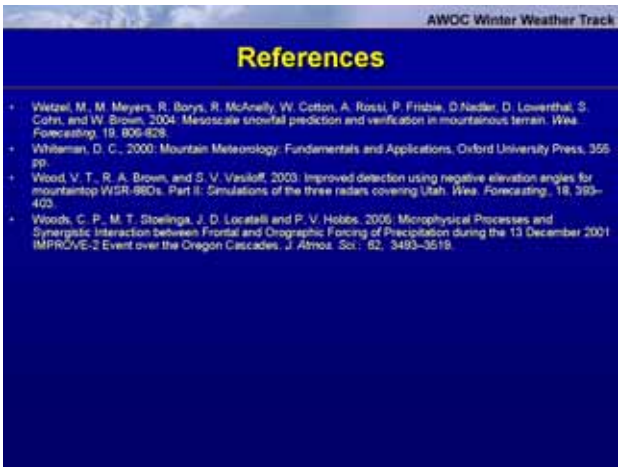
Student Notes:



79. References

Instructor Notes: This slide is the sixth of six slides that contain a list of all the references in this presentation.

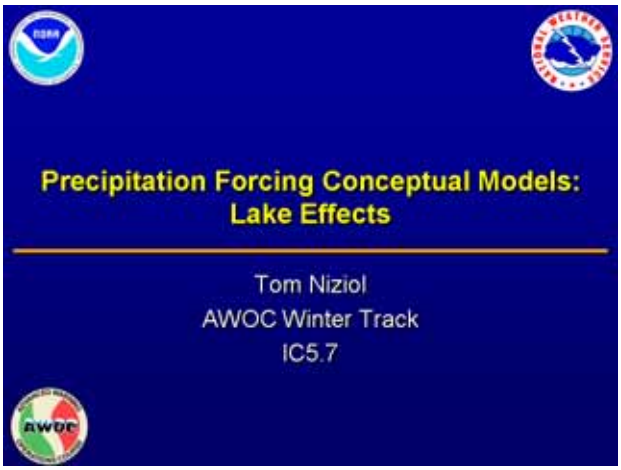
Student Notes:



1. IC5.7: Lake Effects

Instructor Notes: Welcome to AWOC Winter Track IC 5 Lesson 7: Precipitation Forcing Mechanisms and Conceptual Models. Lesson 7 will deal with aspects of lake effect snow.

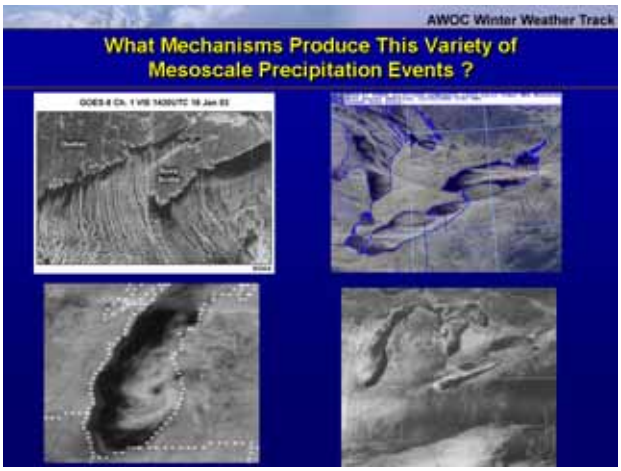
Student Notes:



2. What Mechanisms Produce this Variety of Mesoscale Precipitation Events?

Instructor Notes: Lake and ocean effect snow bands are truly some of the most intriguing displays of winter weather. This module is not meant to provide an in-depth study of lake and ocean effect snow. Rather, it is intended to teach the basic physical processes that combine to produce these mesoscale events. The reader is encouraged however to explore other training areas, such as the MetEd NORLAT (Northern Latitudes) web site for an excellent review of the entire lake/ocean effect process. The link for the site is: http://meted.ucar.edu/norlat/snow/lake_effect/.

Student Notes:



3. Lesson & Learning Objectives

Instructor Notes: Here, we will explore the reasons why lake effect and ocean effect snow bands develop, answering questions about the role that instability plays in modifying an airmass to produce clouds, the effect that frictional and thermal convergence has on snowband development, the effect that the shape and orientation of the body of water and its role in snowband production, and the role that topography has on the development of lake effect snows.

Student Notes:

4. Performance Objective

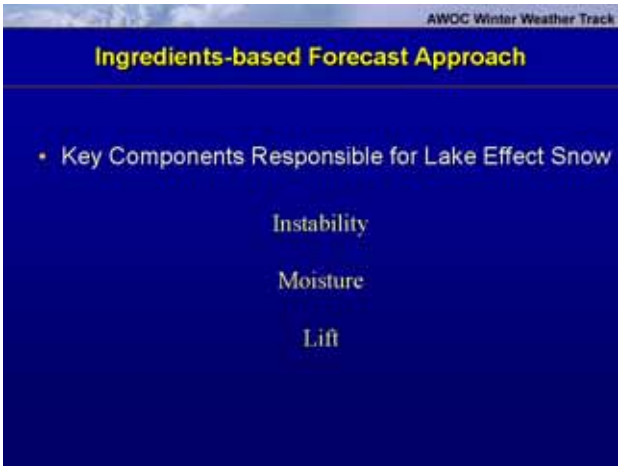
Instructor Notes: Our performance objectives are pretty straightforward. They are to identify the conditions that are favorable for these mesoscale precipitation events, recognize patterns that may be detrimental to organized convective snows, and also understand that the role of local topography has on the location and shape of the bands.

Student Notes:

5. Ingredients-Based Forecast Approach

Instructor Notes: The development of lake effect snow, or convective snows that develop over any warm body of water in general, is (as with all precipitation mechanisms) a result of three main components: instability, moisture, and lift. In the world of lake effect snow, the first two parameters (instability and moisture) are directly linked to the modification of cold air moving across a relatively warm body of water. The third parameter (lift) is related to several other parameters including differences in frictional and thermal forcing in the vicinity of the bodies of water, as well as the surrounding topography. Together, these three parameters combine to produce a diverse array of mesoscale winter weather in select regions around the northern hemisphere.

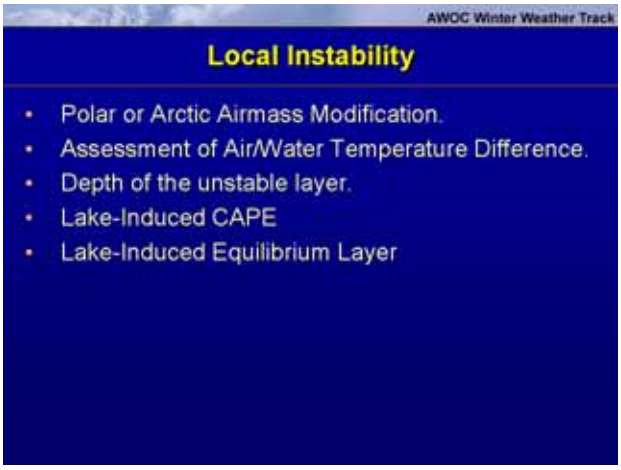
Student Notes:



6. Local Instability

Instructor Notes: Typically, an arctic airmass is not considered to be an environment that promotes a deep layer of instability in the atmosphere. In fact, most arctic airmasses are characterized by a very shallow unstable layer that is generally capped by some sort of subsidence inversion. However, these polar or arctic airmasses do undergo significant modification when that shallow airmass crosses a warm body of water. The modification can result in increases in the depth of the unstable layer. In the next few slides, we will explore the air/water temperature difference and the depth of the unstable layer as the cold airmass crosses the warm water. We will also introduce a couple of terms that are used to help assess the local instability that is a consequence of the modification of the airmass, lake-induced CAPE and lake-induced equilibrium level.

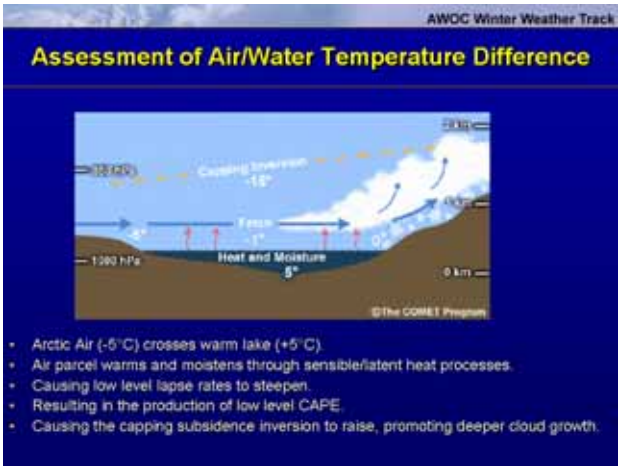
Student Notes:



7. Assessment of Air/Water Temperature Difference

Instructor Notes: So, what are the most important parameters that define the potential for lake effect snow. The single, most important parameter that defines the potential for lake effect snow is the unstable lapse rate that is generated when cold air crosses warm water. A flux of heat and moisture from the warm lake to the cold airmass can create significant instability within the boundary layer. There is a second part to this answer, however. The depth of the cold air, defined by a capping subsidence inversion, will define the height to which convective cloud growth will occur. If there is a strong low level inversion present, then deep convective growth may not be possible. The flux of heat and moisture from the lake will modify and at times completely erode the capping inversion. It is very important, therefore, to have a good understanding of the instability and depth of the unstable layer when assessing the potential for precipitation. The modification of the lower levels of the atmosphere can be very significant at times. In the next few slides, we will look into the modification of the airmass in more detail.

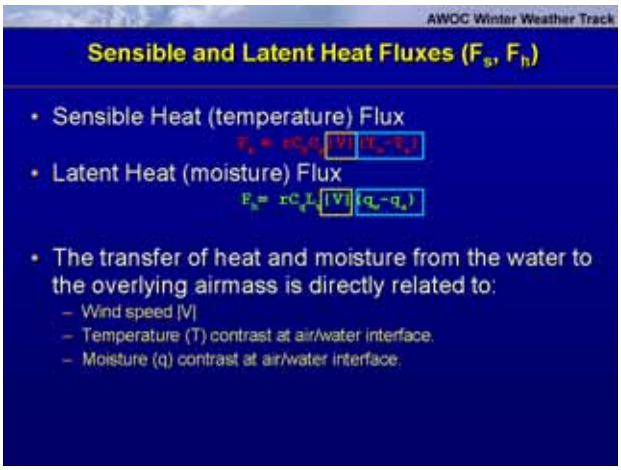
Student Notes:



8. Sensible and Latent Heat Fluxes (Fs, Fh)

Instructor Notes: An unstable lapse rate at low levels, brought about by heating and moistening by the water below, creates an environment favorable for convection. In general, the flux of sensible and latent heat into the lower atmosphere is modulated by the wind speed over the body of water and the temperature and moisture contrast between the water and overriding airmass.

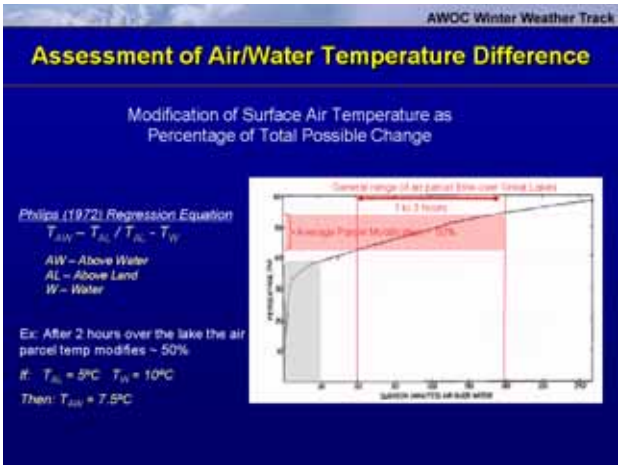
Student Notes:



9. Assessment of Air/Water Temperature Difference

Instructor Notes: Phillips showed through empirical evidence that most of the modification of a parcel's temperature occurs in the first 30 minutes or so over the lake. We further assume that most parcels spend about 1 to 3 hours traversing a typical Great Lake. This broadly suggests that the air parcels moderate about halfway (50%) between their original air temperature and the temperature of the lake. In the example, we begin with and air parcel that has a temperature of 5 degrees C and a lake temperature of 10 degrees C. If we assume about a 50% modification of surface temperature, then the air parcel reaches equilibrium at about 7.5 degrees C. Reference: PHILLIPS, DAVID W.Modification of Surface Air Over Lake Ontario in WinterMonthly Weather Review 1972 100: 662-670 Reference: PHILLIPS, DAVID W.Modification of Surface Air Over Lake Ontario in WinterMonthly Weather Review 1972 100: 662-670

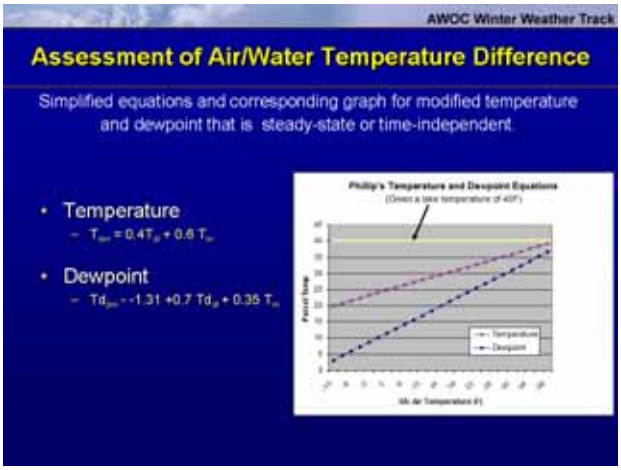
Student Notes:



10. Assessment of Air/Water Temperature Difference

Instructor Notes: If we further assume that the air parcel reaches a steady-state at some point over the body of water, or in other words is time-independent, then the equations can be further simplified as shown. Referring to the graph, I have taken an example where the lake temperature is 40 degrees F, then plotted the modified temperature and dewpoint vs. the original parcel temperature and dewpoint. You can see that there is a much greater response (warming) of the parcel's temperature compared to the moisture response.

Student Notes:

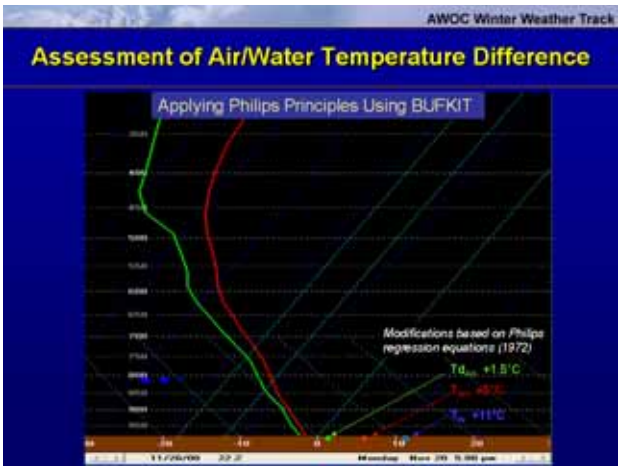


11. Assessment of Air/Water Temperature Difference

Instructor Notes: So, based on the information we learned from the Philips studies and assumptions, let's look at an example of how much modification an air parcel might undergo. We start with a sounding over land (Buffalo, NY), and assume an air temperature of about -1 degrees C and a dewpoint of about -2 degrees C. The water temperature of adjacent Lake Erie is 11 degrees C. So, the air parcel's temperature is 12 degrees C colder than the lake temperature. Philips says that the parcel's temperature will be modi-

fied or warmed to about 5 degrees C, while the dewpoint will warm to about 1.5 degrees C. Based on the modified surface temperature and dewpoint, we end with a very unstable sounding as far as mesoscale winter convection is concerned (as shown in the following slide).

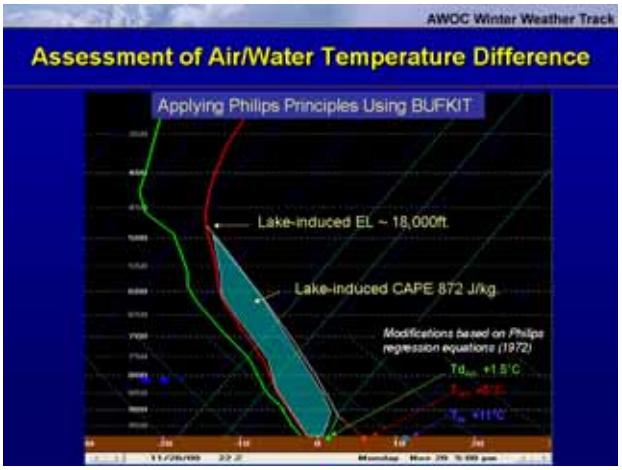
Student Notes:



12. Assessment of Air/Water Temperature Difference

Instructor Notes: That modification of air parcel temperature and dewpoint creates a significant amount of CAPE, allowing convective cloud growth as high as 18,000ft.

Student Notes:



13. Quiz 1: Parcel Modification

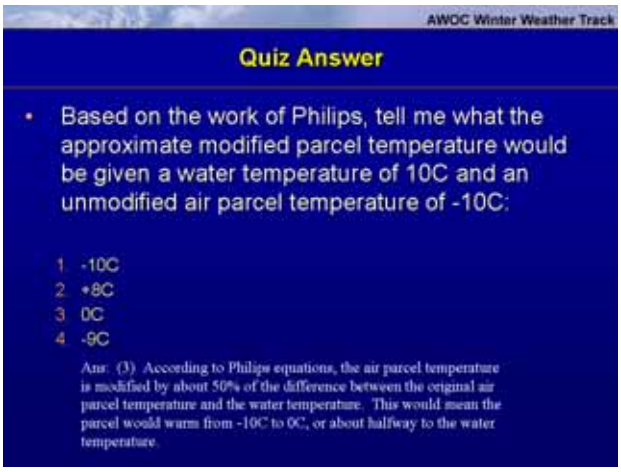
Instructor Notes: Take a moment to complete this quiz.

Student Notes:

14. Quiz 1 Answer

Instructor Notes: The correct answer is 0 degrees C.

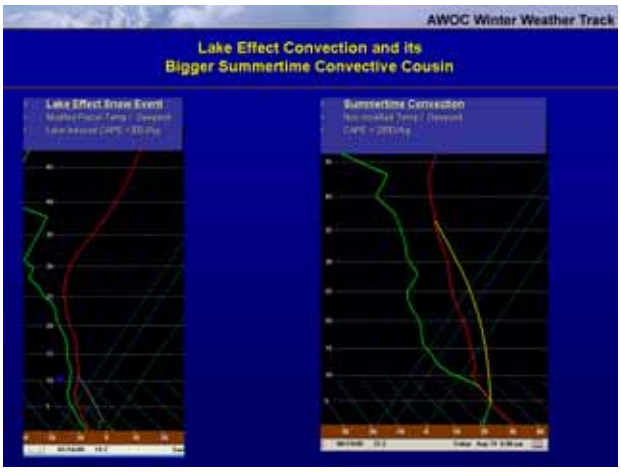
Student Notes:



15. Lake Effect vs. Summer Thunderstorm Sounding

Instructor Notes: Now, a summertime thunderstorm forecaster might say “so what?” Those convective indices are really not that impressive. As a matter of fact, let’s compare a typical lake effect snow sounding (modified due to its passage over a warm lake) and a mid-latitude summer thunderstorm sounding. Can the modification of the lapse rate on such a wimpy vertical scale really have implications in the LOES environment?

Student Notes:

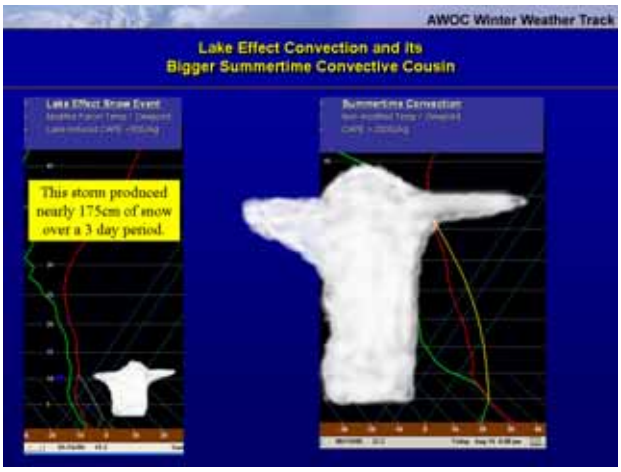


16. Lake Effect Convection and its Bigger Summertime Convective Cousin

Instructor Notes: You bet it can! Although the resulting vertical scale of convection pales in comparison to summertime thunderstorms, most of the processes associated

with summertime convection are there, it just happens on a smaller scale. As long as you can produce a deep enough cloud with the proper temperature and moisture structure, you can also produce respectable precipitation. Whereas LOES events are confined to a much smaller vertical scale, the temporal scale of these steady state events can last several hours and, at times, more than an entire day. As a result, precipitation totals can be impressive. In regions of deeper convection, particularly during the late fall in the Great Lakes Region, heavily rimed snow crystals and graupel can be carried a couple of kilometers into the cloud. That is high enough to produce a charge separation that leads to lightning and thunder. There is nothing like being caught outside in “thundersnow”!

Student Notes:



17. Morphology of Snow Bands

Instructor Notes: Ok, now we have a basic understanding of the modification and resulting instability that an air parcel attains as it moves across the warm body of water. So, what mechanisms contribute to the development of so many different types of snow bands. Let’s explore that question in the next several slides.

Student Notes:

18. Morphology of Snow Bands

Instructor Notes: Once boundary-layer instability over the water has been enhanced by moistening and warming, several mesoscale mechanical lifting mechanisms may help to trigger and/or enhance the convective processes. The buoyancy over the body of water contributes to horizontal roll convection, with the cloud streets lined up parallel to the prevailing flow. In addition, terrain or orographic lifting contributes significantly to snowfall production and, in some cases, channeling of flow. Differences in frictional convergence between a smooth lake surface vs. the rougher land surface (as well as differences in thermal convergence between warm bodies of water and colder adjacent land masses) also play a predominant role in snowband morphology. Finally, the shape and orientation of these bodies of water including the effects of irregular shorelines and bays and inlets also can have a profound influence on snowband development.

Student Notes:

19. Morphology of Snow Bands: Horizontal Roll Convection

Instructor Notes: In a general sense, as you move cold air across a warm body of water, horizontal rolls develop aligned along the prevailing wind direction. Here, the prevailing flow within the cloud layer is into the board. This phenomenon is most often seen on large bodies of water without restricting shorelines such as the offshore portions of the Atlantic Ocean and Gulf of St. Lawrence. In addition, horizontal rolls are common on smaller bodies of water, such as the Great Lakes, when the prevailing wind is directed perpendicular to the longest axis of the lake.

Student Notes:

20. Morphology of Snow Bands: Multiple Bands

Instructor Notes: This graphic is an example of parallel roll convection occurring in arctic northerly flow off the Canadian Maritimes over the Atlantic Ocean. Note, that when air trajectories are directed out over a broad expanse of water, such as an ocean, parallel roll convection is common. However, when the trajectory moves over smaller bodies of water, several types of bands can occur in addition to multiple streamers.

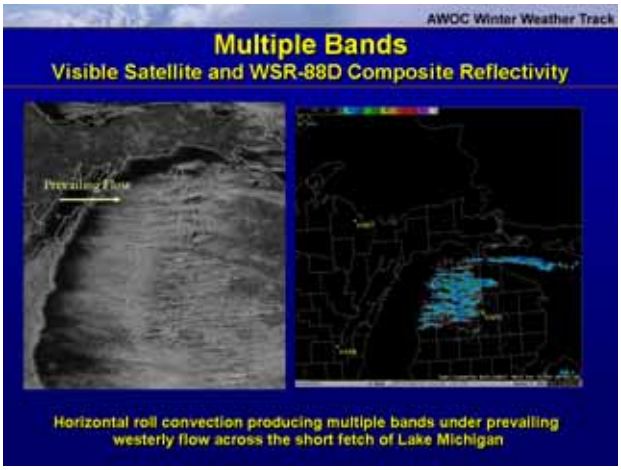
Student Notes:

21. Multiple Bands: Visible Satellite and WSR-88D Composite Reflectivity

Instructor Notes: Over bodies of water such as the Great Lakes, parallel roll convection is likely when the prevailing flow is across the shorter fetch of the lake as we see here on Lake Michigan. You can even see the banded structure in the precipitation echoes in the accompanying radar image here. These types of bands do not necessarily produce the heaviest snowfall amounts, but they can raise havoc for those travelling in the region. It

is not uncommon when driving on roads that parallel the shore to drive in and out of snowfall, reducing visibilities greatly, as you cross each successive band.

Student Notes:



22. Quiz 2: Horizontal Roll Convection

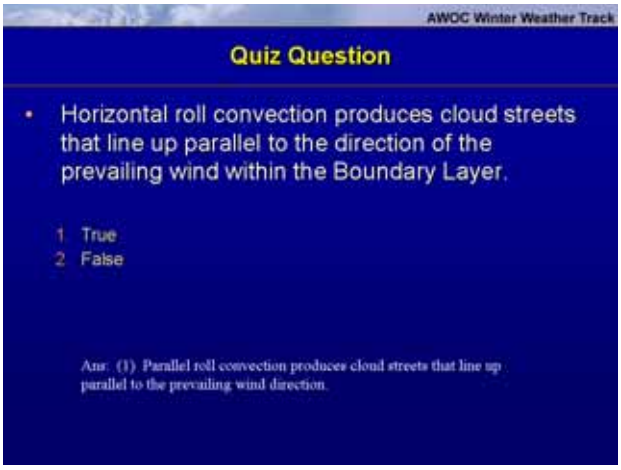
Instructor Notes: Take a moment to complete this interactive quiz.

Student Notes:

23. Quiz 2 Review

Instructor Notes: The correct answer to this question is true.

Student Notes:



24. Morphology of Snowbands: Single Band Development

Instructor Notes: When you are dealing with bodies of water that have shorelines that are parallel to one another such as several of the Great Lakes, differences in frictional and thermal properties of the shore and water combine to produce some interesting effects. Instead of several bands associated with horizontal roll convection, when winds are directed down the long fetch of lakes (with roughly parallel shores) you can end up with one, strong main band of snow.

Student Notes:

25. Morphology of Snowbands: Frictional Convergence - Single Band Development

Instructor Notes: Surface winds moving over water experience very little frictional drag. So, wind speeds are relatively higher than those over land surfaces where hills, vegetation, and even large buildings can reduce wind speed. As a result, fast-moving air over the water converges into slow-moving air over the land, creating a zone of frictional con-

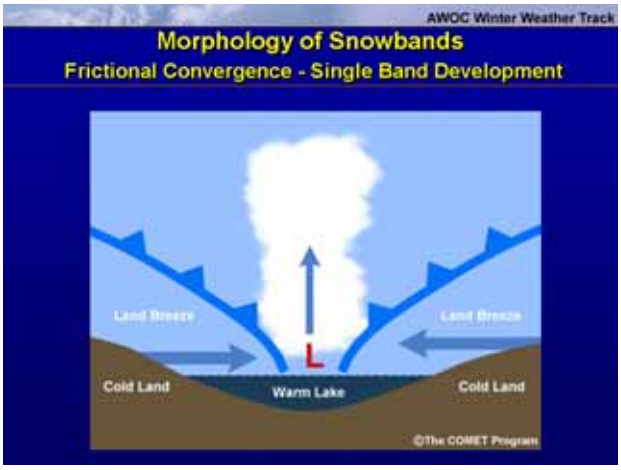
vergence and lift near the leeward shore. The opposite effect occurs along the windward shore, resulting in surface frictional divergences and subsidence. In addition, the winds over land are slowed to a greater extent by friction resulting in a larger leftward deflection across isobars towards lower pressure than that occurring over the water. Therefore, when winds are directed parallel to the long fetch of a body of water, relative to the prevailing low-level wind flow, frictional convergence is favored near the right-hand shoreline, and this can be the dominant factor in creating a single band of convection near the shore. Over time this band may propagate inland away from the original zone of convergence.

Student Notes:

26. Morphology of Snowbands: Frictional Convergence - Single Band Development

Instructor Notes: An additional source of convergence and lift is brought about by the land breeze generated by the thermal gradient between the lake and adjacent land areas. On elliptically shaped bodies of water, or those with parallel shorelines over a narrower portion of the lake, the relatively warm, the moist environment over the water contributes to the formation of a “mesolow” that enhances the convergence of cooler land breezes over the water body. The cooler land breeze helps to lift the unstable air over the water, and this lifting can be particularly significant in cases where land breezes from opposite shores converge in the vicinity of the mesolow. In environments with strong, prevailing synoptic-scale flow, the effect of the land breeze is overshadowed a bit by the prevailing wind, but it still exists.

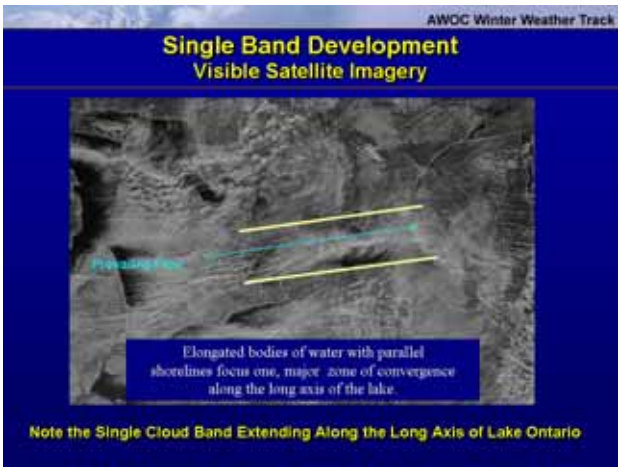
Student Notes:



27. Single Band Development: Visible Satellite Imagery

Instructor Notes: So, let's go back to one of our single band satellite images and look at it more closely in relationship to its orientation and shape with the two parallel shores of lake Ontario. The combination of frictional and thermal convergence when prevailing flow is parallel to the long axis of an elliptically shaped body of water will produce a single, strong convergence zone and snow band over the lake.

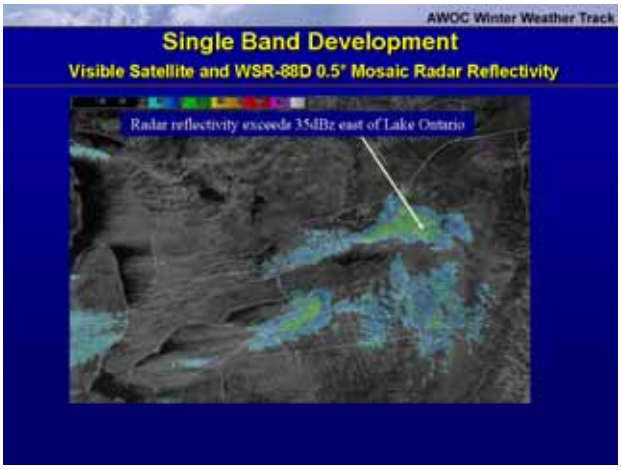
Student Notes:



28. Single Band Development: Visible Satellite and WSR-88D 0.5 Degree Mosaic Radar Reflectivity

Instructor Notes: Here you can see the actual precipitation echoes associated with the cloud band. The single band of snow that is generated in this fashion can produce extreme snowfall rates in excess 4 inches per hour at times. They also are often accompanied by lightning and thunder.

Student Notes:



29. Single Band Development: METAR Reports - Convergence Zone

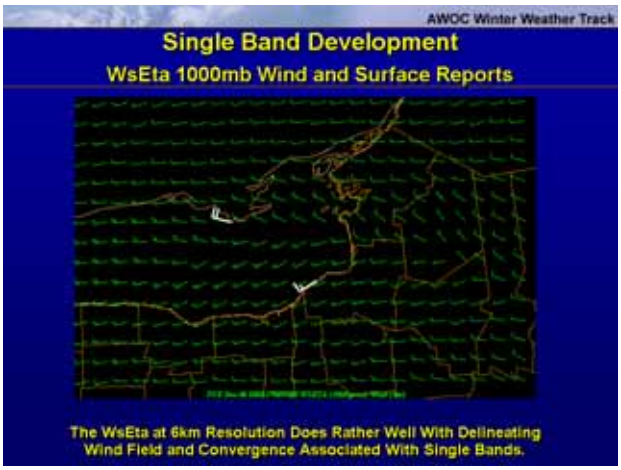
Instructor Notes: As noted, the combination of frictional and thermal convergence when prevailing flow is parallel to the long axis of an elliptically shaped body of water will produce a single, strong convergence zone over the lake. Here you can see the effect that this environment has on opposite shores of the lake. Check out the wind direction and speed on the north shore of Lake Ontario at a place Called Pt. Petre. We have NW wind at 20 (with gusts to 26) kts. Now, just a few miles away, along the south shore of the lake, Oswego is reporting a SW wind of 16 (with gusts to 32) kts. Over a distance that spans less than 40 nm., there is nearly a 90 degree wind shift with significant wind speeds, producing a narrow, strong zone of convergence leading to impressive vertical motions out over the lake.

Student Notes:

30. Single Band Development: WsEta 1000 mb Wind and Surface Reports

Instructor Notes: So let's take this a step further and see if we can diagnose the environment around one of these strong single bands of snow. Here, we are looking at output from one of our higher resolution numerical models to diagnose that same convergence zone. This graphic is from a 6-km version of the Workstation Eta model. I overlaid the approximate locations of the two observations we referred to in the last slide in white onto the model 1000mb wind forecast taken at the same time of the observations. It looks like the model did a relatively good job at picking out that convergence zone. But what kind of convergence are we seeing within that zone over the lake

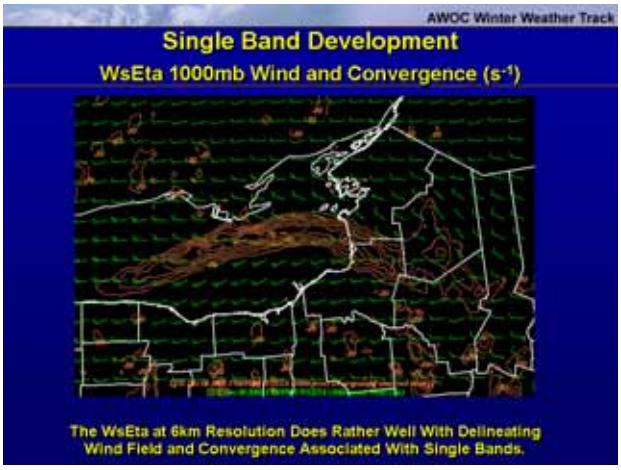
Student Notes:



31. Single Band Development: WsEta 1000 mb Wind and Convergence (s^-1)

Instructor Notes: Now, we overlay the model 1000mb convergence field produced by those winds and you have some idea of the type of lift that is occurring out over the lake.

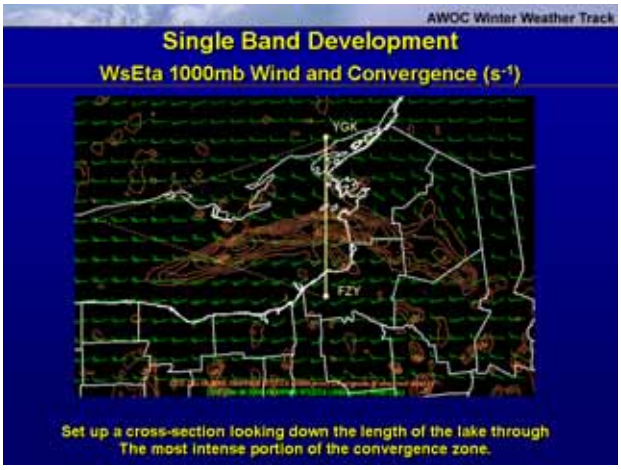
Student Notes:



32. Single Band Development: WS ETA 100mb wind & convergence

Instructor Notes: I want to take this one step further and try to give you a better idea of the vertical and horizontal scales of the convection. So, we will draw a cross-section through the model snow band at the east end of the lake as shown by the line. In the next slide, you will be viewing the cross-section from the west end of Lake Ontario, looking down the long fetch of the lake with the north shore on the left-hand side and the south shore on the right.

Student Notes:

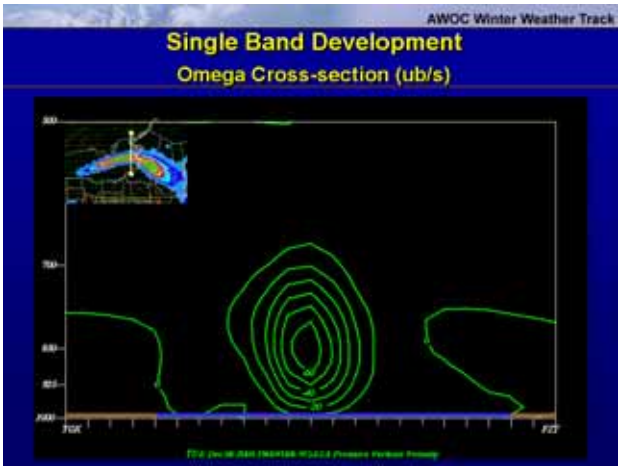


33. Single Band Development: Omega Cross-Section

Instructor Notes: This graphic is the omega field that represents the lake effect snow band out over the east end of the lake. Note: the depth of the omega field is only up through about 700mb with the max somewhere around the 850mb level. The horizontal scale of the omega field is on the order of only about 15 miles in width. If you want to

diagnose the vertical motion field in such lake effect convection, it is often better to look at vertical motion fields well below 700mb, typically in the range of 900 to 850mb.

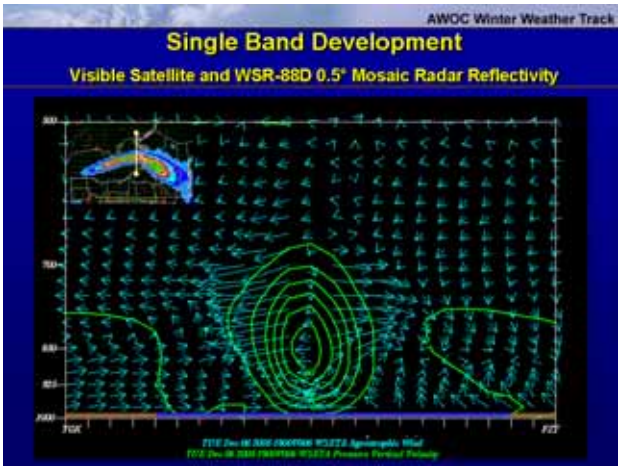
Student Notes:



34. Single Band Development: Visible Satellite and WSR-88D 0.5 Degree Mosaic Radar Reflectivity

Instructor Notes: To complete the understanding of the type of circulation that this environment produces, we overlay the ageostrophic wind onto the circulation. Doing so clearly shows the low-level convergence and midlevel divergence associated with the snow band.

Student Notes:

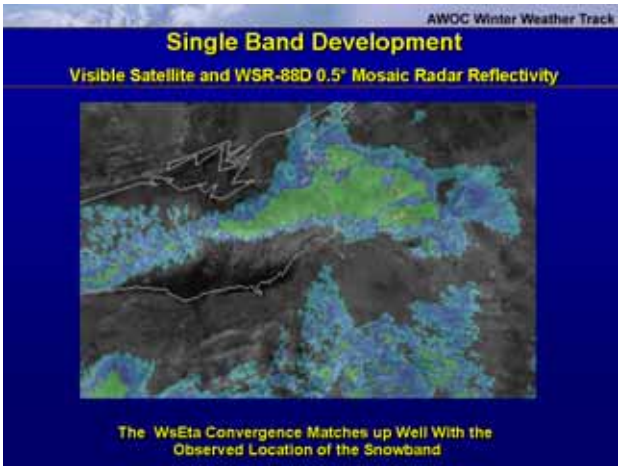


35. Single Band Development: Visible Satellte and WSR-88D 0.5 Degree Mosaic Radar Reflectivity

Instructor Notes: Here is the actual radar/satellite image from that same timeframe. The Workstation ETA (WsEta) model did a pretty good job at capturing the mesoscale

circulation responsible for the development of this single band of heavy snow. This band produced over 2 feet of snow.

Student Notes:



36. Morphology of Snowbands: Land Breeze Snowbands

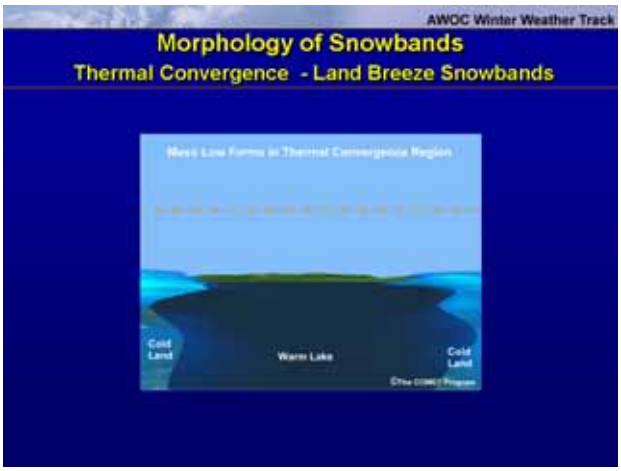
Instructor Notes: This example may look like another wind parallel, single band of snow. However, it formed under different circumstances and is generally much weaker than the single band that we just looked at. If the prevailing flow is very weak and the air-lake temperature difference is significant, there is little contribution from differential frictional convergence; rather, thermal convergence is the main player. In this situation, a well-defined land breeze circulation develops that produces a weak convergence zone over the lake. The resulting snowband may take on the configuration shown, in which the snowband parallels the shore.

Student Notes:

37. Morphology of Snowbands: Thermal Convergence - Land Breeze Snowbands

Instructor Notes: In these types of bands, the predominant mechanism responsible for the location and shape of the snow band is the land breeze generated by the thermal gradient between the lake and adjacent land areas. The relatively warm, moist environment over the water contributes to the formation of a “mesolow” that enhances the convergence of cooler land breezes over the water body. The cooler land breeze helps to lift the unstable air over the water. This lifting can be particularly significant in cases where land breezes from opposite shores converge in the vicinity of the mesolow.

Student Notes:



38. Land Breeze Snowbands

Instructor Notes: At times, the position of this band may be near the shoreline, similar to the location of the band created by frictional convergence, when the larger-scale background flow forces the convergence zone closer to the leeward shore. This suggests that in certain instances multiple convergence mechanisms may be working in concert to enhance the lifting. These types of bands generally do not produce the snowfall amounts that accompany single, wind parallel bands forced by thermal and frictional convergence. Why not? Answer the quiz question next to find out…

Student Notes:

39. Quiz 3: Snowbands

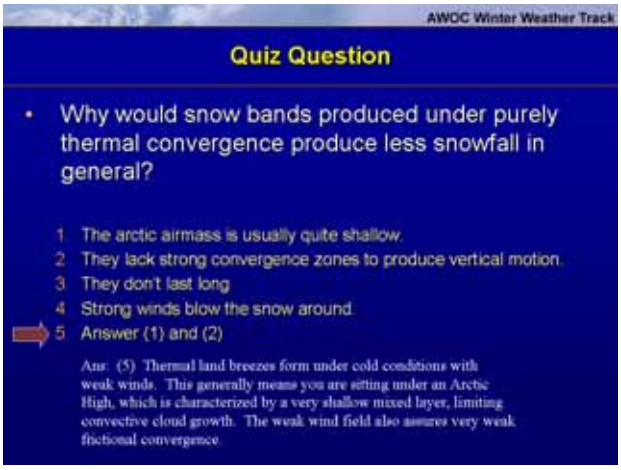
Instructor Notes: Take a moment to complete this quiz.

Student Notes:

40. Quiz 3 Review

Instructor Notes: The correct answer is both #1 and #2.

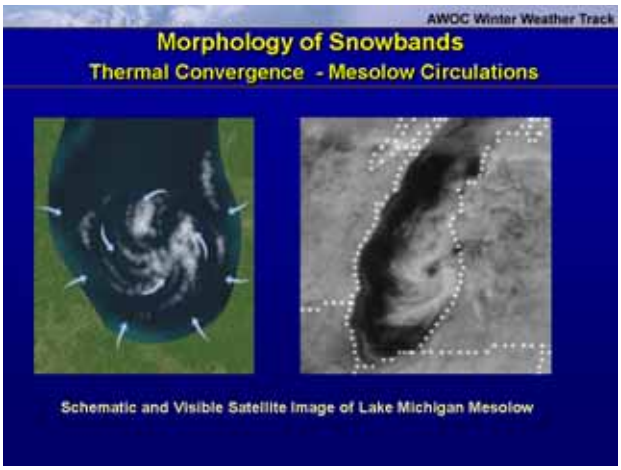
Student Notes:



41. Morphology of Snowbands: Thermal Convergence - Mesolow Circulations

Instructor Notes: In cases where the shoreline takes on a bowl-shaped or more circular configuration, the thermal convergence cab actually produce a rotational circulation or a mesolow. Once again, the type of weather system that typically produces pure, thermal convergence due to weak synoptic-scale wind and very cold temperatures is generally an arctic high, which is capped by a strong subsidence inversion, limiting convective cloud growth and snowfall.

Student Notes:



42. Mesolow Circulations: WsEta Surface Wind and 1-Hour QPF

Instructor Notes: Here is a movie of the Workstation Eta (WsEta) running at 6-km resolution under very weak synoptic-scale flow and significant temperature difference between the land and water. Pay attention to the southern end of Lake Huron, where a land breeze convergence zone has developed along the west shore of the lake. As we

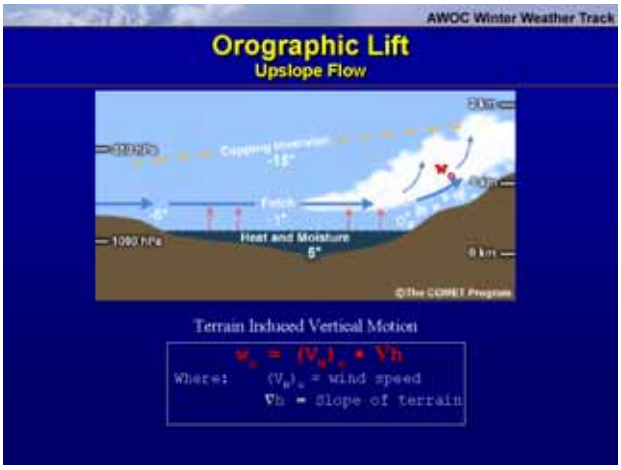
move forward in time in one-hour increments, you will see the plume of precipitation and the associated convergence zone move north, develop a “spin” off the thumb of Michigan, and finally develop into a mesolow out over the relatively bowl-shaped portion of the lake. You can even see a mesolow briefly develop on Lake Erie, where the “bowl-shaped” north shore may be responsible for a “spin-up” too.

Student Notes:

43. Orographic Lift: Upslope Flow

Instructor Notes: Our final ingredient in producing lift is the effect that the topography of the region downwind of the lake has on snow production. As shown in the formula, terrain induced vertical motion is a direct result of wind speed and the slope of the terrain and (as we will see in following slides) there is a surprising amount of lift that can occur as a consequence of orographic features downwind of many lakes.

Student Notes:

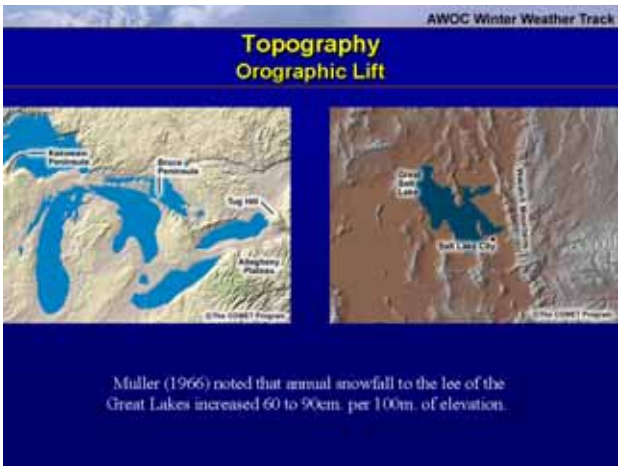


44. Topography: Orographic Lift

Instructor Notes: As snow bands encounter the higher elevations downwind of the lakes, snowfall is enhanced by an increase in the vertical motion produced by the flow.

This effect can be significant, especially when taken over an entire winter season. Muller (1966) noted that annual snowfall to the lee of the Great Lakes increased 60 to 90 cm per 100 m of elevation. In addition, the topography downwind of the body of water can help channel lake effect snow bands. As an example, the region around the Great Salt Lake where alternating north-south ridges and valleys to the southeast of the lake channel the flow. Reference: Muller, Robert, A. 1966. Snowbelts of the Great Lakes. Weatherwise 19, No. 6 (Dec. 1966): 248-55.

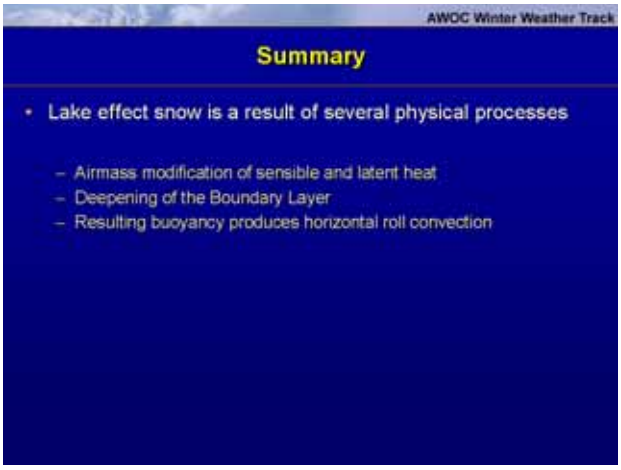
Student Notes:



45. Summary

Instructor Notes: So, in summary, there are several physical processes that contribute to the formation of these mesoscale snow storms, including: the modification of the airmass due to the release of sensible and latent heat as the cold air crosses the warm water, the deepening of the boundary layer from the modification of the lower atmosphere, and the development of convective rolls as the buoyancy of the airmass increases.

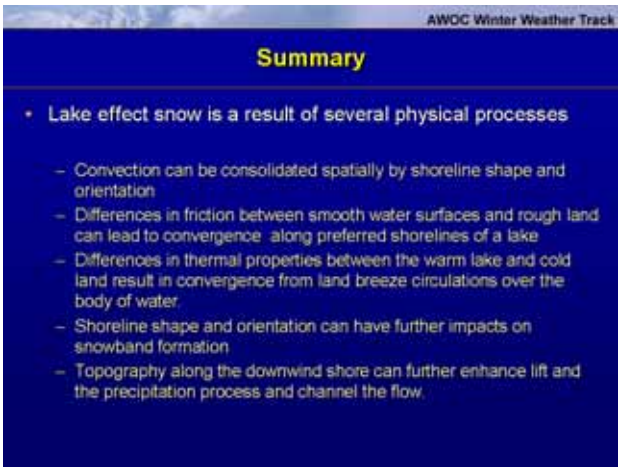
Student Notes:



46. Summary

Instructor Notes: In addition, under conditions such as parallel shorelines on some lakes, the roll convection can be consolidated into one particular band. Frictional effect between land and water will produce preferred areas of convergence. Thermal differences between land and water will create preferred areas of convergence as well. The shape and orientation of the shoreline itself will also contribute to preferred areas of band development. Finally, topography will further enhance lift and precipitation production while also helping to channel flow in some situations.

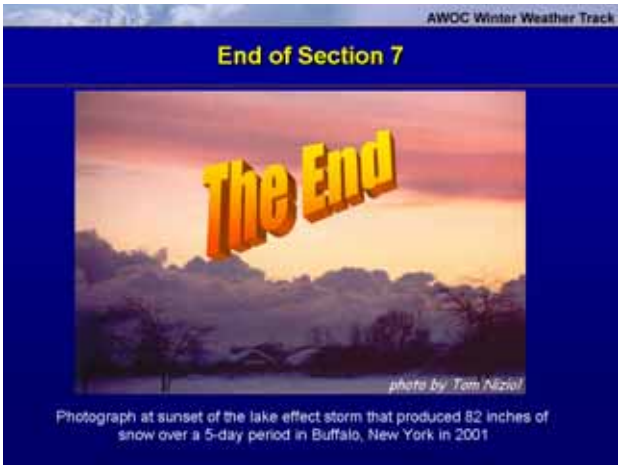
Student Notes:



47. End of Section 7

Instructor Notes: I hope you enjoyed a brief look at the physical processes that contribute to the development of lake snows. Other components of these mesoscale features that we were not able to discuss here, are addressed in other parts of AWOC's Winter Weather Course. I will also point you to the COMET NORLAT or Northern Latitudes web page (available off the MetEd web site) for a more in-depth discussion of lake effect snow.

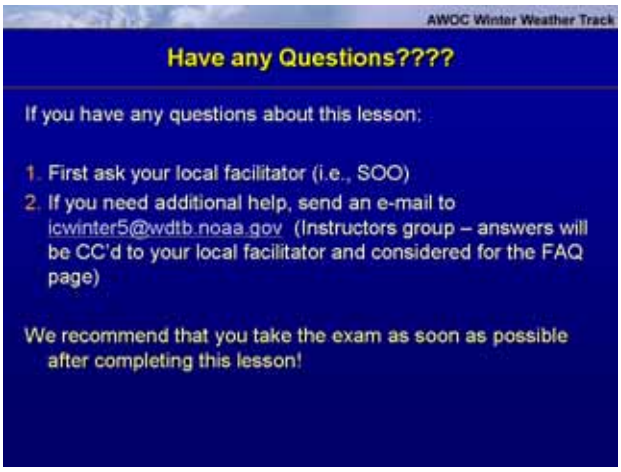
Student Notes:



48. Have Any Questions????

Instructor Notes: If you have any questions about this lesson, first ask your local AWOC facilitator. If you need additional help, send an E-mail to the address provided. When we answer, we will CC your local facilitator and may consider your question for our FAQ page. We strongly recommend that you take the exam as soon as possible after completing this lesson.

Student Notes:



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IC5 Lesson 7

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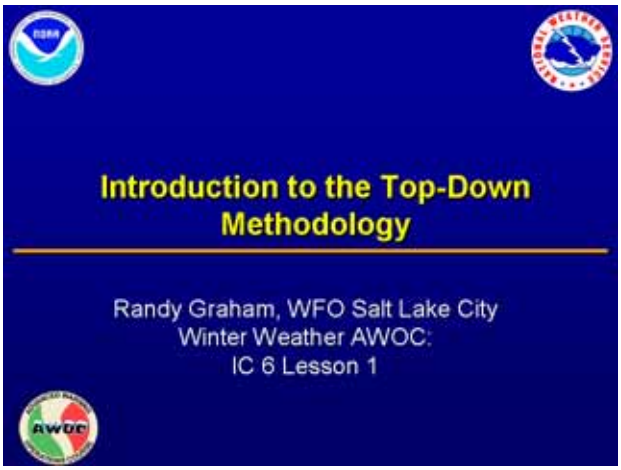
IC Winter 6: Synoptic / Mesoscale Forecasting of Precipitation Type and Amount

1. IC6.1: Introduction to the Top-Down Methodology

Instructor Notes: Welcome to IC 6 lesson 1 Introduction to the Top-Down Methodology. This lesson is 42 slides long and will take approximately 35 minutes to complete.

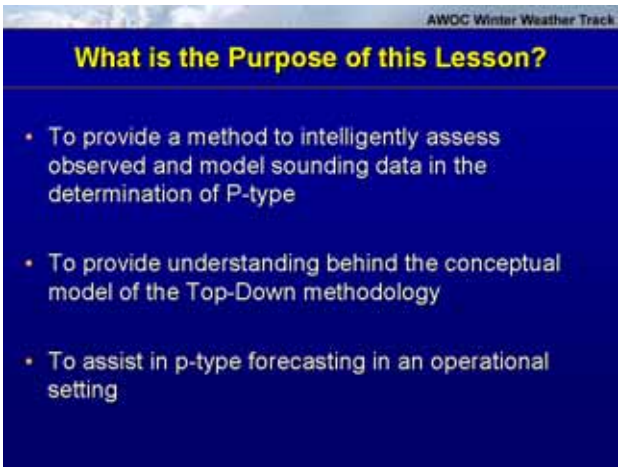
Student Notes:



2. What is the Purpose of this Lesson?

Instructor Notes: This is the 1st lesson in IC6. This lesson will cover the Top-Down methodology for determining precipitation type. Much of the material in this module is built off of work compiled by Dan Baumgardt (SOO, LaCrosse WI). The motivation for this lesson is to enable forecasters to intelligently assess observed and model soundings with respect to the determination of precipitation type. The lesson will examine the reasoning behind the different concepts utilized in the top-down methodology. Ultimately, the lesson will allow us to assess observed and model soundings in a manner which will assist in the determination of precipitation type in an operational setting. The speaker notes for this lesson will contain additional detail above beyond that which on the slides and may serve as a good reference for review.

Student Notes:



3. Outline

Instructor Notes: This lesson is divided into six sections. The first section will provide a brief overview of the learning and performance objectives for this lesson. The final five sections are dedicated to ice nuclei and activation temperatures, warm layer impacts, surface layer considerations and, finally, a complete overview of the top-down methodology.

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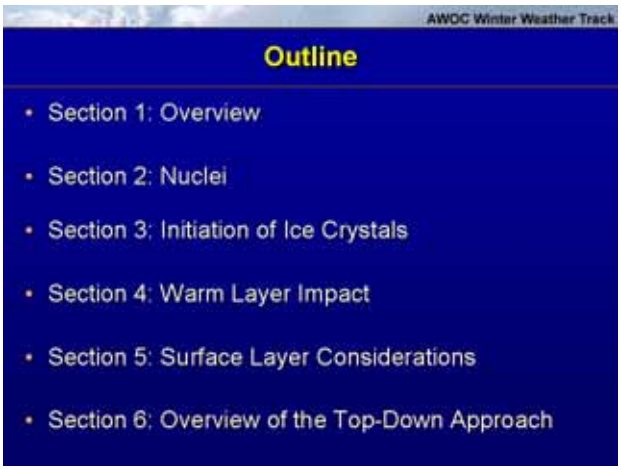
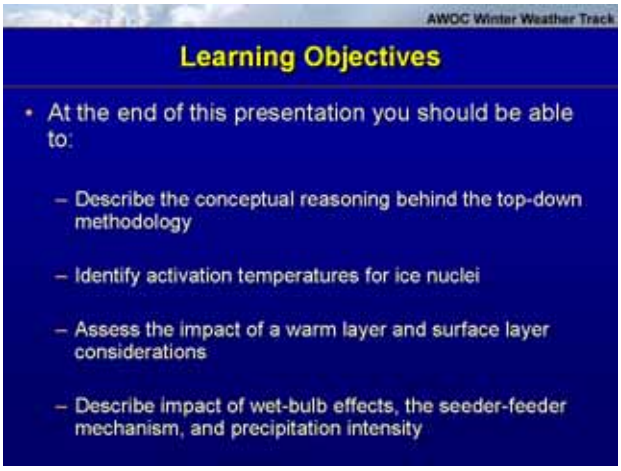


4. Learning Objectives

Instructor Notes: The primary learning objective for this lesson is to understand the conceptual reasoning behind the top-down methodology. After completion of this module you should be able to identify activation temperatures for ice nuclei, be able to assess the impact of a warm layer, as well as understand surface layer considerations. You should also be able to describe the impact of other factors that impact the resultant precipitation type such as wet-bulb temperatures, the seeder-feeder mechanism, and precipitation intensity.

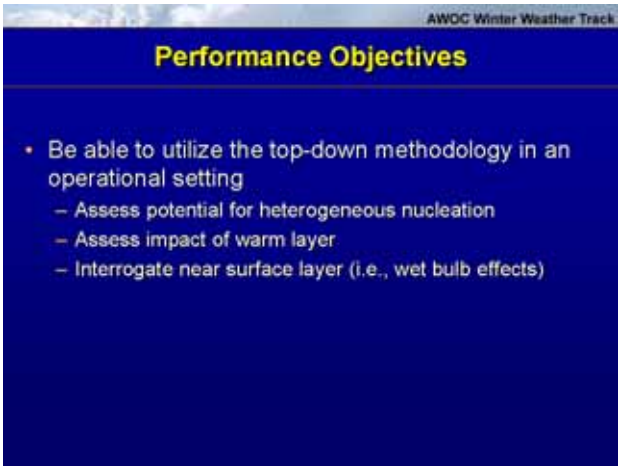
Student Notes:



5. Performance Objectives

Instructor Notes: The ultimate success of the lesson driven by impacting performance in an operational setting. At the end of this lesson you will be able to successfully apply the Top-Down methodology in forecast operations. This includes assessing the potential for heterogeneous nucleation. In other words you will be able to interrogate a sounding and determine the likelihood that a cloud in the environment represented by the sounding will be able to support heterogeneous nucleation. You also will be able to assess the impact of elevated warm layers. For example, if an ice crystal is entering an elevated warm layer will the layer be strong enough to partially or completely melt the ice crystal as it falls through the layer? Additionally, you will be able to interrogate the impact of the near surface layer on the resultant precipitation type in an operational setting. This will include the ability to assess the impact that wet bulb effects and precipitation intensity may have on the precipitation type.

Student Notes:



6. Why Use the Top-Down Methodology?

Instructor Notes: So, why should we use the top-down methodology? When low resolution models were the only form of guidance available forecasters were forced to rely on standard level temperatures and deep layer thickness rules of thumb to assess precipitation type in a forecast environment. Since the advent of gridded data sets we now have the opportunity to more robustly assess the evolution of precipitation particles from their initial development through their descent to the surface. The high resolution data sets that are available today allow us the opportunity to assess the potential for a variety of precipitation types quite readily through the utilization of BUFR profiles of temperature and moisture. The top-down methodology employs microphysical concepts to insinuate the initial phase of the precipitation particles and then attempts to ascertain the evolution of the hydrometeors as they descend through the lower troposphere. The top-down methodology can be applied to both observed and forecast soundings. Of course, when looking at forecast profiles produced by NWP models the forecaster must consider the accuracy of the model before one can reliably utilize the forecast sounding to assess pre-

cipitation type. If the model has a poor handle on the large scale features then the resulting thermal and moisture profiles may be inaccurate and will likely not yield a quality p-type forecast. Also, keep in mind that higher resolution model data may have the right idea, but if, for example, the intense forcing associated with a mesoscale snow band in the guidance is misplaced the vertical profiles may be inaccurate as well. As with any assessment of NWP guidance it is critical that forecasters assess the performance of the model to determine the quality of the NWP forecast. The application of the top-down methodology discussed in this lesson and the microphysical concepts that are the root of the method are readily understood and can easily be applied in an operational setting. In addition, not only do these microphysical concepts tell us something about the precipitation type we can also utilize these concepts to glean information about the potential precipitation intensity for a pending precipitation event which will be covered in subsequent AWOC lessons.

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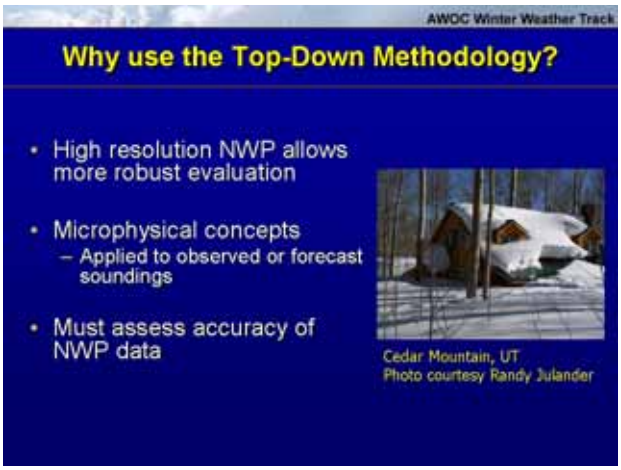

7. This the Core of the Top-Down Methodology

Instructor Notes: To utilize the Top-Down methodology we, as forecasters, have much to consider. However, a good understanding of the concepts upon which the methodology is built will enable us to robustly interrogate both observed and model soundings in anticipation of a variety of precipitation types. The concept of the top-down methodology intuitively begins with an assessment of the initial or predominant hydrometeor state in the cloud. In this module we will discuss how to assess the potential that a cloud contains ice crystals versus one that is dominated by super-cooled water droplets. After assessing the likelihood of ice crystals in the cloud the top-down methodology leads us interrogate any elevated warm layers that may be present. That is, assuming that we have ice crystals entering an elevated warm layer, how warm or deep does it need to be to completely melt the hydrometeors? At what point is a warm layer so shallow or weak that it has little impact on the resultant hydrometeor state? Finally, we will assess the near surface layer to determine if there is a deep enough warm layer to melt ice crystals, or if there is a cold wedge strong enough to re-freeze hydrometeors, possibly melted in an elevated warm layer, into ice pellets. Other concepts that must be considered include the seeder-feeder mechanism through which ice crystals can be introduced into a cloud that other-

wise would not support heterogeneous nucleation. One must also consider wet-bulb effects which can have a significant impact on the ultimate precipitation type if temperatures fall rapidly due to evaporative cooling as hydrometeors descend through a relatively dry layer in the troposphere. Lastly, the impact of precipitation intensity on precipitation type must be considered.

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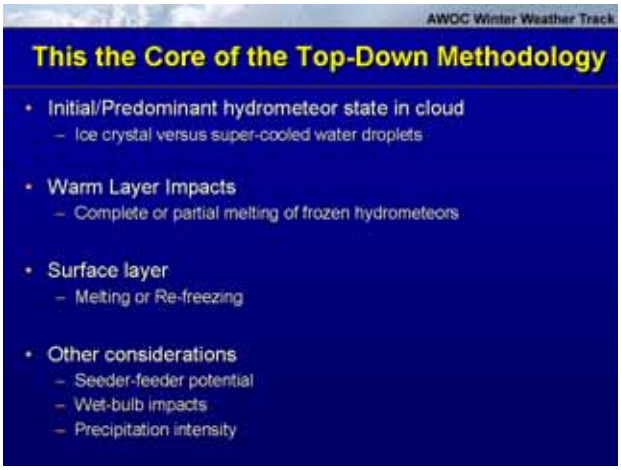
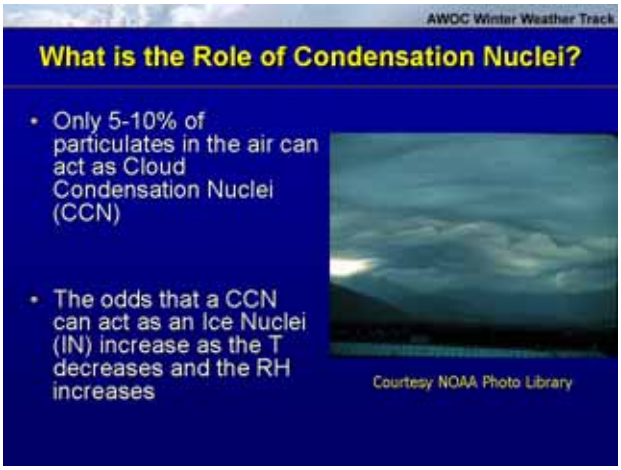


8. What is the Role of Condensation Nuclei?

Instructor Notes: Of all of the particulates in the air only 5-10% of these can act as Cloud Condensation Nuclei (CCN). These are particulates which support the growth of cloud droplets on their surface. Of the available CCNs only a very small number can act as ice nuclei thereby supporting the growth of ice crystals. The odds that a CCN can act as an ice nuclei increase as the temperature decreases and the relative humidity increases. Therefore, heterogeneous nucleation is more likely to occur in the coldest regions of a cloud, which is typically in the upper reaches of the cloud.

Student Notes:



9. Initiation of Crystal Growth

Instructor Notes: Ice Nuclei (IN) are available in the atmosphere at much lower concentrations than are Cloud Condensation Nuclei. IN are hygroscopic molecules, meaning that they attract water. According to Rogers (1979), the hexagonal lattice structure which comprises IN resembles that of natural ice. IN, however, do not become active until the environment in which they are present reaches a certain temperature threshold (assuming saturation with respect to ice). As we shall discuss shortly, the temperature at which these IN become active varies for the different types of IN. One certainty is that as the temperature drops, more IN become available to initiate ice crystal formation. In other words, the concentration of active IN rises as the temperature drops. The term 'Heterogeneous Nucleation' simply refers to crystal initiation or activation on the surface of an ice nucleus. Any liquid drop freezing onto an IN or the process of ice forming on an IN is referred to as heterogeneous nucleation. Essentially, this is the initiation of the ice crystal growth process. Homogeneous (or spontaneous) nucleation occurs when there is no surface for the drop or ice to initially form on. An ice embryo of a critical size (one that won't break up) is formed by the chance aggregation of a sufficient number of water molecules. This occurs around - 36 degrees C to -40 degrees C.

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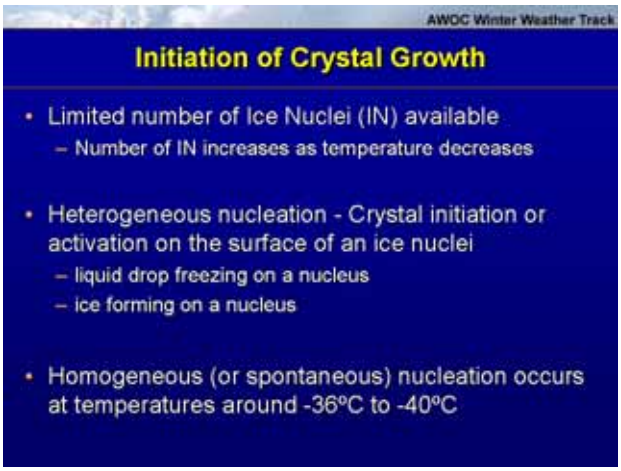

10. What Produces Heterogeneous Nucleation?

Instructor Notes: Though bodies of liquid water freeze when their temperatures reach slightly below 0 degrees C, water droplets in clouds behave quite differently. Observations in clouds have shown that at -10 degrees C it is possible to have only 1 ice crystal per 1 million liquid water droplets. Even at -20 degrees C, the ratio of ice to liquid can be less than 50%. However, some operational studies have noted a predominance of ice in clouds approaching -20 degrees C. In laboratory experiments, cloud temperatures can reach -40 degrees C before clouds are comprised of all ice crystals (Pruppacher and Klett, 1979). Water droplets that are found in temperatures below freezing are referred to as supercooled. Regions of a cloud transformed to ice crystals, where the cloud is saturated with respect to ice, are said to be glaciated. Generally, a cloud with temperature

warmer than around -10 degrees C will typically be primarily composed of supercooled water droplets. Clouds with temperatures between -10 and -20 degrees C will exhibit a mixed phase of supercooled water droplets and ice crystals. Clouds colder than -20 degrees C will be composed primarily of ice. What we want to address when we are looking at saturated layers from a p-type perspective is the likelihood that the corresponding cloud contains ice crystals.

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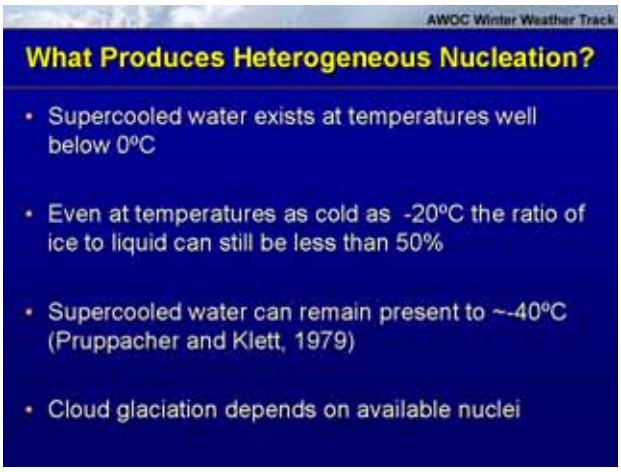
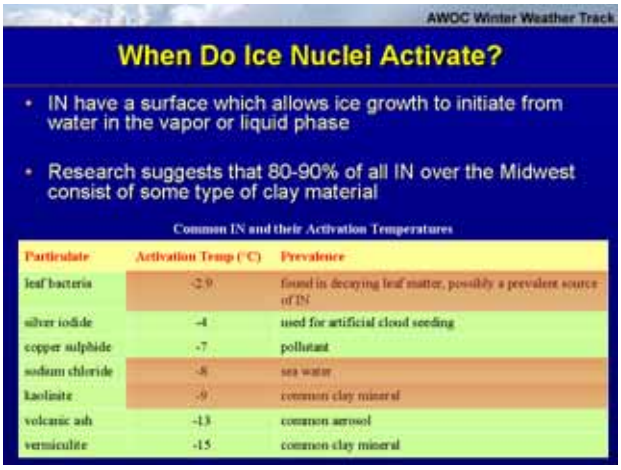


11. When Do Ice Nuclei Activate?

Instructor Notes: IN have a structure similar to ice which enables ice to form readily on their surface. Different types of IN have different activation temperatures. Leaf bacteria which are found in decaying leaf matter can support ice at temperatures as warm as approximately -3 degrees C. Clay materials can be the dominant IN available in some portions of the country such as the Midwest. One of these common clay materials, Kaolinite, has an activation temperature of -9 degrees C. Areas near oceans may have an abundance of sodium chloride available which activates at -8 degrees C. So, depending on the particulates available crystal initiation will occur at different temperatures. While information on available IN is not readily available on a real-time basis a general baseline can be used regionally based on what is believed to be the most prevalent IN in that region. For example, over much of the Great Plains, Great Lakes, the Ohio Valley one might assume that clays such as Kaolinite are the most prevalent IN with activation temperatures at -9 degrees C. Areas in proximity to the ocean might assume that sodium chloride would be abundant with onshore flow resulting in activation temperatures slightly warmer than -10 degrees C. Operationally, we cannot draw hard and fast rules based on these numbers as we are uncertain of the type and distribution of ice nuclei available in a given cloud deck. However, we can apply this in general in that as clouds are present at colder temperatures the likelihood of ice initiation increases.

Student Notes:

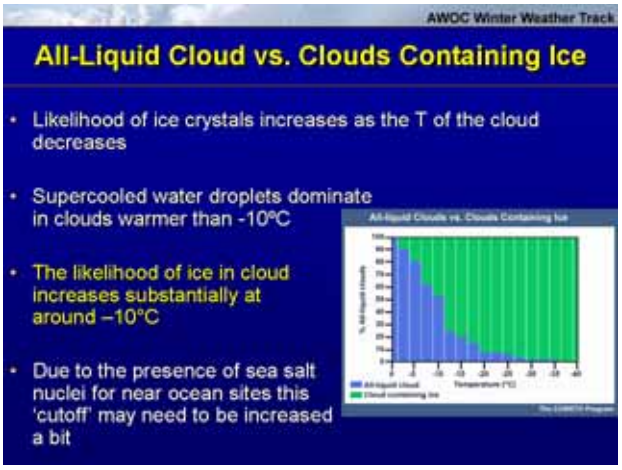


Particulate	Activation Temp (°C)	Prevalence
leaf bacteria	-2.9	found in decaying leaf matter, possibly a prevalent source of IN
silver iodide	-4	used for artificial cloud seeding
copper sulphide	-7	pollutant
sodium chloride	-8	sea water
kaolinite	-9	common clay mineral
volcanic ash	-13	common aerosol
vermiculite	-15	common clay mineral

12. All-Liquid Cloud vs. Clouds Containing Ice

Instructor Notes: Given the activation temperatures that we discussed on the previous slide one can make some inferences as to the likelihood of ice crystals being available in a cloud given the cloud top temperatures. The chart on the right gives an idea of the potential for ice crystals to be contained within a cloud. The y-axis is the percentage of All-liquid clouds while the x-axis is the coldest temperature within the cloud layer. As you can see if the coldest temperature within the cloud layer is -5 degrees C there is about an 80% chance that the cloud will consist entirely of super-cooled water. If the coldest temperature with the cloud layer is -10 degrees C there is a 50-60% chance that the cloud will contain ice. By the time the cloud cools to -15 degrees C there is about an 80% chance that the cloud will contain ice crystals. Operationally, it has been found that the likelihood of ice in a cloud increases substantially around -10 degrees C and this is good break point for assuming that there are ice crystals contained with the cloud. If the coldest temperatures within the cloud layer are warmer than -10 degrees C one can assume that there is a higher probability that the cloud is composed entirely of supercooled water droplets (assuming no introduction of ice crystals from an outside source such as the seeder-feeder mechanism). By the time cloud temperatures drop to -12 degrees C it is quite likely that ice crystals are present in the cloud. Note that these values are not absolute, (i.e., deterministic) it may be best to think in probabilistic terms. If you examine the chart on this slide you will see that there is a population of events in which ice crystals are present and the coldest temperature in the cloud layer is warmer than -10 degrees C. As a forecaster we should think of this in probabilities. In other words, the colder the layer in which the cloud exists the more likely you are to have ice crystals present. Due to the presence of sea salt nuclei for near ocean sites this ‘cutoff’ may need to be increased a bit although maybe not 2-3 degrees C as previously thought.

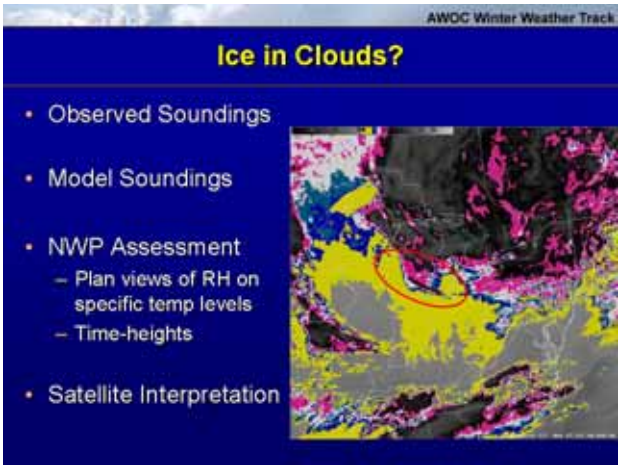
Student Notes:



13. Ice in Clouds?

Instructor Notes: Operationally there are several ways to assess the potential for heterogeneous in a given cloud layer. Looking at observed soundings is an excellent way to assess the state of the troposphere in the vicinity of the upper air site at 0000 and 1200 UTC. One could also examine BUFR data from operational forecast models utilizing AWIPS or a software package such as BUFKIT to assess whether or not the saturation extends to temperatures cold enough to support the initiation of ice crystals. Note that models reach the NWP equivalent of a saturated state at different levels of relative humidity. You could also assess the depth of the saturated conditions by looking at time heights at a variety of locations. To assess whether a given cloud deck has glaciated in a nowcast mode we can look to see if IR cloud top temperatures are -10 degrees C or colder. For example the IR image curve displayed here exhibits yellow cloud tops when the cloud top temperatures are between zero and -8 degrees C transitioning to white when ice becomes likely in the cloud at temperatures -12 to -15 degrees C and ultimately to black when ice should definitely be present in the clouds at temperatures colder than -20 degrees C. A curve such as this can help forecasters assess the likelihood of the presence of ice in a given area. For example, cloud top temperatures across much of northern Indiana and extreme southern Michigan are in the zero to -8 degrees C range and are not likely to contain ice. However, the lake band extending to the southeast off of Lake Michigan is clearly glaciated as are cloud tops across most of northern lower Michigan extending eastward into New York.

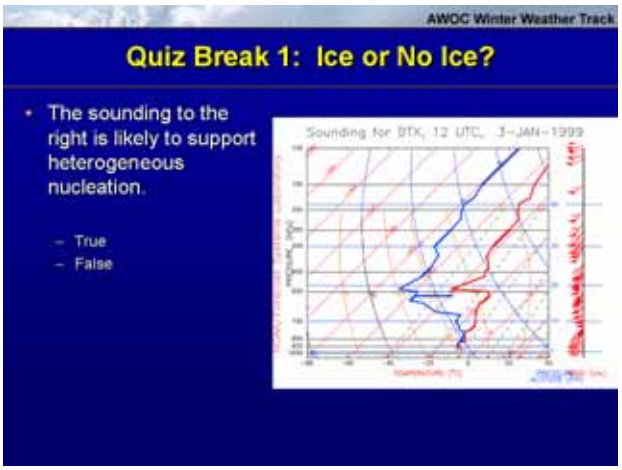
Student Notes:



14. Quiz Break 1: Ice or No Ice?

Instructor Notes: The sounding to the right is likely to support heterogeneous nucleation. True or False? Click on the Next button (highlighting right arrow) to advance when you are ready for the answer.

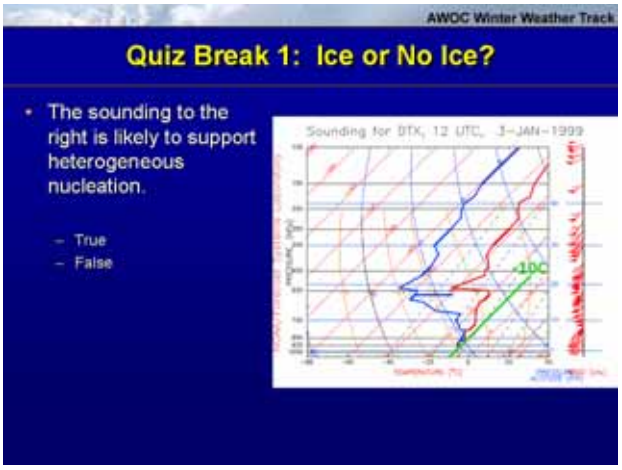
Student Notes:



15. Quiz Break 1: Ice or No Ice?

Instructor Notes: The sounding to the right is likely to support heterogeneous nucleation because the sounding clearly exhibits saturation to temperatures colder than -10C. So the answer is True.

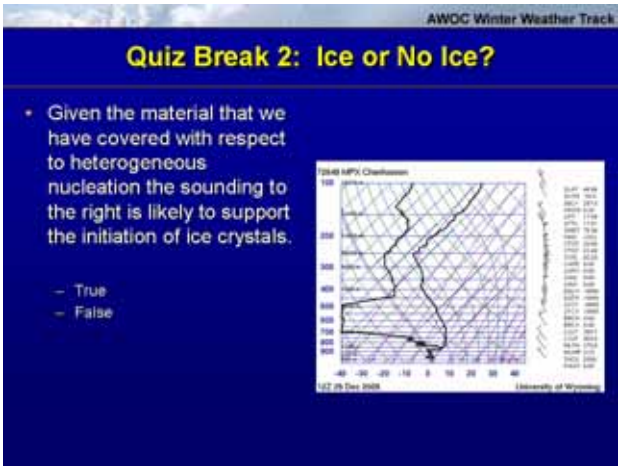
Student Notes:



16. Quiz Break 2: Ice or No Ice?

Instructor Notes: Another True or False. Given the material that we have covered with respect to heterogeneous nucleation the sounding to the right is likely to support the initiation of ice crystals. Click on the Next button when you are ready to advance to the next slide and hear the answer.

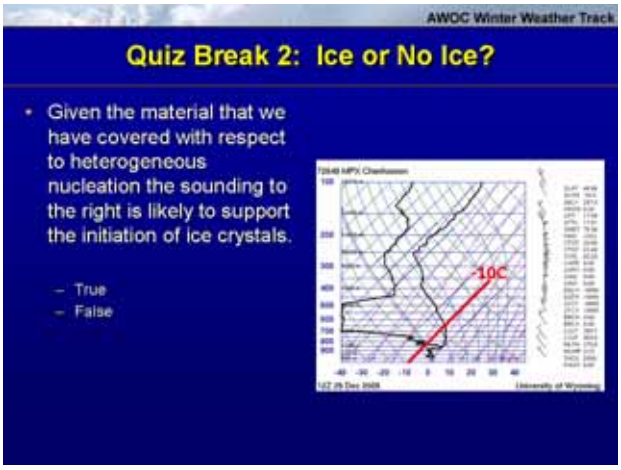
Student Notes:



17. Quiz Break 2: Ice or No Ice?

Instructor Notes: In this case, the sounding is only saturated to around -5 degrees C, so there is only around a 20% chance that ice crystals will be present. So the answer is false.

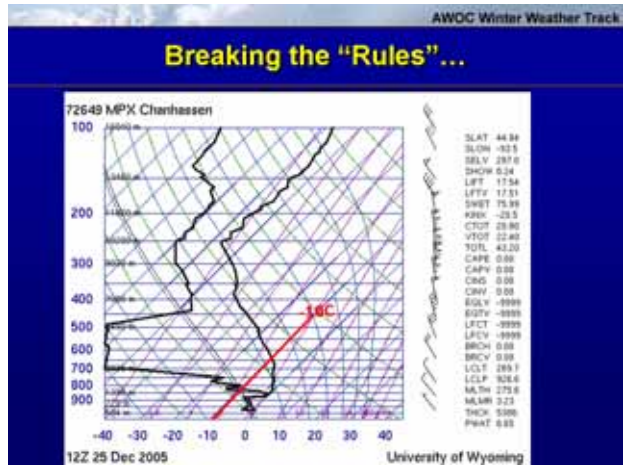
Student Notes:



18. Breaking the "Rules"…

Instructor Notes: As we have discussed previously, we should think of the likelihood of heterogeneous nucleation in probabilistic terms. This an example from December 2005 where snow fell out of a cloud deck which was not saturated to temperatures of -10 degrees C or colder. The area of interest is here in central and southern Minnesota. The 1200 UTC image indicates light snow in several locations including Minneapolis. A look at area observations at 1100 UTC, around sounding release time, indicated that numerous observation sites in this area were reporting light precipitation, with the vast majority reporting light snow. Looking at the corresponding sounding released by the Chanhaussen WFO we can see that saturation did not extend to temperatures of -10 degrees C or colder. In fact, the sounding was only saturated to around -6 degrees C. This example is shown to illustrate that even though the likelihood of heterogeneous nucleation increases markedly around -10 degrees C that there is a population of events where ice is initiated at temperatures warmer than -10 degrees C and a population of events where ice is not present with cloud temperatures colder than -10 degrees C. So, while in the majority of instances the concept of ice crystal initiation around -10 degrees C is perfectly valid there will be outlier events due to the complexity of ice nuclei and the nucleation process. For example, clay material that has previously acted as ice nuclei, but no longer has ice present on its surface will re-activate at temperatures (maybe 3-5 degrees warmer) than it initially would have. Operationally, there is no way to determine this and while the -10 degrees C threshold is a valuable tool for assessing the likelihood of ice crystals in a cloud there will be outlier events that deviate from this.

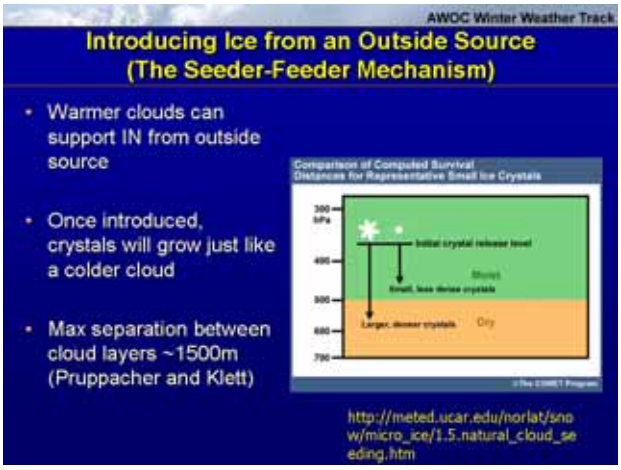
Student Notes:



19. Introducing Ice from an Outside Source (The Seeder-Feeder Mechanism)

Instructor Notes: There is a method through which warmer clouds that otherwise would not contain ice crystals can support ice crystal development. If ice is introduced into a cloud composed entirely of supercooled water droplets the ice crystals will grow preferentially over the supercooled water droplets because the saturation vapor pressure is greater with respect to ice crystals than it is with respect to supercooled water droplets. For example, consider a cloud with cloud-top temperatures warmer than -10 degrees C. Given the IN activation temperatures we have seen this cloud is likely not in an environment supportive of heterogeneous nucleation. In the example to the right we see a theoretical low level cloud deck that consists of supercooled water droplets and no ice crystals. If there exists a cloud layer in a cooler environment above this lower cloud deck and this higher cloud layer contains ice crystals it could 'seed' the lower cloud layer. This occurs when the crystals fall from the higher cloud deck through the saturated cloud layer below. This is called the "seeder-feeder" process. For the "seeder-feeder" process to be a concern the maximum separation between the two cloud layers should around be 1500m (5000 feet) or less. Also, it should be noted that larger denser crystals and are more likely to survive descent through a dry layer than are small less dense crystals. Crystals are also more likely to survive a descent through a moist environment as less sublimation will occur than in a dry environment. One way to assess the potential for the seeder-feeder process to occur is to look at the VWP to determine the separation between cloud layers. Again cloud top temperatures in IR imagery can also be of assistance. If the cloud decks are not separated by a substantial depth a mid level cloud deck can easily seed a lower cloud deck as it moves over the top. This can change a freezing precipitation event to all snow n as the mid cloud deck moves through the area seeding the lower warmer cloud with ice crystals.

Student Notes:



20. What is Impact of an Elevated Warm Layer?

Instructor Notes: After assessing the vertical profile for presence of ice crystals in the upper reaches of the cloud layer we must look for, and assess, elevated warm layers. Elevated warm layers are generally associated with warm fronts and, if present, can play a critical role in the ultimate precipitation type at the surface. When considering the elevated warm layer it is useful to examine both the maximum temperature contained within the layer as well as its depth. Rauber et al (2001) found that there was a strong correlation between the depth of the warm layer and the layer maximum temperature for soundings east of the Rocky Mountains. In most cases, it is easier to assess the maximum temperatures in a warm layer than it is to anticipate the depth of a warm layer. Therefore, we will focus more on the maximum temperature in the warm layer as it relates to the top-down methodology of anticipating p-type. Still, as forecasters, we must be cognizant of the shape of the warm layer in question. The top-down methodology assumes a more classic warm wedge (like a triangle on its side) when assessing the impact of a given warm layer on the p-type. If the warm layer deviates from this assumption the values displayed on this table may not be entirely representative. Although there will be outliers the values displayed here will point to the most probable outcome for a given warm layer. If the warm wedge is a deep (say, 5000 feet) nearly isothermal layer with a max temperature of +2 degrees C it will have a different impact than if it is a shallow (say, 2000 feet) warm wedge with a maximum temperature of +2 degrees C. Although Rauber et al. found a strong correlation between max temperature in the warm layer and the depth of the warm layer we still need to be cognizant of outliers. The table on this slide exhibits the impact that various warm layer maximum temperatures will have on the resultant precipitation type for instances where ice is introduced into the top of the warm layer as well as those cases where supercooled water is introduced into the top of the warm layer. It should be noted that the melting of ice crystals as they fall through an elevated or surface based warm layer is impacted by the size, density and structure of ice crystals. Other factors that play a role in the melting include crystal fall velocity (which is related to size & shape of the crystals) as well as the temperature, depth, lapse rate, and relative humidity of warm layer. Despite the wide range of impacts associated with the efficiency of the melting process we can make some general statements about the most likely outcome of

the melting process based on the maximum temperature in the warm layer. Note that these are simply the most likely outcomes. A warm layer with a maximum temperature of less than 1 degrees C will not be warm enough to melt snow or ice falling though this layer (unless it is abnormally deep). Therefore, the precipitation type would be expected to remain as snow as very limited, if any, melting would occur. For warm layers that have maximum temperatures of 1 degrees C to 3 degrees C melting will occur, but the complete melting of ice crystals is unlikely. As hydrometeors exit the warm layer aloft and enter a surface based cold layer many, if not all, of the partially melted hydrometeors will refreeze. Correspondingly, when the maximum temperature in the warm layer is in the 1-2 degrees C range a mix of ice pellets and snow is likely. For warm layers supporting temperatures closer to 3 degrees C ice pellets will be the most likely precipitation type. Finally, If the maximum temperature in the warm layer is greater than +3 degrees C we would expect complete melting of hydrometeors as they fall through this elevated warm wedge resulting freezing rain or freezing drizzle at the surface (assuming a surface based cold layer). Even with complete melting ice pellets would be possible at the surface if the surface based cold layer was strong enough, say colder than -10 degrees C, to completely re-freeze the hydrometeors. Finally, looking at the column on the right hand side we consider the case where no ice is introduced into the top of this warm layer. If this is the case and there is a surface based cold layer one would anticipate freezing rain or freezing drizzle. If the surface layer was above freezing then we would expect rain or drizzle. This table is based on the maximum temperature in the warm layer. Please be cognizant that if this warm layer is not saturated then the impact of the warm layer will most likely be as indicated in the table above in reference to the maximum temperature of the layer at the initial onset of precipitation. However, if it is not saturated then the profile in the warm layer will cool to the wet-bulb temperature which may have a significant impact on the resulting precipitation-type.

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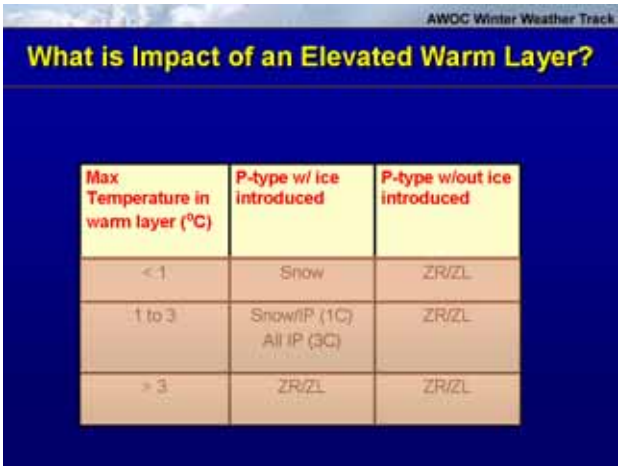

21. Wet Bulb Effects

Instructor Notes: Now let's take a graphical look at the impact of the warm wedge utilizing an applet developed by Tom Whittaker at the University of Wisconsin-Madison. The applet is based on concepts presented by Dan Baumgardt (SOO LaCrosse WI). Note

that in this applet the red line is the dry bulb temperature and the black line is the wet-bulb temperature. In this first example, I will set the maximum temperature in the warm layer to +4.5 degrees C. Note that as ice crystals enter this warm layer they completely melt and with sub-freezing surface temperatures we have a freezing rain event underway. However, if I change the maximum dry-bulb temperature (and wet-bulb temperature) in the warm layer to +1.5 degrees C we will have a scenario in which partial melting occurs. As indicated by the table on the previous slide when the maximum temperature in an elevated warm layer is between +1C and +3 degrees C and we have ice crystals entering that layer we can anticipate a mix of snow and ice pellets. Finally, if we set the max temperature in the warm layer to say +.3 degrees C the warm wedge is not strong enough to substantially melt the ice crystals and the precipitation type remains in the form of snow.

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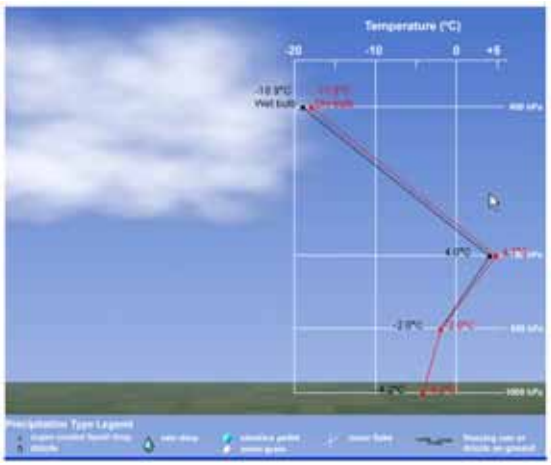

22. What About the Surface Layer?

Instructor Notes: The final region to consider when utilizing the top-down methodology is the surface-based layer. In some cases this can be the most challenging layer to assess in an operational environment. This is particularly true considering that NWP models struggle more in the boundary layer (e.g., with respect to temperatures) than they do aloft. One must consider the terrestrial temperature when anticipating freezing rain or freezing drizzle. For example, if the terrestrial temperature was above freezing before the arrival of cold air and precipitation, particularly if it had been above freezing for a considerable amount of time, surface temperatures may not be initially be cold enough for water to freeze on contact. This is something that we must keep in mind when considering freezing precipitation following periods of above-freezing temperatures. Another consideration is the wet-bulb temperature in the surface layer. The wet bulb temperature is the final temperature that an air parcel will attain after saturation is reached. The wet bulb temperature can be especially useful for distinguishing between liquid and frozen precipitation. It plays a significant role in determining the resultant precipitation type and anticipating wet-bulb impacts is especially important when dealing with sub-cloud layers that are dry at the onset of precipitation.

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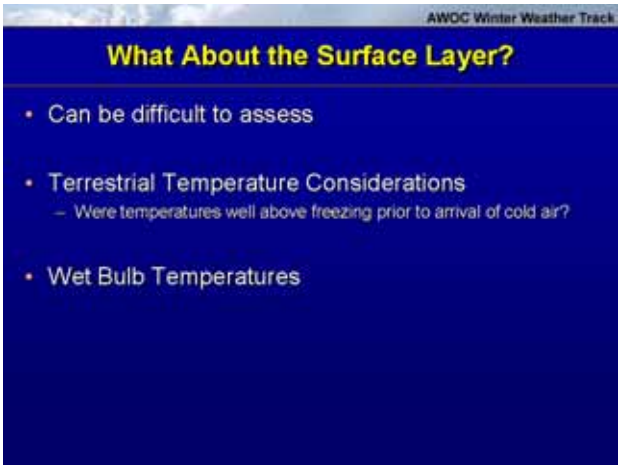

23. How to Consider the Wet Bulb Temperature

Instructor Notes: The wet-bulb temperature (Tw) represents the temperature that a given parcel will attain as saturation is achieved. The wet-bulb temperature is an important consideration when attempting to distinguish between liquid and frozen precipitation. As hydrometeors fall into an unsaturated environment they will begin to evaporate if liquid and melt or sublime if frozen. This process adds heat to the hydrometeor and removes heat from the environment, while also adding water vapor to the environment, causing the temperature to drop while the dewpoint rises with both values moving towards the wet- bulb temperature (Tw). Penn (1957) suggested that cooling due to evaporation can be as much as 5-7 degrees per hour, so wet-bulb affects can obviously be quite significant. When assessing an observed or model sounding we should consider how much cooling may occur if hydrometeors were to fall into an unsaturated layer in the profile. Wet-bulb considerations are also important to consider at the surface when anticipating precipitation type. If the wet-bulb temperature is > 1 degrees C for a depth of at least 300 m above the surface ice crystals will likely completely melt and rain is the most likely p-type. If the surface wet-bulb temperature is around 1.5 degrees C or greater then the precipitation type will likely be rain, in other words the maximum surface wet-bulb temperature supportive of snow is around 1.5 degrees C.

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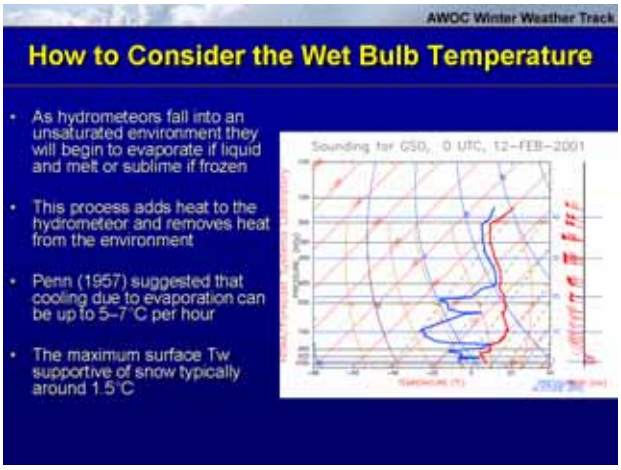

24. Warm Layer Effects

Instructor Notes: As an example, consider this profile where at the 750 mb level the dry-bulb T is ~4.5 degrees C and the Tw is –0.5 degrees C. Snow falling into this layer will initially be subject to melting. With time evaporation and sublimation will lower the temperature of this level to the wet-bulb temperature. Once the layer is completely saturated the temperature at 750 mb will equal the initial wet-bulb temperature. So, initially the hydrometeors will completely melt as they fall through the warm wedge as the maximum temperature in the warm layer is greater than +3 degrees C. In this scenario, with sub-freezing surface temperatures, we would have an initial precipitation type of freezing rain. Over time, as the layer cools, we will transition to a mix of precipitation types in the form of ice pellets and snow and finally as the maximum temperature in the warm wedge approaches the wet-bulb temperature, which is sub-freezing, the precipitation will remain in the form of snow. It is important to note that you cannot simply assess the wet-bulb temperature at 750 mb to determine the precipitation type in this instance. At the onset of precipitation, knowledge of the maximum temperature in this warm layer is critical to anticipate the degree of melting that will occur as hydrometeors descend through this layer. So, the maximum temperature in this layer is important at the onset of precipitation. With time the temperature migrates towards the wet bulb temperature at which point the wet bulb temperature is the determining factor in precipitation type. Also, it should be noted that precipitation intensity plays a role in the impact of the maximum temperature of a layer. If the precipitation rate is heavy the maximum temperature will be important for a shorter duration as the ambient air temperature will cool to the wet bulb temperature more quickly.

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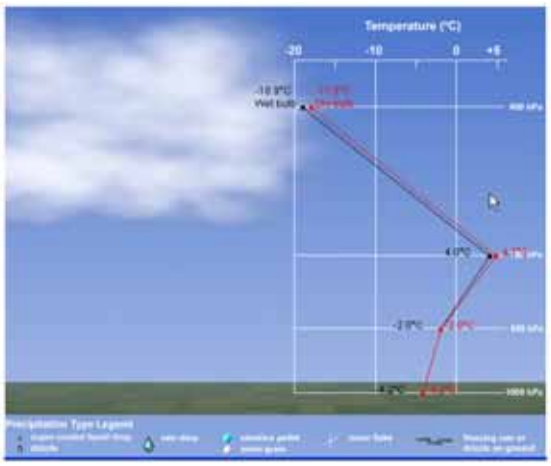

25. Effects of Depth of the Surface Melting Layer

Instructor Notes: When assessing a surface based warm layer one must consider the depth of the warm layer to determine if ice crystals entering this layer will melt or remain largely frozen. The depth of above freezing air that is required to melt snowflakes typically varies from around 750 feet to around 1500 feet. Generally, if the warm layer is deeper than 1500 feet it will be deep enough to melt the ice crystals and if it is shallower than approximately 750 feet it will typically not be deep enough to completely melt the ice crystals. The depth varies depending on the mass of the snowflakes and the lapse rate in the melting layer. For example, when the lapse rate is small the melting layer is weak and it would require a greater depth of above freezing air to melt the ice crystals. Conversely, when the lapse rate is large the melting occurs more rapidly and, correspondingly, a shallower layer is required to completely melt the ice crystals. This is something to keep in mind when assessing the depth of a surface based warm layer, particularly in those marginal cases when the depth of the layer is between 750 and 1500 feet.

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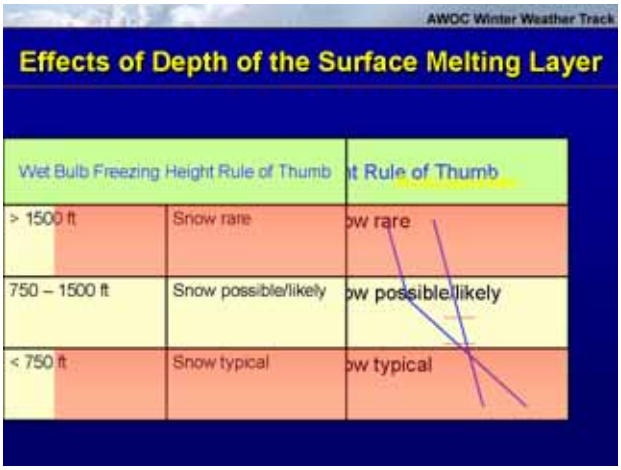
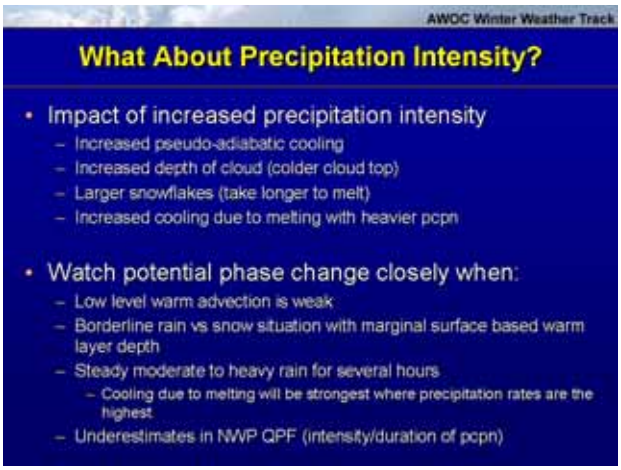


26. What About Precipitation Intensity?

Instructor Notes: Another aspect that we must keep in mind is the impact of precipitation intensity. It is not uncommon to see a borderline rain versus snow event in which the precipitation type changes to snow in locations that are experiencing heavier precipitation rates. Increased precipitation intensity has several impacts that may result in the precipitation changing from rain to snow in these marginal cases. Increased precipitation intensity is associated with enhanced vertical motion which will lead to greater pseudo-adiabatic cooling. Heavier precipitation rates would also typically be associated with deeper cloud depths which may allow the cloud top to extend to regions that support heterogeneous nucleation. Other impacts include the potential for larger snowflakes which take longer to melt and increased cooling associated with the melting of these larger flakes. While no explicit rules exist this concept is something to keep in mind when making forecasts in marginal rain versus snow situations. Watch for the potential for rain to change to snow due to cooling in the surface based melting layer in the following scenarios: 1) Low level warm advection is weak, 2) You are dealing with a borderline rain versus snow scenario due to the depth of a surface based melting layer, and 3) Steady moderate to heavy rain for several hours. A heavier precipitation rate such as would be expected in this scenario requires significant melting in the surface based layer which can ultimately lead to column cooling changing the precipitation to snow. - If NWP guidance significantly underestimates the amount precipitation (i.e., intensity and duration of precipitation) it may not correctly assess the potential for column cooling.

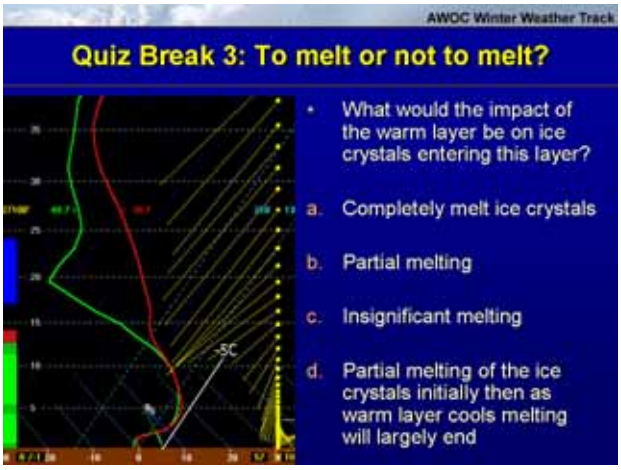
Student Notes:



27. Quiz Break 3: To Melt or Not to Melt?

Instructor Notes: Assume that you have ice crystals entering the warm layer in this BUFKIT example. What would the impact of the warm layer be on ice crystals entering this layer? Advance to the next slide when you are ready to hear the answer.

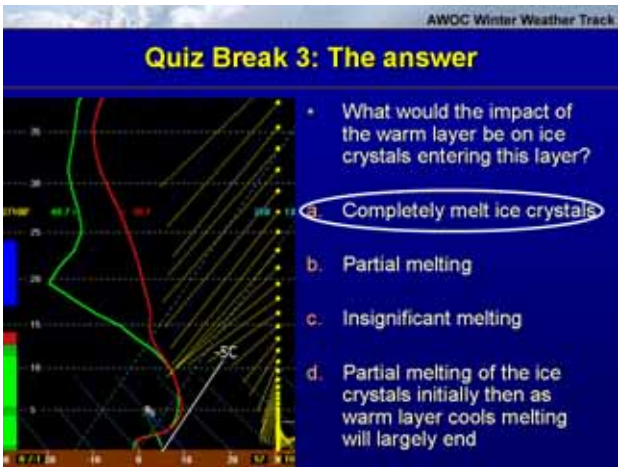
Student Notes:



28. Quiz Break 3: The Answer

Instructor Notes: The Max T in the warm layer is +4 degrees C and given what we reviewed earlier in the module this should be enough to completely melt the ice crystals. Assuming that we have ice crystals entering the layer, which is very near saturation through the entirety of its depth, and the surface based layer is sub-freezing all the way to the ground, I would expect freezing rain.

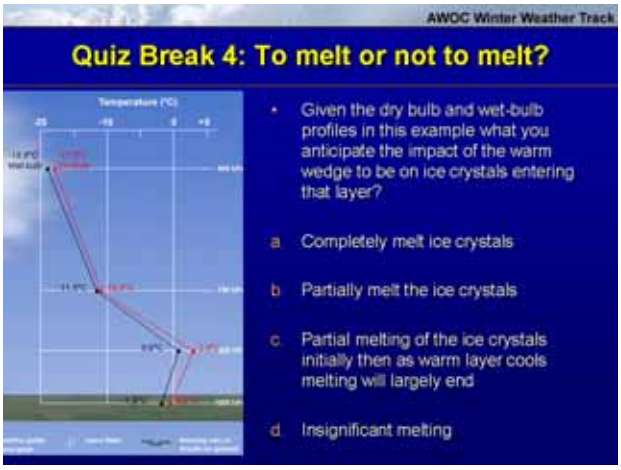
Student Notes:



29. Quiz Break 4: To Melt or Not to Melt?

Instructor Notes: Given the dry-bulb and wet-bulb profiles in this example what you anticipate the impact of the warm wedge to be on ice crystals entering that layer? Click to the next slide when you are ready to hear the answer.

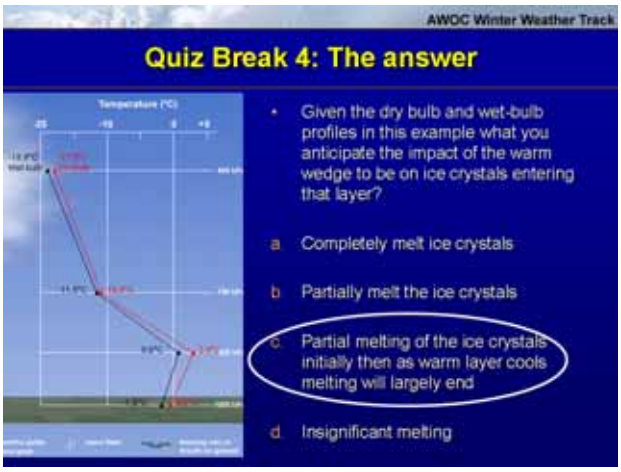
Student Notes:



30. Quiz Break 4: The Answer

Instructor Notes: Initially as ice crystals enter this warm layer, the most reasonable expectation is for the ice crystals to nearly completely melt. However, given that the warm layer is not saturated we would anticipate evaporative cooling to occur as the ice crystals fall through this layer. The max temperature in the layer will cool to the wet-bulb temperature which is +.6 degrees C. This temperature will not be warm enough to result in substantial melting of the ice crystals (unless it occurred over an abnormally deep layer). Therefore the correct answer in this case is c. Initially the ice crystals will likely nearly completely melt then as the warm layer cools the melting will largely end.

Student Notes:



31. Components of Top-Down Methodology

Instructor Notes: This is a review of the slide that was presented near the beginning of this module. We have covered each of the components from the likelihood of ice in the cloud, to the warm layer impacts, surface layer considerations, and ancillary topics such as the seeder-feeder mechanism and wet bulb impacts. We will now attempt to bring the whole process together in a step-by-step manner.

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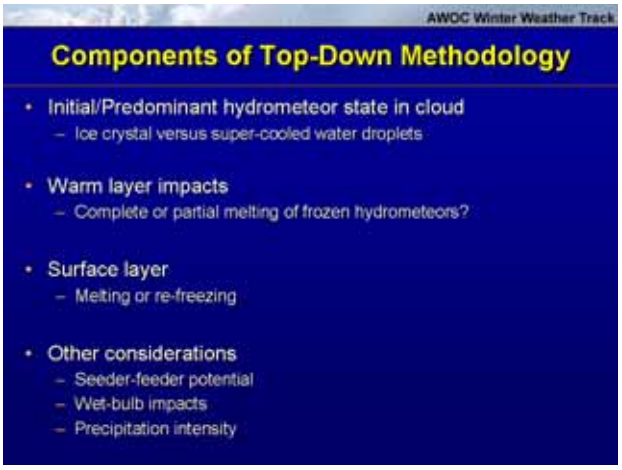
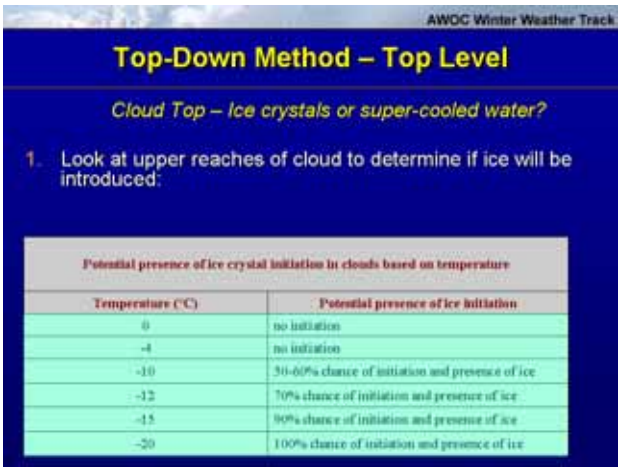


32. Top-Down Method – Top Level

Instructor Notes: The top-down method begins with a determination as to the potential presence of ice crystals in the cloud. To complete this initial step we will look at the upper reaches of the cloud to determine if ice crystals will likely be present. If the cloud top temperatures are -4C or warmer it can be assumed that ice crystals are not present in the cloud (assuming no seeder-feeder process in place). If cloud temperatures are colder than -10 degrees C it is assumed that ice crystals will likely be present in the cloud as there is at least a 50% chance of ice crystals being present. By the time cloud top temperatures reach -15 degrees C it is highly likely that ice crystals are present. So, the initial determination is whether or not ice crystals will be present in the cloud for the time frame of concern. Once you have determined this we will assess the presence of any elevated warm layers.

Student Notes:



33. Top-Down Approach – Midlevels

Instructor Notes: The second step in the Top-Down methodology is to determine if there is an elevated warm layer. If not, and ice crystals are present then you can simply

move on to assess the surface layer. If ice crystals are entering an elevated warm layer then you must address the degree of melting that will take place in this warm wedge. If the maximum temperature in the warm layer is less than +1 degrees C then the precipitation should remain as ice crystals, i.e., snow as it exits the layer. If the maximum temperature in the warm layer is between +1 to +3 degrees C then we can assume that partial melting will occur. Finally, if the maximum temperature in the warm layer is greater than +3 degrees C then you can assume that the ice crystals will completely melt with liquid precipitation exiting the bottom of the warm layer. When you assess a warm layer it is important that you consider wet-bulb effects on the strength of the warm layer. In other words, if there is a strong warm wedge, but it is relatively dry in this layer, consider how much cooling will occur in this layer as a result of evaporative cooling. For example, based on the maximum temperature in the elevated warm layer we may initially anticipate the complete melting of the ice crystals as they fall through this layer. However, if the layer is initially dry, as evaporative cooling occurs the elevated warm layer may no longer support substantial melting depending on the wet-bulb temperature of the layer.

Student Notes:

34. Top-Down Approach – Surface Layer

Instructor Notes: Finally, we will assess the lower levels of the thermal profile. Let's assume that we have ice crystals entering the lower levels of the profile. In this evaluation of the near surface layer we will address the wet-bulb temperature. If ice crystals are entering this lowest layer and the wet-bulb temperature is very near 0 degrees C or colder down to the surface then assume the precipitation type will be snow. However, if the Tw is warmer than 0 degrees C above the surface and the surface Tw is > 1.5 degrees C then Rain or a mix of Rain and Snow is possible. If we have a mix entering this lowest level (i.e., the elevated warm layer is between +1C and 3 degrees C) and the wet-bulb temperature or ambient air temperature is less than 0 degrees C the particle will immediately refreeze to form ice pellets at the surface. This occurs because the crystal only partially melted leaving an ice embryo at it's center which can quickly initiate freezing in a sub-zero layer. However, if a mix is entering the near surface layer and the Tw is near or above 0 degrees C and the surface Tw is greater than 1.5 degrees C then expect rain. We can also assess the depth of a surface based warm layer by looking at the

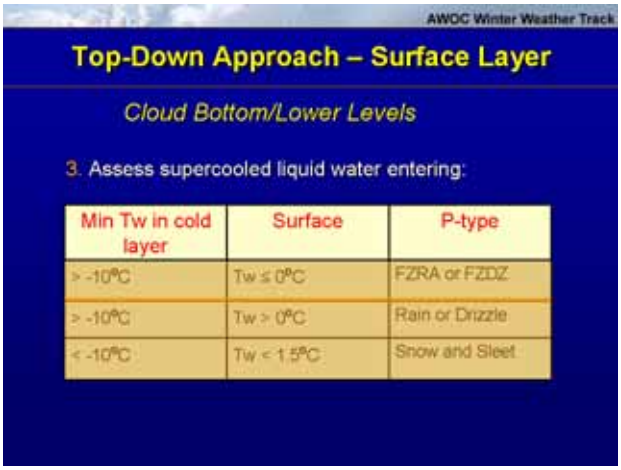
height of the wet-bulb zero. If the wet-bulb zero height is > 1500 ft. then snow is unlikely while if the wet-bulb zero is less than 750 feet snow is quite likely. In marginal cases we must also consider the precipitation rates.

Student Notes:

35. Top-Down Approach – Surface Layer

Instructor Notes: Finally, let's consider what would occur with supercooled water droplets entering the lower levels. If the minimum temperature in the near surface layer is warmer than -10 degrees C and the surface wet-bulb temperature is 0 degrees C or less then you would anticipate freezing drizzle or freezing rain depending on the droplet size. If supercooled water is entering a low level profile in which the minimum temperature is warmer than -10 degrees C and the surface wet-bulb temperature is warmer than 0 degrees C you would anticipate rain or drizzle. Finally, if supercooled water enters a near surface layer in which the minimum temperature is less than -10 degrees C and the surface wet-bulb temperature is less than 1.5 degrees C you can expect snow and sleet.

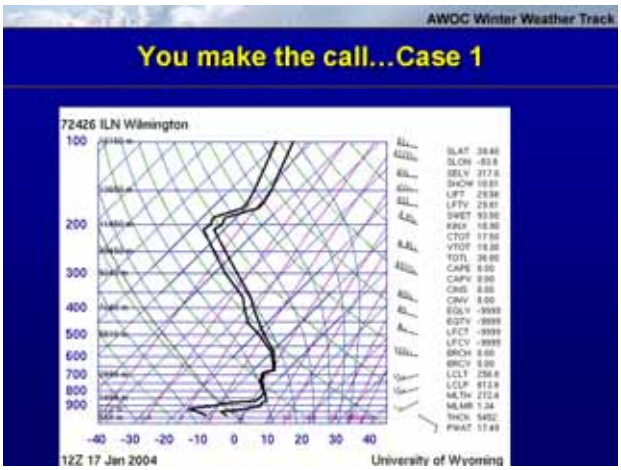
Student Notes:



36. You Make the Call…Case 1

Instructor Notes: Make an assessment of p-type for this sounding. Click on the next button when you are ready for the answer.

Student Notes:



37. Case 1…Expert Analysis

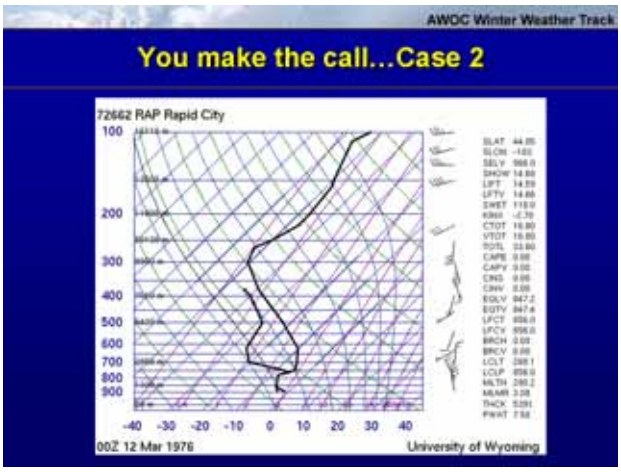
Instructor Notes: In this example, we see that saturation extends to temperatures well below -10 degrees C. In fact, it is saturated to around -20 degrees C so we can have very high confidence that ice crystals will be present in the cloud. The warm layer assessment is more intriguing. Note that the max temperature in the warm layer is between +2 and +3 degrees C. Recalling the table referencing the impact of the warm layer on frozen hydrometeors we can anticipate the likely impact of the warm layer on the ice crystals. This does not look like an anomalously deep warm layer as it has the classic wedge appearance, so we can look at the expected degree melting with some confidence. Since the warm layer is between +2 and +3 degrees C we would anticipate significant, but not complete melting of the ice crystals which would lead us to believe that with a cold wedge at the surface (which is present in this case) we could then anticipate re-freezing of the hydrometeors into the form of ice pellets with possibly some snow as well. This appears to be likely at the onset given the maximum temperature in the warm layer, but what about the impact of wet-bulb effects? Note that there is separation between the temperature and dewpoint curves in the profile indicating that the layer will experience wet-bulb cooling as hydrometeors enter this layer and begin to melt. This cooling would likely occur relatively quickly with the temperature in the layer cooling to the wet-bulb temperature. With this in mind you might anticipate a period of ice pellets changing over to snow as the warm layer cools. Obviously in a situation such as this it would be prudent to mention a combination of snow and ice pellets in the forecast.

Student Notes:

38. You Make the Call…Case 2

Instructor Notes: Now, make an assessment of p-type for this sounding. Once again, when you are ready for the answer, advance to the next slide.

Student Notes:

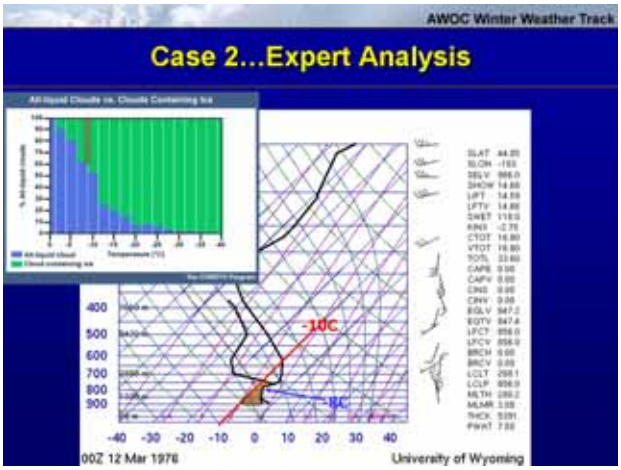


39. Case 2…Expert Analysis

Instructor Notes: As usual we will start at the top and work our way down through the sounding. So, will this profile support heterogeneous nucleation? Let's first identify how cold the temperatures are in the saturated layer. We can see that the sounding is not saturated to -10 degrees C. Identifying the coldest temperature that exhibits saturation in the sounding we see that it is about -8 degrees C. Therefore, it is not likely that this cloud will support heterogeneous nucleation. However, as we discussed earlier in the module there is certainly a chance that this cloud would support heterogeneous nucleation (around 40% chance). However, the most likely outcome is that the profile will not support the initiation of ice crystals and the cloud will be populated with supercooled water droplets. Given that the cloud is most likely composed of supercooled water droplets and

the surface temperature is below freezing the most probable precipitation type associated with this sounding is freezing drizzle.

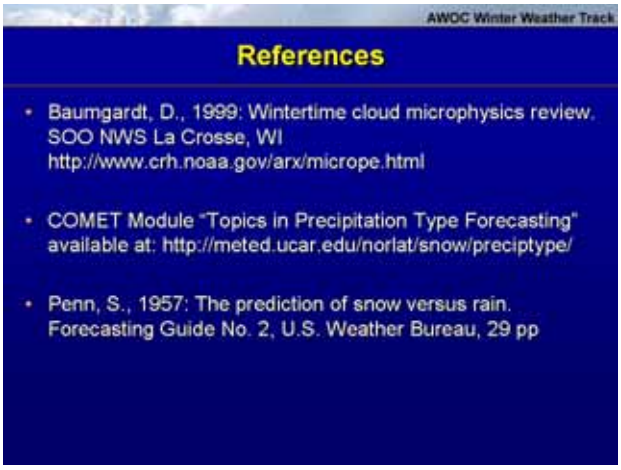
Student Notes:



40. References

Instructor Notes: Here is the first of two slides listing the references cited during the presentation.

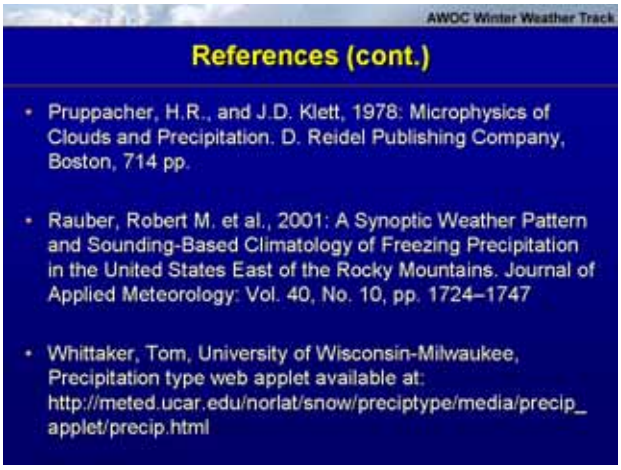
Student Notes:



41. References (Cont.)

Instructor Notes: Here is the second of two slides listing the references cited during the presentation.

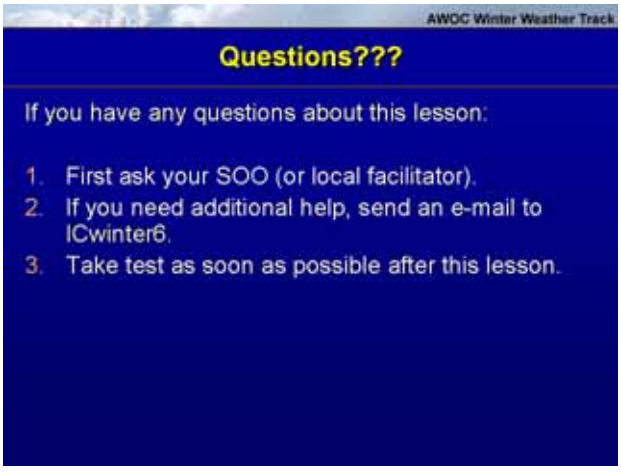
Student Notes:



42. Questions???

Instructor Notes: After going through this lesson if you have any questions, first ask your SOO or your local AWOC Winter facilitator. Your AWOC facilitator should be able to help answer most questions. If you need additional info from what your SOO provided, please send an E-mail to the address on the slide. This address sends the message to the instructors who developed this IC. Our answer will be CC'd to your SOO so that they can answer any similar questions that come up in the future. We may also consider the question and answer for our FAQ page. Thanks for your time and good luck on the exam!

Student Notes:



IC6.1: Optional Job Sheet

Introduction to the Top-Down Methodology

Objective: Examine a winter weather case and practice the top-down approach to forecasting as seen in the IC 6 Lesson 1 training module.

Data: 24 February 2003 winter weather event across Texas. You will be using D2D for this exercise.

Instructions:
Load the 24 February 2003 Winter Weather AWOC case on your WES machine in case review mode, using the FWD localization. You will be examining the **18 UTC NAM 40 model initialization** from 24 February 2003 and observational data. Set the D2D clock to 19 UTC, 24 February, 2003.
On the regional scale, load a satellite IR image and overlay lightning data. Check the cursor readout of the cloud top temperatures across northern Texas and southern Texas.
In another pane load a time height display of NAM 40 RH and Temperature from a point in south central Texas.
Where are the clouds supportive of ice crystal growth? Based on the NAM40 time-height plot, infer when ice crystals are possible in south central Texas.

In another regional scale pane, load NAM 40 model soundings using points placed over Ardmore, OK; Dallas, TX; Austin, TX; and Abilene, TX. Also load RAOBs from OUN, FWD, and CRP.
Which soundings will support ice in the cloud layer?

Focus on the 18Z FWD RAOB, and in a separate pane create a plan view of NAM 40 and MSAS surface wet-bulb temperatures (+1.5 ^{o}C is + 34.7 ^{o}F). Using the plan view web-bulb surface temperatures and the FWD RAOB, answer the following questions:

What is the maximum temperature in the warm layer? _____ ^{o}C
Is the warm layer unsaturated (circle one)? **YES/NO**
Based on this warm layer, will precip **melt**, **partially melt**, or **remain as snow** (circle one)?
What is the wet-bulb zero height? _____feet
What is the surface wet-bulb zero temperature in the Dallas area?

_____^{o}C.
Is this supportive of snow (circle one)? **YES/NO**

What are the low-level lapse rates like--**Steep or weak** (circle one)? What does that say about precipitation type?

Based on the top-down approach you have taken with this sounding, put it all together and make a forecast of just P-type and the evolution of the P-type using the NAM 40 sounding for the Dallas/Ft. Worth Metroplex from 18 Z on the 24th through 12 Z on the 25th?

Examine the Austin, TX NAM 40 sounding.
Using the top-down approach, what is the expected P-type and evolution from 18 Z on the 24th through 12 Z on the 25th for Austin based on this sounding?

Examine the Ardmore, OK NAM 40 sounding.
Using the top down approach, what is the expected P-type and evolution from 18Z on the 24th through 12 Z on the 25th for Ardmore based on this sounding?

An answer key is available for this job sheet. Please see your local AWOC Winter Weather facilitator to obtain a copy.

1. IC6.2 Part 1: Strength and Weaknesses of P-Type Algorithms

Instructor Notes: Welcome to IC 6 lesson 2, Part 1. This lesson is approximately 30 slides long and will take approximately 20 minutes to complete.

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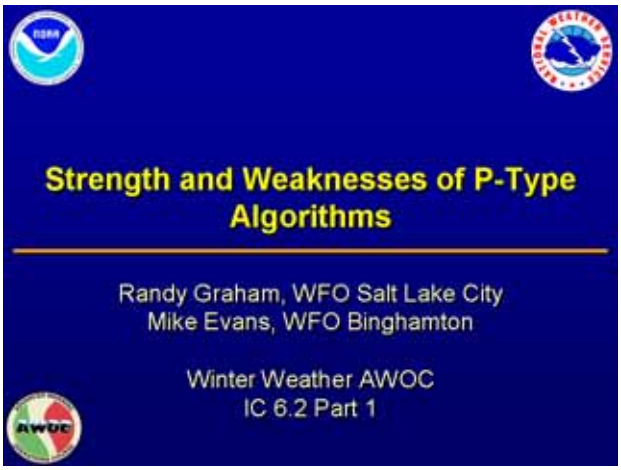

2. Assessing P-Type Algorithms

Instructor Notes: This is the 2nd lesson in IC6 and covers the strengths and weaknesses of several precipitation type algorithms. Part 1 will hit on the Baldwin technique and Ramer technique. This lesson will supply information on a variety of p-type algorithms that are widely utilized in the meteorological community at the present time and will present background material that will help you assess their output. The motivation for this lesson is to enable forecasters to intelligently assess algorithm output in an operational setting and to provide the tools needed to identify each algorithms strengths and weaknesses which should ultimately assist you in the determination of their skill in a given precipitation type forecast. The speaker notes for this lesson will contain additional detail above beyond that which on the slides and may serve as a good reference for review.

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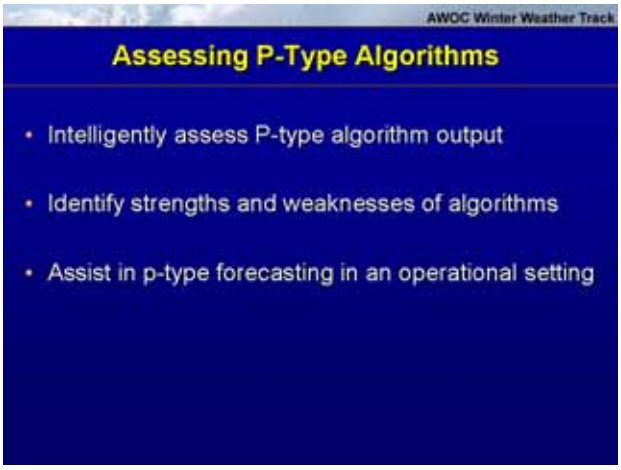

3. Outline

Instructor Notes: This lesson is divided into five sections. The first section will provide a brief overview of the learning and performance objectives and the need for precipitation type (p-type) algorithms. The next two sections are dedicated to 4 different p-type algorithms beginning with the Baldwin technique and the Ramer technique.

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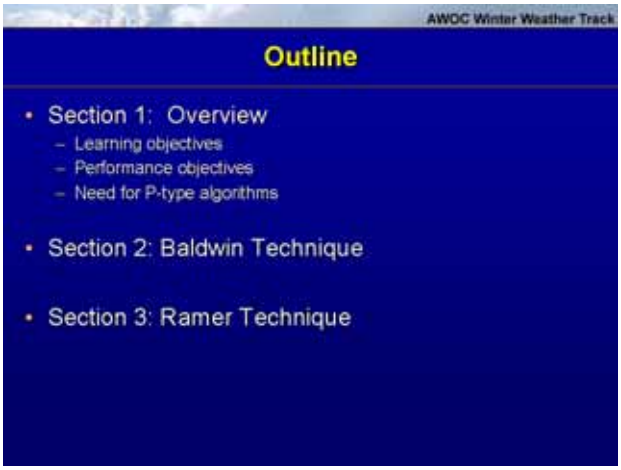

4. Learning Objectives

Instructor Notes: The goal of this lesson to provide a basic understanding of the primary precipitation type algorithms in use in operational Numerical Weather Prediction and heavily utilized local applications. The learning objectives for this lesson are to simply identify the strengths and weaknesses of various p-type algorithms as well assess the algorithms primary failure modes.

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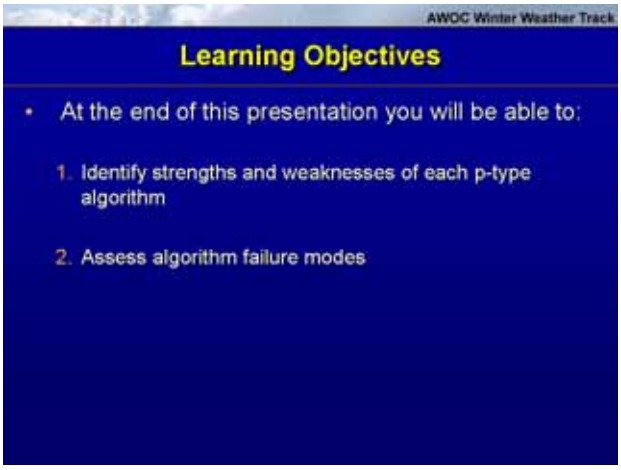

5. Performance Objectives

Instructor Notes: The ultimate success of this lesson is driven by impacting performance in an operational setting. The performance objectives for this lesson are: To be able to assess the validity of algorithm output in different situations; To be able to assess potential algorithm failures in an operational setting; and To be able to compare algorithm output with an understanding of the algorithm structure as well as their strengths and weaknesses.

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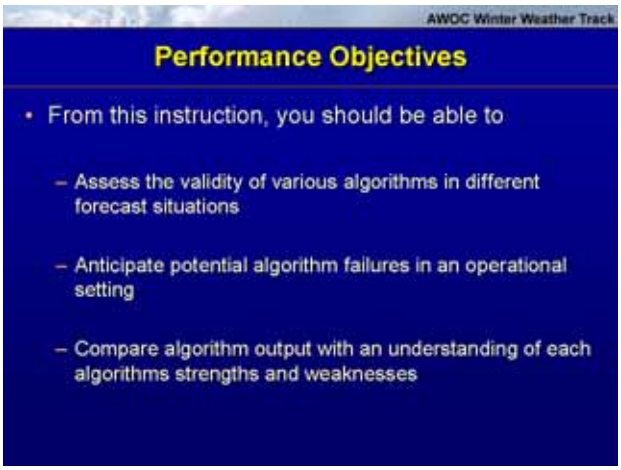

6. Why Precipitation Type Algorithms?

Instructor Notes: Forecasting precipitation type continues to present a significant challenge to forecasters across much of the United States during the cold season. Over the years a variety of precipitation type algorithms have been developed in an effort to address this forecast challenge. The methodologies encapsulated in these algorithms have different assumptions and can behave quite differently when given the same vertical profile. The observed precipitation type will depend a variety of atmospheric inputs including the vertical profiles of temperature and moisture, the distribution of vertical

motion, and the type of cloud and ice nuclei present. This lesson will provide basic information on the logic utilized in a variety of precipitation type algorithms. The lesson (broken into 2 parts) will focus on the Baldwin Technique, the Bourgouin Method, the Ramer Technique, and the Partial Thickness approach. The lesson will identify the strengths and weaknesses of each precipitation type algorithm. Due to time constraints we will not cover every possible p-type determination for each method, but instead will discuss the philosophy of each method and cover some of the primary considerations that they utilize to assess p-type as well as things to watch for when utilizing these algorithms. One thing to consider as we go through the presentation is the idea of utilizing an ensemble approach by comparing the output of the different algorithms. Some have found this to be a successful approach in which the output from several algorithms can expose the bias of a single algorithm. As each algorithm or methodology has its own strengths and weaknesses an ensemble of the algorithms may yield the best answer in many cases.

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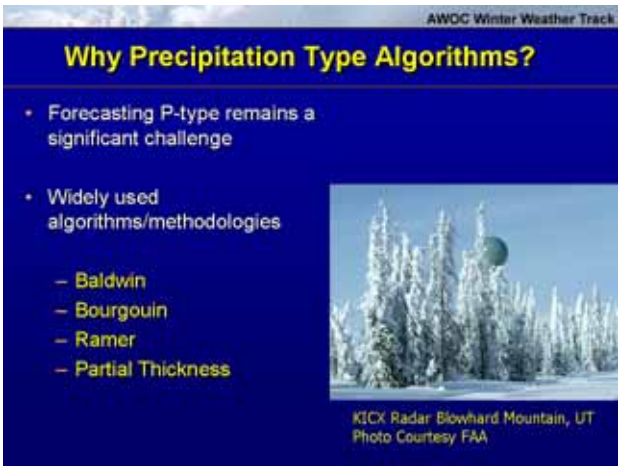

7. What About Baldwin Method?

Instructor Notes: The technique was developed in the mid-1990s. The method was tuned by utilizing vertical profiles supplied from the ETA model, which at the time was running at 40 km horizontal grid spacing, with hourly precipitation reports at 259 sites across North America. The Baldwin method is applied during post-processing of model data. In other words, it is not direct model output, but, rather is a technique applied to a vertical profile produced by a numerical model. Output from the Baldwin technique is available in many locations including NAM output in BUFKIT and AWIPS.

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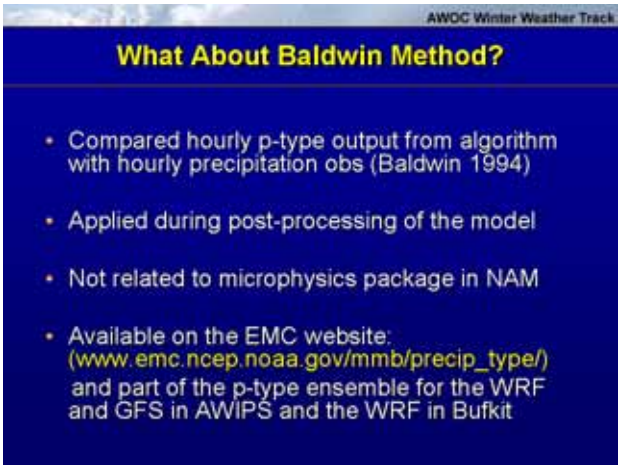

8. Baldwin Scheme – The Basics

Instructor Notes: The Baldwin scheme utilizes a simple decision tree in its determination of P-type. The method utilizes variables, such as ambient and wet-bulb temperatures at the surface and aloft, which play a significant role in hydrometeor initiation and melting and freezing. Warm and cold layers are identified by calculating areas bounded by the 0 degree C or -4 degree C isotherm and the sounding wet-bulb temperature. We will go through some examples as to how these layers are calculated shortly. These warm and cold layers and calculated individually and then used in combination with the surface temperatures to identify the precipitation type.

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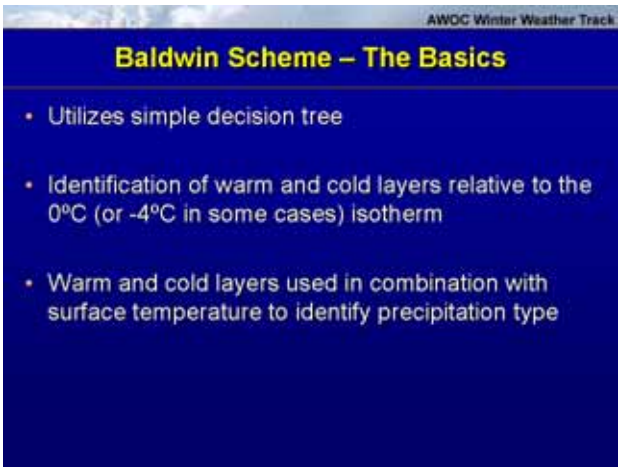

9. Steps to Precipitation-Type Diagnosis

Instructor Notes: The Baldwin scheme first identifies the highest saturated layer, where saturation is defined as a dewpoint depression of 6 degree C or less. The scheme then considers this layer the ‘precipitation generation layer’. Then the algorithm determines the initial state of these hydrometeors. If the temperature in this saturated layer is less than -4 degrees C it is assumed that the hydrometeors initiate as ice crystals. With tem-

peratures warmer than -4 degrees C it is assumed that the precipitation initiates as supercooled water droplets. Ultimately, the precipitation diagnosis relies on the coldest temperature in a saturated layer, which determines if the hydrometeors initiate as ice or supercooled water, the magnitude of areas bounded by the sounding Tw curve relative to the 0 degree C and -4 degree C isotherms, and finally the surface temperature.

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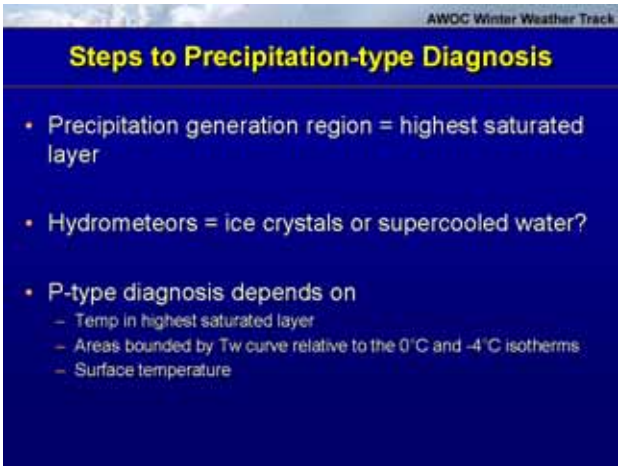

10. The Concept of Degree Meters

Instructor Notes: When assessing warm and cold layers in a sounding the Baldwin scheme utilizes the concept of degree meters to assess the strength of the layer being examined. This is an important concept with respect to understanding how the Baldwin method determines precipitation type. The degree meters for a given area are calculated by simply taking the depth of the layer and multiplying this by the average wet-bulb temperature within this layer. Note that it is not the highest or lowest wet-bulb temperature in the layer, but rather the average wet-bulb temperature. Also be aware that the reference wet bulb temperature is not always 0 degrees C, in some checks within the Baldwin scheme the warm and cold layers are calculated with respect to the -4 degree C isotherm. As an example of how the degree meters are calculated let's look at the diagram to the left. The vertical line is the reference wet-bulb temperature whether that be 0 degrees C or -4 degrees C. To calculate the warm nose to the right of the reference temperature we will take the depth, which in this case is 1500 m, and multiply it by the average wet-bulb temperature in the layer, which in this case is +2 degrees C, which ultimately yields 3000 degree meters.

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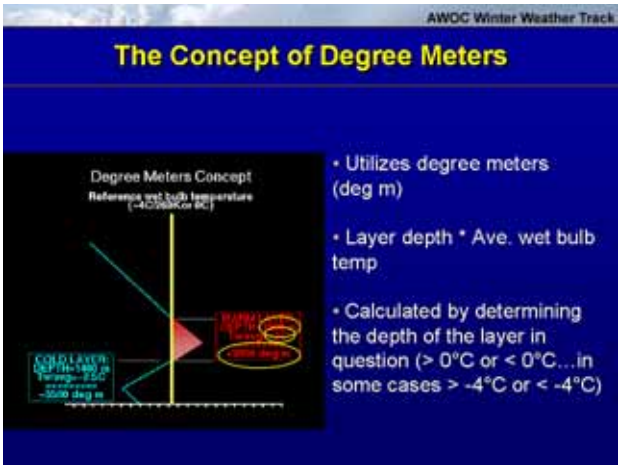

11. Baldwin Scheme Logic

Instructor Notes: The decision tree to the left is the core of the Baldwin scheme. As we discussed previously the first check that it completes is to determine whether or not the coldest temperature in a saturated layer is warmer than -4 degrees C. If it is warmer than -4 degrees C the hydrometeors are assumed to initiate as supercooled water and if it is colder than -4 degrees C the hydrometeors are assumed to initiate as ice crystals. If the coldest temperature in a saturated layer is warmer than -4 degrees C it then checks to determine if the temperature in the lowest model layer is less than 0 degrees C in which case it forecasts freezing rain. Conversely, if the lowest layer temperature is greater than 0 degrees C then it outputs a p-type of rain.

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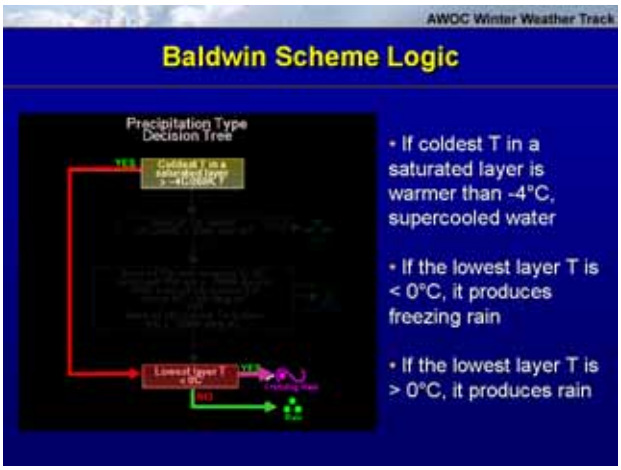

12. Baldwin Scheme Logic

Instructor Notes: Now let's step through the decision tree for a case in which the coldest temperature in a saturated layer is less than -4 degrees C. Once it has assumed that ice crystals are present the algorithm calculates the degree meters relative to the -4 degrees C isotherm. If the area between the -4 degrees C isotherm and the wet-bulb

temperature profile in the sounding is less than 3000 deg m the Baldwin scheme will indicate snow. If there are more than 3000 deg m of area between the -4 degrees C isotherm and the Tw profile in the sounding, then the algorithm assumes melting of the ice crystals and it then steps down the flowchart to determine if the precipitation type will be ice pellets, freezing rain, or rain.

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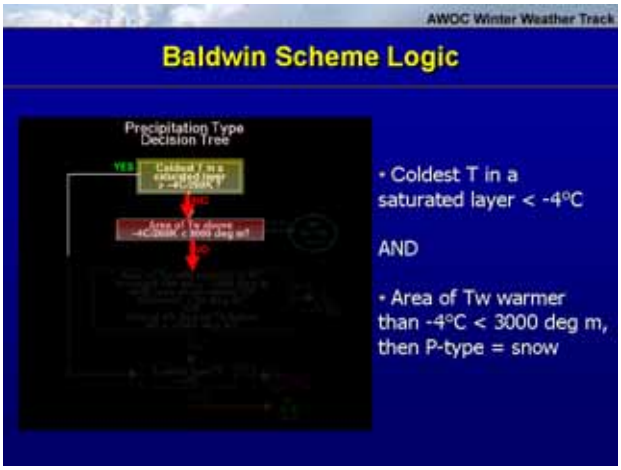

13. Baldwin Method Failure Mode

Instructor Notes: One problem with this technique has to do with the check determining if the area between the -4 degree C isotherm and the sounding wet-bulb temperature curve is less than 3000 deg m. If there are more than 3000 deg m between the -4 degree C isotherm and the wet-bulb temperature profile the algorithm assumes that the ice crystals have melted and it then moves on to check if the hydrometeors re-freeze into ice pellets or if they fall to the surface as rain or freezing rain. Thus the scheme can forecast freezing rain from a sounding that clearly supports heterogeneous nucleation and is entirely below freezing. Correspondingly, the algorithm may forecast liquid precipitation for a snow event in which the sounding clearly supports heterogeneous nucleation and has only a very shallow layer above freezing. The key is to watch for near surface deep isothermal layers between 0 degrees C and -4 degrees C. This is something to be cognizant of when assessing output from the Baldwin scheme. Failures such as this are quickly identified utilizing the top-down method. Let’s go through an example which should better illustrate this issue.

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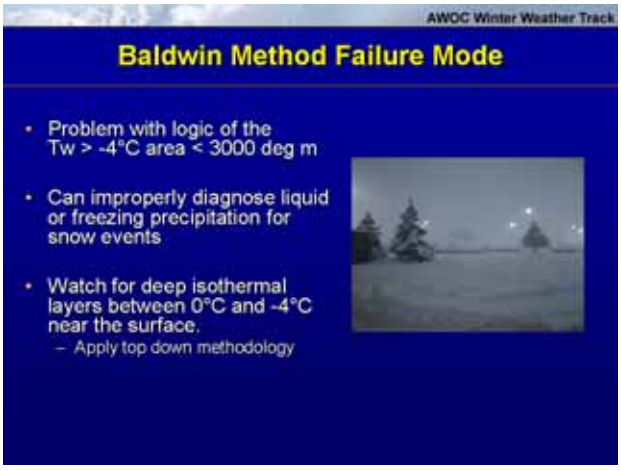
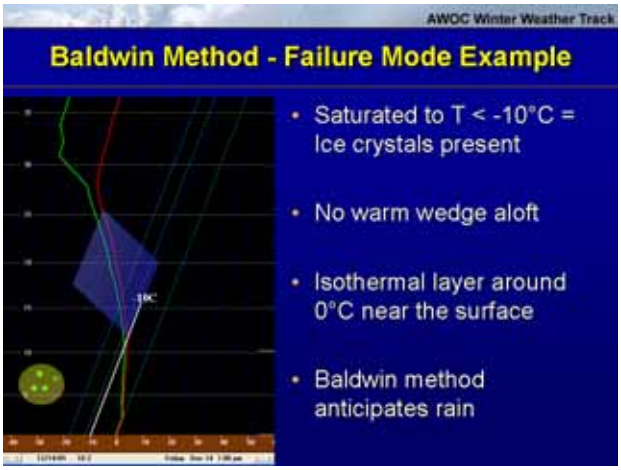


14. Baldwin Method - Failure Mode Example

Instructor Notes: Let's take a look at a case where the Baldwin scheme's failure mode with respect to deep isothermal layers is exposed. Following a top-down methodology we can assume that there is ice in the cloud as it is clearly saturated at temperatures colder than -10 degrees C which is supportive of heterogeneous nucleation and the development of ice crystals. In other words, ice would clearly be present in this cloud layer. As we follow a crystal down from the saturated layer aloft we see that do not encounter a warm nose to melt the crystal. The last several thousand feet of the sounding exhibits a near isothermal layer around 0 degrees C. If this vertical temperature and moisture profile was accurate the ice crystal clearly would not melt as it descends. However, the Baldwin scheme outputs a P-type of rain in this case.

Student Notes:

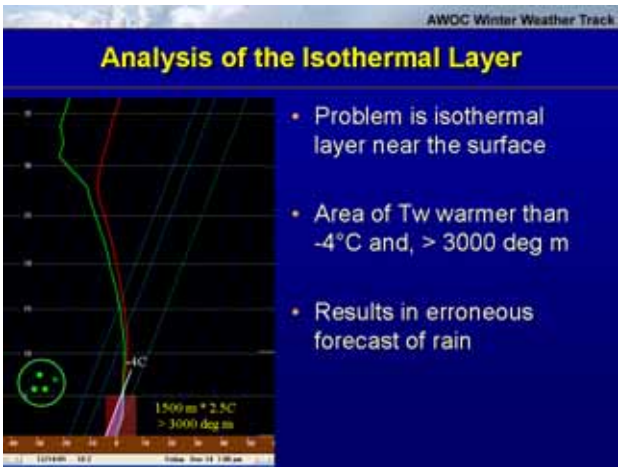


15. Analysis of the Isothermal Layer

Instructor Notes: Taking a closer look at the logic utilized in the Baldwin algorithm we will see that the culprit in the failure is the deep isothermal layer near the surface. In blue I have outlined the wet-bulb temperature profile. When we overlay the -4 degree C iso-

therm we see that there is a pretty good size area swept out between these two lines. The area between these two lines is certainly greater than 3000 deg m. This deep isothermal results in the check on the degree meters between the wet-bulb temperature profile and the -4 degree C isotherm failing and as a result the algorithm incorrectly anticipates rain in this case. In this particular event forecasters were looking at the algorithm output leading up to the event and the output from the Baldwin scheme raised some questions about the resultant precipitation type anticipated by the algorithm. The forecasters working the event correctly anticipated that the precipitation would fall as snow in what turned out to be an advisory level event.

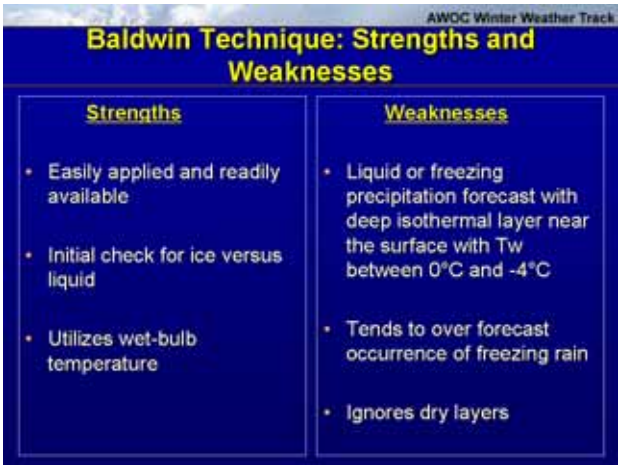
Student Notes:



16. Baldwin Technique: Strengths and Weaknesses

Instructor Notes: The strengths of the Baldwin technique begin with easy application and widespread availability. The algorithm is easy to understand which makes interpretation more straightforward. The algorithm also employs a check for the initial phase of the hydrometeor. Another strength is that the algorithm utilizes the wet-bulb temperature in some of its checks to determine precipitation type. This is a more robust methodology than simply utilizing the temperature. The Baldwin method also has several weaknesses. The primary failure is that it will forecast liquid or freezing precipitation when the sounding contains a deep near surface isothermal layer in which the wet-bulb temperature is between 0 degrees C and -4 degrees C. It may forecast liquid or freezing precipitation even if ice is introduced into this layer and the temperature in the profile is never greater than 0 degrees C. Fortunately, once we are aware of this weakness it is easy to identify. A related weakness for the Baldwin scheme is that it tends to overforecast the occurrence of freezing rain and ice pellets. Another weakness in this approach is that it ignores dry layers. So, while it does utilize the wet-bulb temperature it does not account for the impact of a dry layer. For example, as hydrometeors fall through a warm dry layer the hydrometeors will initially be impacted by ambient air temperature in this layer and as the temperature cools to the wet-bulb temperature we may see a change in the precipitation-type and the algorithm does not account for this process.

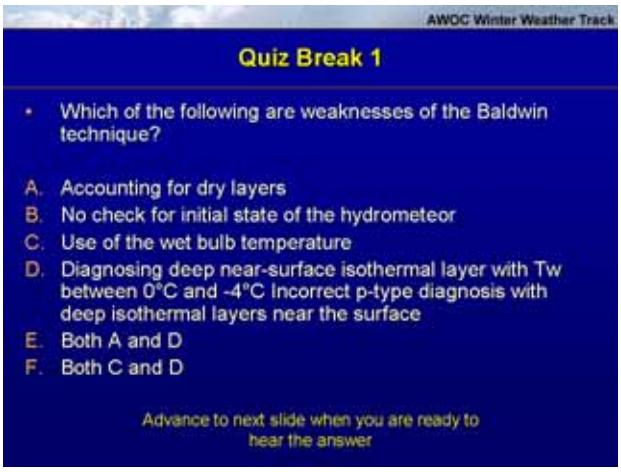
Student Notes:



17. Quiz Break 1

Instructor Notes: Given the material that we have covered which of the following are weaknesses of the Baldwin technique?

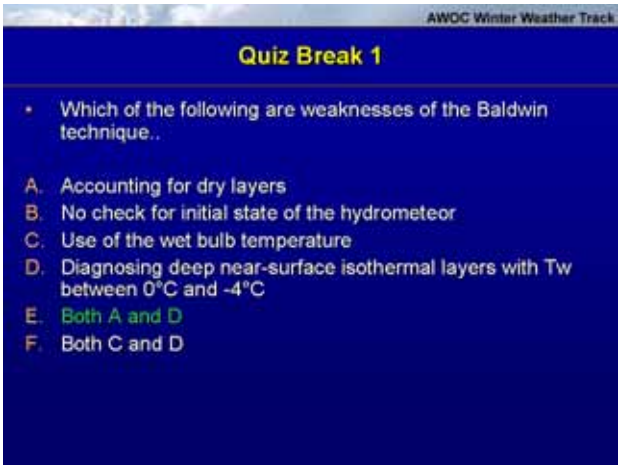
Student Notes:



18. Quiz Break 1

Instructor Notes: The correct answer is E. The Baldwin technique has a weakness with respect to diagnosing deep near-surface isothermal layers with Tw between 0 degrees C and -4 degrees C. The technique will frequently generate an incorrect precipitation type in these scenarios. The technique also has a weakness in that it does not account for dry layers. So the correct answer is E.

Student Notes:



19. What About the Ramer Method?

Instructor Notes: The Ramer method was developed in the early 1990s. From a data set of over twelve thousand soundings the algorithm was tuned utilizing over 2000 cases in which the upper air sounding and a surface observation (located within 30 km of sounding site) were both detecting precipitation (Ramer 1993). The technique utilizes temperature, relative humidity, and the wet-bulb temperature at different pressure levels as input. These parameters are utilized to identify layers where precipitation is likely to be generated and also to control what is referred to as the 'ice fraction' which determines the resultant precipitation type. Essentially the technique follows an idealized precipitation parcel down to the ground from a precipitation generating level (which will be discussed shortly) anticipating the state of the hydrometeor as it descends based on the temperature, relative humidity, and wet-bulb temperature at various levels. The Ramer output is available for the GFS BUFR output in BUFKIT. It is also available in AWIPS in the LAPS precipitation type output.

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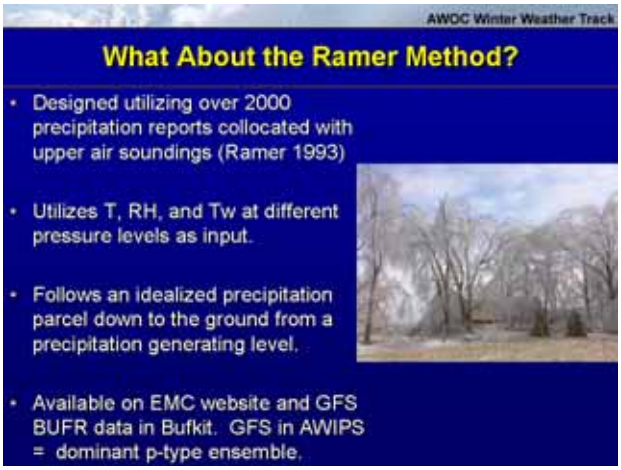

20. Preliminary P-Type Checks

Instructor Notes: Before the Ramer method does a full calculation of the ice fraction two preliminary checks are complete. The first check is simply whether or not the wet-bulb temperature at the surface is > 2 degrees C. If this is the case then rain is diagnosed. This check was put in place in that none of the cases in their data set had a p-type other than rain when the surface Tw was > 2 degrees C. The second check determines if the surface temperature is less than 2 degrees C and the remainder of the vertical profile is < -6.6 degrees C then snow is diagnosed. If neither of these checks passes then a full calculation of the ice fraction of the precipitation particles is undertaken.

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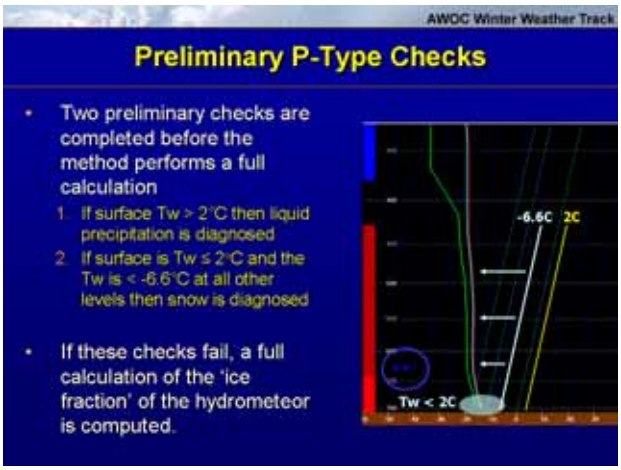

21. Determining Initial Hydrometeor State

Instructor Notes: To begin the full calculation the Ramer method attempts to identify what is termed the “precipitation generation level”. To do this it identifies the highest layer where the RH is > 90%. This level must be at or below 400 mb. This level is determined to be the precipitation generating level. Once this level is identified a determination is made as to the initial state of the hydrometeors. If the Tw at this level is < -6.6 degrees C the hydrometeors as considered to be completely frozen and given an ice fraction of 1. If the Tw is > -6.6 degrees C then the hydrometeors are considered to be entirely liquid and given an ice fraction of 0. The cutoff of -6.6 degrees C was utilized as this resulted in the most optimal performance of the algorithm during its development.

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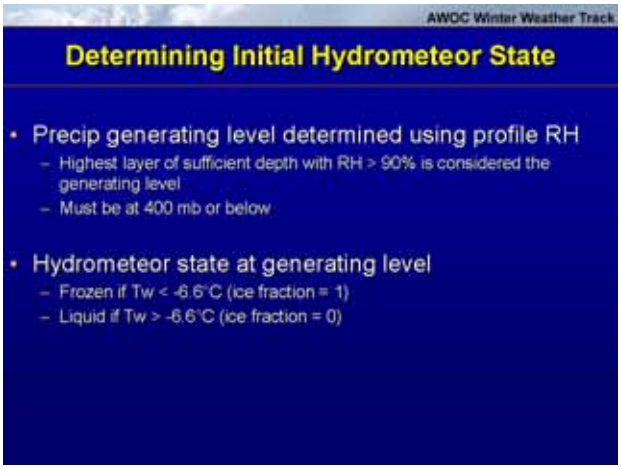

22. How Does the Method Determine P-type?

Instructor Notes: Ultimately, what is called the “ice fraction” determines the precipitation type. After the initial determination of the hydrometeor state the algorithm utilizes an empirically derived calculation to essentially follow the theoretical hydrometeor through the profile. The algorithm utilizes the wet-bulb temperature at different pressure levels as the hydrometeor descends to determine the final ice fraction. An ice fraction of 1 indicates that the hydrometeor is completely frozen while an ice fraction of 0 indicates that the hydrometeor is completely liquid. As the hydrometeor descends the algorithm determines the amount of freezing or melting, if any, that the hydrometeor will undergo. If a hydrometeor begins as liquid (ice fraction of 0) it will not begin to freeze until it hits a layer where the Tw < -6.6 degrees C. Conversely, if a hydrometeor initiates as ice (ice fraction of 1) it will not begin to melt until it encounters a layer where the Tw is > 0.

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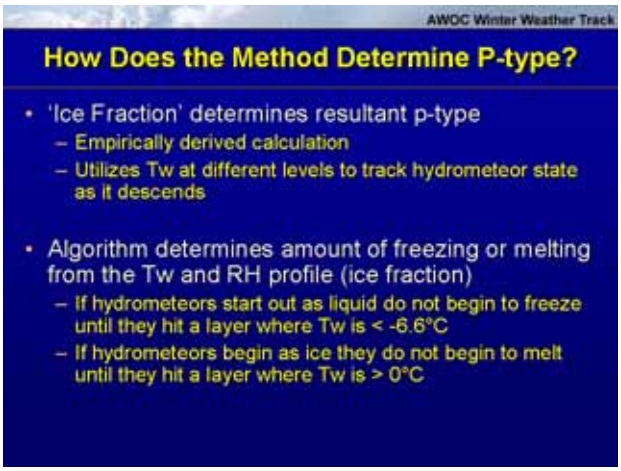
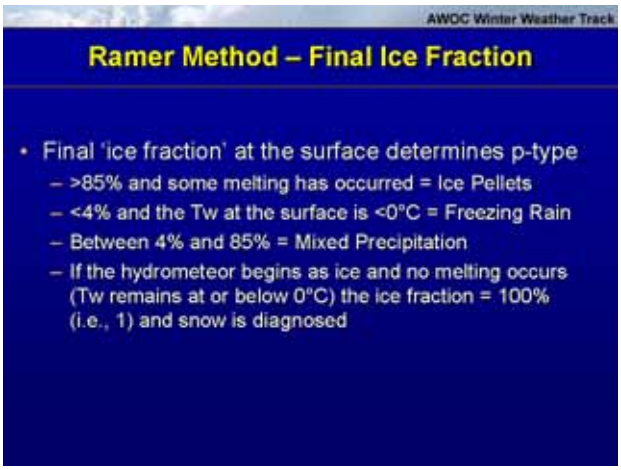


23. Ramer Method – Final Ice Fraction

Instructor Notes: As the hydrometeor descends through the profile the Ramer method simply identifies layers that are warmer than 0 degrees C and layers that are colder than

-6.6 degrees C and melts or freezes hydrometeors based on the average wet-bulb temperature and the depth of these layers. The final ice fraction of the hydrometeor at the surface determines the p-type. If some melting has occurred and the ice fraction is greater than 85% then the algorithm will forecast Ice Pellets. If the ice fraction is < 4% and the Tw at the surface is < 0 degrees C then it will produce freezing rain. An ice fraction between 4 and 85% will result in mixed freezing and frozen precipitation. If the hydrometeor begins as ice and no melting occurs (Tw remains at or below 0 degrees C) then the ice fraction = 1 and snow is diagnosed The Ramer Method is the most difficult of the precipitation type methods to visualize due to its empirical nature. This make is more difficult to assess operationally than the Baldwin Method, for example.

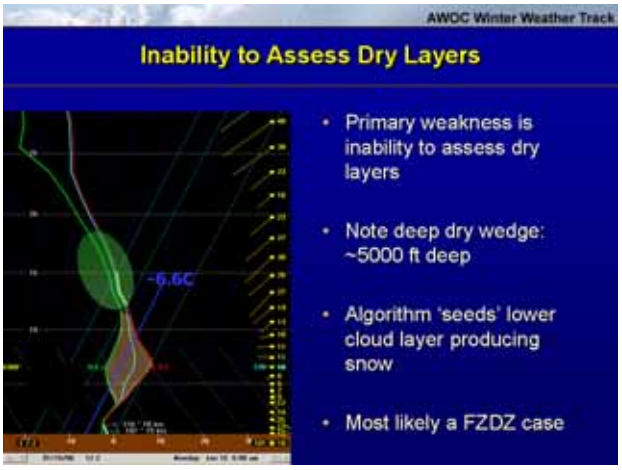
Student Notes:



24. Inability to Assess Dry Layers

Instructor Notes: While the Ramer method is statistically a strong method, it too has weaknesses. One limitation of the Ramer method is that is has no knowledge of dry layers. While utilizing the wet-bulb temperature in a top-down approach is a robust methodology the inability to assess dry layers in the vertical profile can have a negative impact on the Ramer output. In this example we see a sounding which contains a deep dry wedge which is about 5000 feet deep. The Ramer method identifies the highest saturated layer below 400 mb and identifies this as precipitation generation level. It then determines the initial hydrometeor state as being ice crystals since the coldest temperature in this saturated layer is colder than -6.6 degrees C. The algorithm follows the hydrometeor as it descends utilizing the wet-bulb temperature to determine if any melting would occur. A problem with the Ramer method is exposed in this example as there is a considerable dry wedge over which sublimation could occur. The Ramer method does not account for this dry layer and essentially seeds the lower cloud deck producing snow. In reality, if we were to see precipitation out of this sounding it would likely be freezing drizzle if the low level cloud layer is of sufficient depth. Over time the dry wedge would likely be eroded as hydrometeors fall from the higher level cloud deck through the dry layer. Eventually snow would develop as this layer saturates and the ice crystals from the higher deck seed the low level clouds. However, the Ramer method would initially incorrectly diagnose this sounding by not accounting for the dry layer.

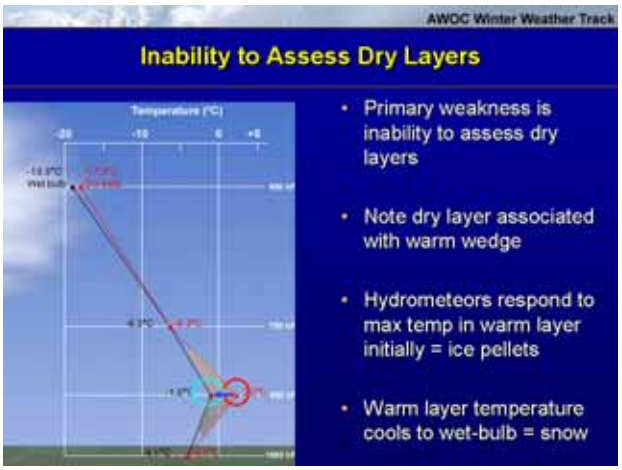
Student Notes:



25. Inability to Assess Dry Layers

Instructor Notes: The impact of a dry layer would also be evident in a case such as this where the maximum temperature in the warm layer was say +2 or +3 degrees C while the wet-bulb temperature was below 0C. Again in this case we see that there is a decent dry layer in place. Initially the hydrometeors would undergo partial melting based on the strength of the warm layer. Given the cold temperatures in the near surface layer we would likely see ice pellets at the onset of precipitation in a case such as this. As the temperature in the warm wedge migrated towards the wet-bulb temperature the precipitation type would change to snow. However, the Ramer method which would not account for the maximum temperature in the warm layer would simply forecast snow given the wet-bulb temperature profile. As a result it would incorrectly diagnose the precipitation type at the onset of precipitation. This inability to account for dry layers in the Ramer method is something to be cognizant of if you utilize its output.

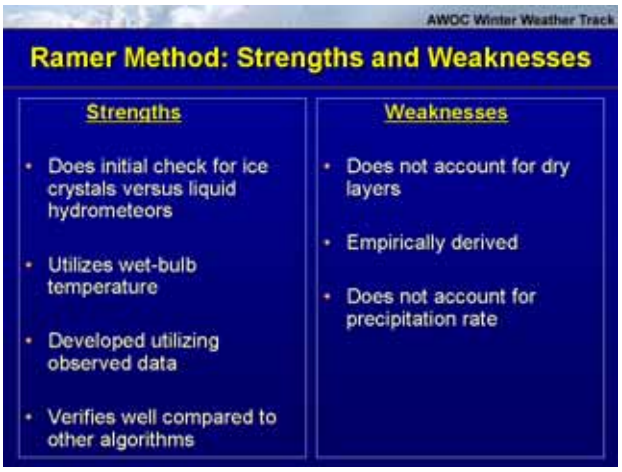
Student Notes:



26. Ramer Method: Strengths and Weaknesses

Instructor Notes: The Ramer algorithm has several strengths. The algorithm does an initial check for the phase of the hydrometeor. It also utilizes the wet-bulb temperature to diagnose the state of hydrometeors as they descend. Another strength of the algorithm is that it was developed utilizing observed data as opposed to model soundings. Finally, the Ramer technique verifies very well. Statistically speaking it is the strongest of the precipitation type algorithms with respect to probability of detection for snow (94%) and freezing rain (60%). It also has the lowest false alarm rate for ice pellets, but has a correspondingly poor probability of detection for ice pellets. Overall, it is statistically the strongest method. As we have discussed the primary weakness of the algorithm is that it does not account for dry layers. Other aspects that could be considered as weaknesses are that it was empirically derived and that it does not account for precipitation rate. Of course, precipitation rate is not accounted for in any of the algorithms that we have or will examine.

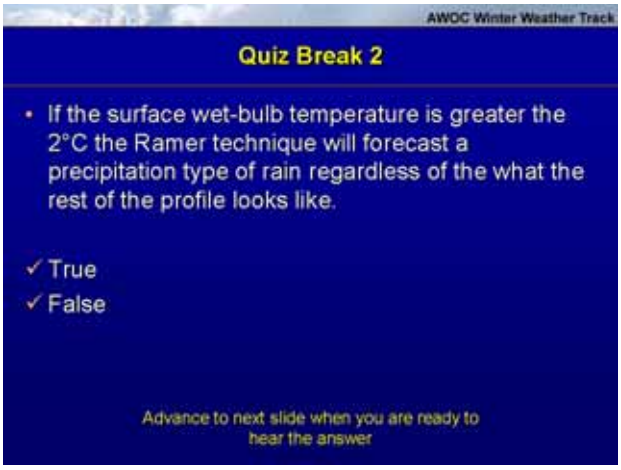
Student Notes:



27. Quiz Break 2

Instructor Notes: Time for another short quiz break. If the surface wet-bulb temperature is greater the 2 degrees C the Ramer technique will forecast a precipitation type of rain regardless of the what the rest of the profile looks like.

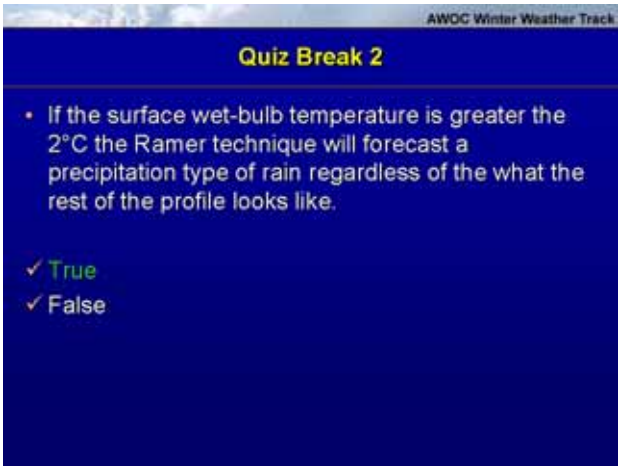
Student Notes:



28. Quiz Break 2

Instructor Notes: The correct answer is true. Two preliminary checks are completed before the Ramer method performs a full calculation. If surface Tw > 2 degrees C then liquid precipitation is diagnosed. Alternatively, if surface is Tw ≤ 2 degrees C and the Tw is < -6.6 degrees C at all other levels, then snow is diagnosed.

Student Notes:



29. P-Type

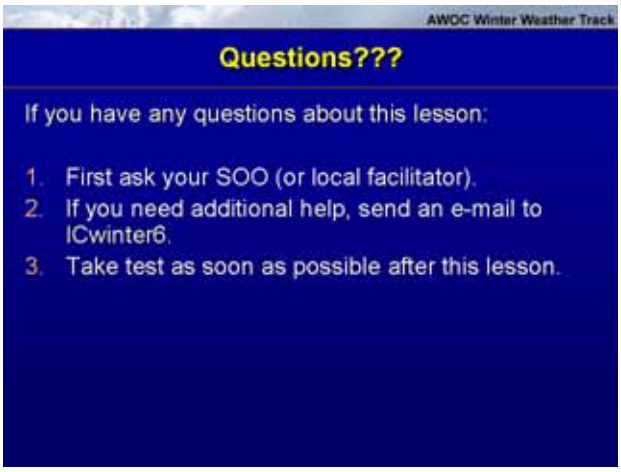
Instructor Notes: Take a few moments to complete this interactive quiz.

Student Notes:

30. Questions???

Instructor Notes: After going through this lesson if you have any questions, first ask your SOO. Your SOO is your local facilitator and should be able to help answer many questions. If you need additional info from what your SOO provided, send an E-mail to the address on the slide. This address sends the message to all the instructors involved with this IC. Our answer will be CC'd to your SOO so that they can answer any similar questions that come up in the future. We may also consider the question and answer for our FAQ page. Thanks for your time and good luck on the exam!"

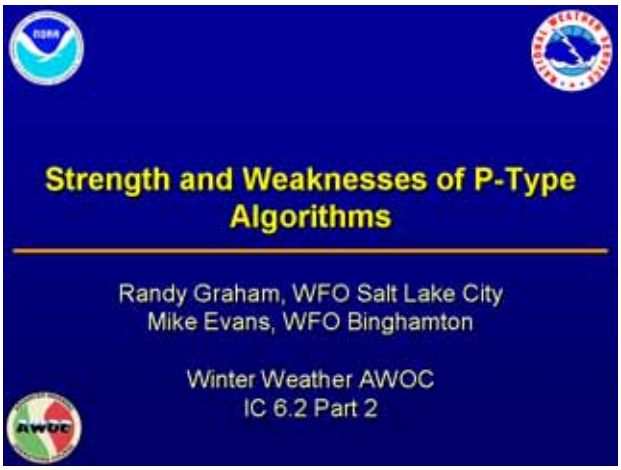
Student Notes:



1. IC6.2 Part 2: Strength and Weaknesses of P-Type Algorithms

Instructor Notes: Welcome to IC6 lesson 2, Part 2. This lesson is about 30 slides long and will take approximately 25 minutes to complete.

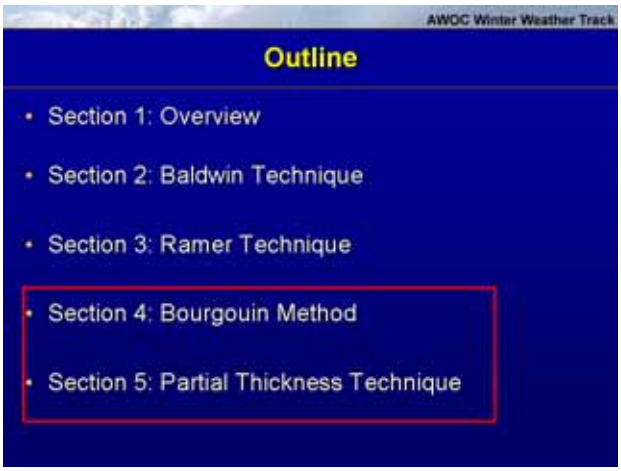
Student Notes:



2. Outline

Instructor Notes: Lesson 2 of IC 6 is divided into five sections. In Part 1 we discussed the learning and performance objectives, the utility of p-type algorithms, and then we focused on the Baldwin technique and the Ramer technique. Now, in Part 2, we will discuss the Bourgouin Method and Partial Thickness Method.

Student Notes:

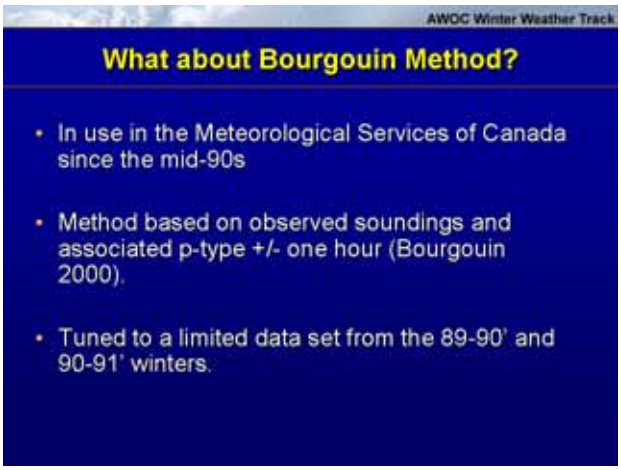


3. What about Bourgouin Method?

Instructor Notes: This method was developed by Bourgouin of the Canadian Meteorological Centre in Dorval, Quebec in the early 1990's and it has been in use in the Meteo-

rological Services of Canada since the mid 1990's. The method was developed by looking at a data set of cases in which surface precipitation observations were collocated with upper air soundings. The upper air soundings provided the vertical temperature structure needed to establish the criteria utilized in the method. RAOB drift was not accounted for and values were assumed to be above the sounding site. The precipitation had to be reported within one hour of the time that the sounding was taken and at the same location for it to be included in the data set utilized to tune the method. This criteria and the fact that the technique was tuned over only two winter seasons (1989-90 and 1990-91) resulted in a small training data set. For example, it was initially tuned to 54 cases of freezing rain versus ice pellets, 119 cases of rain versus snow, and 3-5 cases of ice pellets versus rain. The number of cases with respect to ice pellets versus rain is uncertain in that there is no information on the exact state of the hydrometeor aloft, (i.e., as it enters a surface based warm layer) so the number of cases is estimated.

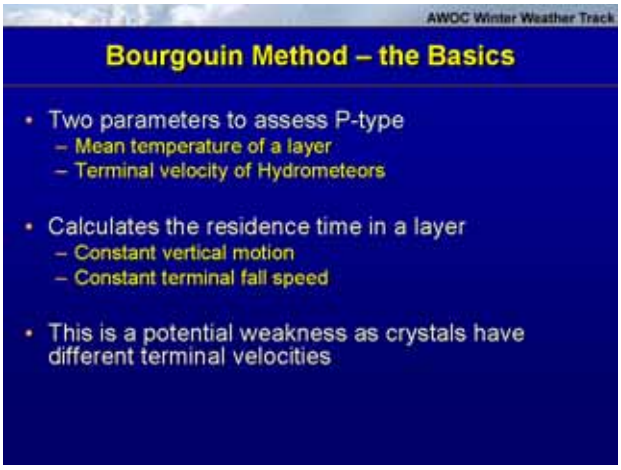
Student Notes:



4. Bourgouin Method – the Basics

Instructor Notes: The method is built on the premise that the temperature variation of a falling hydrometeor and its resulting phase changes are predominately driven by the temperature of the environment through which the hydrometeor falls. Clearly, a hydrometeor falling through a layer with temperatures above freezing temperatures will become liquid if it resides in this layer for a sufficient time. Given this premise, the method assumes that two parameters drive p-type, the mean temperature of a layer and the residence time of the hydrometeor in this layer. The mean temperature of a given layer can be readily computed for both observed and forecast soundings. The same cannot be said of the residence time of the hydrometeor in a layer as the residence time is dependant on the depth of the layer, the terminal velocity of the hydrometeors, and the mean vertical motion. Therefore, the method assumes a constant vertical motion and terminal velocity. The assumption of a constant terminal velocity could be considered a weakness as different crystal structures have different falls speeds. However, it is not clear how significant this variation could be or how one could account for it operationally.

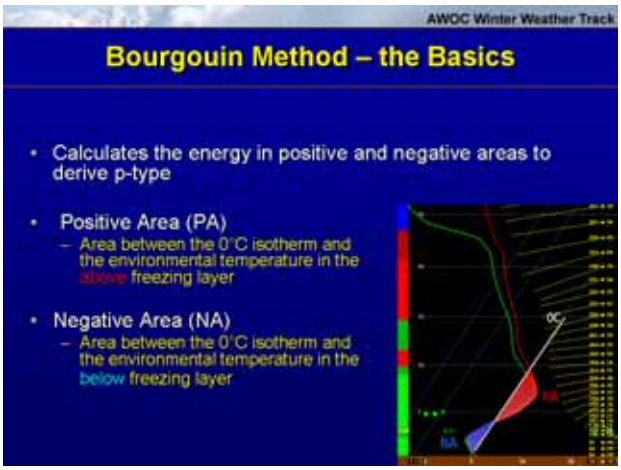
Student Notes:



5. Bourgouin Method – the Basics

Instructor Notes: Given these concepts it is clear that one can combine the mean temperature of a layer and the height of a layer by multiplying them together which will give you a value proportional to the area covered by the layer in question. Essentially, the algorithm determines if there is sufficient energy to melt or freeze hydrometeors as they fall. A positive area is defined as the area between the 0 degree C isotherm and the environmental temperature in the above freezing layer. Conversely, a negative area is defined as the area between the 0 degree C isotherm and the environmental temperature in the below freezing layer. Positive and negative areas in a given sounding are computed, bounded by the 0 degree C isotherm and the environmental temperature curve. The precipitation type (snow, freezing rain, ice pellets, or rain) is determined by the magnitude of the positive and negative areas. In cases where two precipitation types are determined to be of equal likelihood, one or the other is chosen randomly.

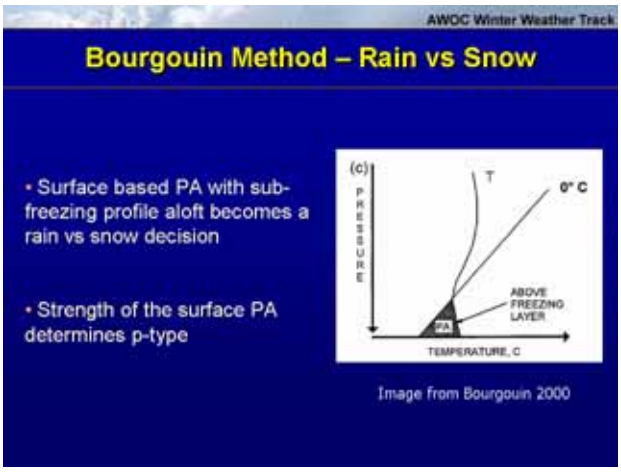
Student Notes:



6. Bourgouin Method – Rain vs. Snow

Instructor Notes: The most obvious forecast is when ice crystals are present and the entire profile is sub-freezing then you will have snow or the entire profile is above freezing in which case you will obviously have rain. Obviously, rain versus snow considerations get much more complex than this. When you have a surface based warm layer (or positive area) with no warm air aloft (in other words all negative area aloft) the possibilities are confined to rain, snow, or a mix of the two. To differentiate between profiles of this type the Bourgouin method interrogates the positive area at the surface.

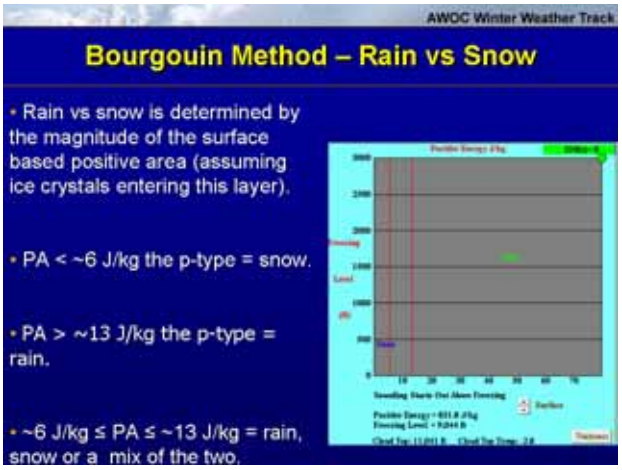
Student Notes:



7. Bourgouin Method – Rain vs. Snow

Instructor Notes: In cases such as the one we just described, the table on the right is utilized to differentiate between rain and snow. If the surface based positive area is less than roughly 5.5 J/kg it will predict snow. If the surface based positive area is greater than a little over 13 J/kg it is determined to be rain. Between these two values the method assumes a rain/snow mix. Here is an example of how the snow versus rain table looks when displayed in the Bufkit software. Note they only considered cases with small surface based positive areas (less than 20 J/kg) as surface warm layers stronger than this were associated with surface temperatures well above freezing and were clearly strong enough to completely melt any frozen hydrometeors. Also, it is important to note that the Bourgouin method assumes ice crystals are entering the surface layer. It does not perform a check for the initial state of the hydrometeor.

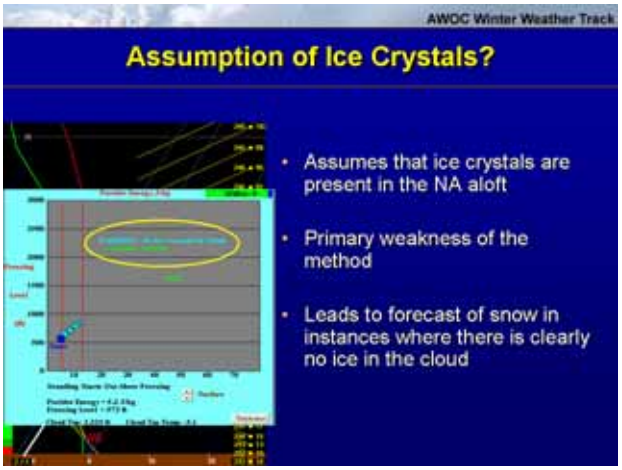
Student Notes:



8. Assumption of Ice Crystals?

Instructor Notes: The Bourgouin Method does not check the negative area aloft for saturation to ensure that the moisture is deep enough and temperature cold enough to support heterogeneous nucleation of ice crystals. This is the primary weakness of the method and one that you should keep in mind when you look at output from the Bourgouin method. Note in the example shown that the saturated layer only extends to a temperature of -4 or -5 degrees C and that the profile is very dry at temperatures of -10 degrees C and below. Clearly this is a case where it would be unlikely that we would have ice crystals present. However, the output from the Bourgouin algorithm indicates snow. Utilizing the top-down methodology you will quickly catch this, but if you were to look at the algorithm output in a vacuum you may get a forecast of snow in what turns out to be a freezing drizzle event. BUFKIT has an added check to account for this and will display a message (as seen on this slide) alerting you to the likelihood that heterogeneous nucleation may not occur in the given profile.

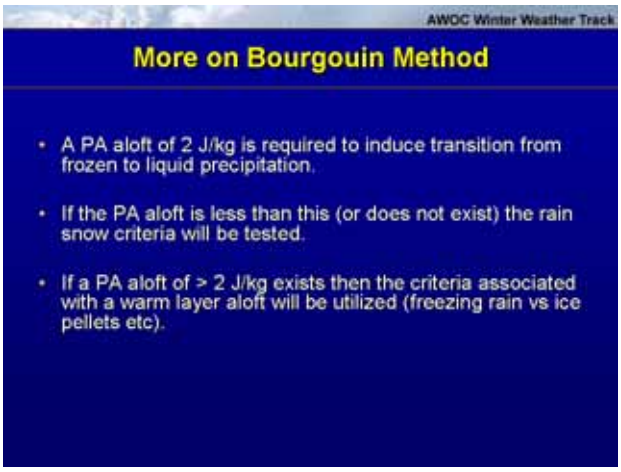
Student Notes:



9. More on Bourgouin Method

Instructor Notes: The database utilized to tune the Bourgouin method did not contain, or only contained a very small number of, cases of mixed snow and freezing rain or mixed snow and ice pellets, so these scenarios are not addressed by the method. Based on the soundings studied during development of the algorithm it was found that it only took a positive area of 2 J/kg to induce the transition from frozen to liquid precipitation. If the positive area aloft (if any) is less than 2 J/kg then it assumes that the ice crystals are not melted and it will look at the low levels to test the rain versus snow criteria. If there is a positive area of 2 J/kg or greater aloft then the algorithm assumes complete melting of the ice crystals and then it will look at the low level to determine if the resultant precipitation type should freezing rain, ice pellets, or rain.

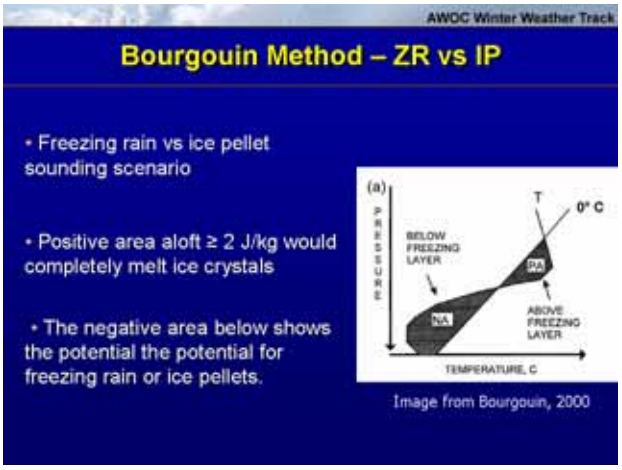
Student Notes:



10. Bourgouin Method – ZR vs. IP

Instructor Notes: This example demonstrates how the Bourgouin method would consider a freezing rain or ice pellet case. It was found in the research that the most promising predictors of ice pellet versus freezing rain cases were the positive and negative areas in the sounding (that is a positive area above a surface based negative area). The positive area aloft would be enough to melt any frozen hydrometeors, in this example. If the hydrometeor completely melts and then falls into a sub-freezing surface layer then the question becomes is there enough negative area to completely re-freeze the hydrometeors as ice pellets or will it reach the surface as freezing rain.

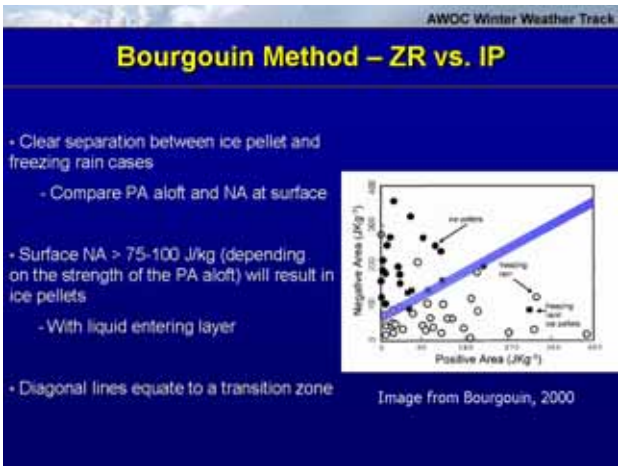
Student Notes:



11. Bourgouin Method – ZR vs. IP

Instructor Notes: The Bourgouin study actually found a pretty clear delineation between freezing rain and ice pellets in scenarios such as this based on the strength of the positive area aloft and the negative area near the surface. They found that even a small positive area aloft (say, greater than 2 J/kg) will lead to freezing rain so long as the surface based negative area is relatively small (say, less than 50 J/kg). For cases with a weak positive area (left hand side of the image) it was found that a negative area greater than around 100 J/kg would lead to ice pellets while cases with stronger positive areas aloft would require a stronger negative area to completely refreeze the hydrometeors to ice pellets. The study noted that with a small positive area (2 J/kg or less), it is possible to get some snow mixed in with the freezing rain or ice pellets. However, they did not attempt to discriminate whether or not freezing rain or ice pellets would be mixed with snow. Obviously, if you have a reliable sounding near these thresholds you will likely want to forecast a mix of precipitation types. The resultant diagram shown on this image is utilized in the Bourgouin method to differentiate between ice pellets and freezing rain when you have a positive area aloft and a negative area at the surface.

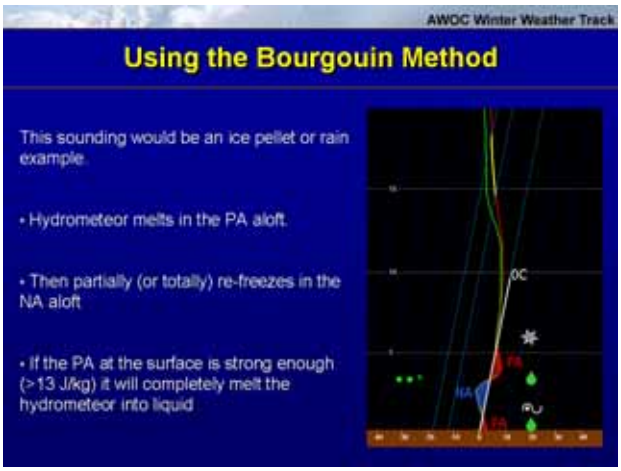
Student Notes:



12. Using the Bourgouin Method

Instructor Notes: The area (or Bourgouin) method follows a theoretical hydrometeor as it falls through different temperature layers. In the sounding you will note that there are two positive areas (one at the surface and one aloft) with a negative area in between the two. To determine the p-type in a scenario such as this the method will attempt to mimic the behavior of the hydrometeor as it descends. Let's look at how the Bourgouin technique would handle a scenario such as this. The method assumes that the hydrometeors start off as ice crystals, so the first question is whether the positive area aloft is sufficient to melt the ice crystals. As the crystal enters the positive area aloft the method would assume complete melting as this positive area is greater the 2 J/kg. So, as it exits the positive area aloft the method would treat hydrometeors as being in liquid form. It would then check to determine if the negative area is strong enough to completely re-freeze the hydrometeors by looking the strength of the positive area aloft and the negative area beneath it. If the negative area is less than 75-100 J/kg it will treat the hydrometeors as liquid as they exit the bottom of the negative area. Then as the hydrometeors enter the surface based positive layer, in this case, the method will determine the resultant precipitation type as rain.

Student Notes:

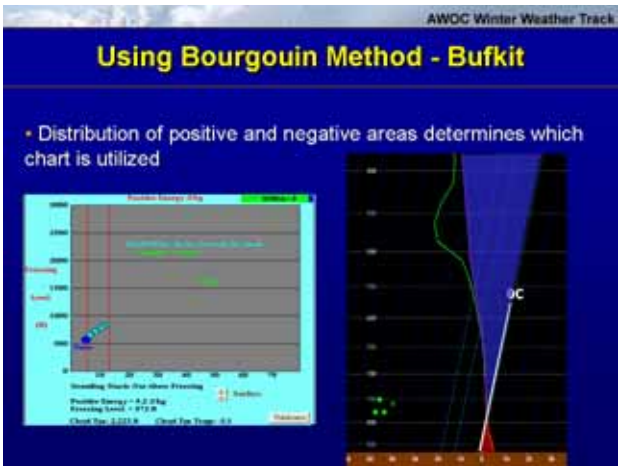


13. Using Bourgouin Method - BUFKIT

Instructor Notes: Keep in mind that the appearance of the Bourgouin charts will change depending on the vertical temperature profile. Depending on the vertical distribution of the positive and negative areas different charts are utilized to assess the resultant p-type. In this first example, we have two positive areas adjacent to an elevated negative area. The Bourgouin method treats this as a sleet versus rain decision and utilizes the chart shown on the left. In this next example, we have a positive area aloft and a negative area at the surface. This is treated as a freezing rain versus sleet scenario. Finally, in this last example we have a negative area aloft and a positive area at the surface. This is a rain versus snow decision and the Bourgouin method utilizes the chart displayed on the left. Keep in mind that as you step through time the vertical profile will change. As the

vertical profile changes the distribution of the positive and negative areas will change as well which may result in different Bourgouin charts being utilized for different time periods in the forecast time frame of concern. The best place to view the output from the Bourgouin technique is in the BUFKIT software. In BUFKIT the Bourgouin output can be displayed for any model sounding. As you step through the hourly or three hourly soundings, with the Bourgouin technique toggled on, the appropriate chart will display based on the distribution of the positive and negative areas in the profile.

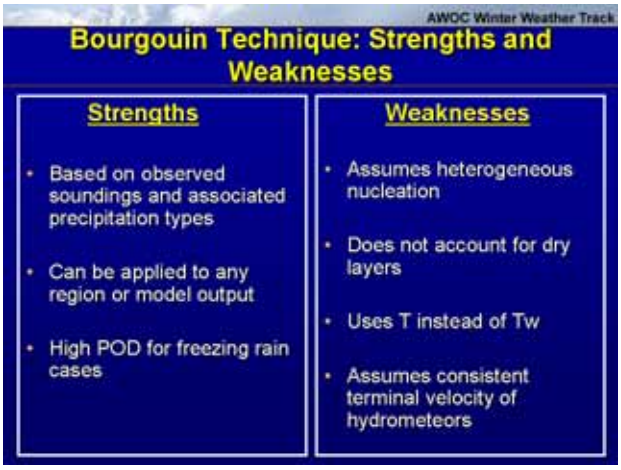
Student Notes:



14. Bourgouin Technique: Strengths and Weaknesses

Instructor Notes: The Bourgouin technique has several strengths. First, it was developed based on observed soundings and the precipitation type associated with those soundings. It can also be applied to any region or model output. The technique also has a high POD for freezing rain cases. There are also several weaknesses to the method. Foremost of these is the assumption that ice crystals are present. The assumption that heterogeneous nucleation has occurred can easily lead to precipitation type forecast failures. Another weakness is that it does not account for dry layers. This has the same effect as what was discussed with the Ramer technique in that hydrometeors are not allowed to sublime. This is compounded by the methodology's use of the temperature as opposed to the wet-bulb temperature. By utilizing the temperature and ignoring dry layers the technique does not appropriately consider sublimation or evaporation and the associated wet-bulb cooling as hydrometeors fall through an unsaturated layer. Finally, the technique assumes a constant terminal velocity of hydrometeors. Hydrometeors have different terminal velocities based on their size and shape and this impacts the residence time of a hydrometeor in a given layer.

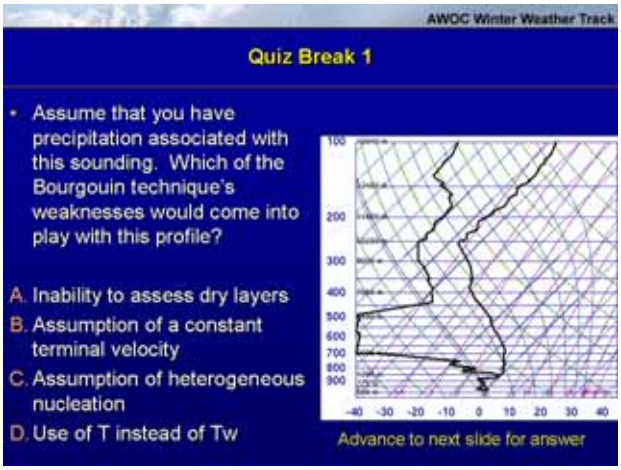
Student Notes:



15. Quiz Break 1

Instructor Notes: Time for a short Quiz Break. Assume that you have precipitation associated with this sounding. Which of the Bourgouin technique's weaknesses would come into play with this profile? When you are ready to see the answer click 'Next' to advance to the next slide.

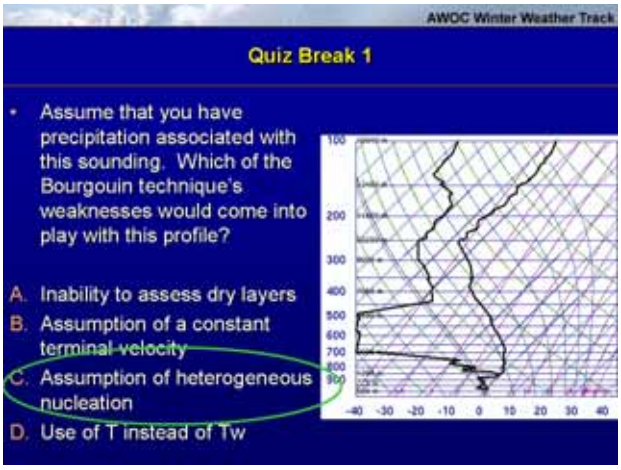
Student Notes:



16. Quiz Break 1

Instructor Notes: The correct answer is C. Given that the profile is saturated to only -5 degrees C the Bourgouin technique's assumption that ice crystals are present would come into play in this example. The Bourgouin would assume that ice crystals are present and since there is no positive area in the sounding it would forecast a precipitation type of snow. Since the sounding is only saturated to around -5 degrees C it is unlikely that ice crystals are present in this cloud layer and the most likely precipitation type would actually be freezing rain.

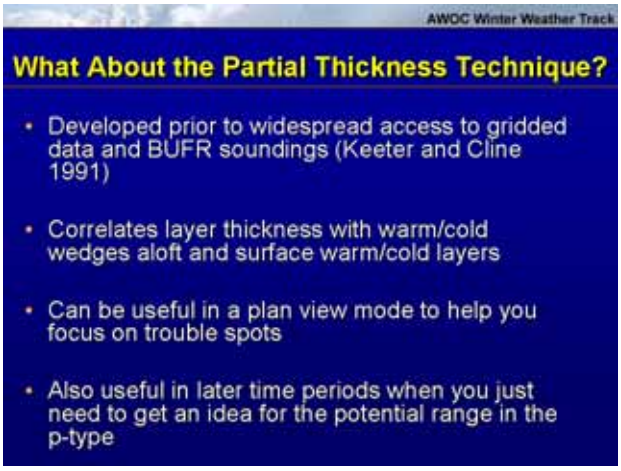
Student Notes:



17. What About the Partial Thickness Technique?

Instructor Notes: The partial thickness method was developed prior to widespread access to gridded data and BUFR soundings. Essentially, the method assesses layer thickness values to interrogate warm and cold wedges aloft and at the surface. While the technique is not as detailed as more rigorous sounding analysis methods such as the top-down methodology it can be useful in plan view mode as it may assist the forecaster in the identification of areas that require more thorough inspection. This methodology is also useful in later time periods when you are looking to get handle on the potential range in the precipitation type and not as confident in the details of the vertical profile.

Student Notes:

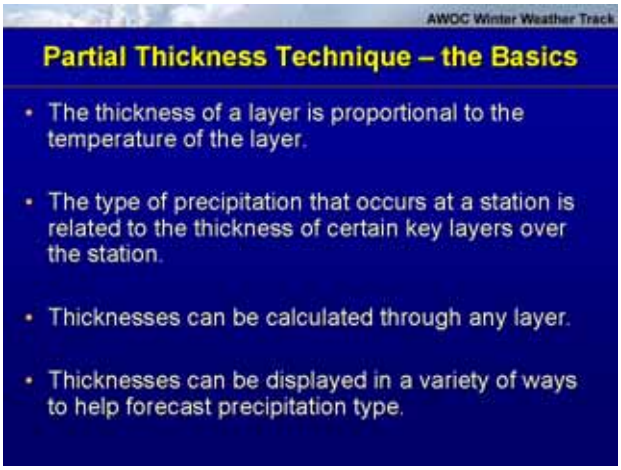


18. Partial Thickness Technique – the Basics

Instructor Notes: Forecasters have been using thickness to forecast precipitation type for many years. However, recent advances in computing power have allowed forecasters and researchers to develop and apply some new approaches to this technique. Thickness techniques are based on the fact that the thickness of a layer, defined by 2 constant pressure levels, is proportional to the temperature of the layer, with lower thicknesses

corresponding to lower temperatures. Previous research has shown that reliable precipitation type thresholds for thicknesses can be determined for a given station. For example, it was determined many years ago that snow was favored over rain at many locations when the 1000-500 mb thickness is below 540 dm. Similar thresholds have been determined at many locations for smaller layers, such as 1000 to 850 mb and the 850 to 700 mb. The term “Partial” in Partial Thickness refers to the fact that these layers comprise only part of the traditional 1000 to 500 mb layer. Modern computing power now allows forecasters to easily compute observed and model forecast thicknesses for a variety of layers, and allows forecasters to combine and display combinations of various thicknesses in a variety of ways in order to visualize the horizontal and vertical temperature profile in an effort to forecast precipitation type.

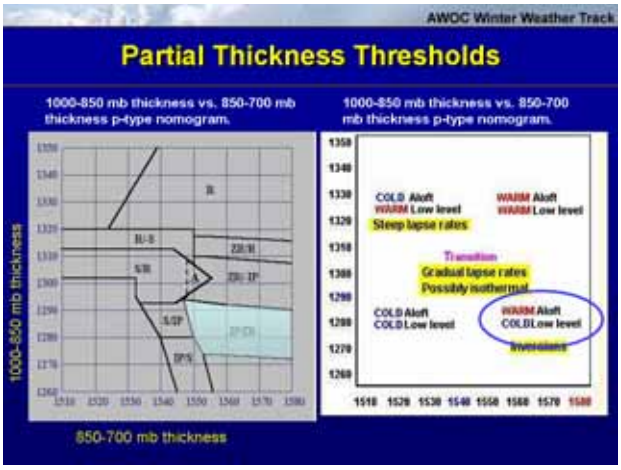
Student Notes:



19. Partial Thickness Thresholds

Instructor Notes: The thickness thresholds indicated by the nomograms shown on this slide were developed for Greensboro, North Carolina. Research in the Carolinas indicate that these thresholds work well at locations with elevations ranging from sea-level to around 1500 feet above sea-level. Note that the forecast technique suggested by these nomograms involves combining low-level thickness with mid-level thickness to derive precipitation type. For example, a small 1000-850 mb thickness in combination with a large 850-700 mb thickness (the lower-right portion of the nomogram) implies cold air at low levels, with warmer air aloft, and the likelihood of freezing precipitation.

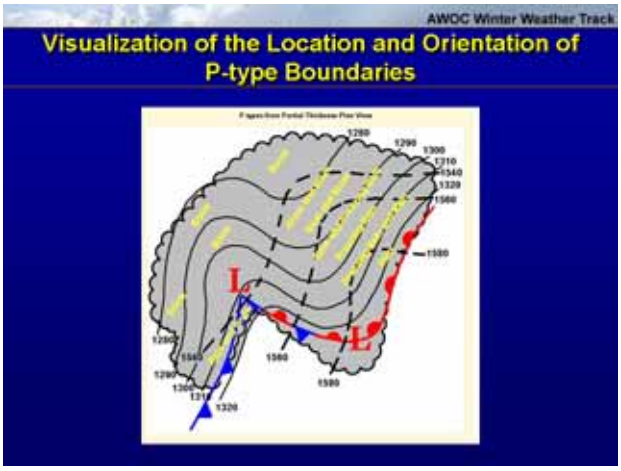
Student Notes:



20. Visualization of the Location and Orientation of P-type Boundaries

Instructor Notes: One advantage of utilizing the partial thickness method in the forecast process is the increased ability to visualize the location and movement of precipitation type boundaries across wide areas in plan view. In the example shown on this slide, the plot of partial thickness values would help the forecaster visualize the likely location of precipitation type boundaries in a complex situation. The forecaster would then be able to further refine his or her forecast by performing a high resolution sounding analysis at a few key locations utilizing a more rigorous methodology such as the top-down method. In addition, viewing this type of display in a time-lapse mode would also allow forecasters to visualize the evolution of the atmospheric thermal environment; for example, the advance or retreat of cold air at low or midlevels.

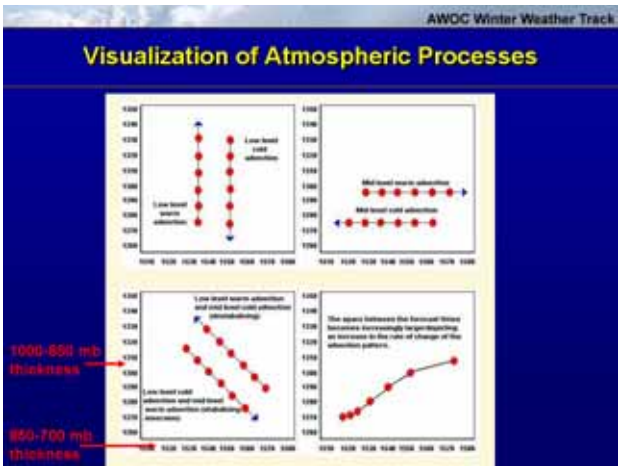
Student Notes:



21. Visualization of Atmospheric Processes

Instructor Notes: Another application of partial thickness is shown on this slide. Viewing the time-evolution of partial thickness values at a particular site can give the forecaster insight into what kind of atmospheric processes are at work. For example, in the graph at the upper left, low-level temperature advection, in the absence of mid-level temperature advection, is indicated when the low-level thickness is changing, but the mid-level thickness remains constant. The graph at the upper right shows the opposite condition; mid-level temperature advections are indicated with an absence of low-level temperature advection, when the mid-level thickness values change while the low-level thickness values remain constant. The 2 graphs at the bottom of this slide show the response of the thickness values in sample situations for various combinations of lower and mid-level temperature advection.

Student Notes:

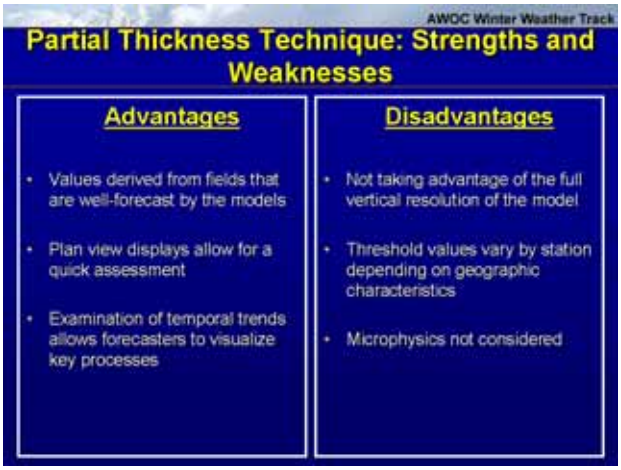


22. Partial Thickness Technique: Strengths and Weaknesses

Instructor Notes: In summary, the use of partial thickness to forecast precipitation type has both strengths and weaknesses. The first strength is that partial thickness values are derived from fields, specifically height fields, that are well-forecast by the models. In contrast, sounding interrogation techniques sometimes rely on accurate model forecasts of shallow warm layers, and subtle boundary layer temperature structures, that may not be as well-forecast. Another strength is that partial thicknesses can be displayed in ways that help the forecaster visualize the location and movement of precipitation type boundaries, and to visualize the atmospheric processes that are affecting the vertical profile. The primary weakness of the partial thickness technique is that it does not take advantage of the full vertical resolution of the model. For example, the NAM model currently has a vertical resolution of 60 layers, with the majority of those layers located below 500 mb. Partial thickness techniques only involve the diagnosis of a very limited number of those layers (typically 2), and may sometimes miss important details in the forecast verti-

cal structure of the atmosphere, especially in situations where very shallow layers of warm or cold air are present. For example, rain can sometimes occur at stations near large, unfrozen bodies of water when partial thickness values are below typical rain/snow thresholds, if a shallow, mild layer of maritime air is present near the surface. Another weakness of partial thickness is that threshold values can vary by station, depending on the geographic characteristics of the station. For example, locations at higher elevations tend to have higher rain/snow thresholds of partial thickness. Forecasters should also keep in mind that microphysical processes are not accounted for in any partial thickness technique. For example, the partial thickness technique may erroneously predict snow in situations where the entire sounding is below freezing, yet the moist layer does not extend into a layer where the temperature is below -10 degrees C and therefore the profile is not likely to support heterogeneous nucleation. Because of these weaknesses, it is not recommended that partial thickness forecasting techniques be used alone to forecast precipitation type. If you choose to utilize the partial thickness technique it may be best to utilize partial thicknesses for plan view visualization, and visualization of atmospheric processes, and then utilize more through sounding interrogation to account for shallow warm and cold layers, as well as for microphysical considerations.

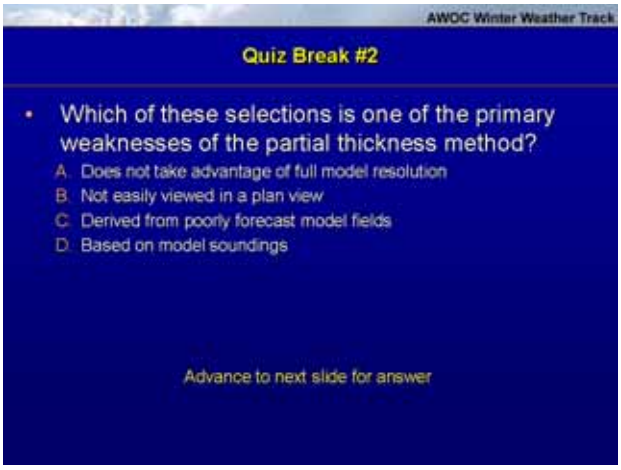
Student Notes:



23. Quiz Break #2

Instructor Notes: Time for a short quiz break. Which of these selections is one of the primary weaknesses of the partial thickness method? Click ‘next’ to advance to the next slide.

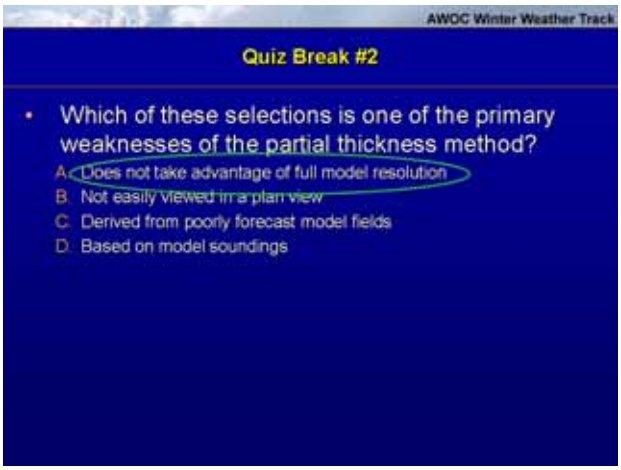
Student Notes:



24. Quiz Break #2

Instructor Notes: The correct answer is A. One of the weaknesses of the partial thickness technique is that it does not take advantage of the full vertical resolution of current numerical models.

Student Notes:

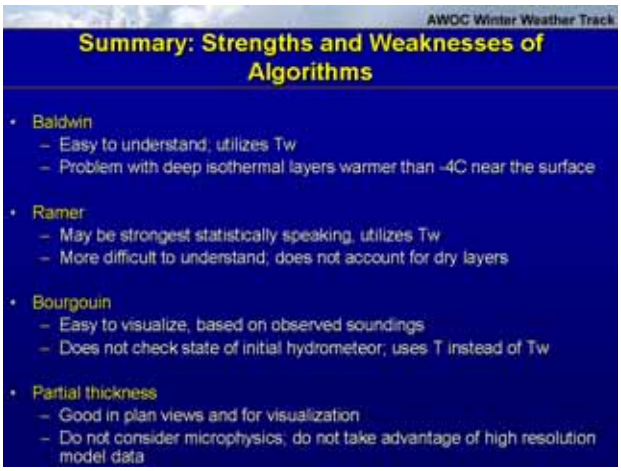


25. Summary: Strengths and Weaknesses of Algorithms

Instructor Notes: One key aspect to take away from this presentation is that all p-type algorithms have individual strengths and weaknesses. The best way to determine precipitation type is to utilize your own knowledge of the environment and potential model errors while applying the top-down methodology. However, p-type algorithms can assist you in the process of making the determination of p-type, particularly when you are looking at many points and time periods. The Baldwin method is widely available and is easy to understand and visualize why it is producing a given precipitation type. Another strength is it's use of the wet-bulb temperature to determine precipitation type. The pri-

mary weakness of the Baldwin method is with how it handles deep isothermal layers near the surface with temperatures between 0 degrees C and -4 degrees C. If these layers are sufficiently deep the Baldwin method will produce a forecast of rain or freezing rain it what is ultimately a snow sounding. The Ramer method may be the strongest algorithm statistically speaking. Another strength is its use of the wet-bulb temperature in a top-down process to determine precipitation type. It may be a more robust algorithm than the others, but it is correspondingly more difficult to understand how it arrived at a given precipitation type. While it is not as visually appealing as the others the primary weakness of the method is it's inability to assess dry layers. The Bourgouin method again is easy to understand and has very useful charts to help visualize why it is producing a given precipitation type. The method is based on precipitation types associated with actual observed soundings which is a strength. However, the Bourgouin method does not check the initial state of the hydrometeor and, as a result, will assume ice crystals are present in some situations where heterogeneous nucleation has not been achieved. Another significant weakness is the use of T instead of Tw. Partial thickness concepts are particularly useful in plan views and for visualization of the potential distribution of precipitation. The methodology itself may not be as detailed as the others, but it readily lends itself assessing a larger area without requiring us as forecasters to look at a multitude of point soundings. Significant weaknesses of partial thickness techniques are that they do not consider microphysical concepts and do not take advantage of the details available in high resolution model data.

Student Notes:

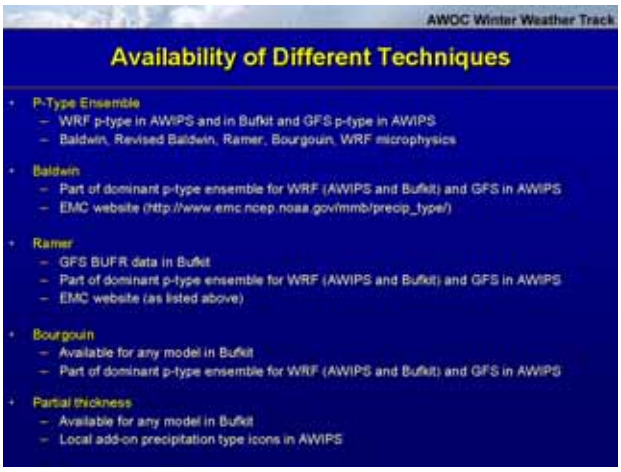


26. Availability of Different Techniques

Instructor Notes: Here is a brief review on the availability of the different algorithms. The Baldwin technique is available for the NAM BUFR data in BUFKIT and the NAM precipitation type selections in the AWIPS browser. It is also available on the EMC web site which shows an ensemble of precipitation type algorithm output. The Ramer technique is available for the GFS BUFR data in BUFKIT and is also available with the LAPS precipitation type display in AWIPS. The Ramer output is also displayed on the EMC web site alongside the Baldwin technique output. The Bourgouin method output can be displayed for any BUFR data output in BUFKIT. However, it is not available in AWIPS at this

time. Output from the partial thickness method can be displayed for any BUFR output in BUFKIT. It is also available in AWIPS as a local add-on to the Volume Browser selections.

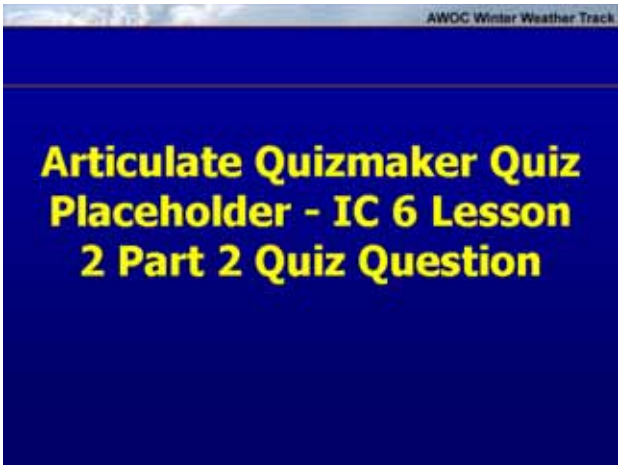
Student Notes:



27. Interactive Quiz

Instructor Notes: Take a few moments to complete this interactive quiz.

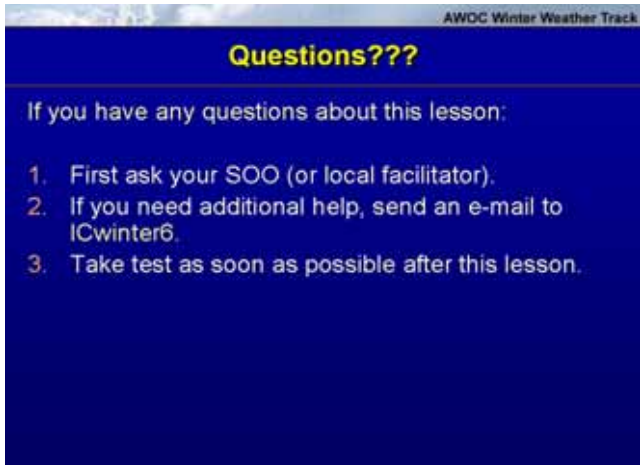
Student Notes:



28. Questions???

Instructor Notes: After going through this lesson if you have any questions, first ask your SOO, or local AWOC winter track facilitator. Your SOO or local facilitator should be able to help answer many questions. If you need additional info from what your SOO provided, send an E-mail to the address on the slide. This address sends the message to all the instructors involved with this IC. Our answer will be CC'd to your SOO so that they can answer any similar questions that come up in the future. We may also consider the question and answer for our FAQ page. Thanks for your time and good luck on the exam!

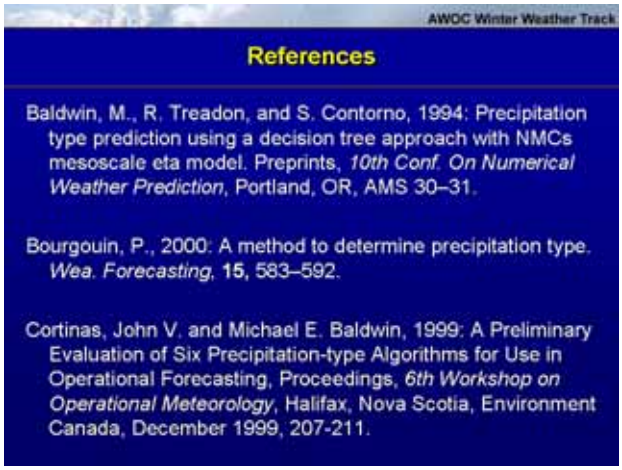
Student Notes:



29. References

Instructor Notes: References

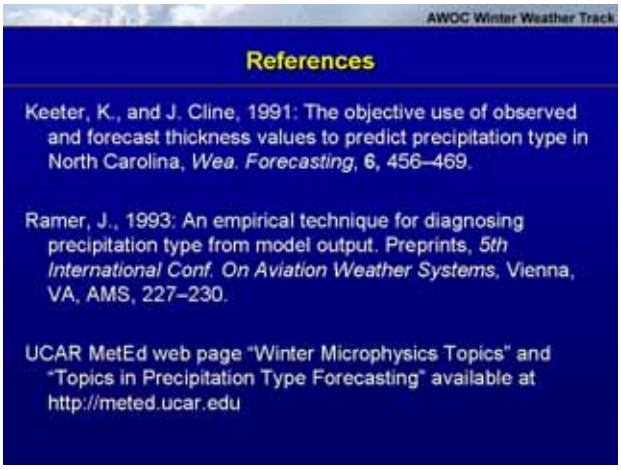
Student Notes:



30. References

Instructor Notes: Additional references

Student Notes:



IC6.2: Optional Job Sheet

Strengths and Weaknesses of P-Type Algorithms

Objective: Utilize AWIPS and BUFKIT to determine P-type for a winter precipitation event. In the IC 6 Lesson 1 job sheet you examined soundings using the top-down approach and arrived at P-type forecasts without the aid of algorithms. In this job sheet, you will utilize algorithm output from the same winter weather event.

Data: 24 February 2003 winter storm across Texas. You will be using AWIPS D2D in case review mode and BUFKIT in this job sheet.

Instructions:
AWIPS D2D Case Review Mode Task:
Load the 24 February 2003 Winter Weather AWOC case on your WES machine in case review mode, using the FWD localization. You will be examining the 18 UTC NAM 40 model run from 24 February 2003.
First, set the pane to state scale with cities plotted, and use the volume browser to load NAM 40 model accumulated snowfall and P-type icons, which are a product of the Baldwin technique. Overlay the Thickness probability icons which utilize the partial thickness method. Step forward to the 9 hr forecast valid at 03 UTC on 25 February.
In another pane load a point sounding in the center of the max snowfall in southern Oklahoma.
Do you notice any potential sources of error with the Baldwin technique for snowfall based on this 03 UTC forecast sounding? Explain your reasoning.

Load a NAM 40 sounding just northwest of Austin, TX in the region where the Partial Thickness method indicates freezing rain for the 03 UTC February 25 forecast. Explain why the Baldwin method indicates snow, while the Partial thickness method indicates freezing rain.

BUFKIT Task: For the same event, you may now examine BUFKIT profiles.
Instructions:
Install the latest version of BUFKIT (version 4.71) from the CD provided by WDTB. If you already have it installed, skip ahead to #5. If you don't have the CD handy and want to install BUFKIT and the WW AWOC data on your personal PC, you can go to http://www.wdtb.noaa.gov/tools/BUFKIT.

Unzip the file into a temporary directory.

Model Run	Site	Forecast Hour	Post Processor (Baldwin)	Bourgouin	Eta Microphysics	Thickness
2/24/03 18z	DFW	F09				
2/24/03 18z	ADM	F09				
2/24/03 18z	ABI	F09				
2/24/03 18z	AUS	F09				

Run the program "setup.exe"
This setup program will install Bufkit and all the needed support and data files.
To begin, go to the Windows start button, click “programs” → BUFKIT Winter Weather AWOC, then click on the icon corresponding to BUFKIT Winter Weather AWOC.
View the Profile Screen.
Select the Model by clicking on the radio button: **Eta**.
Select the Site by clicking the “select” button in the top right, then moving over to the left side of the screen and selecting the profile: **kdfw**
Use the vertical scroll bar to scroll to Forecast Hour **9**.
Make sure the control panel is displaying: **Controls**.
To determine the Eta post processor solution make sure the option box labeled **Bourgouin Precip Type on Profile** is <u>unchecked</u>. Look for the solution on the bottom left section of the profile panel. Precipitation type will show up as Blue (snow), Green (rain), Red (freezing rain), or Orange (sleet). **Fill in the table above with the expected P-type.**
To determine the Bourgouin solution, <u>check the box</u> next to **Bourgouin Precip Type on Profile**. Look for the solution on the bottom left section of the profile panel. To see how Bufkit came to this solution, click on the **Precip Type** panel on the data panel section. Note the cloud top height and the temperature of the cloud top displayed near the bottom of the Precip Type panel. Also note any warning messages that Bufkit may identify with the Bourgouin solution. **Write the P-type in the appropriate box.**
The Eta Microphysics solution is also displayed on the **Precip Type** panel in the data section. Look in the very upper-right corner of the display for the model output parameter **SNRA**. The **SNRA** parameter is the percent of hydrometeors that are frozen. **Enter this value into the appropriate box above.**
Partial Thickness solution. Extra Credit. On the **Precip Type** panel, click on the button in the lower-right corner labeled **Thickness**. Note the nomogram plot of 1000-850 mb

thickness (Y-axis) versus 850-700 mb thickness (X-axis). The largest circle is the solution for the current forecast hour with smaller circles representing earlier forecast hours. Hint: The circles may obscure the nomogram solution. In this case, just scroll the forecast hour a few hours ahead or back to view the solution. **Write the P-type in the appropriate box.**

Repeat for 3 other profiles: Ardmore, OK (ADM), Abiliene, TX (ABI), and Austin, TX (AUS) each for the 9 hour forecast.

After filling out the table, answer the following 3 questions.

In the DFW and ABI soundings, explain the characteristics of the profiles that resulted in all techniques indicating sleet during the ~0-14 hr forecast period.

In the AUS sounding, explain why Bourgouin indicated rain/freezing rain at the 9 hr forecast, versus the sleet indicated by the Baldwin and Partial thickness methods.

In the ADM sounding and from what you learned in IC 6 Lesson 1 about the strength/ depth of the warm layer, do you believe the any of the techniques that indication sleet in the 0-6hr timeframe? Explain why.

Based on the information you processed using both D2D and BUFKIT, use the attached map below to draw P-type contours valid at 03 UTC on 25 Februray, 2003.

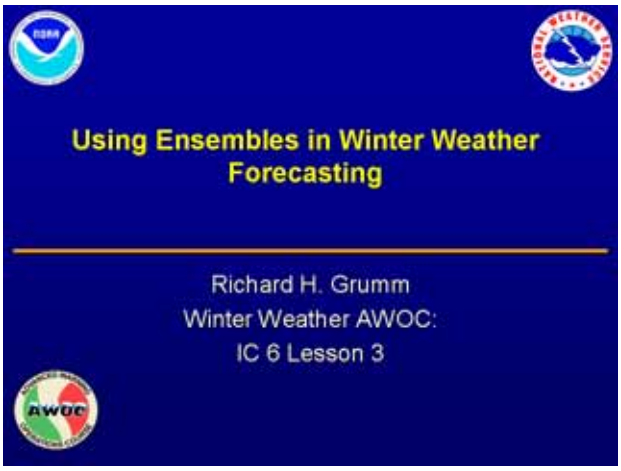
An answer key is available for this job sheet. Please see your local AWOC Winter Weather facilitator to obtain a copy.

AMISTAD
CANADIAN
HENNESSEY
TULSA
FAYETTEVILLE
AMARILLO
ELK CITY
OKLAHOMA CITY
CHECOTAH
BROADVIEW
MEMPHIS
ADA
LAWTON
MENA
PLAINVIEW
ARDMORE
MORTON
WICHITA FALLS
NASHVILLE
SPUR
SHERMAN
TEXARKANA
BROWNFIELD
GRAHAM
SNYDER
DALLAS
BENTON
CISCO
TYLER
MIDLAND
BLACKWELL
WACO
NACOGDOCHES
SAN ANGELO
FORT STOCKTON
SONORA
BRYAN
SANDERSON
AUSTIN
KERRVILLE
BEAUMONT
LOMA ALTA
HOUSTON
DEL RIO
SAN ANTONIO
GALVESTON
EDNA
EAGLE PASS
BEEVILLE
ARTESIA

1. IC6.3: Using Ensembles in Winter Weather Forecasting

Instructor Notes: Welcome to IC 6 Lesson 3. My name is Richard Grumm and this lesson will focus on using ensemble output in forecasting winter weather.

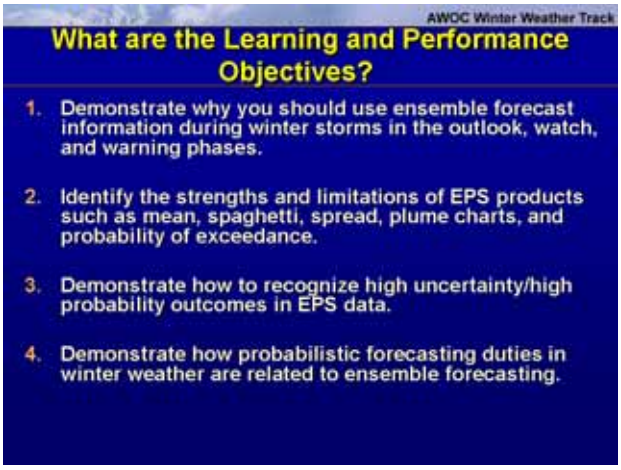
Student Notes:



2. What are the Learning and Performance Objectives?

Instructor Notes: These are the 4 primary objectives for this module: The learning objectives are the basis for post-test items. The performance objectives (the ones that start with "demonstrate", #1, 3-4, are evaluated via WES simulations and/or a post-training instrument (questionnaire, survey, etc.). The objectives are: 1.Demonstrate why you should use ensemble forecast information during winter storms in the outlook, watch, and warning phases. 2.Identify the strengths and limitations of EPS products such as mean, spaghetti, spread, plume charts, and probability of exceedance. 3.Demonstrate how to recognize high uncertainty/high probability outcomes in EPS data. 4.Demonstrate how probabilistic forecasting duties in winter weather are related to ensemble forecasting.

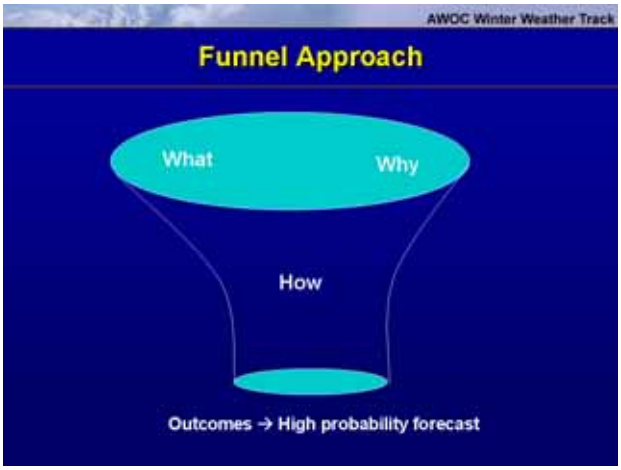
Student Notes:



3. Funnel Approach

Instructor Notes: What we will be talking about is ENSEMBLES. Why? To help improve forecasts of significant winter weather events. How? We will review ensemble products which can be used to forecast winter weather. The desired outcome is higher probability forecasts of winter weather.

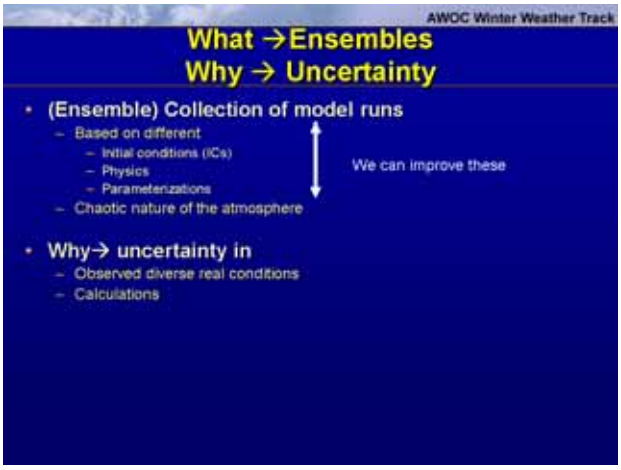
Student Notes:



4. What? Ensembles. Why? Uncertainty.

Instructor Notes: We need ensembles to deal with the UNCERTAINY in forecasting. An ensemble is a collection of the output numerical weather prediction models (NWP). The individual members of the ensemble may have been initialized with different Initial Conditions (ICs) or use different mathematical formulations and physics packages in their Model Core (MC). The more diverse the Ensemble Prediction System (EPS) the better your forecast will become. We also need to deal with the chaotic nature of the atmosphere which we will most likely never be overcome. Why do we want ensembles? Due to the uncertainty in initial conditions and the calculations in our models which in and of themselves can change the outcome of a forecast.

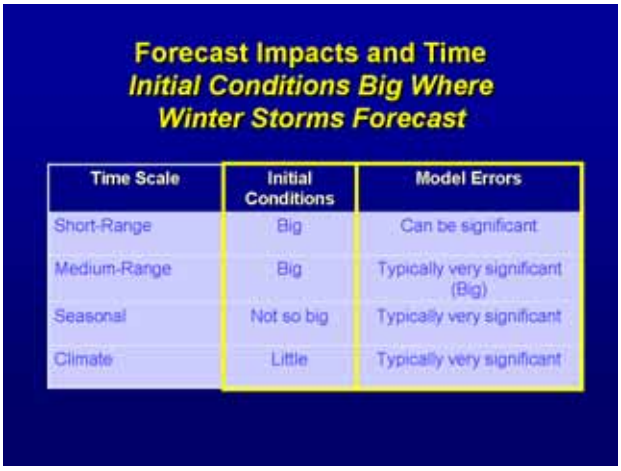
Student Notes:



5. Forecast Impacts and Time: Initial Conditions Big Where Winter Storms Forecast

Instructor Notes: This table summarizes the impact of ICs and model errors on forecasts from the short-range to the range of climatic models. For the operational forecaster note the BIG impact ICs can have at both the short- and medium-range. In addition to the big impacts of ICs on the forecast note that model errors too can be quite significant. There is an excellent paper by Zhang, Snyder, and Rotunno about the effects of moist convection on predictability in the Journal of Atmospheric Sciences published in 2003. In this study they showed how changing the convective parameterization scheme significantly impacted the forecasts. After 30-hours time the convective scheme caused each version of the MM5 to produce markedly different forecasts; thus the big effect on the Model Core and the model's ability to introduce errors in the forecasts.

Student Notes:

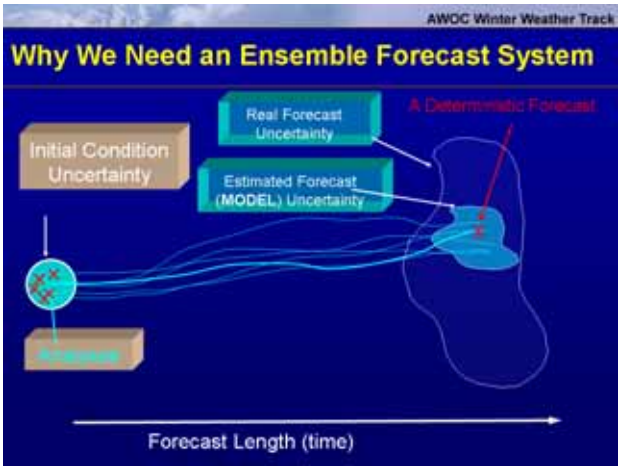


Time Scale	Initial Conditions	Model Errors
Short-Range	Big	Can be significant
Medium-Range	Big	Typically very significant (Big)
Seasonal	Not so big	Typically very significant
Climate	Little	Typically very significant

6. Basic Ensemble Diagram

Instructor Notes: So, why do we need ensembles? First, we need to overcome the uncertainty in initial conditions. Each X is a potential set of initial conditions. The circle around them represents what conditions we might expect based on climatology and our sensors. Once we have these sets of initial conditions we can run our model or models to make a forecast. Each line represents a set of forecasts. At some time X they make a forecast. The range of these forecasts is represented by the cyan area in the figure. The outer area represents the potential range of solutions we might expect which might be the normal spread of climatology. In this case, our ensemble spread is shown to be SMALLER than the SPREAD we might expect from climatology. Thus, we have an example where our ensembles have skill over climatology. Some confidence measures, which we will not discuss, leverage this information about ensemble spread and the expected spread to develop confidence measures of the ensemble forecast system.

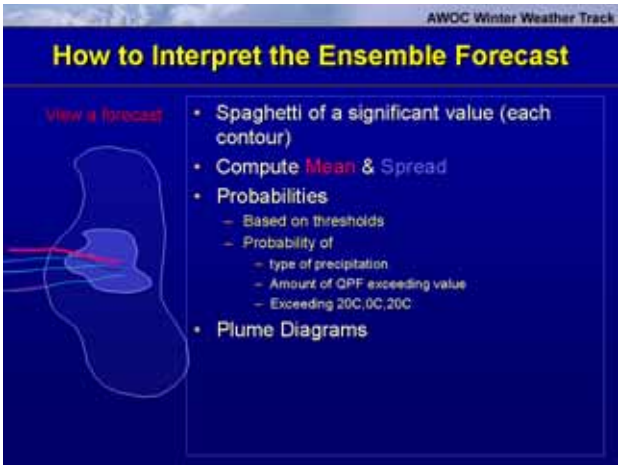
Student Notes:



7. How Products to View the Ensemble Forecast

Instructor Notes: Understanding what an ensemble is important. It is also important to know how to interpret the output of the ensemble prediction system (EPS). We will discuss some of these output products. The concept of a spaghetti diagram is most obvious from the lines that represent each forecast in the picture. But we can also compute the mean and the spread about the mean to show uncertainty. We will now examine the strength and weaknesses of several ensemble display strategies.

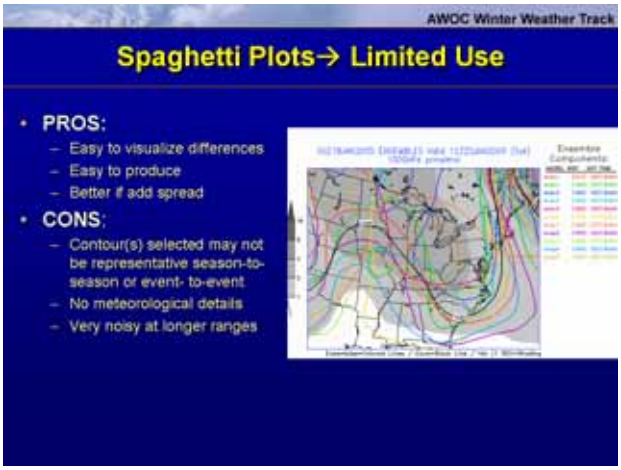
Student Notes:



8. Spaghetti Plots --> Limited Use

Instructor Notes: Spaghetti plots are probably the most widely known. We will not discuss the thumbnails of each member. The upside a spaghetti plots include the fact that they are easy to produce and readily allow the user to visualize differences. They are enhanced when shown with the spread. Some of the limits include that fact that the select contours may not be valid season-to-season and location to location, they lack meteorological details, and can become noisy at longer ranges. Actually, this latter point is also useful forecast information. The noisier, the more uncertain the forecast!

Student Notes:

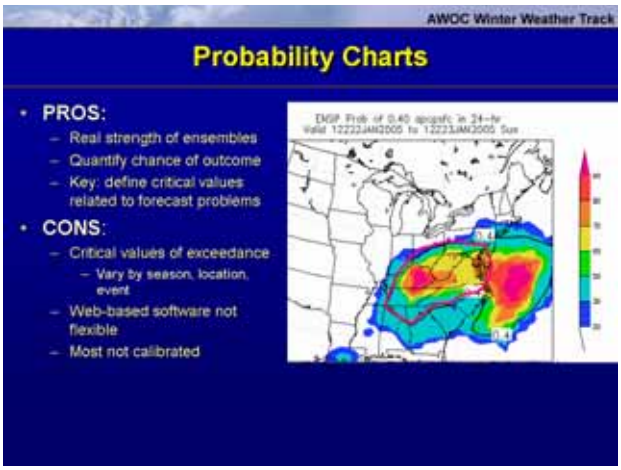


9. Probability Charts

Instructor Notes: Probability charts represent one of the main strengths of ensemble data. They allow the user to quantify a probability to an outcome. The key is often defining the probability for the parameter or parameters that meet your needs. Some of the CONS include the fact that the critical threshold value YOU require may not be available. These thresholds may vary from season to season, location, and for the event. For example, the probability of 850 hPa and 2m temperatures below 0 degrees C may have

little value to you in July. Or if your criteria is 3 inches for advisory snow, at a first guess you might want to see the probability of meeting or exceeding 0.30 inches of QPF in 12 hours. However...If you expect a 20:1 ratio during that event, you might want to see the 0.15 QPF exceedance probabilities. Web based probabilities are normally fixed and are not flexible. Additionally, there are few calibrated probabilities available. Calibrated ensemble probabilities will likely evolve over the next 2-6 years. In our example here, we can see very high probabilities that the QPF will exceed 0.4" across the Mid Atlantic region. The big thick contour (line) represents the ensemble mean of the 0.4" value. The highest probabilities of receiving at least 0.4" of liquid are located in Tennessee and Kentucky.

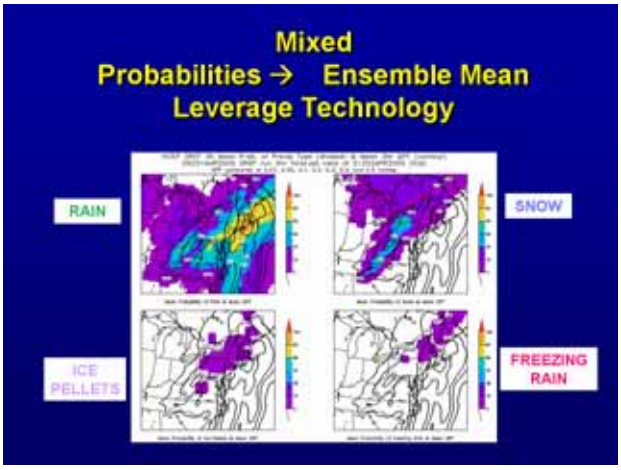
Student Notes:



10. Mixed Probabilities --> Ensemble Mean Leverage Technology

Instructor Notes: Mixed mode products are also quite valuable. This example shows the probability of precipitation type (PTYPE) as forecast by the SREF for each of the four types in the model. In addition to the PTYPE, the ensemble mean 3-hour precipitation is overlaid. These data allow the forecaster to see potential accumulation of precipitation by type. They also could be used to get conditional probabilities of rain, snow, ice, and ice pellet amounts.

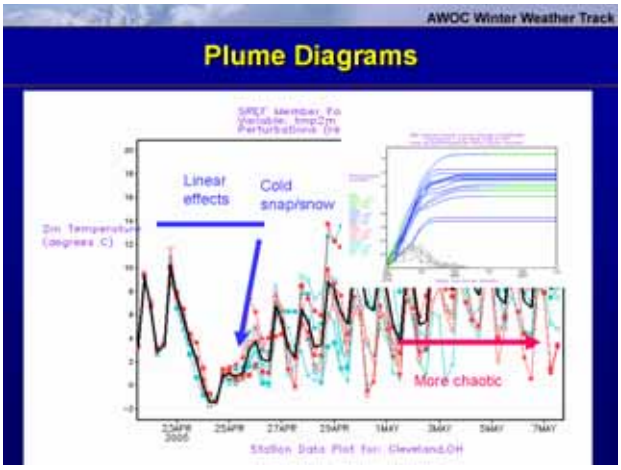
Student Notes:



11. Plume Diagrams

Instructor Notes: Plume diagrams have not been well exploited in the United States. They are basically point diagrams that are very similar to a spaghetti plot. The advantages of plumes include that they are good at a single point over time. The user can visually assess the probability distribution function (PDF), see clustering, and estimate the mode and mean visually. The cons include the fact that these products are geographically specialized, there are many parameters to display and they may not meet YOUR needs. Plume generation requires specialized application software. As an example, we can see that a plume can help refine the timing and the onset of precipitation. They can help the forecaster focus on times of heavy precipitation, and in this example, when it is mostly likely to be snow as the plume is color coded by precipitation type. This is another example of a plume from April 2005. It shows 2m temperatures. Note how the initial forecasts were in good agreement. However, over time the forecasts agree less. Toward the end, many of the forecasts are out of phase with each other. Like a spaghetti plot, plumes show us where the linear effects dominate and we have high confidence in the forecast, when the non-linear effects begin to impact the forecast, and finally, where the non-linear effects dominate. As the non-linear affects become larger, we need to account for the uncertainty and move toward more probabilistic tools. BTW: Cleveland and Detroit had record snowfall on the cold day forecast by the MREF!

Student Notes:



12. EPS

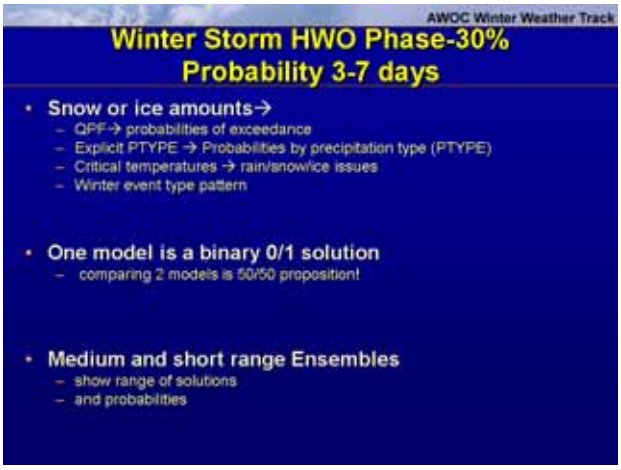
Instructor Notes: Here is a quiz based on what you've learned so far.

Student Notes:

13. Winter Storm HWO Phase-30% Probability 3-7 Days

Instructor Notes: We will now discuss using ensemble prediction products to help with the NWS winter weather program related to forecasting winter storms. We will move from the Hazardous Weather Outlook (HWO) phase of a potential event to the Warning phase. Critical questions we need to extract from EPS data include: The amounts and timing of precipitation, Precipitation type explicitly forecast by the EPS, and Critical temperatures for rain/snow/ice considerations. We also want to identify a known event pattern from the data. Is it an ice storm or snow storm? Is it a typical or an atypical event? If we use 1 model this it is pretty much hit or miss. Both Medium and short range ensembles may help us arrive at some probabilities we can match to our 30% HWO criteria.

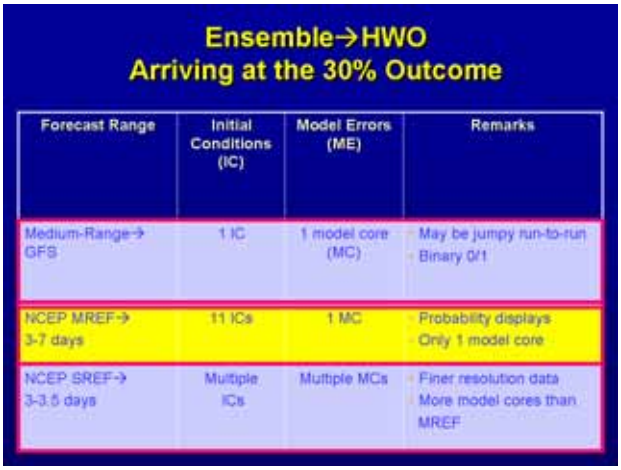
Student Notes:



14. Ensemble HWO: Arriving at the 30% Outcome

Instructor Notes: For the HWO, we rely on the NCEP Medium range ensemble forecast system which we call MREF for the greatest lead time (>3.5 days). In the 3.5 day range we can use the NCEP short range ensemble forecast system which we call the SREF. If we use the output from the Global Forecast System (GFS) alone we get 1 set of initial conditions and 1 model core. We want to avoid the binary solution and we do not want to deal with jumpiness issues. Jumpiness is defined as big changes in model forecasts between consecutive model runs. The MREF gives us 11 sets if IC's. But, a critical weakness to this system is the single model core. A strength of the Canadian EPS is its diverse model cores. But, the MREF does provide use with probabilistic tools. As the forecast length shortens, the SREF comes into play. The SREF gives us multiple IC's like the MREF but it also has diversity in its model cores. At this time the SREF has 5 RSM member, 10 NAM members 5 each with the Kain-Fritsch and Betts-Miller convective schemes, and 6 WRF members. Model diversity is an added strength of the SREF.

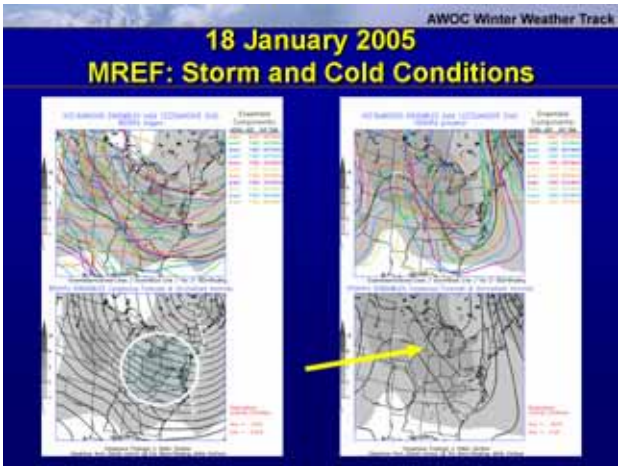
Student Notes:



15. 18 January 2005 MREF: Storm and Cold Conditions

Instructor Notes: We will now do a small case study to show how to use ensemble forecast data during a winter storm. The 22-23 January 2005 winter storm is used. You may recognize the lower panel on the right from our discussion on using the mean and spread. In this example we have MREF data from 18 January showing the EPS mean 850 hPa temperatures and MSLP forecasts. Note the noise in the spaghetti of 850 temperatures and the large spread over the Ohio Valley. Some uncertainty here. Our pattern suggests that from Chicago to Washington it may be cold enough for snow on the north side of our cyclone. Note the large spread in the pressure field north and east of our surface low. There is considerably uncertainty with the location, and depth of our surface low. We will look at the MSLP and some QPF forecasts more in a bit.

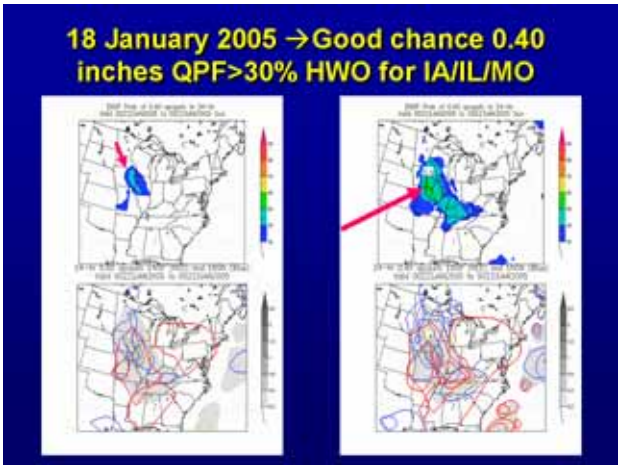
Student Notes:



16. 18 January 2005 --> Good Chance 0.40 Inches QPF > 30% HWO for IA/IL/MO

Instructor Notes: These 24-hour precipitation probability forecast are valid at 0000 UTC 23 January 2005. Upper panels show the probabilities and the lower panels show the ensemble mean QPF with spaghetti of the specified amount overlaid. In this time period there is a high probability of exceeding 0.40 inches of QPF from IA to eastern Kentucky. Note that the mean 0.40 inch contour is over IL-IA and MO. The probability of exceeding 0.60 inches is less and covers a smaller area. To a first guess we can see that storm has potential to produce a 4 inch or greater snowfall over the Mid-west. Though not shown, this precipitation shield was forecast to move over the Mid-Atlantic region over the following 12-24 hours. The next slide will show the forecast track of our storm.

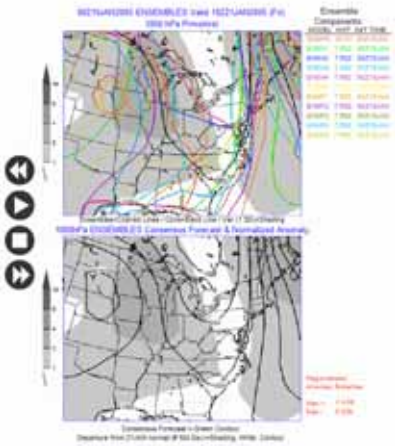
Student Notes:



17. MSLP-Loop with Mean and Spaghetti

Instructor Notes: We will now look at the MREF forecasts initialized at 0000 UTC 19 January 2005. These forecasts show the MSLP forecasts. The upper panels show the spaghetti plots and dispersion about the mean and the lower panels show the ensemble mean and the dispersion about the mean. The mean and dispersion charts allow us to put the event in a meteorological context. Watching the loop go by, we can clearly see a clipper like low in the mean with the potential for secondary re-development along the coast. Note how the spaghetti plots show us where there is big disagreement. This plot has each member's 1012 and 1020 contour plotted along with the mean position (thick black). Few members have a 1012 contour initially so there is no contour in some of the early images. Note how the spread is largest, initially north and east of the cyclone. As the surface low reaches the coast, the area of largest uncertainty shifts north of the cyclone. Timing, position, and intensity issues all impact the location of the cyclone in each member contributing to the uncertainty. Since the MREF uses 1 model core, we are seeing the impact of initial conditions on the forecast.

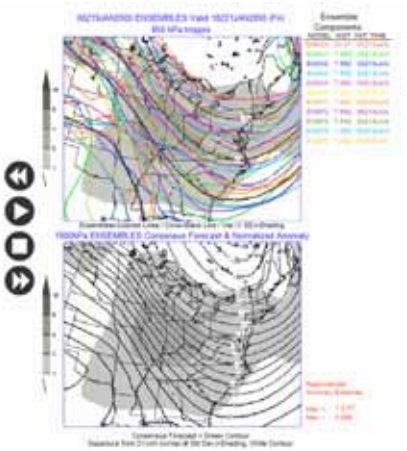
Student Notes:



18. 850 hPa Temperature Loop

Instructor Notes: This loop shows the evolution of our 850 hPa mean and spread. Later we will look at some probabilities. There are some areas along the southern edge where precipitation type issues may arise. We will now examine the QPF forecasts.

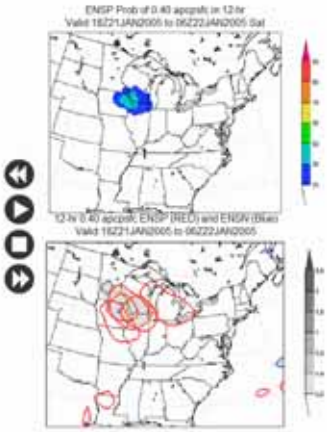
Student Notes:



19. Probability QPF Loop

Instructor Notes: This slide shows the evolution of the MREF QPF fields over time. The forecast is for 0.40 or more QPF in a 12-hour period. We have a confidence in SNOW with 0.40 inches or greater QPF from Illinois to Maryland based on these images. For 4 inch warning criteria the confidence is in the 30 or greater range…good enough for a 30% HWO. Later we will look deeper into precipitation type issues.

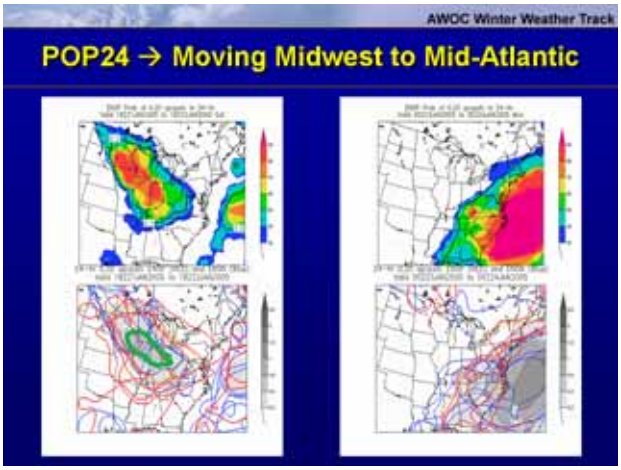
Student Notes:



20. POP24 Moving Midwest to Mid-Atlantic

Instructor Notes: These images show the probability of 0.20 inches or more of PRECIPITATION for the 24 hour periods ending at 18Z Saturday 22 January 2005 and 00Z Monday 24 January 2005. These images show a stripe of high probability in the Midwest on Saturday and along the coast on Sunday. We will see a loop of the evolution of the precipitation shield shortly. Note that the ensemble mean in the lower panels shows a broad area of 0.40 inches or more QPF over the Midwest on Saturday.

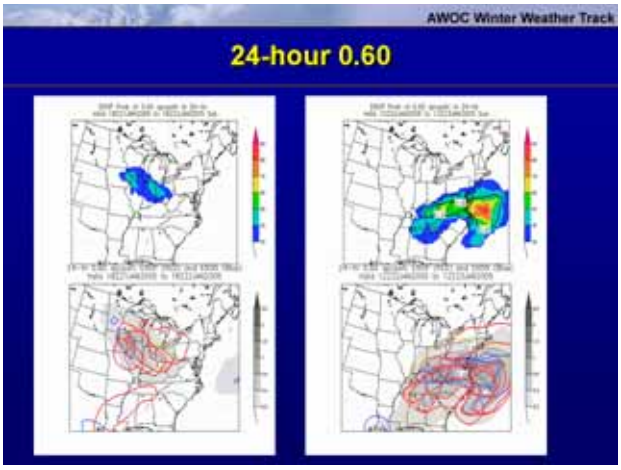
Student Notes:



21. 24-Hour 0.60

Instructor Notes: These two charts show the 24-hour exceedance of 0.60 inches of QPF...or the potential for 6 or more inches of snow along the path of our storm. The times selected are to illustrate a few points...lets look at the Midwest panel on the left. First, in the mean there is no 0.60 contour. Our probabilities show a broad 20% area in the blue color and two smaller 30-50% areas in the cyan color. There is a small area of 50-60% over IL and IA. Once the storm gets to the coast note that there is more QPF and the ensemble mean does produce a 0.60 contour. The probabilities are much higher, 50% or higher with some areas exceeding 70%. Unfortunately, as we will see later on the precipitation type in the Mid-Atlantic region was not certain to be snow.

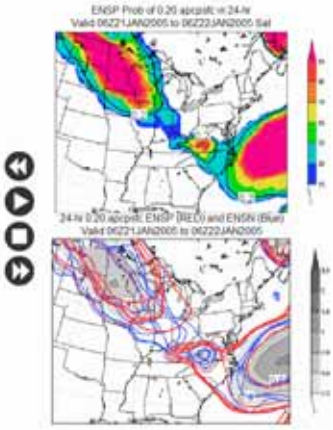
Student Notes:



22. Loop of 0.20 Inch Probability

Instructor Notes: This is a loop of the 0.20 inch probabilities in 24 hour periods. They illustrate how the precipitation shield moves along with our cyclone. The lower panels show the ensemble mean QPF for each time period and each members forecast location of the 0.20 contour if it was present. We want to exploit the information available in both the mean forecasts and the probability forecasts.

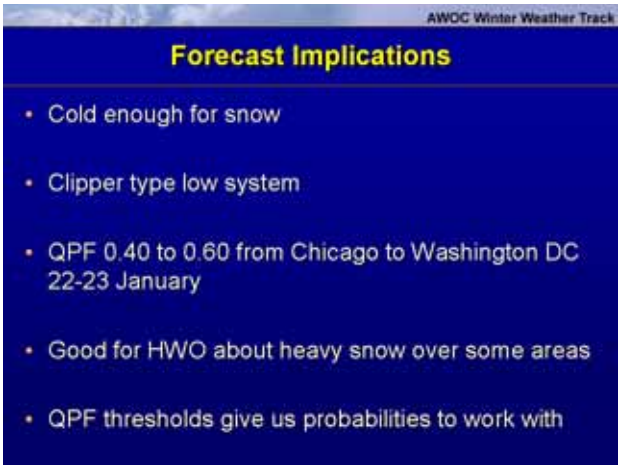
Student Notes:



23. Forecast Implications

Instructor Notes: These forecasts show us the high probability based on the 30% threshold for 0.4 and 0.60 inches of QPF and conditions cold enough for snow. Thus we might have some quantifiable confidence in an HWO for a winter storm along the path of this potential snow swath. We did not look to closely at mixed precipitation implications though they exist and we will examine these problems later.

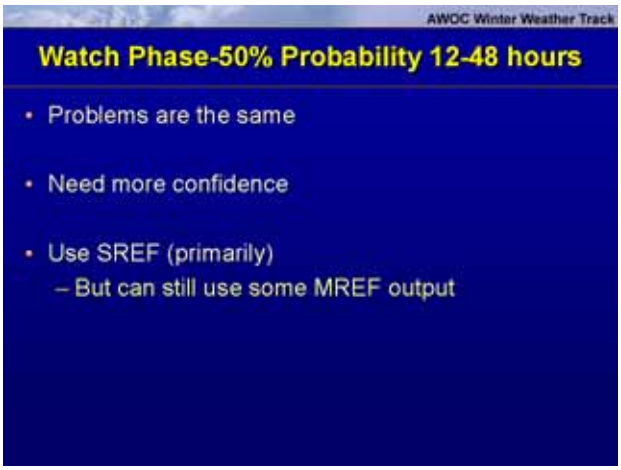
Student Notes:



24. Watch Phase-50% Probability 12-48 Hours

Instructor Notes: Now we move into the watch phase...the 50% percent outcome solution. The problems are still the same, we just need to attach more confidence to these forecasts as we are now looking at the 50% probability outcome. At this time frame, the SREF will encompass the entire forecast. But, we will still use some MREF forecasts for demonstration purposes. Additionally, the MREF shows some skill and should be used in forecast from about 18 hours on out. It offers different ICs and a different model core.

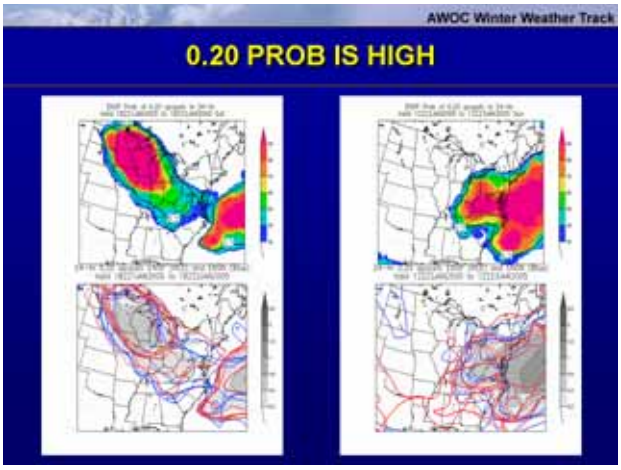
Student Notes:



25. 0.20 Prob is High

Instructor Notes: For brevity we do not show the PTYPE or 850 hPa temperatures, but for the most part, snow is the primary type and the mixed precipitation issues are only along the southern 1/3 of the shield. At this threshold we see a high probability of precipitation. Many locations should see at least 2 inches of snow.

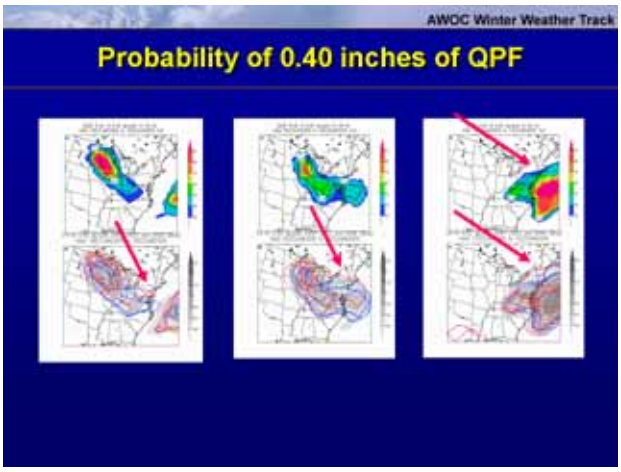
Student Notes:



26. Probability of 0.40 Inches of QPF

Instructor Notes: The probabilities of 0.40 inches of QPF are a bit lower but they still show an area of concern similar to the 0.20 forecasts. A Band of at least 4 inches of snow is forecast from Minnesota to Maryland. Note the few outliers with some precipitation faster and farther east. Next time period we still see some faster and farther north outliers. In the panel on the far right, note that a few members forecast the precipitation shield to extent farther to the north. These outliers would prove to be quite prescient as the heaviest snow in this case was observed in southeastern New England. There were so few that the probabilities based on our contour intervals did not register.

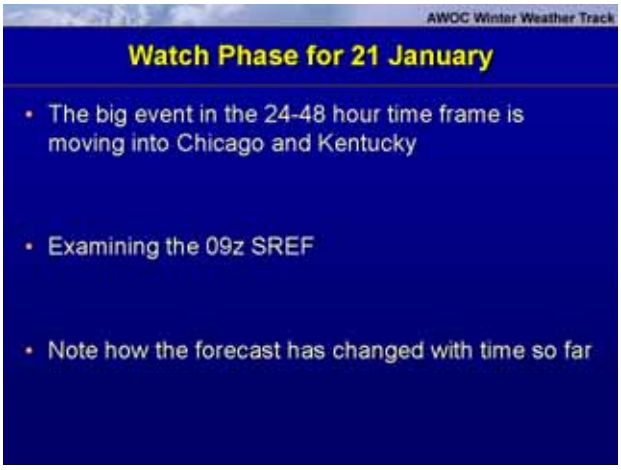
Student Notes:



27. Watch Phase for 21 January

Instructor Notes: At this point we could still use MREF data. But for brevity, we shift to SREF imagery. Experience has shown that there is value in the MREFs in the 18-48 hour range. The data from the MREFs should be considered and an ensemble that mixes the two data sets would have some unique applications in the near future. Recall the SREF has several advantages: It has at least 3 model cores. It has finer resolution.

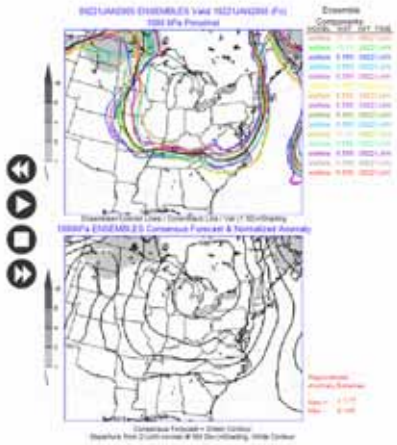
Student Notes:



28. Loop of SREF MSLP Forecast

Instructor Notes: This loop shows the SREF MSLP forecasts from forecasts initialized at 09Z 21 January. In the interest of time, we start the loop deeper into the forecast. Just watching the loop we can clearly see how uncertainty grows with time and we can see that most uncertainty is focused where the weather is going to be significant. The spaghetti plots quickly get quite noisy! A few things to note, compared to our earlier MREF loop, these forecasts are initialized 2 days later so they should be more accurate. Show more detail because the SREF is of higher resolution thus it captures the secondary development better. Stop the loop at 21Z on the 22nd and move to 00Z on the 23rd. Note that in the mean by 00Z there is a secondary low along the coast over the Delmarva. But there is big spread showing lots of uncertainty in the timing, location, and intensity of the secondary cyclone. By 03Z all members have a low over the western Atlantic with big spread to the north due to timing, intensity, and location issues. The noisy spaghetti is telling us the same thing. Uncertainty is a significant issue!

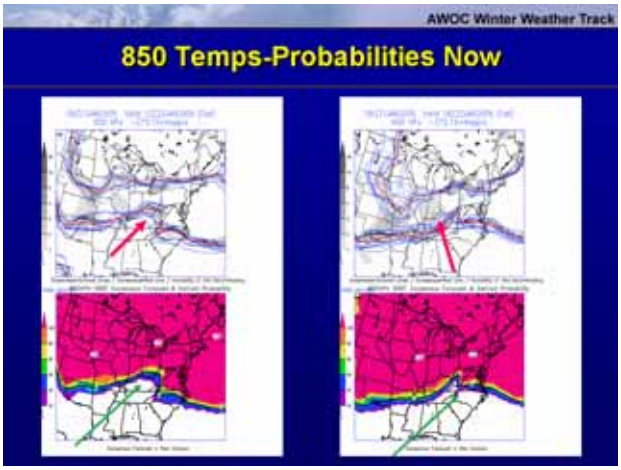
Student Notes:



29. 850 Temps-Probabilities Now

Instructor Notes: The probabilities of the 850 hPa temperature being 0 degrees C or less are shown in these two images. The red area is clearly cold enough for snow. Based on the cyclone track in the previous loop, it was clear that some warm air could work into the precipitation shield ahead of the primary cyclone. We can see that from southern Illinois to Ohio there is a chance of the 850 hPa temperatures being at or above 0 degrees C. The red arrows highlight the areas where each SREFs 0 degrees C contour appear to show considerable variation. In the right hand panel, the spread is quite large in this region. The GREEN arrows in the lower panels show the same areas of uncertainty put in a quantifiable context...a percentage. On the left hand side, we can see that mixed precipitation was a concern over northern Ohio and Kentucky at this time. Observations revealed that mixed precipitation did occur over Ohio (not shown). 2 m temperature probabilities would help define further refine areas of potential freezing rain.

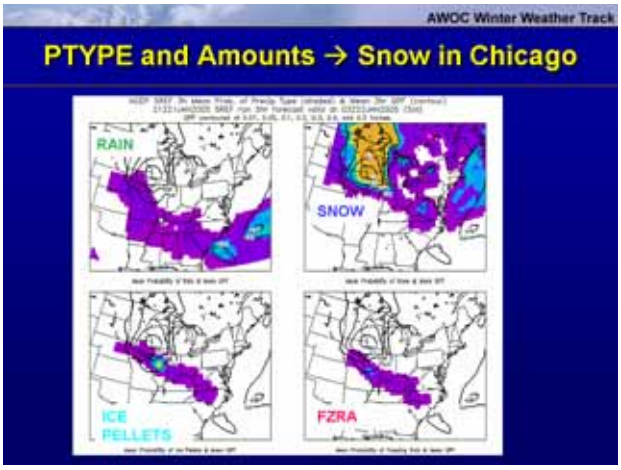
Student Notes:



30. PTYPE and Amounts: Snow in Chicago

Instructor Notes: These forecasts show the probability of precipitation by type. They also show the instantaneous 3-hour ensemble mean QPF. As our previous 850 mb temperatures suggested, we can see the risk of freezing rain and ice pellets along the southern edge of our baroclinic zone. The cold areas, like the Chicago area, are pretty much forecast to be snow. On the next slide, we will look at a plume diagram for Chicago in the cold air. Comparing critical temperature probabilities to model PTYPES can help reinforce conceptual models and reinforce confidence in snow and mixed precipitation areas. We could compare PTYPE, 850 hPa and 2m temperatures during an event to help with the forecast process.

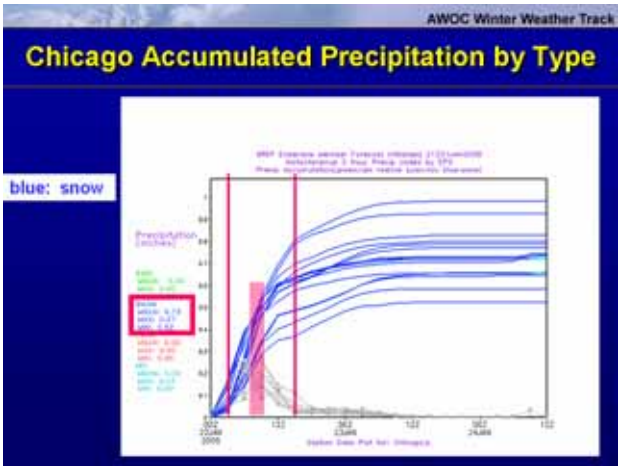
Student Notes:



31. Chicago Accumulated Precipitation by Type

Instructor Notes: This plume diagram is for Chicago. It is color coded by PTYPE. Blue is snow. The smaller contours show the 3-hour precipitation forecasts for each SREF member. We do not know which member any forecast is from. These data tell us that Chicago will get all the precipitation as snow. Most of the snow will accumulate between about 03Z and 15Z on the 22 of January. If your warning criteria was for 6 inches of snow, using a first guess 10:1 ratio, you might expect a high probability of meeting the warning criteria around 09Z on the 22nd. For impacts, clearly TAFS would need snow in them at the time indicated. Road crews would probably be busy just trying to keep up with the snow accumulations between 06 and 15 UTC on 22 January. It would appear that around 0.70 inches of QPF is close to the median.

Student Notes:

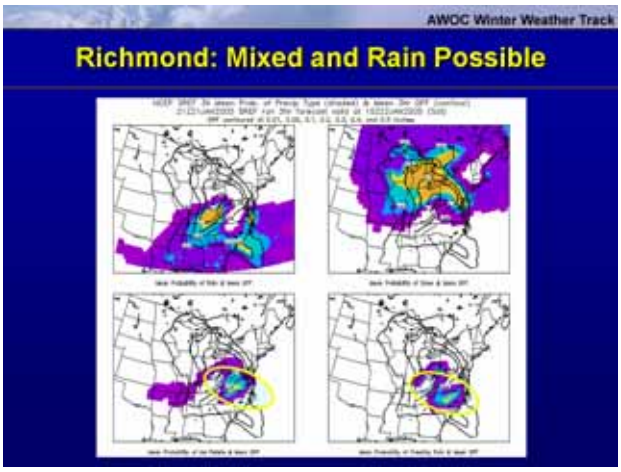


32. Richmond: Mixed and Rain Possible

Instructor Notes: This is another PTYPE diagram from the same SREF run just valid later in time. Base on our previous 850 hPa temperature forecasts we can see that the areas of concern (yellow circles) based on our knowledge of 850 hPa temperatures are

being identified by the PTYPE forecasts in the members too. In this time period, freezing rain and ice pellets are a concern in Virginia and North Carolina. We could use a plume diagram to delve deeper into this issue.

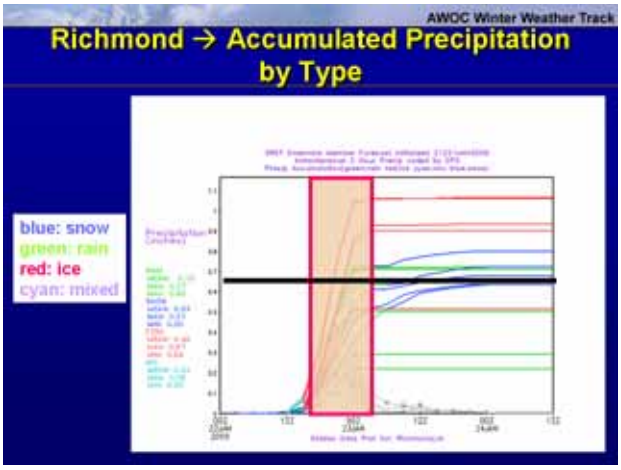
Student Notes:



33. Richmond: Accumulated Precipitation by Type

Instructor Notes: This is a plume diagram for Richmond, VA. The red and cyan lines show freezing rain and ice pellet potential. A few members also show the chance of rain (GREEN) and snow (Blue). The time of maximum QPF and potential ice accretion appears to be from 15 UTC on the 22 to about 03UTC on the 23rd. Big snow is a low probability outcome here. Note the large range of potential QPF and a clustering around 0.65. This diagram has PDF that shows lots of uncertainty in total QPF and lots of uncertainty in precipitation type.

Student Notes:

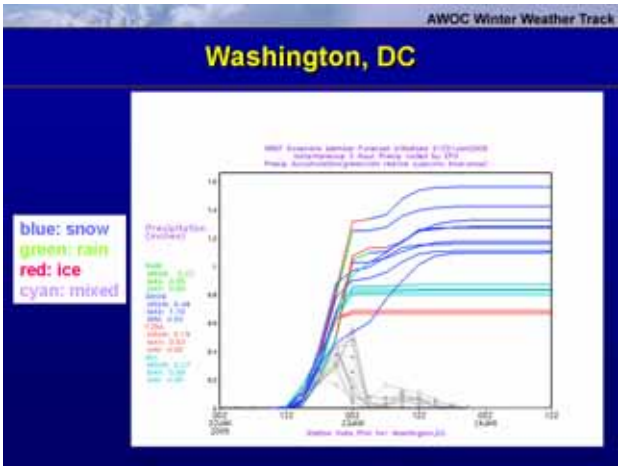


34. Washington, DC

Instructor Notes: This plume is for Washington, DC. Unlike Richmond, less freezing rain and more ice pellets are forecast. There are only a few members that show any time

of rain. Snow is the dominant precipitation type. But ice pellets and freezing rain were still a forecast concern.

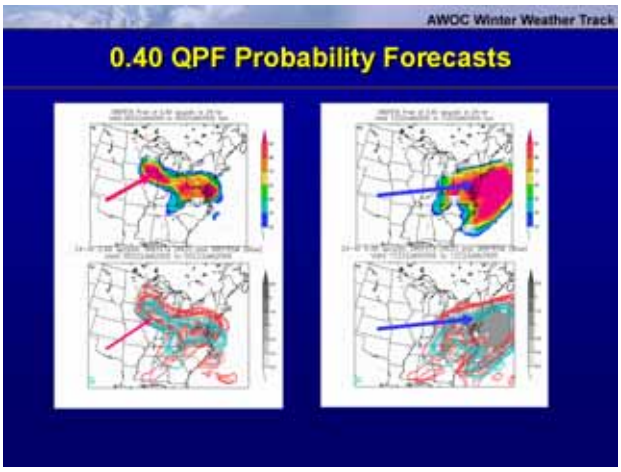
Student Notes:



35. 0.40 QPF Probability Forecasts

Instructor Notes: These two images show the probability of exceeding 0.40 inches of QPF in a 24 hour period and the ensemble mean and spaghetti plots in the lower panels. The red arrows show us the high potential for 0.40 inches or more QPF in Chicago. We already know this region is cold enough for snow and the PTYPE in the SREF is 100% snow. As the storm moves to the east, the blue arrows show a higher probability of 0.40 inches of snow. These forecasts significantly underestimated the observed snowfall in southern New England. Note, however, that there is a 0.60 contour in the ensemble mean. With a 10:1 ratio we have confidence in a 4 inch or greater snowfall in Chicago in along the East Coast from this storm. If our warning criterion was 4 inches we would be good to go for a watch or warning depending if you were forecasting in Chicago or New York. But if we had a 6 inch criterion you might want to see the 0.60 probabilities OR if you expected a 20:1 ratio you might want to see another threshold QPF.

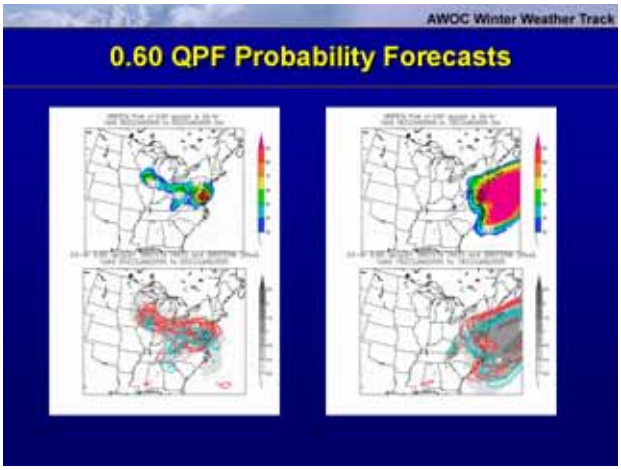
Student Notes:



36. 0.60 QPF Probability Forecasts

Instructor Notes: As luck would have it, the ensemble gods provided us these two images showing the probability of exceeding 0.60 inches of QPF in a 24 hour period and the ensemble mean and spaghetti plots in the lower panels. Our confidence is high for some 6 inch snows in and south of Chicago land on Saturday (left) and along the East Coast on Sunday. Other time periods, though not shown, provided more details of areas in between.

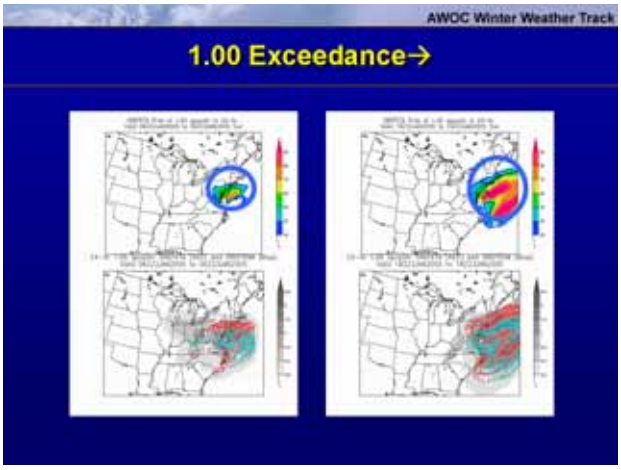
Student Notes:



37. 1.00 Exceedance

Instructor Notes: Ah, and for the really big snows...we have the 1.0 inch exceedance. We can see our confidence goes down as the areas get smaller. One could see the value of various potential thresholds in winter storms of snow amounts and in rain events depending on your flash flood thresholds. Thus illustrating both the strength and limits of these charts. We need to get better at developing thresholds for various needs!

Student Notes:



38. Ensemble Watch 12-48 Hours and 50%

Instructor Notes: This table summarizes the watch process models and the ensemble forecast products. Other than we are now looking for the 50% probability outcome, not much has changed. Our two single models are quite deterministic when used by themselves. But they too can be mixed into the ensemble. Due to the finer resolution these “deterministic” models deserve a big weight in a blended ensemble. They are valuable forecast tools and should not be overlooked. However, our SREF and MREF offer us the best set of tools. The SREF having the added advantage of multiple ICs and multiple MCs.

Student Notes:

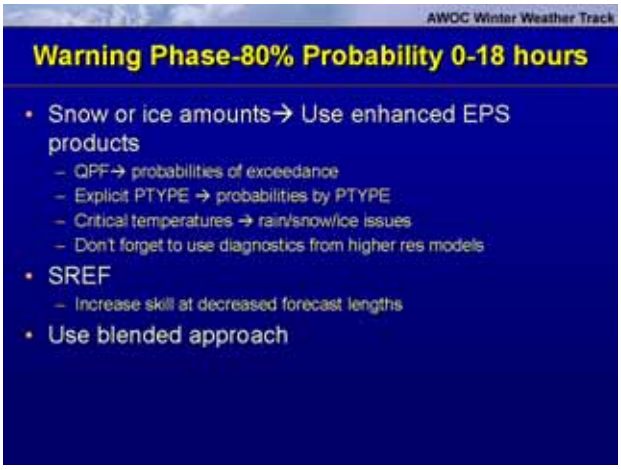
Ensemble → Watch
12-48 hours and 50%

Forecast Range	Initial Conditions (IC)	Model Errors (ME)	Remarks
Short-Range→ NAM	1 IC	1 Model Core (MC)	May be jumpy run-to-run Binary 0/1 High resolution makes it valuable ensemble member
Short-Range→ GFS	1 IC	1 MC	May be jumpy run-to-run Binary 0/1 Valuable ensemble member
NCEP MREF→ 12-48 hours	11 ICs	1 MC	Probability displays Only 1 Model core
NCEP SREF→ 12-48 hours	Multiple ICs	Multiple MCs	Finer resolution data More model cores than MREF

39. Warning Phase-80%, Probability 0-18 Hours

Instructor Notes: The warning phase is a shorter term forecast but with it comes increased expectations. The NWS would like warnings to be the 80% likely outcome event. The forecast issues change little and EPS tools change very little, unless the event takes you by surprise and is an extremely short-term event. Due to uncertainty in forecasting it is clear why such short lead times are in order. Longer fused warnings will more than likely be lower probability outcomes. Ideally would have local scale ensembles for this time period. We could use enhanced ensemble products and blend ensembles with climatic anomalies. The tools are the same. At very short-ranges 0-12 hours, diagnostics from the higher resolution model may be in order. It should be noted that experiences and case studies show increased skill at decreased forecast length in the SREFs. A blended ensemble with the SREF and deterministic models may have added value here for updating the forecasts.

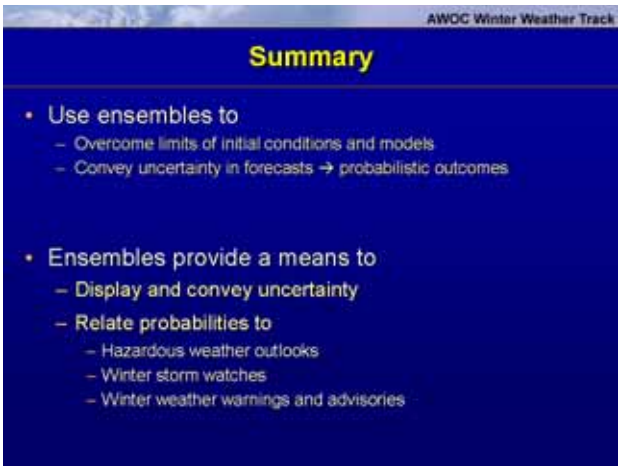
Student Notes:



40. Summary

Instructor Notes: We discussed why you need to use ensembles in the forecast process. Our goal is to overcome uncertainty in the initial conditions and the errors introduced by the models themselves. There is no perfect model. Chaos in weather forecasting and increased uncertainty with forecast length is an issue we will never overcome. Output from ensembles help us visualize and quantify uncertainty in weather forecasts. The probabilistic displays attach a quantitative measure to the forecast process. With these probabilities, we can make better decisions and provide users better decision making capabilities. Ensembles will help us improve at designing the decision. We worked through a brief case study showing ensemble products that may be of value in forecasting a winter storm. These products, such as the QPF where it was forecast to be snow, help us assign probabilities which we can than match to our HWO, and WSW products. Not quite a perfect match but one that is getting incrementally better.

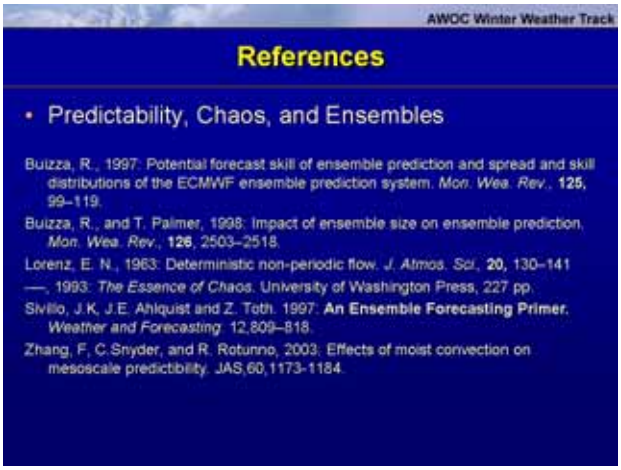
Student Notes:



41. References

Instructor Notes: I have included a few references on predictability, chaos, and ensembles here. There are many other good papers. I strongly recommend the Zhang paper for those interest in just how sensitive our models can be based on physics packages.

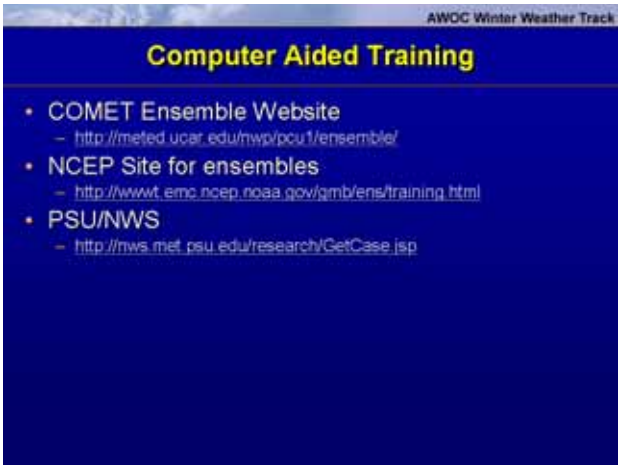
Student Notes:



42. Computer Aided Training

Instructor Notes: There is a plethora of information available on the web to facilitate ensemble training. I have shown just 3 sites. I highly recommend the COMET web site for those just starting out learning about ensembles. I also find the NCEP site quite valuable. Our local site in State College also has useful information and cases studies related to ensembles and winter storms.

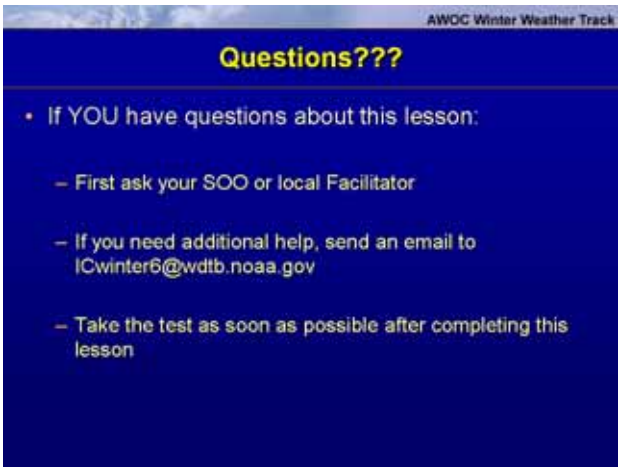
Student Notes:



43. Questions???

Student Notes: After going through this lesson if you have any questions, first ask your SOO or your local AWOC Winter facilitator. Your AWOC facilitator should be able to help answer most questions. If you need additional info from what your SOO provided, please send an e-mail to the address on the slide. This address sends the message to the instructors who developed this IC. Our answer will be CC'd to your SOO so that they can answer any similar questions that come up in the future. We may also consider the question and answer for our FAQ page. Thanks for your time and good luck on the exam!

Student Notes:



IC6.3: Optional Job Sheet

Using Ensembles in Winter Weather Forecasting

Objectives:
Examine SREF data to aid in the forecasting of a winter weather event
Use online ensemble web pages to learn how to access data (like that used in the lesson) for future analysis

Data: NCEP SREF data from 20 December 2004, the 21 UTC run. A new tool, the picflip viewer will be used to browse the data. The internet will also be used to create graphics like those used in the lesson.

Instructions: For the first part of this exercise you will be using the picflip viewer to answer questions in this jobsheet.
Your Winter Weather AWOC facilitator will be able to tell you where the picflip viewer is located, as it could be on a training PC or on the WES box, or both. Check with your facilitator on how to start the viewer. After it loads, a menu will pop up that looks like Figure 1, and you will be ready to begin. Because you will be using the picflip viewer during the winter weather AWOC WES simulation, this is a good opportunity to become familiar with its controls.

Fig. 1: The picflip start menu

Using the picflip viewer, load the spaghetti plot of 2 m 0°C by clicking the button located at the top of the picflip menu shown in Figure 1. The viewer loads a spaghetti plot of the location of the 2 meter AGL freezing line (top) and a probability chart (bottom).

Notice the navigation buttons at the top of the picflip viewer (shown below). Use the < > buttons to step forward or backward, << >> to skip 5 frames forward or backward, and |< >| to skip to the beginning and end of the forecast loop.

Fig 2: The picflip controls console

Examine the "2m $0^{o}C$" surface freezing line forecast valid at 12 UTC on 22 December across the Ohio and Lower Mississippi Valleys, and answer the following two questions:
Where is the variability in 2 m temperatures maximized at 12 UTC on the 22nd (illustrated by the grey shading in the upper plot)?

In southern Indiana at 12 UTC on the 22nd, is it likely that it will be significantly warmer or colder than freezing? (i.e. examine location of the 2m temperature variability relative to the spaghetti plot)

Load the NCEP SREF precipitation-type probabilities by clicking on the "P-Type" button. Scroll ahead to 12 UTC on Dec 22. This loads the mean probability of rain (top left), snow (top right), sleet (bottom left), and freezing rain (bottom right), with mean 3 hr QPF overlaid with black contours.
Where is the snow most likely to fall?

What is the highest probability of sleet and freezing rain, and where are those two most likely to fall?

Based only on these graphics, briefly describe the types of precipitation you expect across the state of Indiana from 12 UTC on the 22nd through 00 UTC on the 23rd.

Load the probability of exceeding of 0.5 inch in 24 hours (click on POP0.5). Step to the forecast valid from 00 UTC on 22 December to 00 UTC on 23 December.
Where is the highest probability for 0.5 inches of liquid equivalent in 24 hours?

Based on this graphic and the P-Type graphic where is the most likely location for significant accumulations of winter precip?

Feel free to load any of the other SREF products in order to become familiar with SREF data and the picflip viewer.

Real-time SREF/MREF Data

Go to the subsequent websites to learn where to access CONUS or OCONUS ensemble information for the SREF and MREF data. Although winter weather may not be in the forecast when the website is accessed, learning how and where to apply the information from this lesson can still a valid exercise. Bookmark any sites you find useful.

For CONUS weather, access the following website (this may take up to a minute to load):

http://eyewall.met.psu.edu/ensembles/index.html

Select “SREF” as the model and “US/MSLP” as the product, and navigate through the loop using the player keys. Look for areas of low pressure in the mean of the ensembles in the bottom plot (green isobars). Look for areas of high variability in the ensemble members in the top plot (grey shading). Where variability in the ensemble members overlaps with the low in the mean values is where uncertainty in strength of the low exists. If the high variability in the ensemble members is displaced from the low, position differences are likely between the ensemble members.
Select “SREF” as the model and “US/POP240.20” as the product, and navigate through the loop using the player keys. Look for areas of high probability of precipitation > 0.2 in 24 hours.
Select “SREF” as the model and “PTYPE” as the product, and navigate through the loop using the player keys. Evaluate the phase of precipitation along with the amounts. Explore other parameters in the list if interested.

For OCONUS weather (Alaska or Hawaii), access the following website:

http://wwwt.emc.ncep.noaa.gov/mmb/SREF/SREF.html

and click on “Alaska” or “Hawaii” links under the General Weather Forecasting.

Select “Mean&Spread” under “Change Type” and “Pressure” under “Change Field” to load the mslp mean (isobars) and spread (shading). Look for the relative position of the low and the spread of mslp. Where spread in the ensemble members overlaps with the low is where uncertainty in strength of the low exists. If the high spread in the ensemble members is displaced from the low, position differences are likely between the ensemble members.
Select “Probability” under “Change Type” and “24hr prcp(in)” under “Change Field” and “>0.25(inch)” under “Select a Threshold” to load the probability of precip > 0.25 inches. Look for areas of high probabilities of 24 hour precip.
Select “Probability” under “Change Type” and “24Hr Snow(in)” under “Change Field” and “2(inch)” under “Select a Threshold” to load the probability of 2 inch accumulations of snow. Look for areas of high probabilities of 24 hour snow.
Explore other parameters in the list if interested.

A list of ensemble prediction data sites to explore:
NCEP’s Official SREF site is:
http://wwwt.emc.ncep.noaa.gov/mmb/SREF/SREF.html
NCEP’s Official MREF site is:
http://www.emc.ncep.noaa.gov/gmb/ens/
Storm Prediction Centers ensemble pages(with severe parameters) :
http://www.spc.noaa.gov/exper/sref/

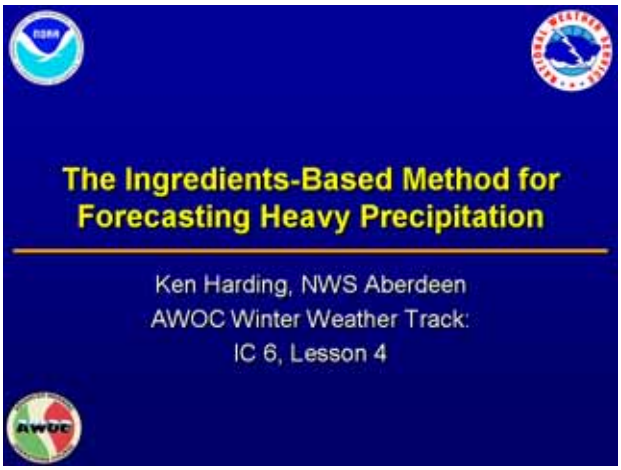
PSU-NWS jump page for ensemble links
http://nws.met.psu.edu/models/index.htm

An answer key is available for this job sheet. Please see your local AWOC Winter Weather facilitator to obtain a copy.

1. IC6.4: The Ingredients-Based Method for Forecasting Heavy Precipitation

Instructor Notes: Welcome to AWOC Winter Weather Track Instructional Component 6, lesson 4. My name is Ken Harding, and this lesson focuses on the ingredients based method for forecasting heavy precipitation. While we are concentrating on heavy snow in this version of AWOC, this method is applicable able to many heavy precipitation scenarios.

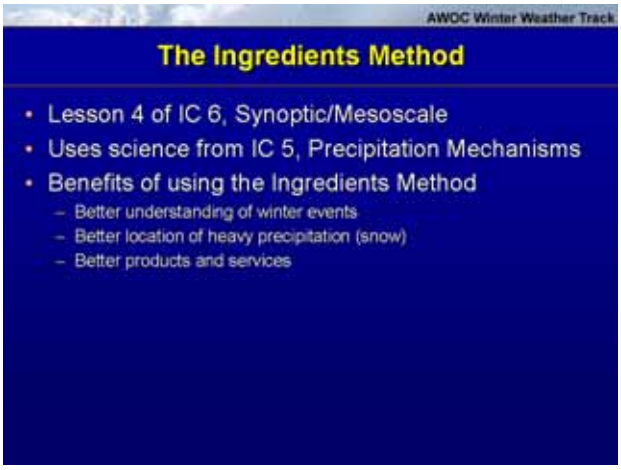
Student Notes:



2. The Ingredients Method

Instructor Notes: This is lesson 4 of instructional component 6, Synoptic/Mesoscale forecasting of precipitation type and amount. This lesson references much of the science from IC 5, precipitation forcing mechanisms and associated diagnosis for winter weather and other lessons of IC 6. The idea here is to put all of this science together in an orderly manner to better conceptualize the potential for heavy precipitation. When combined with microphysical information, this method is one method for heavy snow forecasting. This will allow us to produce better forecast and warning products for our customers.

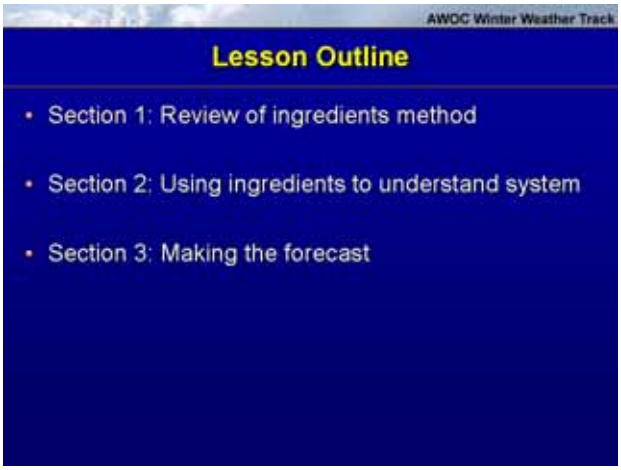
Student Notes:



3. Lesson Outline

Instructor Notes: In this lesson, I'll provide a frame work for applying the ingredients method in forecasting heavy precipitation. After a review of the ingredients, I will use the ingredients to understand the overall synoptic/mesoscale weather systems. While I won't specifically concentrate on heavy snow, the emphasis is on winter precipitation.

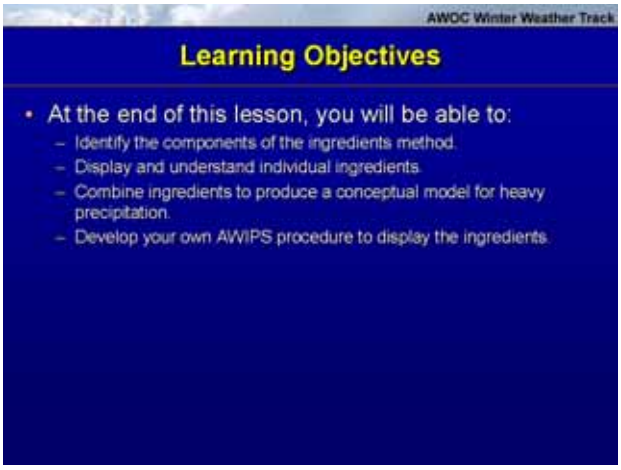
Student Notes:



4. Learning Objectives

Instructor Notes: The learning objectives for this lesson are straight forward. Being able to identify and understand the main ingredients that are responsible for the production of heavy snow, and combining these ingredients into a conceptual model of the snow event. An example AWIPS procedure based on this method will be provided to your SOO with the WES scenario for Winter AWOC.

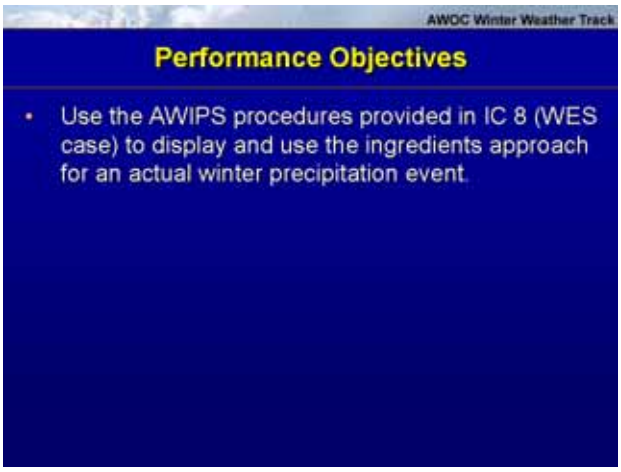
Student Notes:



5. Performance Objectives

Instructor Notes: During your WES case, you will be provided a procedure based on this presentation of the ingredients method.

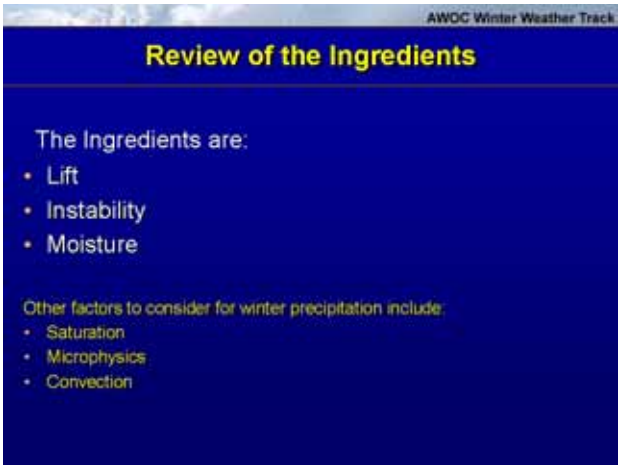
Student Notes:



6. Review of the Ingredients

Instructor Notes: Specifically, heavy precipitation is the result of sustained high precipitation rates. To achieve these rates, you need sufficient deep lift, an atmosphere that is unstable to vertical forcing, and sufficient moisture for both precipitation production and replenishment of lost moisture. Precipitation efficiency is also related to several items covered in other lessons including degree of saturation, microphysics of snowfall production and release of convective instabilities, either slanted or upright. The top-down approach should be used to determine precipitation type and whether dendritic crystal growth will be prevalent.

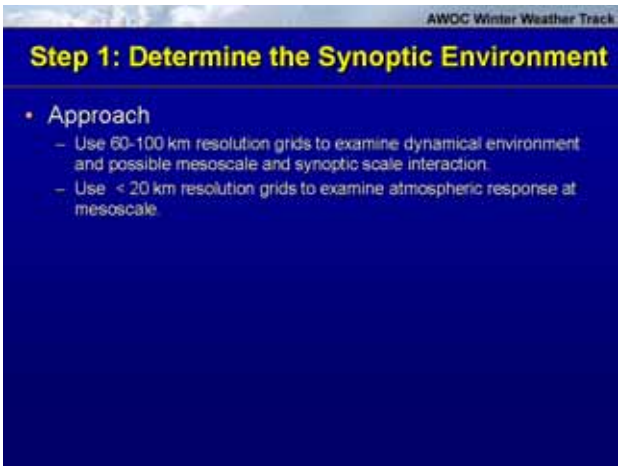
Student Notes:



7. Step 1: Determine the Synoptic Environment

Instructor Notes: The ingredients method really starts with a forecast funnel mentality. First, we are going to determine the synoptic potential for sustained lift. In this step, I'll be using Q vectors. In order to use Q vectors, I need to make the quasi-geostrophic approximation. Thus, I will look at model output at a fairly coarse scale, around 80 kilometers, so the QG approximation remains valid. When querying the mesoscale for sustained lift, we should look at much higher resolution model output to determine areas and times. A word of caution: moisture is one of the poorest variables forecast in the numerical weather prediction models. Errors in location and timing of mesoscale forcing and response may be a result of a poor moisture forecast by the models.

Student Notes:

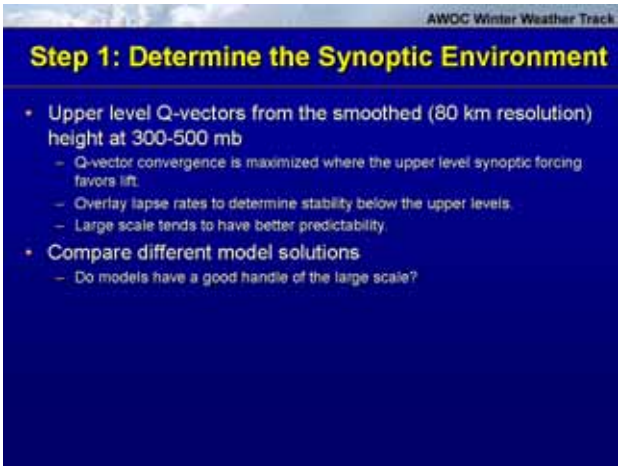


8. Step 1: Determine the Synoptic Environment

Instructor Notes: Is this example, we'll look at convergence of Q vectors to asses the potential for synoptic lift. We choose a layer in the top half of the troposphere. This fairly deep layer from 500 to 300 mb will show maximum Q vector convergence where upper level forcing is greatest. In order to see how effective this forcing will be in producing lift,

overlay a layer stability product below these forcing layers. The more unstable the layer is, the more lift will occur for a given amount of forcing. It is critical not to use only one model or one cycle to determine synoptic lift. Most of the operational NWP models do a good job with synoptic lift, so run to run and multiple model consistency should be checked.

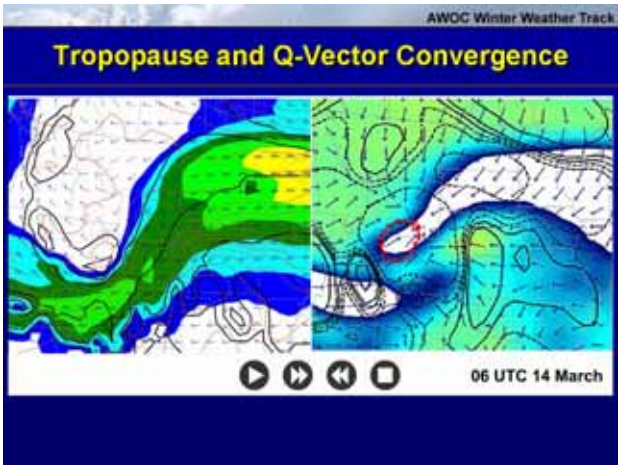
Student Notes:



9. Tropopause and Q-Vector Convergence

Instructor Notes: This loop shows the tropopause pressure (black lines) and tropopause wind speed (image) on the left along with 500-300 mb Q vector convergence (black lines) and 700-500 mb lapse rates (color image). The warmer colors represent more unstable lapse rates. An area of maximized Q-vector convergence is shown with a dashed red line. This loop, running from 06 UTC 14 March through 00 UTC 15 March shows the evolution of the deepening trof and area of upper level forcing represented by the q-vector graphic. The importance of looking at a dynamic tropopause map can't be overstated. If one looks at standard pressure levels, you can miss may details of the tropopause/jet structure such as coupled jets and tropopause folds. One standard pressure level isn't likely to capture both the sub-tropical and polar jets. Thus jet structure and tropopause information should be evaluated at the model tropopause level instead of just 300 mb (or your favorite upper level). It is also important to look at the effects upper level forcing, represented here by the q-vector graphic, and the underlying stability of the air. Strong upper level forcing that overlies unstable air will allow deeper vertical circulations. Building displays of these combined elements is critical to understanding the ingredients necessary to produce heavy precipitation.

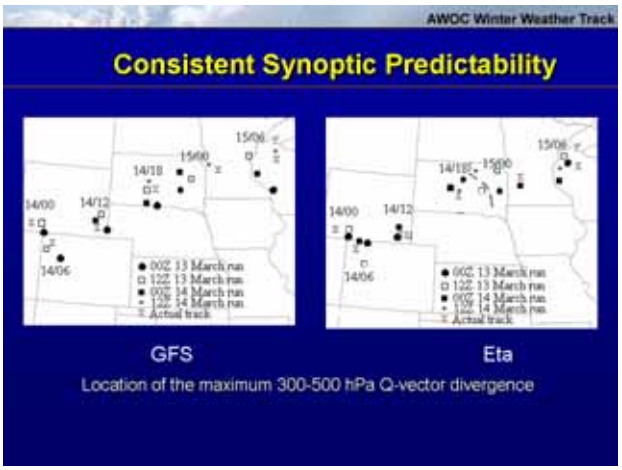
Student Notes:



10. Consistent Synoptic Predictability

Instructor Notes: Shown are the central locations of the max Q vector convergence over 4 model runs with the model analysis indicated with a red X. Even though the 4 previous model runs had very different positions of the surface low and mid level frontogenesis, the location of the synoptic forcing maximum was consistent. If there are large differences in the run to run location of the synoptic forcing, going down to the mesoscale is very difficult at best.

Student Notes:

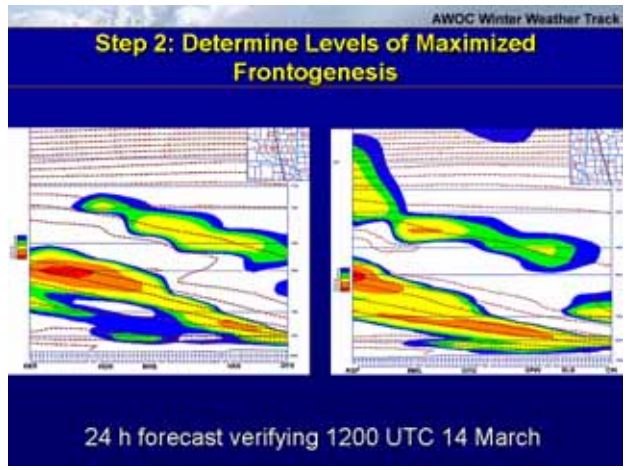


11. Step 2: Determine Levels of Maximized Frontogenesis

Instructor Notes: Now observe cross sections plotted across the area of interest. Make frontogenesis an image and overlay with a plot of equivalent potential temperature. Here we are looking for the vertical distribution of frontogenesis, and the vertical separation between equivalent potential surfaces represents a quick check on stability; the further apart in the vertical the equivalent potential surfaces are, the more vertical motion

occurs for a given amount of forcing. Note the levels where frontogenesis is strong in the area of interest, and how these levels change with time. In this case, on the left graphic, we see strong frontogenesis centered around 500 mb to the north, sloping to around 850 mb in the south.

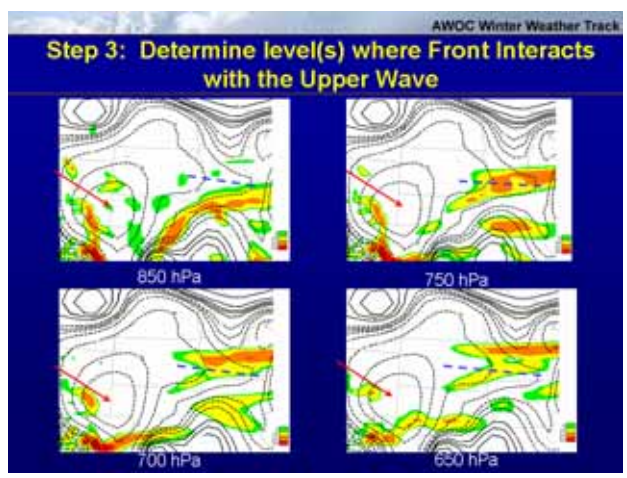
Student Notes:



12. Step 3: Determine Level Where Front Interacts with Upper Wave

Instructor Notes: This slide depicts a 4 level analysis of 500-300 mb Q-vector convergence, shown as dotted black lines, and frontogenesis at a specific level. The red arrow points to the maximum area of Q-vector convergence. The dashed blue line shows a relative high area of Q-vector convergence. Just by looking at the depicted levels, you can see the frontogenesis at 750 mb (and to a slightly lesser extent, 700 mb) is best aligned with the upper level forcing. When lower level frontogenesis aligns with upper level forcing, deep vertical responses are possible, given enough instability. We'll examine the affects of instability in the next slide.

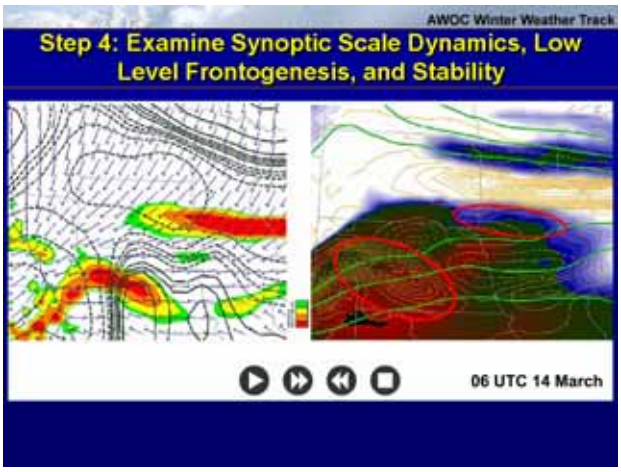
Student Notes:



13. Step 4: Examine Synoptic Scale Dynamics, Low Level Frontogenesis, and Stability

Instructor Notes: In this loop, the left graphic represents 500-300 mb Q-vectors (black arrows), convergence of Q (black lines), and 700 mb frontogenesis (color image). The right graphic depicts relative 600-500 mb relative humidity (green lines), equivalent potential vorticity of less than 0.25 PV units (color image), and 700 mb frontogenesis (orange lines). We are looking for areas where low level frontogenesis and upper level forcing (left graphic) line up with unstable air (EPV image on the right) in a saturated environment. On the right graphic, I have indicated areas where this occurs with a red oval. The affects of stability can not be stressed enough. Vertical motions resulting from strong low level frontogenesis forcing will only produce a deep vertical response if the air above the forcing is unstable. Technically, we should be looking for saturated areas where EPV < 0, but due to model smoothing and errors, I suggest looking at areas where EPV < 0.25. The layer chosen to evaluate negative EPV can be located using cross sections and time sections of EPV and frontogenesis. Choose an appropriate layer above the level of maximum frontogenesis to evaluate the vertical depth and time continuity of the negative EPV layer and the frontogenesis. At 06 UTC 14 March, 2 areas of interest are indicated, one in west central Nebraska and one near the Iowa/South Dakota/Minnesota border. The tri-state area of interest is characterized by frontogenesis, saturation indicated by RH > 90%, and EPV < 0.25, co-located with an area of q-vector convergence. As we step forward, notice how these parameters remain relatively persistent over this area. This is an area that one would need to pay close attention to for heavy precipitation.

Student Notes:

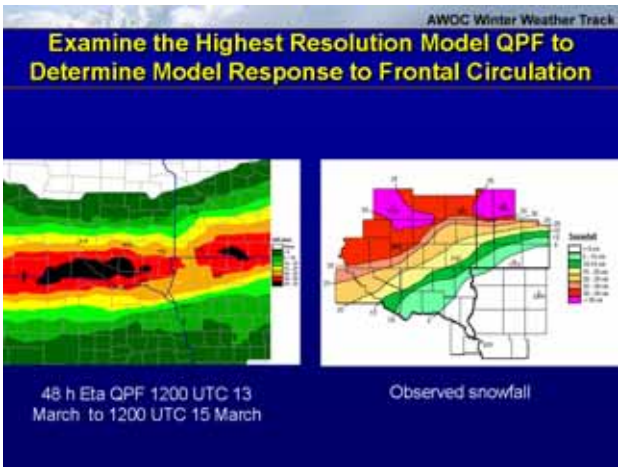


14. Examine the Highest Resolution Model QPF to Determine Model Response to Frontal Circulation

Instructor Notes: In this case, the highest resolution QPF output from the Eta model produced nearly 1.4 inches of liquid. The largest values are located along a line roughly

corresponding to the intersection of the maximum mesoscale forcing and most unstable air. However, when the verification snow amounts are plotted, the heaviest snow amounts were measured north of the model depiction. In this case, the heaviest snow amounts, while produced by mesoscale lift, were more closely located in the area coupled by the upper level synoptic scale forcing and the lower level mesoscale forcing. As stated before, moisture is one of the poorest forecast variables in the numerical models. Poor moisture representation and convective parameterization errors can lead to low QPF forecasts and often miss the highest values. Use the model QPF output very carefully, and don't use the values literally; instead, look for trends over several model cycles.

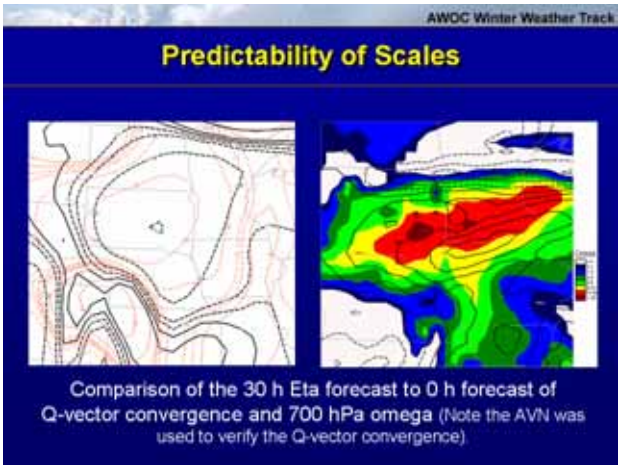
Student Notes:



15. Predictability of Scales

Instructor Notes: Even with higher resolution mesoscale models available to forecasters, there is still a need for lower resolution model output. If we want to use QG theory and visualize q-vectors, we must use a data resolution that supports the QG approximation. Generally, model grids in the 70 km resolution and above are good to use for your QG diagnosis. On the left, notice how consistent the synoptic scale forecast of Q-vector divergence (black lines) was with the verifying model analysis (orange lines). On the right side of the slide is the 700-mb vertical velocity forecast and verifying model analysis. Notice how far the maximum upward motion shifted from the 30 hour forecast (black lines) to the analysis time (color image). Even with a very consistent synoptic scale, mesoscale details often shift dramatically from run to run. The key here is to adjust forecast areas of strong mesoscale forcing towards the consistent synoptic scale forcing. If you see consistency in the synoptic scale forecast, you can examine the mesoscale more closely. However, if the synoptic scale has high run to run and model to model variability, use caution when transitioning to the mesoscale.

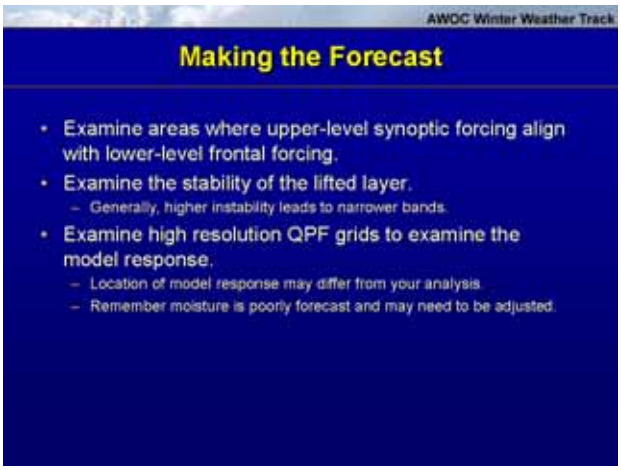
Student Notes:



16. Making the Forecast

Instructor Notes: When making the forecast, we are looking for areas where upper level synoptic forcing and lower level frontal forcing align the best in the most unstable air. It is here that deep mesoscale responses are possible. The more unstable the environment, the more narrow the resulting band will be. Once you have identified an area of mesoscale concern, use the highest resolution QPF grids available. This helps preserve the tight gradients and results in less smoothing of high amounts. Use caution with the placement of the model QPF as often the precipitation processes in the NWP models are not tied directly to the dynamics of the model. You may need to adjust the placement of the precipitation towards the best superposition of moisture, lift and instability.

Student Notes:

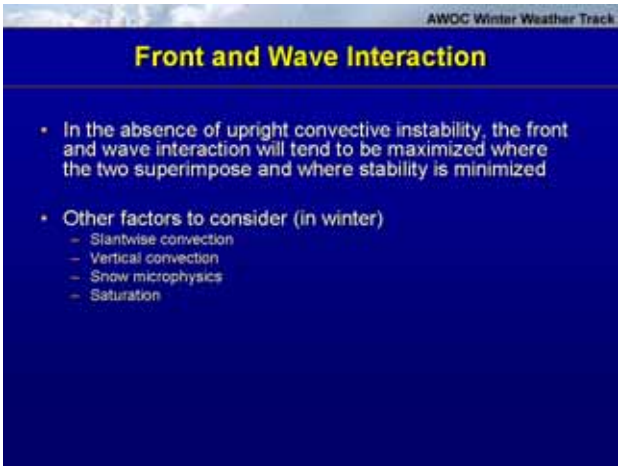


17. Front and Wave Interaction

Instructor Notes: Here is the key when looking for a deep mesoscale circulation. Look for the best area where all 3 components are favorable, not just the area of best lift or highest moisture. It is also important to remember the affects of convection, microphysics

(including crystal type and snow ratios), and the depth and timing of saturation. These critical topics are covered in other sections of this course.

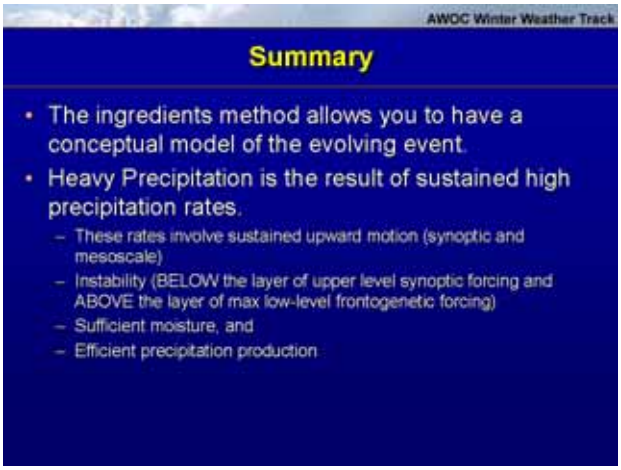
Student Notes:



18. Summary

Instructor Notes: If we understand the ingredients that produce heavy precipitation (or snow), we can directly analyze each and understand when one or more of them changes and becomes more or less favorable. This leads to an orderly forecast approach to the necessary conditions for heavy precipitation.

Student Notes:



19. Ingredients Quiz

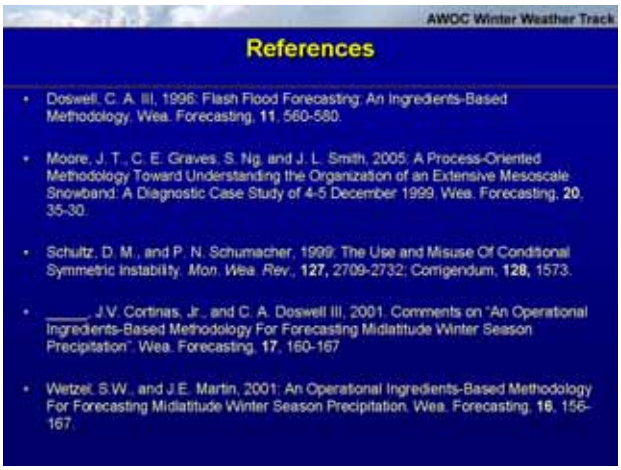
Instructor Notes: Take a few moments to complete this interactive quiz.

Student Notes:

20. References

Instructor Notes: Here are some useful papers with references to ingredient-based forecasting.

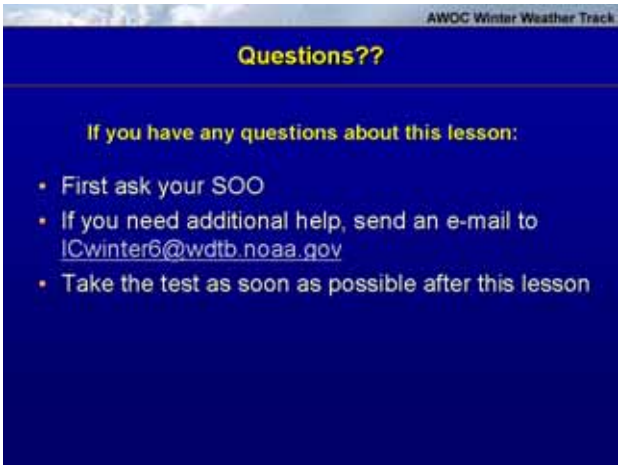
Student Notes:



21. Questions?

Instructor Notes: If you have questions, your first stop is your SOO. For additional help, contact the WDTB using the E-mail above. There are also help resources located on the main Winter AWOC web page. Good luck with the test!

Student Notes:



IC6.4: Optional Job Sheet

Ingredients-based Method for Forecasting Heavy Precipitation

Objective: Examine AWIPS procedures designed to assist in the ingredients-based methodology of forecasting heavy precipitation, as discussed in the IC6 Lesson 4 training module. Specifically, you will be able to find areas of potential symmetric instability (PSI) or conditional symmetric instability (CSI), and determine a lifting mechanism that may release the instabilities.

Data: 24 February 2003 winter weather event across Texas. You will be using D2D for this exercise.

Background: Since CSI is almost always released by frontogenetical forcing, you'll notice in this procedure we are using divergence of $\overrightarrow{F_n}$ vectors to assess forcing, saturated geostrophic equivalent potential vorticity to assess instability, and condensation pressure deficit and/or relative humidity to assess moisture. The main difference between CSI and PSI is the use of saturated equivalent potential temperature (CSI) vs. equivalent potential temperature (PSI). The potential in PSI is because the parcel is not saturated. At saturation PSI = CSI.

Instructions: (Instructions numbered 1., 2., … questions numbered 1), 2), …)

1. Load the 24 February 2003 Winter Weather AWOC case on your WES machine in case review mode, using the FWD localization. Set the D2D clock to 24 February 2003 18 UTC. You will be examining the 24 February 18 UTC NAM 40 model initialization, 6 hr NAM 80 forecast valid at 18 UTC, and observational data. So when answering the questions below, ensure that your answers are based on the 24 February 18 UTC initialization run.
2. With these procedures, always feel free to modify and save them as your own. How to visualize D2D data is subjective, and picking colors, products, and overlays that are comfortable to you is what is most important.
3. First, assess the potential for lift. Open the procedure "CSI_PSI" and load "Synoptic Forcing". This loads potential vorticity, geostrophic equivalent potential vorticity both saturated and unsaturated at 4 different layers, Divergence of Q vectors at 3 different layers, and tropopause pressure.
    1) Where geographically is Q vector convergence strongest?

    _____

    2) In which layer is Q vector convergence strongest?

_____mb to _____mb layer

3) Where geographically is potential vorticity at a maximum?

_____

4) In which level or layer is potential vorticity strongest?

_____mb

5) Which layer is moist EPV_g at a minimum?

_____mb to _____mb layer

4. Examine areas where PV anomalies or Q vector convergence is coupled with frontogenesis. Load from the CSI_PSI procedure "Frotogenetic Forcing, Stability".

   This procedure loads NAM 40 2-D frontogenesis and Divergence of $\vec{F}_n$ at 25-50 mb increments up to 650 mb. It also loads Saturated EPV_g (MPV_g)at 5 different layers.

   6) Where and at what level is frontogenesis strongest? If several strong areas and levels of frontogenesis, list them all.

_____

   7) Is there potential instability above the strong areas of frontogenesis? If so, which layers are potentially unstable within 50-100 mb above the level of frontogenesis?

_____

   8) Using the information from questions 1-4, where geographically are the frontogenetical forcing and synoptic forcing coupled?

_____

5. Next step is to see if 'upright' convection is a concern. If the atmosphere is unstable to both upright and slantwise convection, the upright will be released first. In your uncluttered pane, load the procedure "Upright Convection". This loads NAM 40 ThetaE lapse rates at 800-700 mb, 700-600 mb, 600-500 mb, 750-700 mb, and 700-650 layers. Because the volume browser does not have *saturated* ThetaE lapse rates, the procedure contains RH at those same levels. You'll be looking for RH values greater than 80%. Load each ThetaE lapse rate as an image as you step through them, and shade only negative values.

   9) Circle the appropriate choices for 80% RH and negative lapse rates

800-700 mb Instability present over the eastern half of Texas? **YES/NO**
700-600 mb Instability present over the eastern half of Texas? **YES/NO**
600-500 mb Instability present over the eastern half of Texas? **YES/NO**
750-700 mb Instability present over the eastern half of Texas? **YES/NO**
700-650 mb Instability present over the eastern half of Texas? **YES/NO**

10) Where is the inferred potential upright convection most impressive, and in which layer?

6. To visualize in a plan view all the important ingredients to examine, load in a new pane the NAM 40 2-D frontogenesis levels from answer #6, NAM 80 Q-Vector divergence layers from answer #2, NAM 40 MPV_g from answer #7, and NAM 40 RH/ ThetaE lapse rate from answer #10. This pane is useful because it isn't as cluttered with product descriptions. It's not a bad idea to load MPV_g and ThetaE lapse rate as toggle images, and shade only values less than + 0.25 PV for MPV_g, and values less than 0 K/km for lapse rates. With this pane, you should have a good idea where the strongest synoptic forcing, frontogenetical forcing, coupling between the two, and instability reside at 18 UTC.
7. With the pane in step 6 in mind, load NAM 40 QPF in a new window. Mentally adjust the QPF towards the area where synoptic and mesoscale forcing are most in alignment.

11) Where do you expect the heaviest precip to fall over the next 12 hours (through 06 UTC 25 February)?

An answer key is available for this job sheet. Please see your local AWOC Winter Weather facilitator to obtain a copy.

1. IC6.5 Part 1: Snowfall Forecasting

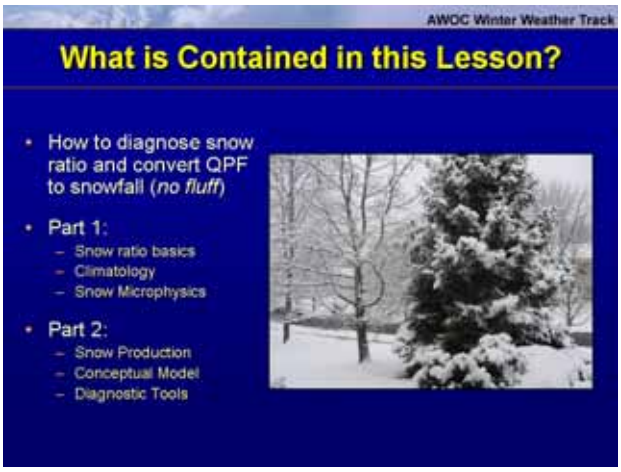
Instructor Notes: Welcome to IC 6, Lesson 5: Snowfall Forecasting.

Student Notes:

2. What is Contained in this Lesson?

Instructor Notes: The focus of this lesson is to assess potential snowfall given a forecast QPF. This will be done by diagnosing the most likely snow ratio and then applying that ratio to convert QPF into a forecast of snowfall. When combined with the previous IC-6 lessons, you will be able to fully diagnose the potential of a winter storm in terms of snowfall - for example, the diagnosis of snow as the precipitation type; secondly, its duration and intensity; thirdly, an understanding and ability to communicate forecast uncertainty; and lastly, with this lesson a means of understanding and expressing the amount and character of the snowfall itself.

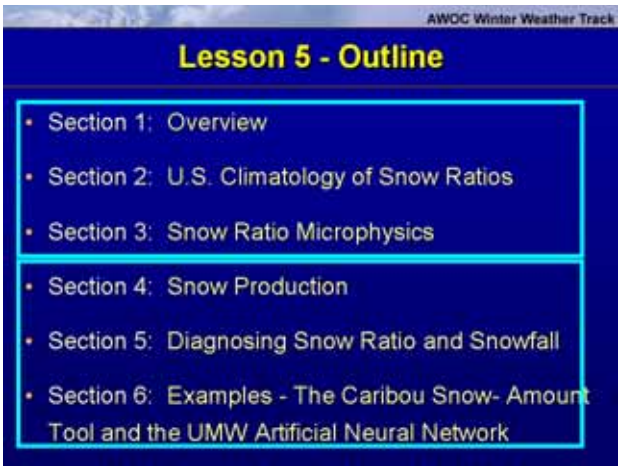
Student Notes:



3. Lesson 5 - Outline

Instructor Notes: This lesson is divided into 6 sections. Part 1 of this lesson will discuss the first 3 sections. Part 2 will cover the last three sections. Section 1: Overview; Section 2: U.S. Climatology of Snow Ratios; Section 3: Snow Ratio Microphysics; Section 4: Snow Production; Section 5: Diagnosing Snow Ratio and Snowfall; and Section 6: (Examples - The Caribou Snow-Amount Tool and the UMW Artificial Neural Network).

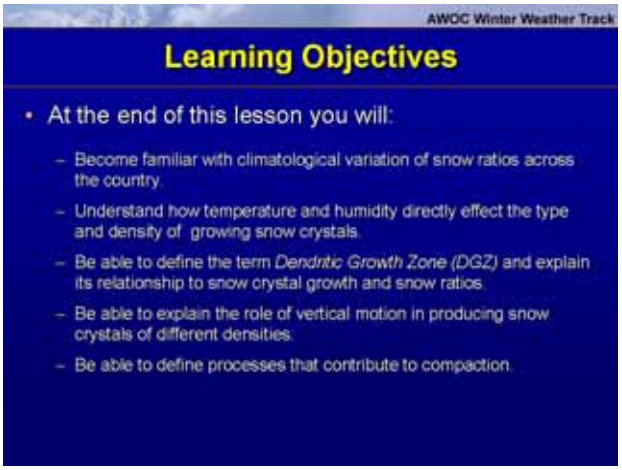
Student Notes:



4. Learning Objectives

Instructor Notes: The learning objectives for this lesson are to be able to identify the conditions of ice crystal growth in clouds, and how changes to crystal structure occur due to both sub-cloud processes and surface processes, including melting and compaction. Students should learn the long term averages of snow ratios and their variability to provide important background information on forecasting snowfall events and distributions.

Student Notes:



5. Performance Objectives

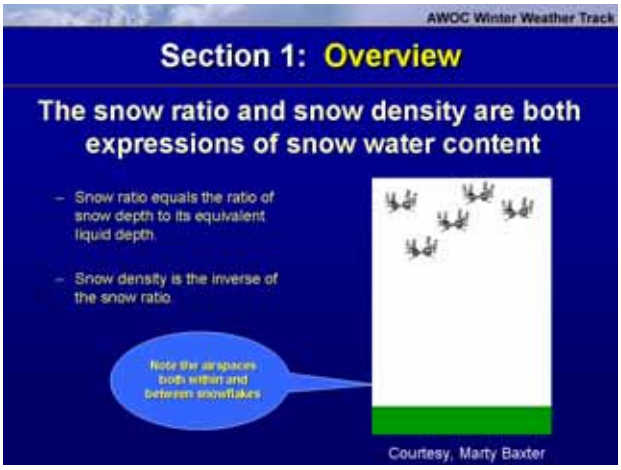
Instructor Notes: The performance objectives for this lesson are to improve estimates of snow density. You should be able to do this by: diagnosing the snow ratio category (light, average, heavy) through inspection of NWP profiles of temperature, dewpoint, and vertical motion modifying snowfall accumulation rates based on sub-cloud and surface conditions and, converting NWP forecasts of equivalent liquid precipitation to snowfall. In addition, you should be able to demonstrate how to use two diagnostic tools to assess snow ratio and expected snowfall, the Caribou forecast tool and the UWM Neural Net.

Student Notes:

6. Section 1: Overview

Instructor Notes: Let's review the definitions of snow ratio and snow density, which we'll use throughout the session. The snow ratio is the ratio of snow depth to its melted equivalent liquid depth. For example, a ten to one ratio (10:1) indicated that ten inches of snow fell for every inch of melted liquid equivalent, or a thirteen to one ratio indicated thirteen inches of snow fell for each inch of liquid equivalent. The snow density or water-to-snow ratio is the inverse of snow ratio, or the equivalent liquid depth divided by its measured snow depth. For example a 10:1 snow ratio would be equivalent to a snow density of 0.10. A low density snow would provide relatively high accumulations, and a high density snow would lead to low accumulations. Here, the animation illustrates the role of snow density in impacting accumulations. The density of a snowfall is determined by the amount of airspace between and within snowflakes.

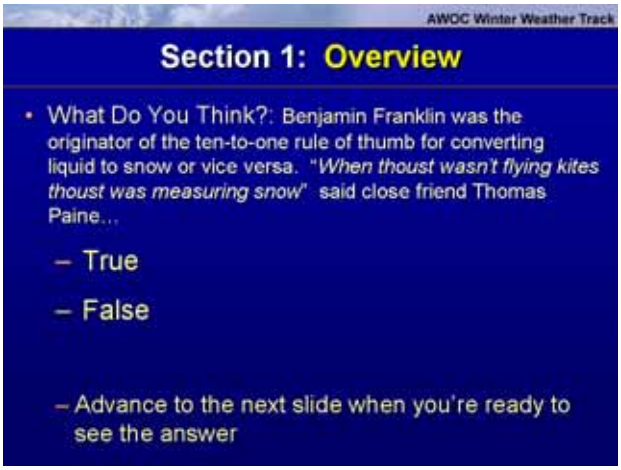
Student Notes:



7. What Do You Think?

Instructor Notes: Our first quiz question provides a little background on previous misguided attempts to determine a snow to liquid ratio. This is still one on the toughest operational problems we have, so let's explore further why we need better guidelines for determining the snow to liquid ratio.

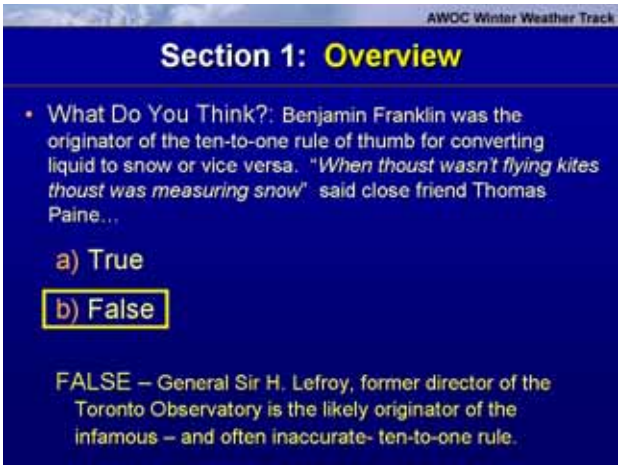
Student Notes:



8. Answer

Instructor Notes: The answer is false. General Sir H Lefroy, director of the Toronto observatory is the likely originator of the infamous, and often inaccurate, ten-to-one rule. Our first quiz question provides a little background on previous misguided attempts to determine a snow to liquid ratio. This is still one on the toughest operational problems we have, so let's explore further why we need better guidelines for determining the snow to liquid ratio.

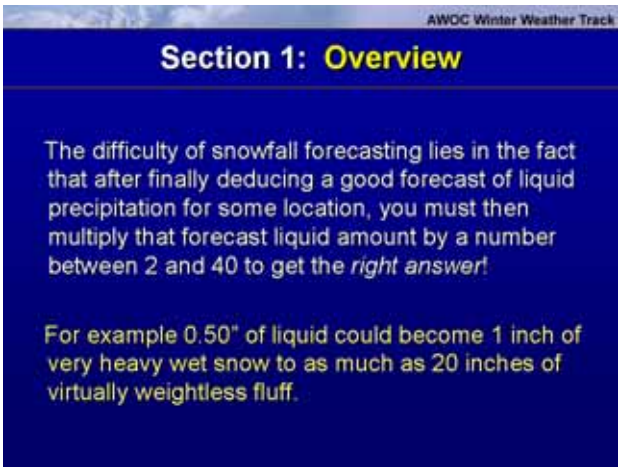
Student Notes:



9. Section 1: Overview

Instructor Notes: The difficulty of snowfall forecasting lies in the fact that after finally deducing a good forecast of liquid precipitation for some location, you must then multiply that forecast liquid amount by a number between 2 and 40 to get the right answer! For example 0.50" of liquid could become 1 inch of very heavy wet snow to as much as 20 inches of virtually weightless fluff.

Student Notes:

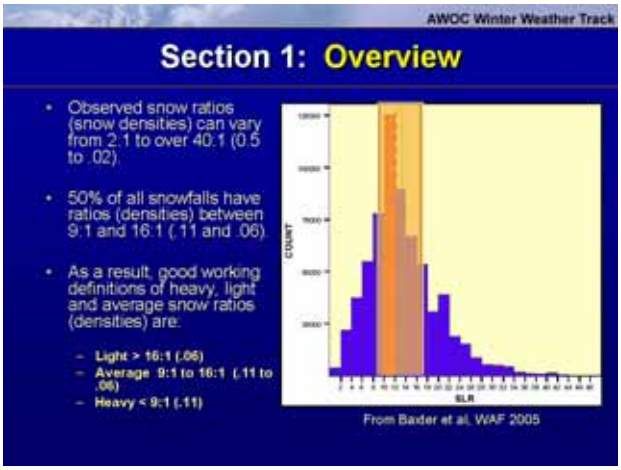


10. Section 1: Overview

Instructor Notes: Let's review the total distribution of 30 years of observed snow to liquid ratios. Notice the well defined peak near 10:1 snow to liquid ratios and the wide range from 2:1 to over 40:1. Interviews with NWS forecasters have indicated instances in which the designated 10:1 ratio was the result of an estimate, rather than an actual measurement of melted snow and computation of the snow ratio based on the liquid equivalent, so we believe the peak is too high. While 50 percent of events have snow to liquid ratios between 9:1 to 16:1, notice the steep reduction in the number of events of snow to liquid ratios of less than 6:1 and also the much longer right tail of the distribution of higher

ratios as you go above 20:1. This is reinforced by the average snow to liquid ratio nationwide is 13:1, as the snowier regions of the country over the long term average higher snow to liquid ratios. This distribution with well defined clustering of events between 9:1 and 16:1 snow ratios leads to working definitions of an average event within this range, with light density snow events (higher accumulations) are those greater than 16:1; average snow events are those between 9:1 and 16:1; and heavy events, or those wet snows with high water content, less than 9:1. The orange outlined area highlights the peak cluster of events between 9:1 and 16:1.

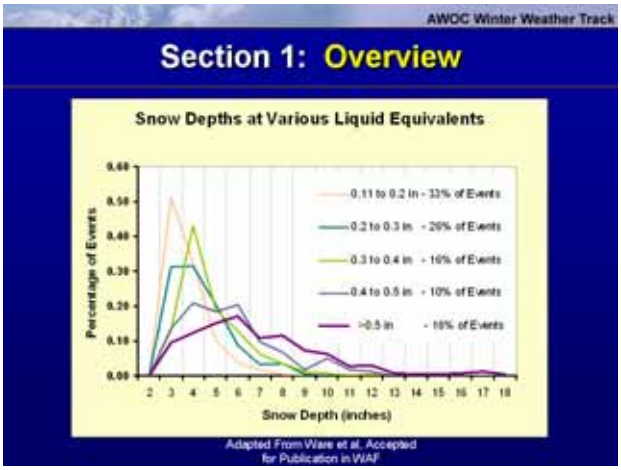
Student Notes:



11. Section 1: Overview

Instructor Notes: This figure shows the range of snow depths for ranges of liquid equivalent precipitation. Notice that as you go toward higher liquid amounts, the total range of observed snowfall increases. This means there is both considerable variability in snow ratios from event to event and also during an event, reinforcing the importance of determining snow-ratio in predicting snowfall accumulations. Note the purple contour for half inch or greater liquid equivalent amounts resulted in snowfall reports ranging from 2 to 18 inches.

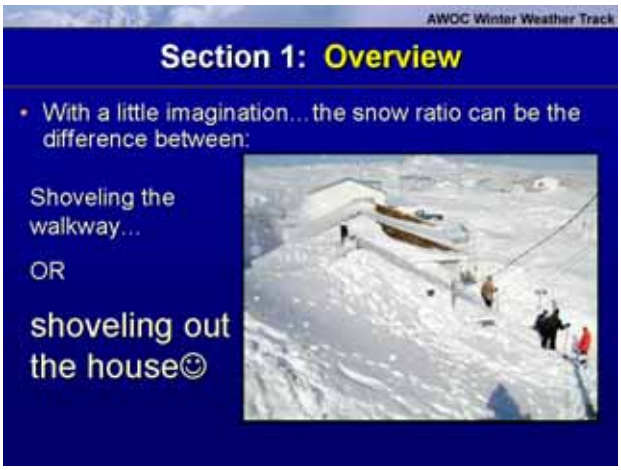
Student Notes:



12. Section 1: Overview

Instructor Notes: And thus you can see that variations in snow to liquid ratio lead to large variations in both predicted and observed snowfall.

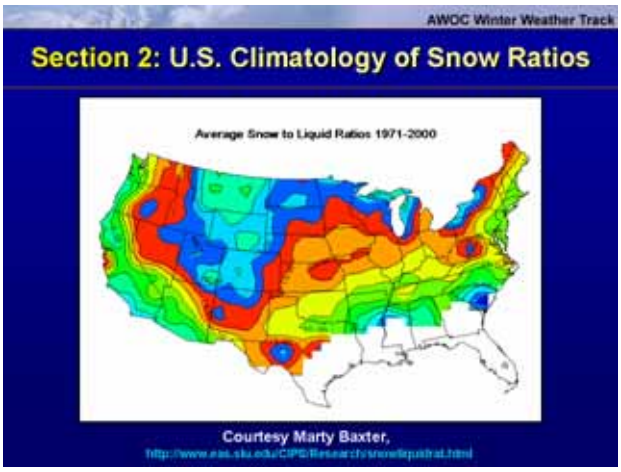
Student Notes:



13. Section 2: U.S. Climatology of Snow Ratios

Instructor Notes: We previously referred to the outdated notion of the 10:1 rule for snow ratios, as the national average snow ratio is near 13:1. Here, you can see the geographical distribution indicating many of the locations which receive heavy snow, such as around the Great Lakes, have higher ratios. The lower ratio areas are either warmer locales or close to where cyclones ingest relatively warm maritime air, such as in the coastal areas of the mid Atlantic and New England, and over the ranges of northern CA and west OR and WA.

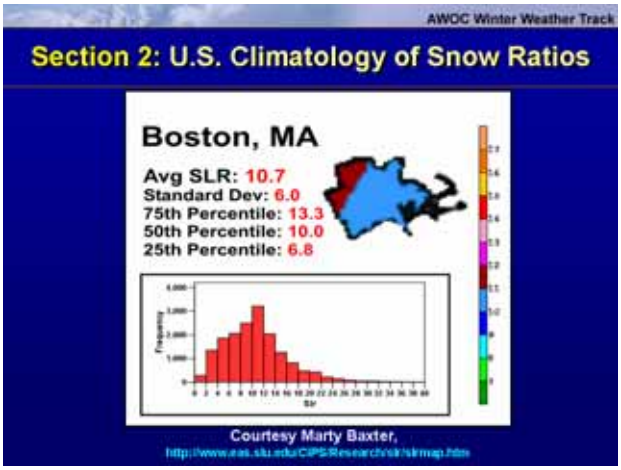
Student Notes:



14. Section 2: U.S. Climatology of Snow Ratios

Instructor Notes: Here we show a sample of four National Weather Service Forecast Office snow to liquid ratios, the standard deviation of the amounts for each area of responsibility. Here is the snow to liquid ratio distribution for Portland OR. It's location in western OR and proximity to the Pacific Ocean lead to relatively low snow ratios and low variability. In contrast, look at the higher snow ratios and higher variability at Great Falls MT. Buffalo NY has a similar average of ratios but a wide spread in its distribution. And here the Boston MA area has lower than average snow to liquid ratios and variability. Look at the website at the bottom of the page to see how your CWA compares to these examples (http://www.eas.slu.edu/CIPS/Research/slr/slrmap.htm).

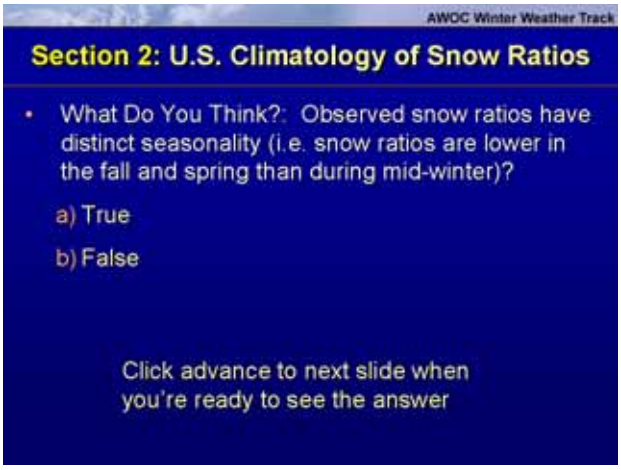
Student Notes:



15. What do you think?

Instructor Notes: Here is a quiz question on whether snow ratios change with the seasons.

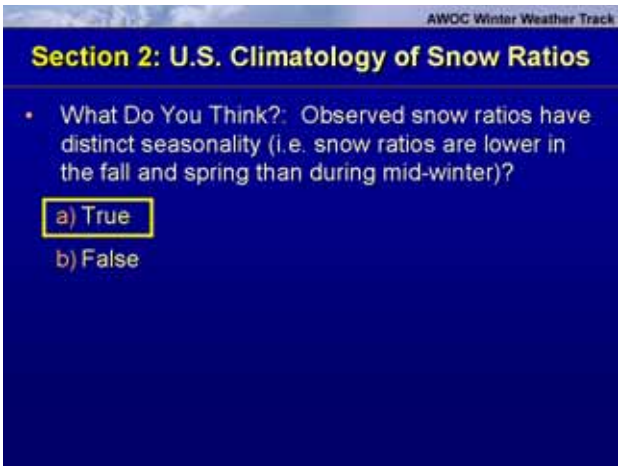
Student Notes:



16. Answer

Instructor Notes: The answer is true and we'll review the changes that occur over the seasons.

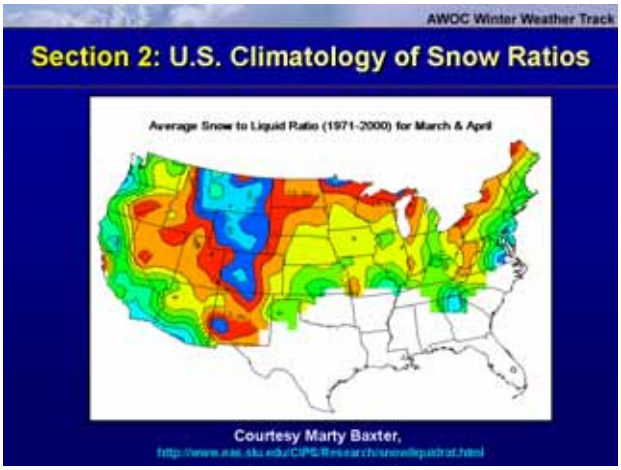
Student Notes:



17. Section 2: U.S. Climatology of Snow Ratios

Instructor Notes: Here are the values for fall. Higher values are inland and in the Rockies. Warm surface temperatures lead to relatively small values on the coast. Here are the peak winter ratios, which are the highest of all seasons matching the coldest time of the year; about 3 times that of fall. Springtime ratios return to smaller values as solar angle increases and so does melting.

Student Notes:

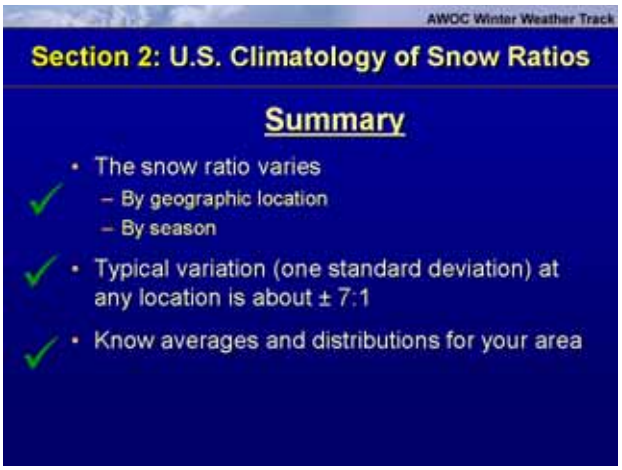


18. Section 2: U.S. Climatology of Snow Ratios

Instructor Notes: We have seen that the snow ratios vary by event, season, and temperature and solar radiation impacts, among others. The significant event to event vari-

ability is reinforced by a standard deviation near 7 across the contiguous US. A station whose average snow to liquid ratio is 13 would have about two thirds of its events with snow ratios between 6:1 and 20:1. Knowing these averages and distributions for each area is important in determining the most likely snow ratios for each event.

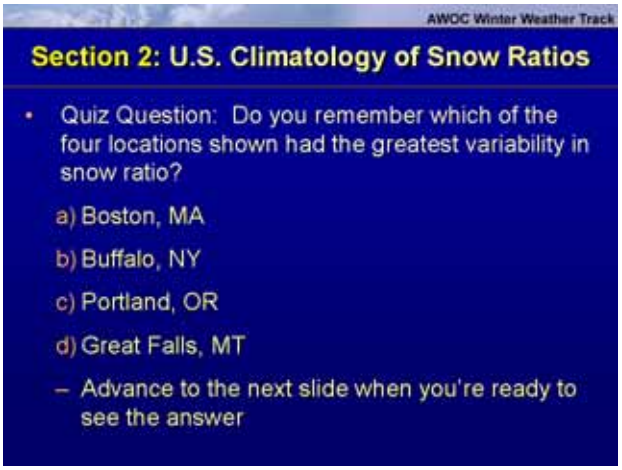
Student Notes:



19. Quiz Question

Instructor Notes: Do you remember which of the four locations shown had the greatest variability in snow ratio?

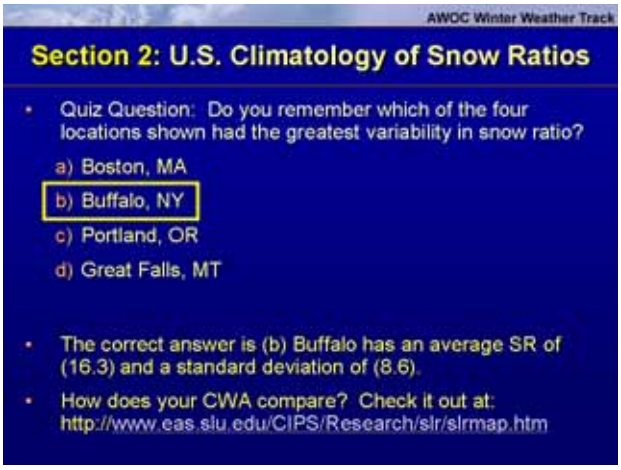
Student Notes:



20. Section 2: U.S. Climatology of Snow Ratios

Instructor Notes: The station with the most variability (highest standard deviation) in snow ratios among those in the contiguous US is Buffalo NY, which results from a wide variety of situations in which snowfall occurs, from synoptic events to mesoscale events.

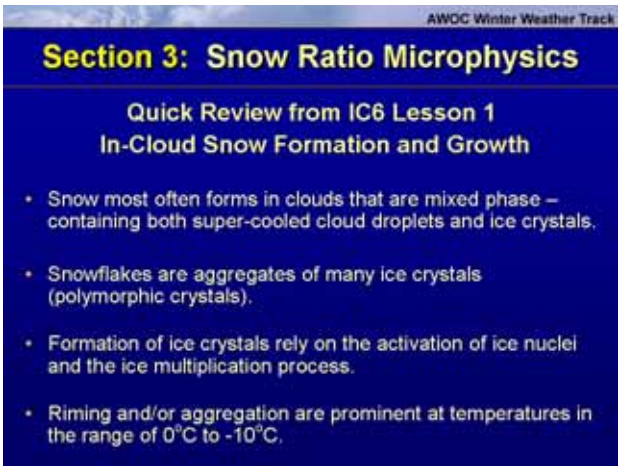
Student Notes:



21. Section 3: Snow Ratio Microphysics

Instructor Notes: In section 3, the discussion will focus on snow growth within clouds including preferred crystal habit or type, growth rates, and associated snow ratios of some common aggregates. I will also briefly discuss the effects of sub-cloud and near surface physics that can alter the snow ratio, but before we discuss snow microphysics in detail, let's take a minute to review some basic cloud microphysics from lesson 1 of IC6. The first is that snow forms in mixed phase clouds, that is clouds that contain both water and ice crystals. Snowflakes are aggregates of ice or snow crystals. The aggregates can be either homogenous or heterogeneous that is made up of just one type or several types of ice crystals. The activation of ice-nuclei at temperatures colder than -8 degrees C is an important key to the formation of ice crystals and in initiating the ice multiplication process. And lastly, ice crystal riming is often prominent at temps from 0 to -10 degrees C.

Student Notes:



22. Section 3: Snow Ratio Microphysics

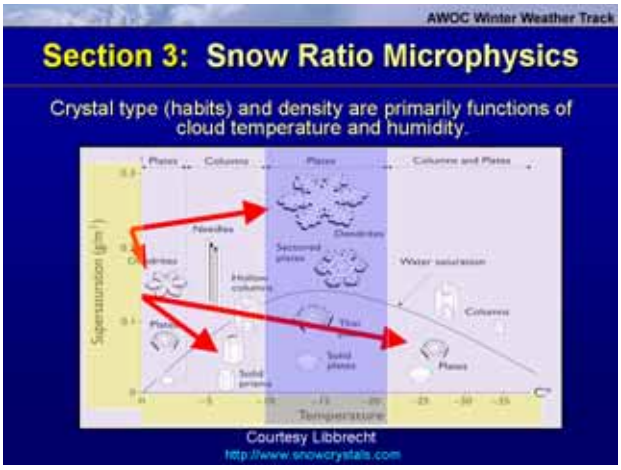
Instructor Notes: Snow microphysics can be broken down into three key processes: 1) The first is the in-cloud formation of ice crystals which depend primarily upon temperature and humidity. 2) Below the cloud sublimation or partial melting can occur - both of which lead to higher snow density. 3) And once on the ground – settling, sublimation and/or melting can again lead to lower ratios or a denser snowfall.

Student Notes:

23. Section 3: Snow Ratio Microphysics

Instructor Notes: This diagram from SnowCrystals.Com (a great web site) shows how ice crystal habit or type is a function of both temperature and humidity. Temperature controls whether the crystal will be more plate or column like while humidity controls the spatial extent of the crystal. Temperature is depicted here along the X axis in degrees C, while the y axis represents humidity with respect to saturation over ice (i.e. 0.1 is 100.1% RH with respect to ice). At relatively low supersaturation – ice crystal habits tend to be more compact taking on the shape of prisms or plates depending upon the temperature at which they form. On the other hand, at higher degrees of supersaturation, crystals tend to branch forming star shaped crystals called dendrites or needle like structures, again the shape, needle or dendrite, depends on the temperature at which the crystal is growing. The potentially largest and least dense crystals form at temperatures between -10 and -20 degrees C. These crystals are called stellar dendrites. In fact, I like to refer to this temperature zone as the “Dendritic Growth Zone”. It has some other interesting properties with respect to snow formation that we’ll discuss in just a minute.

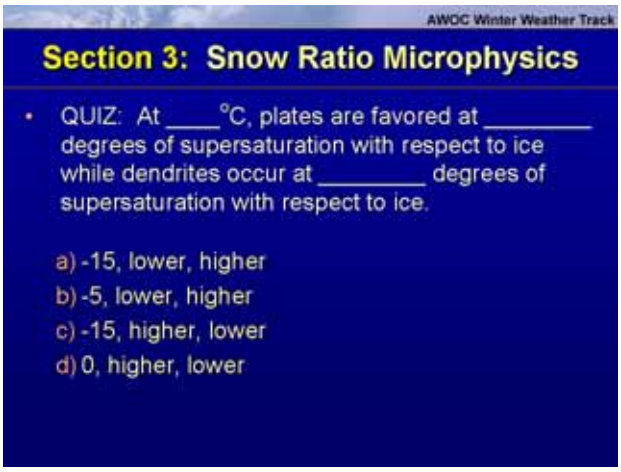
Student Notes:



24. Quiz Question

Instructor Notes: Quiz time – I'll give you a few seconds to consider this one. When you've got the answer – proceed to the next slide.

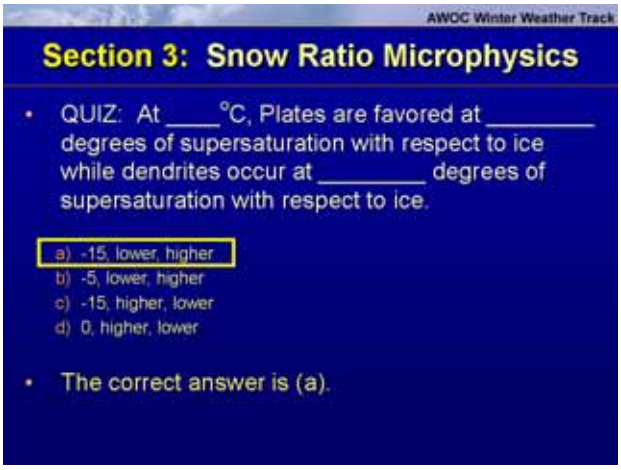
Student Notes:



25. Section 3: Snow Ratio Microphysics

Instructor Notes: Here is the answer to the quiz question.

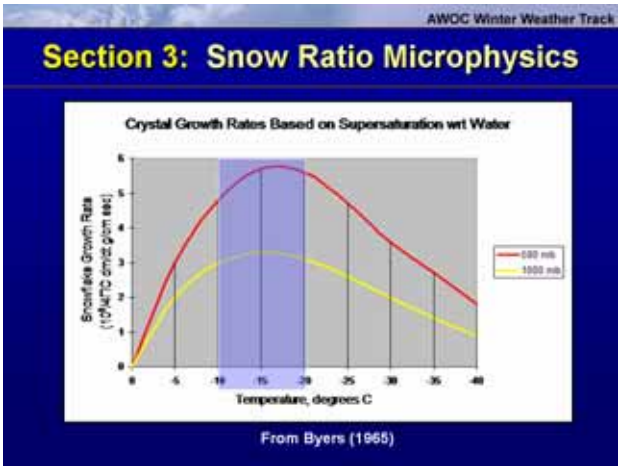
Student Notes:



26. Section 3: Snow Ratio Microphysics

Instructor Notes: This diagram depicts the growth rate of crystals as a function of temperature. Temperature decreases along the X axis while growth rate increases along the Y axis. The yellow curve depicts growth rates at pressures of 1000 mb while the red curve depicts growth rates at 500 mb. Here I have highlighted the Dendritic Growth Zone (DGZ), notice how well it correlates to the peak of the two curves. That's another special property of the DGZ that dendrites are spatially large (low density) and are the fastest growing crystal given sufficient degrees of supersaturation.

Student Notes:

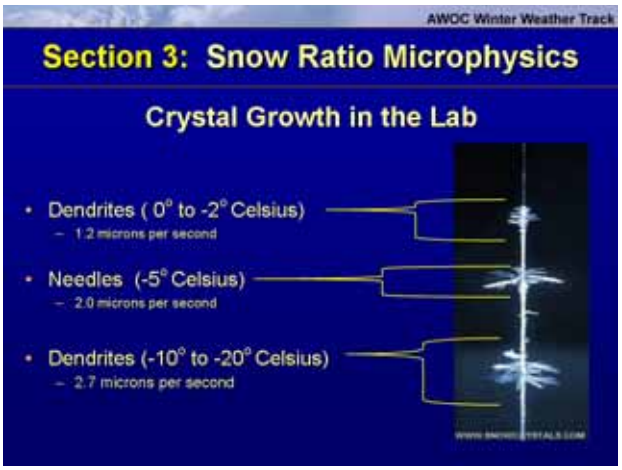


27. Section 3: Snow Ratio Microphysics

Instructor Notes: Now let's take a look at growth rates in the lab. In the picture at right, crystals are being grown on a fine wire hanging inside of a diffusion chamber. The temperature is highly stratified in the chamber ranging from above freezing at the top of the picture to colder than -20 degrees C at the bottom. Humidity is also carefully controlled to maintain supersaturation with respect to ice throughout the chamber. Overall, growth rates in the laboratory agree well with theory. The observed maximum growth rate in the

chamber of 2.7 microns/second occurred at -15 degrees C. What is interesting is the quantum like growth that is seen here with pronounced crystal habit spikes as one moves from slow dendritic growth near freezing...to brisk columnar growth with needles at -5 degrees C...and then rapid dendritic growth in the DGZ.

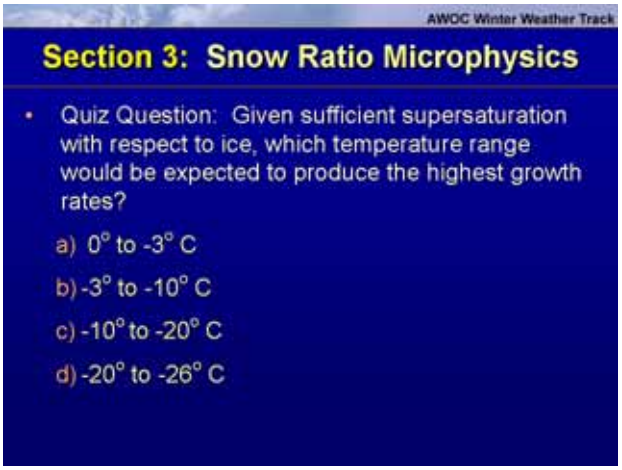
Student Notes:



28. Quiz Question

Instructor Notes: Here's another quiz question for you. When you've got the answer, proceed to the next slide.

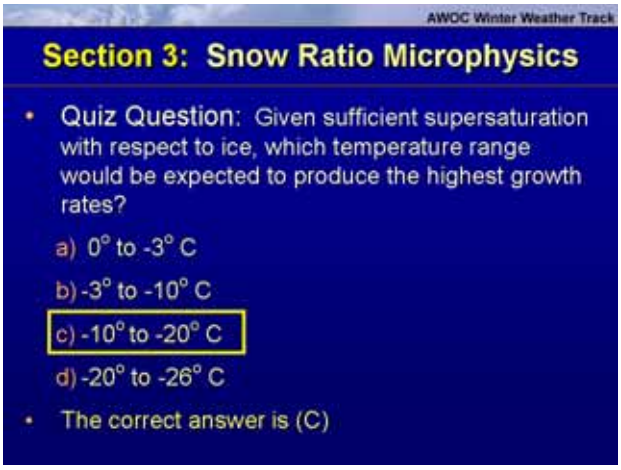
Student Notes:



29. Answer

Instructor Notes: The correct answer is C. The DGZ supports the fastest crystal growth rates…and also the lowest density crystals.

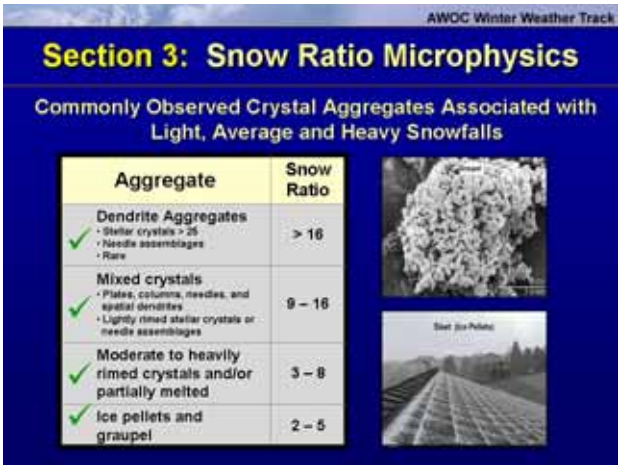
Student Notes:



30. Section 3: Snow Ratio Microphysics

Instructor Notes: Okay, we've spent some time looking at the growth of ice crystals. Now let's relate ice crystal to the snow ratio. This table is adapted from work by Ivan Dube of the Canadian Weather Service. I followed on Dube's observations for a three year period in northern Maine. This table is not meant to be absolute but more of a guideline to help one map observed snowflakes to a likely snow ratio once the snow has fallen. Of course surface effects like melting must also be considered in this mapping. Dendritic snowflakes are typically the lightest with snow ratios for stellar dendrites exceeding 25:1. These kind of snows are common with cold convective clouds occurring in the NW quadrant of a winter cyclones or associated with lake or ocean effect snows. Common in many overrunning situations, these snowflakes contain a variety of ice crystals including bullets, plates, spatial plates, dendrites, needles and columns. Spatial dendrites are actually a crystal hybrid. They start out as columns or small assemblage of plates...that subsequently encounter temperature and humidity conditions conducive to dendritic growth. Also, these snowflakes are quite often slightly rimed. Mixed crystals will in general...fit more tightly together resulting in average snow ratios of between 9 and 16 to 1. Moderate to heavy riming of snowflakes will result in low snow ratios of less than 9:1. Depending on the kind of snowflakes falling into the cloud riming layer – observed snowflakes can range from sleet like snow grains to monster sized wet snowflakes. Classically, heavily rimed flakes are associated with elevated warm layers containing near freezing temperatures...and can be thought of as a warmer subset of the warm frontal or overrunning scenario. Ice pellets and graupel have ratios smaller than 5:1. Graupel is typically the result of extremely rimed snowflakes and is often associated with convective clouds that intersect the -10 to -20 degrees C temperature range. Sleet on the other hand is the result of partial melting and subsequent re-freezing of snowflakes.

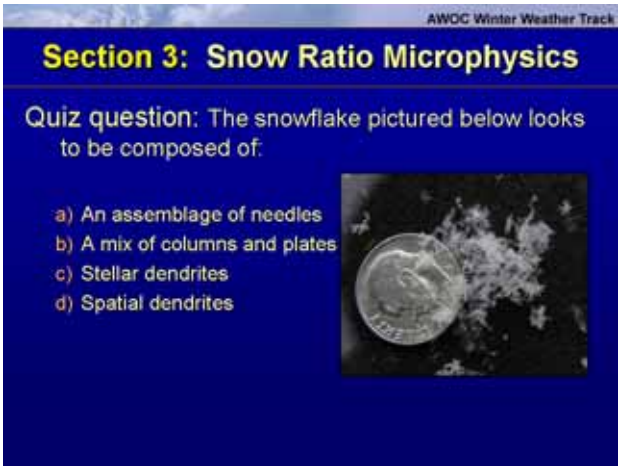
Student Notes:



31. Quiz Question

Instructor Notes: When you've got the answer, proceed to the next slide.

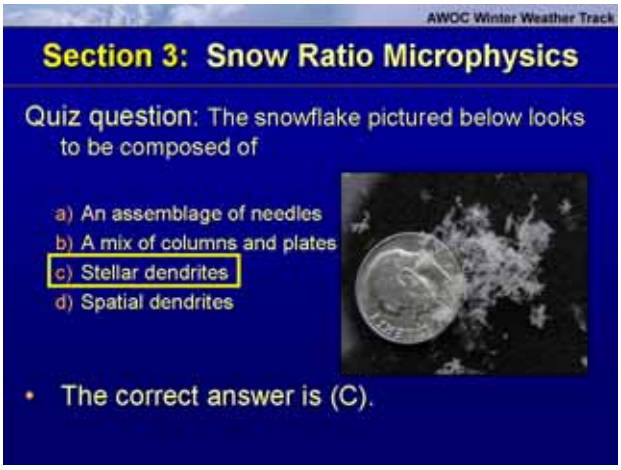
Student Notes:



32. Answer

Instructor Notes: The correct answer is C. This picture is of a single snowflake composed of stellar dendrites. It fell as part of a brief snow shower associated with a band of puffy wintertime cumulus. The cumulus had bases of about 2,500 ft. with tops under 10,000 Ft.

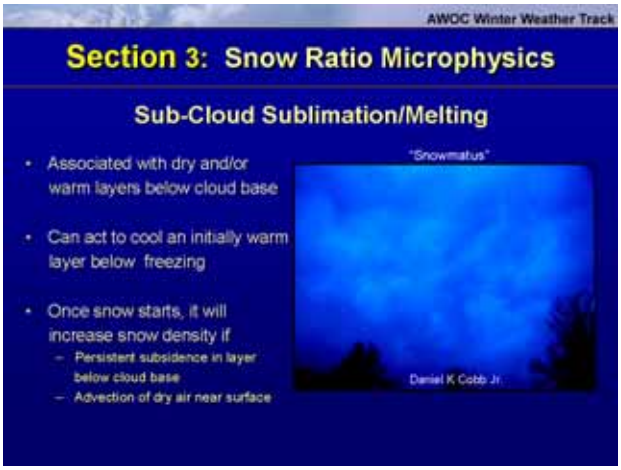
Student Notes:



33. Section 3: Snow Ratio Microphysics

Instructor Notes: Now I'll change gears and talk about the sub-cloud and surface effects. This picture of a turbulent looking sky was taken about 15 minutes before light snow began. This situation occurred with steep lapse rates and dry air below cloud base. As snowflakes at the leading edge of the precipitation sublimated, they cooled this layer creating shallow super-adiabatic lapse rates between the layer just cooled and the layer immediately below. Auto-convective currents formed within this layer, giving the turbulent look to the leading edge of the falling snow. More generally, sublimation and melting are associated with dry and/or warm layers below cloud base. This process can cool an initially warm layer below freezing; the wet bulb profile is often a good discriminator of such a possibility. In terms of the snow ratio, both sublimation and melting will increase the snow density. For sublimation, look for advection of dry air at or below the cloud base. This is common on the leading edge of WAA where snow formation may be above 10,000ft. Also look for subsiding air at or near the surface.

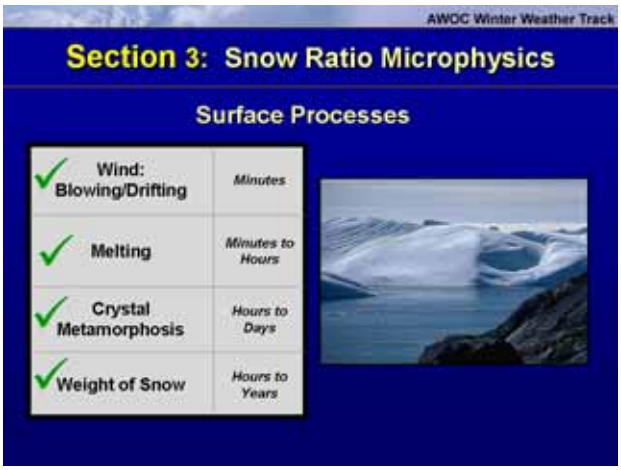
Student Notes:



34. Section 3: Snow Ratio Microphysics

Instructor Notes: Surface processes can act very quickly or very slowly...and in general all act to lower observed snow ratios. Here...we are mainly concerned with processes that affect the snow ratio while the storm is in progress...that is between 6 hourly synoptic snow measurements or at most...the 24 hr. cooperative observer measurements. Through blowing and drifting - Wind causes spatial crystals like dendrites to fracture into smaller more compact pieces which lowers snow-ratios. This process occurs very quickly – as the snow falls. Partial melting of fallen snow can occur almost immediately with temperatures near freezing. Crystal metamorphosis describes the collapse of spatial crystals into more dense forms. Metamorphosis is a slower process which occurs most rapidly as temperatures approach freezing…but for our discussion...it is generally more of a concern for the 24 hr. cooperative observations. Compaction of fallen snow can also occur as crystals in the lower layers of newly fallen snow fracture and are pushed together by the weight of new layers above. This can happen quickly or slowly depending upon the crystal structures, temperatures, and accumulation rates.

Student Notes:



35. Section 3: Snow Ratio Microphysics

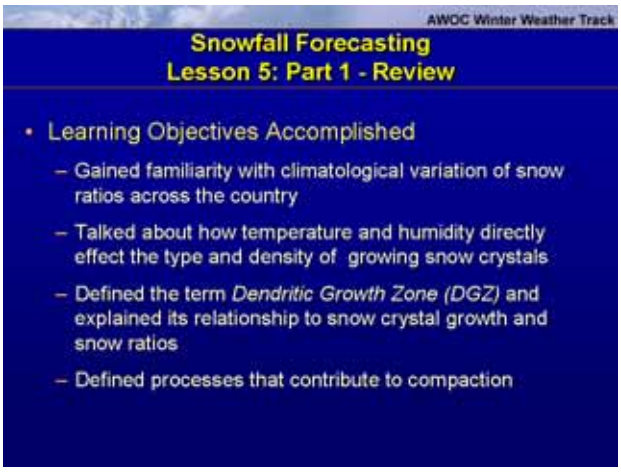
Instructor Notes: We talked about seasonal dependence in section 2 – climatologies – but wanted to briefly discuss it once again in this section. In general – high solar elevation angles that are most prominent in late winter and early spring along with warm ground temperatures that are common in the fall can both act to accelerate surface processes like melting, crystal metamorphosis, and sublimation.

Student Notes:

36. Snowfall Forecasting Lesson 5: Part 1 - Review

Instructor Notes: What we discussed on this part of IC 6 lesson 5, we gained familiarity with climatological variation of snow ratios across the country. We talked about how temperature and humidity directly effect the type and density of growing snow crystals. We defined the term, Dendritic Growth Zone (DGZ) and explained its relationship to snow crystal growth and snow ratios. We defined processes that contribute to compaction.

Student Notes:



37. Good Bye

Instructor Notes: This is the end of Lesson 5, Part1. When you are ready, proceed to Part 2 of this lesson.

Student Notes:

38. Recommended Web-Based References

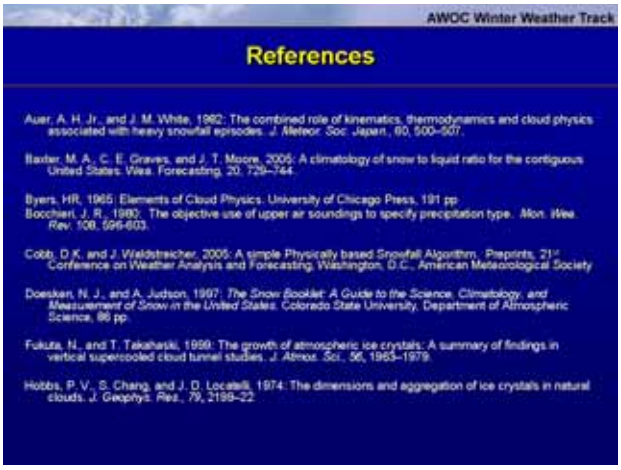
Instructor Notes: This slide is the first of three pages of references cited in the lesson.

Student Notes:

39. References

Instructor Notes: This slide is the second of three pages of references cited in the lesson.

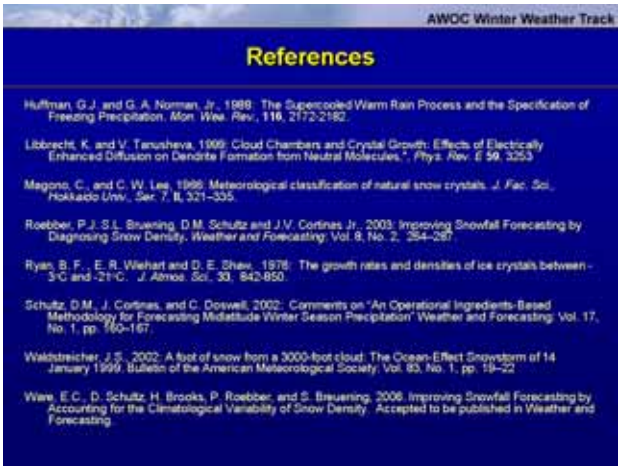
Student Notes:



40. References

Instructor Notes: This slide is the third of three pages of references cited in the lesson.

Student Notes:



1. IC6.5 Part 2: Snowfall Forecasting

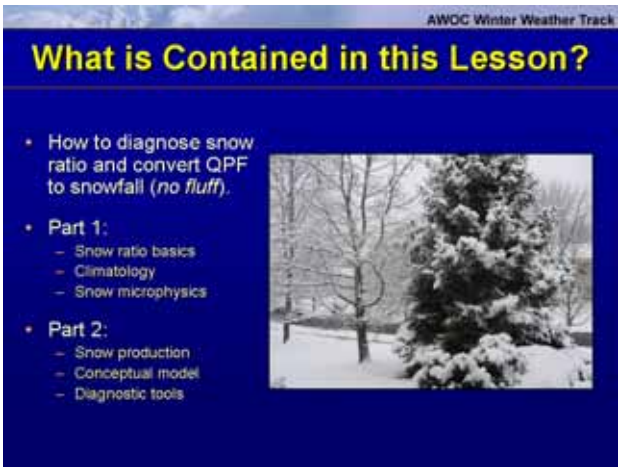
Instructor Notes: Welcome to IC 6, Lesson 5: Snowfall Forecasting. This is Part 2.

Student Notes:

2. What is Contained in this Lesson?

Instructor Notes: As a quick review – the purpose of this less is to learn how to diagnose snow ratio and use it to convert a QPF into a snowfall forecast. In part one, we discussed snow ratio basics, climatology, and snow microphysics. Now in part two, we will cover snow production, conceptual ways to diagnose snow ratio tools, and 2 diagnostic tools for estimating snowfall amounts.

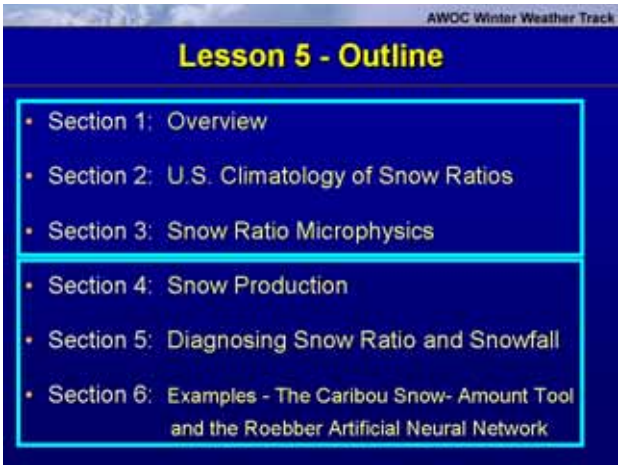
Student Notes:



3. Lesson 5 - Outline

Instructor Notes: This is the lesson outline. In part 2 we will cover sections 4-6.

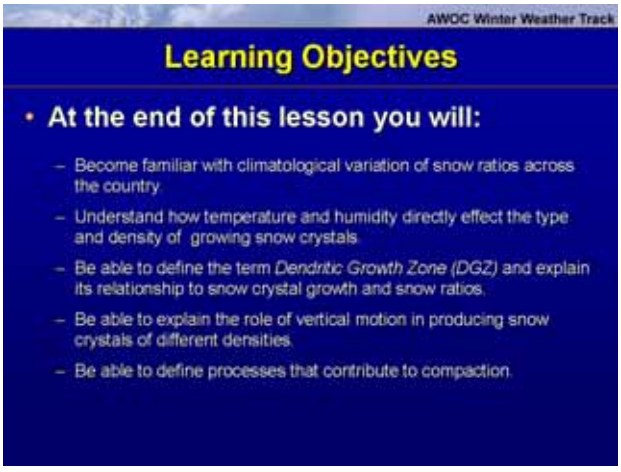
Student Notes:



4. Learning Objectives

Instructor Notes: The learning objectives for IC 6 lesson 5 are: Become familiar with climatological variation of snow ratios across the country, Understand how temperature and humidity directly effect the type and density of growing snow crystals, Be able to define the term Dendritic Growth Zone (DGZ), and Explain its relationship to snow crystal growth and snow ratios. Be able to explain the role of vertical motion in producing snow crystals of different densities, and be able to define processes that contribute to compaction.

Student Notes:

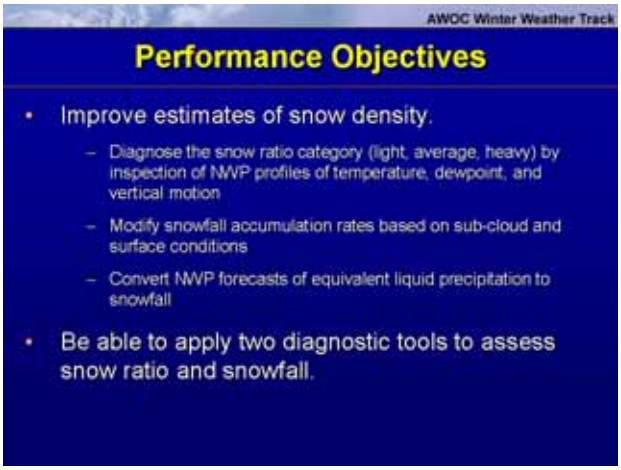


5. Performance Objectives

Instructor Notes: The performance objectives for this lesson are to improve estimates of snow density. You should be able to do this by: Diagnosing the snow ratio category (light, average, heavy) through inspection of NWP profiles of temperature, dewpoint, and vertical motion, Modifying snowfall accumulation rates based on sub-cloud and surface conditions and, Converting NWP forecasts of equivalent liquid precipitation to snowfall. In part 2, we will focus on the 2nd performance objective: Demonstrating how to use two

diagnostic tools to assess snow ratio and expected snowfall, the Caribou forecast tool and the UWM Neural Net.

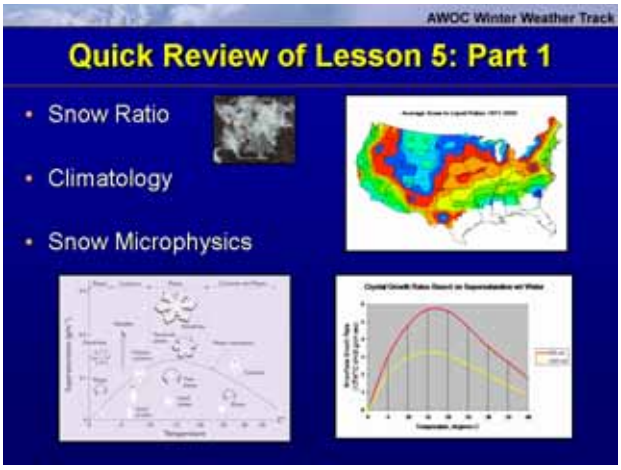
Student Notes:



6. Quick Review of Lesson 5: Part 1

Instructor Notes: As a quick warm-up, I want to briefly discuss some highlights of Lesson 5 - Part 1. We defined the forecast problem by showing the potentially large variation in snowfall given an accurate QPF and a sampling of commonly observed snow ratios. A look at some climatologies revealed that light snows are favored away from the coast, at both higher elevations and latitudes, and that there is a distinct seasonality with the denser snows associated with warmer ground temperatures in the fall and higher sun angles in the spring. We learned about the DGZ, where fast growing spatial dendrites are favored at temperatures between -10 and -20C. And that stellar snowflakes are often associated with snow ratios of greater than 25:1. Snowflakes of mixed crystals often lead to average snow ratios, and heavy snows are associated with heavily rimed or partially melted or melting snowflakes.

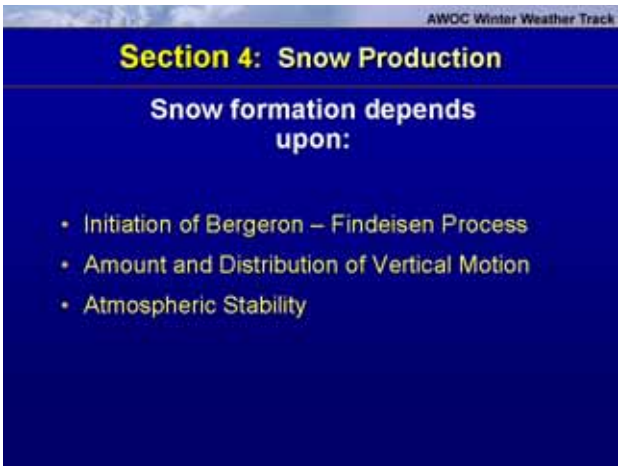
Student Notes:



7. Section 4: Snow Production

Instructor Notes: Snowfall production is influenced by the following: initiation of the Bergeron-Findeisen Process, the amount and distribution of vertical motion, and modification by atmospheric stability, which is related to cloud types and their properties. Some miscellaneous notes: 1) Rising air currents cool air to saturation which supports the formation of cloud water droplets or ice crystals (cloud mixing ratio) which then fall out as precipitation. For cold clouds, the layer with greatest vertical motion and secondarily with relatively warmest temperature will produce the greatest cloud mixing ratio. 2) A second potential source of cloud mixing ratio occurs as warm and relatively moist air above the inversion slowly mixes with the cooler air below the inversion producing and maintaining saturation within the inversion layer. 3) Ice crystal formation in mixed phase clouds is a very important process for enhancing formation of precipitation. 4) Optimal precipitation production would be expected to occur when vertical motion maxima is collocated with optimal ice crystal growth rates (i.e. Dendritic or optimal Snow Growth Zone (SGZ) -12 to -18 degree C). 5) Vertical motion influences the observed snow ratio in two critical ways: (a) First, assuming saturated conditions, it is directly related to the rate of precipitation production. (b) Secondly with respect to ice formation, it influences the persistence and the degree to which supersaturation can be maintained in the presence of growing ice crystals. The degree of supersaturation directly influences crystal density through the branching potential of growing ice crystals (Libbrecht 1999). In terms of the Bergeron-Findeisen precipitation process, the SGZ represents a region of increased precipitation efficiency (relative to cold precipitation processes) in which low density crystals are likely to form. This infers that to a first approximation, a persistent vertical motion maxima collocated with the SGZ would be very conducive to producing both high snowfall rates and high ratio dendritic snowfalls. Such a correlation was noted and dubbed the "Cross-Hair Approach" in a study by Waldstriecher (2001). Other studies by Baumgardt et al. (1999) and Dubè et al. (2003) further support such an approach.

Student Notes:



8. Section 4: Snow Production

Instructor Notes: Let's take a look at a conceptualization of the Bergeron-Findeisen process as it relates to snow production. We'll use as a ball park figure -12 C as our critical temperature for initiation of ice multiplication; of course this temperature will vary depending upon the availability of different ice deposition nuclei. Initially consider the case where cloud temperatures are warmer than -12 C. In this scenario, the cloud is too warm to produce enough ice to initiate snow production. Also, it is too shallow for the collision coalescence process to produce super-cooled drizzle droplets. Now cloud temperatures are below -12 C and the ice multiplication process is fully activated. Additionally, the turbulent nature of the stratocumulus clouds will produce supersaturated conditions leading to rapid growth of dendritic crystals and their aggregation into snowflakes. This example is operationally relevant to the forecast problem of whether lake or marine stratocumulus is likely to produce snow showers. It also helps us to understand why deeper stratocumulus, that are warmer than -12C, can produce freezing drizzle or rain, even without a melting or above freezing layer present in the sounding. Some miscellaneous notes: A presentation "Cloud-Top Temperatures for Precipitating Winter Clouds" at the 2005 Washington DC AMS meeting by Jay Hanna et al indicated, "Snowfall reports tend to exhibit a Gaussian distribution that is skewed heavily towards higher temperatures with a pronounced mode at -16°C. A very sharp drop in the frequency distribution warmer than -12°C is indicative of the depletion of ice nuclei with progressively higher temperatures." This reinforces the findings that the Bergeron Findeisen Process is less effective at producing ice crystal growth at warmer temperatures and occurs most effectively at temperatures starting at -12C down to -18C, due to more ice nuclei being activated at these temperatures.

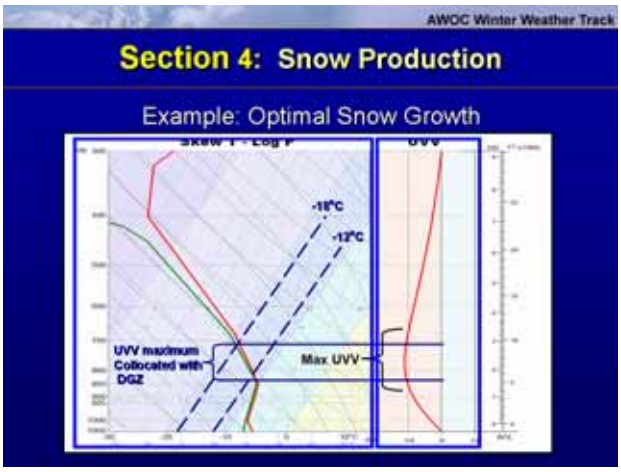
Student Notes:

9. Section 4: Snow Production

Instructor Notes: On this diagram - I want to conceptually illustrate conditions favorable for optimal snow production. This diagram features a sounding on the left using a skewT-logP diagram; the red line depicts temperature and the green line is dewpoint. On the

right side, the vertical profile of omega is shown where negative values represent upward vertical motion. On the sounding I am highlighting the -12 and -18 C isotherms to give an idea of where the sounding intersects the core of the DGZ. Now let's highlight the region of highest upward vertical motion. Putting it all together, the region of strongest upward vertical velocities intersects the DGZ. The result is that water vapor is supplied most rapidly to a region where it can be most efficiently converted into snow. The diagnosis of this intersection of the maximum Upward Vertical Motion (UVV) with the DGZ is referred to as the cross-hair approach, which has been used as a conceptual tool for discriminating significant snowfall events.

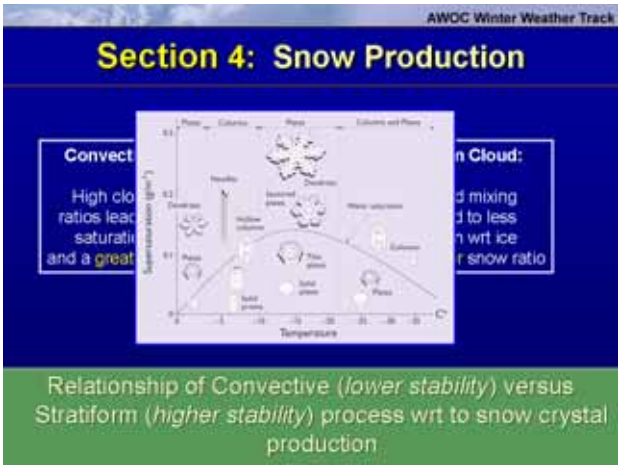
Student Notes:



10. Section 4: Snow Production

Instructor Notes: The last point about snow production pertains to stability. Stability can both inhibit or amplify local vertical motion and mixing both of which influences growing ice crystals. Remember the ice crystal type morphology diagram where dense crystals grow at marginal degrees of supersaturation while light crystals grow at higher degrees of supersaturation. In the case of low stability or steeper lapse rates, cumuliform clouds are favored which tend to have relatively high water content, and given cloud temperatures below -12 deg C, will tend to produce lighter dendritic crystals and higher snow ratios. However, stratus clouds existing in a stable layer with similar temperatures will contain relatively low water content, and will tend to produce denser crystals (less branching).

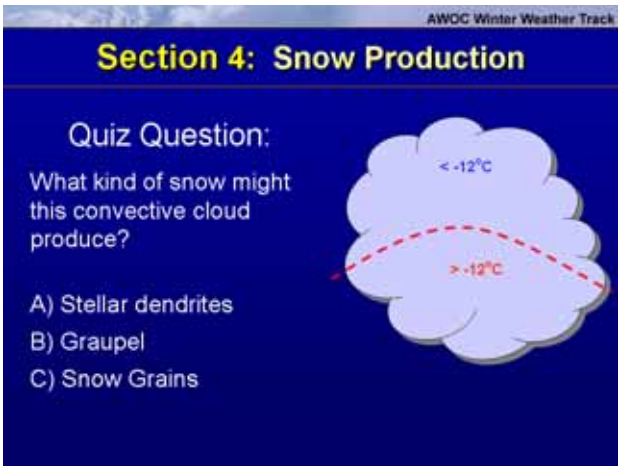
Student Notes:



11. Section 4: Quiz Question

Instructor Notes: Quiz Question: Okay, first quiz question of part 2! What kind of snow might this convective cloud produce. Please proceed to the next frame when you're ready for the answer.

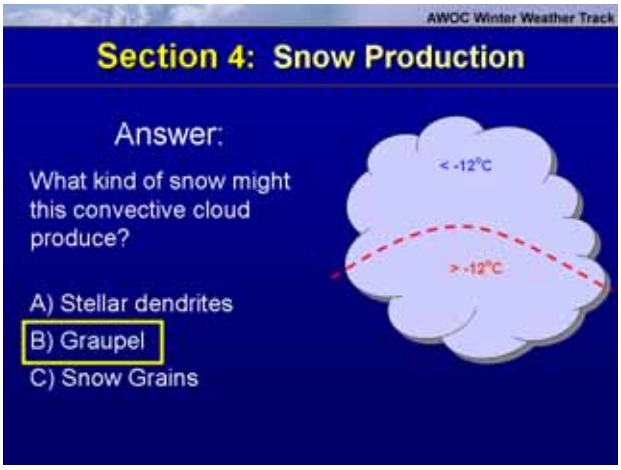
Student Notes:



12. Section 4: Quiz Answer

Instructor Notes: The answer is (B) Graupel – The upper portion of this wintertime cumulus cloud is cold enough to produce dendritic snow which might then fall into the warmer region below where further aggregation and riming turn the initial snowflakes into graupel. If the cumulus cloud were deeper with stronger updrafts then the formation of small hail would be possible. If this had been a stratus cloud with the same temperature distribution, then snow grains or moderately rimed aggregates of plates and columns would have been favored.

Student Notes:



13. Section 5: Diagnosing Snow Ratio and Snowfall

Instructor Notes: Now we'll move on to Section 5 - Diagnosing snow ratio and potential snowfall. In this section, soundings and time-sections from several snow cases will be presented. You'll first be asked to identify the snow ratio class given a representative Buf-kit sounding from the event. We'll then step through the diagnosis of the case using a three step top-down approach. The first step is to assess the snow density potential of the cloudy layers. In the second step, one assesses the sub-cloud layer. Finally, in the third step, surface conditions are considered. Together these three steps give us a practical approach to conceptually diagnosing the most likely observed snow ratio.

Student Notes:

14. Section 5: Diagnosing Snow Ratio and Snowfall

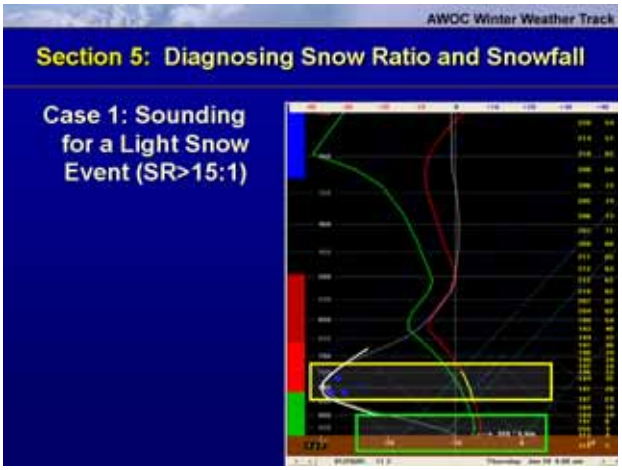
Instructor Notes: What-do-You-Think? Given the sounding below – which of the snow ratio classes would be more likely heavy, average, or light? When you're ready - Proceed to the next slide for a discussion.

Student Notes:

15. Section 5: Diagnosing Snow Ratio and Snowfall

Instructor Notes: This is a good example of a sounding for a light snow event with SR > 15:1. Step 1) First from a cloud perspective – this sounding features a pronounced cross-hair signature with a nearly 40 microbar/s vertical velocity maxima collocated with the DGZ. Secondly, lapse rates through this region are nearly moist adiabatic indicating the possibility of convection and cumuliform clouds properties. Also, significant riming would not be a big threat … as there is only a shallow cloud layer with temperatures above -10C near the surface and the vertical motion in this layer is quite modest which would limit the production of super-cooled cloud droplets. Step 2 & 3) Cloud bases are low and there is no subsidence indicated below cloud base so sublimation would not be a factor. Additionally, surface temperatures are forecast to be near 20 F, with winds of around only 5 kts and lastly, it is the middle of January, so one would not expect any substantial reduction of snow density due to compaction by melting, wind, or crystal metamorphosis.

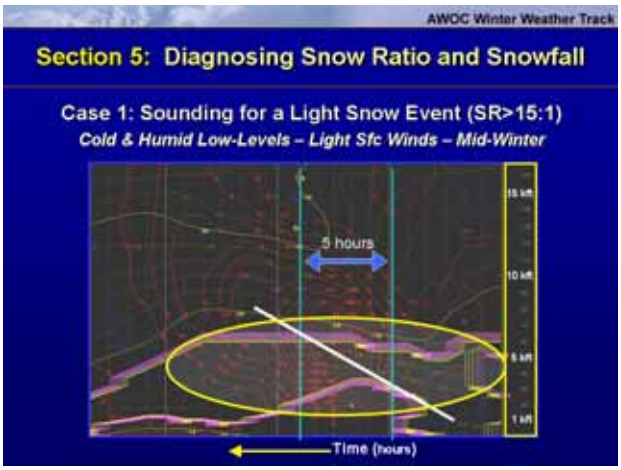
Student Notes:



16. Section 5: Diagnosing Snow Ratio and Snowfall

Instructor Notes: Here is a look at the time-section for the light event case. Time is increasing from right to left and on the right side of the time-section altitude is shown in thousands of feet. Temperatures (light beige contours) and vertical velocities (the red and blue contours) are plotted with the DGZ (depicted w/ magenta contours (let me high-light this for a moment)). The intersection of the upward vertical velocity max with the DGZ lasted about 5 hours with most of the observed snowfall also occurring within that time window. Snow accumulation rates occasionally exceeded 3 inches per hour during this window.

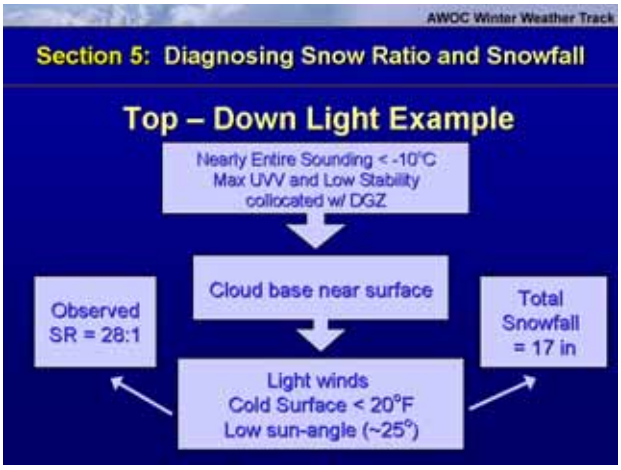
Student Notes:



17. Section 5: Diagnosing Snow Ratio and Snowfall

Instructor Notes: So, once more from the top-down perspective here are the key points: 1) Nearly Entire Sounding < -10C and Max UVV and Low Stability collocated w/ DGZ. 2) Little opportunity for sublimation with low cloud base and vertical motion max. 3) Light winds, Cold Surface < 20F, and Low sun-angle (~25 degrees) afford little chance of rapid surface compaction. 4) Observed SR of 30:1 – one of the fluffiest snows I have ever observed. 5) and with little over a half inch of liquid equivalent – total snowfall was 17 inches!

Student Notes:



18. Section 5: Diagnosing Snow Ratio and Snowfall

Instructor Notes: Lets take a look at another event - What-do-You-Think? Given the sounding below – which of the snow ratio classes would be more likely heavy, average, or light? When you're ready, proceed to the next slide for a discussion.

Student Notes:

19. Section 5: Diagnosing Snow Ratio and Snowfall

Instructor Notes: This is a good example of a sounding associated with a heavy snow event with SR < 9:1. 1) In terms of cloud snow production, the pronounced warm nose between 850 and 700 mb, where temperatures range from near 0 to -5 C immediately catches the eye. The maximum region of upward ascent (about 20 microbars/s) closely coincides with the warm nose being just a bit below the tip of the nose itself. This coupling would likely produce copious amounts of supercooled water droplets and a high potential for significant riming. The potential for riming is further increased by the dry air within and above the DGZ. Cloud top temperatures are roughly between -10 and -15C with little upward ascent at those temperatures. So in many ways this sounding is the opposite of the first case. You might also be thinking that in terms of Top-Down Precipita-

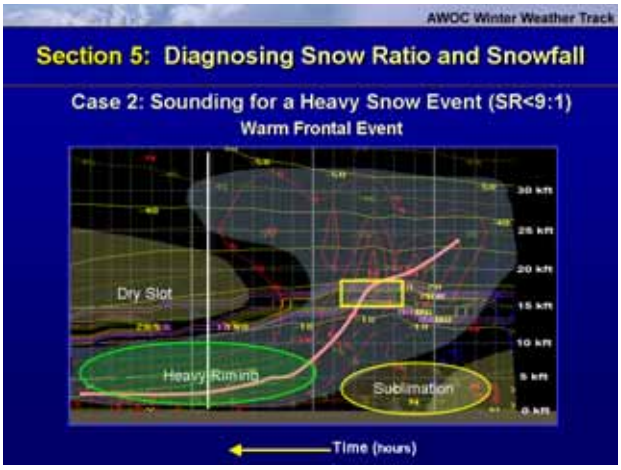
tion type thinking - that this sounding is marginal for producing ice and snow at all. The availability of ice nuclei, like sea salt, from the relatively nearby Atlantic Ocean probably tipped the scales in favor of snow for this case. The surface temperature is near 30F, but the sun angle is at one of the lowest points of the year and there was already snow-cover present so this might be a wash. However, winds sustained near 15 kts could be conducive to densification of falling snow.

Student Notes:

20. Section 5: Diagnosing Snow Ratio and Snowfall

Instructor Notes: The time-section shows a nice warm-frontal signature with the level of maximum ascent lowering with time. I have shaded the cloudy regions in grey and the dry regions in yellow. For reference, the sounding from the last slide was for the time shown by the long tick mark. Early on, there is briefly, a pretty good cross-hair signature between 15 and 20 kft., which is pretty high-up. However, below that layer there is dry air, dry air advection associated with a departing surface high, and some modest downward motion (shown by the yellow circle). This would be a good set-up for sublimation. Later on, the conditions flipped with the ideal riming conditions at lower levels and dry air aloft. So, overall there was little opportunity for lighter crystals to form and make it to the surface.

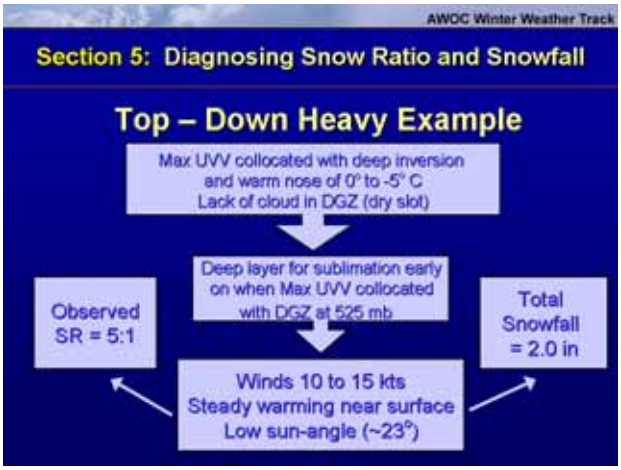
Student Notes:



21. Section 5: Diagnosing Snow Ratio and Snowfall

Instructor Notes: So for case 2 - from the top-down perspective here are the key points: 1) The maximum UVV was collocated with a deep inversion and warm nose of 0 to -5 C for most of event - there was also lack of cloud in DGZ (due to dry slot) over this time. 2) A deep layer for sublimation existed early on when maximum level of ascent was briefly collocated with DGZ at 525 mb. 3) As far as surface compaction there were some winds of 10 to 15 kts. 4) Steady warming occurred near the surface but not above freezing and was coupled with low sun angle of 23 degrees. 5) Observed snow ratio of 5:1 was one of the more dense snowfall I have observed, and in case you were wondering there were trace amounts of sleet in the snow. The sleet pellets occurred towards the end of the occurrence of the cross-hair signature. 6) Like the last case - the liquid equivalent was just over a half inch - but this time total snowfall was only 2 inches! The snow had the consistency of sand and was similar in texture to the man-made snow you might see at a ski area.

Student Notes:



22. Section 5: Diagnosing Snow Ratio and Snowfall

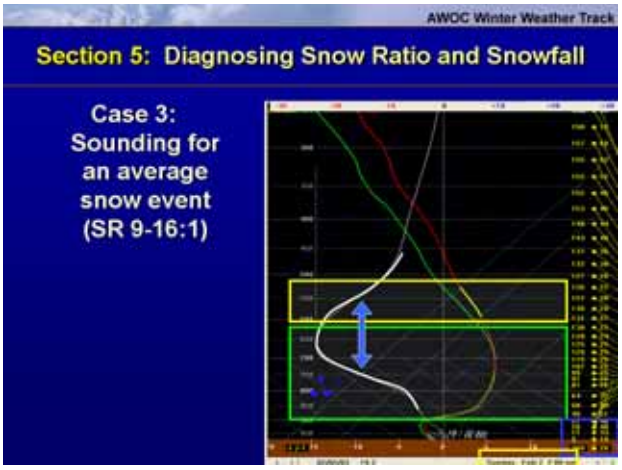
Instructor Notes: Last Event - What-do-You-Think? What are some reasons this might be an example where an average snow ratio class was observed? When you're ready, proceed to the next slide for a discussion.

Student Notes:

23. Section 5: Diagnosing Snow Ratio and Snowfall

Instructor Notes: The first thing that strikes me about this sounding is the depth of the ascent maximum. It's about 250 mb deep with a peak of 25 microbars/s. Secondly, just about half of the ascent maxima lies in the DGZ and the other half overlaps a potential riming layer. The DGZ has steeper lapse rates while the warmer layer below is more stable. Most of the vertical motion in the rime layer is at temperatures between -5 and -10 C which is about 5 degrees colder than in the previous heavy snow example. So, we have indications of both good dendritic growth potential as well as rime potential. I believe what is happening in this example is that the DGZ is providing enough ice to the warmer layer below such that ice-crystal multiplication is helping reduce the amount of liquid cloud droplets thereby reducing the probability of heavy rime icing and a heavy snowfall. There is no chance for sublimation with the sounding saturated to the surface. Again, temperatures are near 30F, but this time it is later in the season, which might enhance the compaction rate. Also, winds are about 20 kt, which would tend to break apart the larger snowflakes into smaller more tightly fitting pieces.

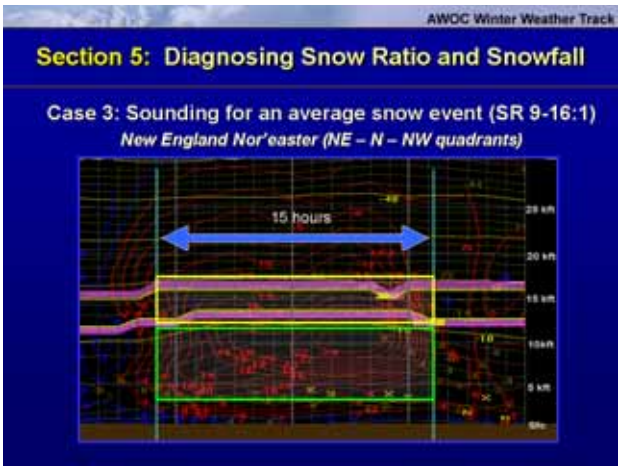
Student Notes:



24. Section 5: Diagnosing Snow Ratio and Snowfall

Instructor Notes: From a time-section one can see that this was a pretty long lasting event at about 15 hours of significant snowfall. Secondly, that the vertical motion maxima was pretty uniform throughout the event in its magnitude and height, saddling the DGZ and the 0 to -10 C thermal layer throughout the storm. Temperature-wise, there was modest cooling of the warm nose at 850 mb after the previous 2 pm sounding but otherwise pretty uniform as well. Observed snowflakes varied throughout the event with generally light-moderately rimed aggregates of spatial dendrites and plates. However, at times – large aggregates of spatial dendrites were observed and at other times – small heavily rimed plate were observed.

Student Notes:

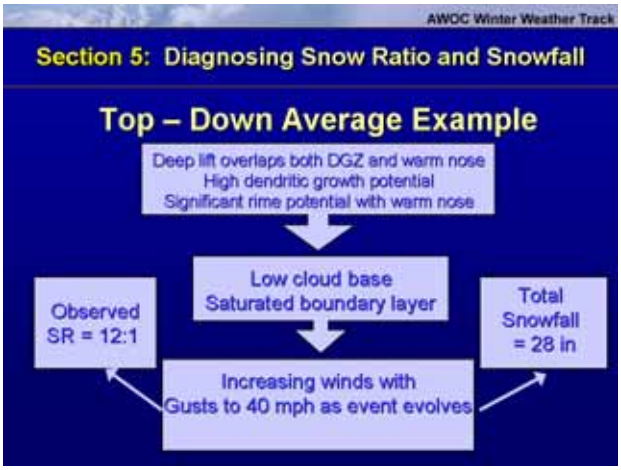


25. Section 5: Diagnosing Snow Ratio and Snowfall

Instructor Notes: So for the last, Case 3, from the top-down perspective here are the key points: 1) Deep lift overlaps both DGZ and the potential rime layer of 0 to -10 C. 2) Low cloud base negates sublimation potential. 3) Increasing winds w/ gusts to 40 m.p.h. as event evolves. 4) Observed SR of 12:1 which is a bit below climatological expected

value of 14:1. 5) Fifteen hour event with just over 2 inches of liquid equivalent resulted in the 3rd largest snow storm recorded in Caribou with Total Snowfall of 28 in.

Student Notes:



26. Quiz

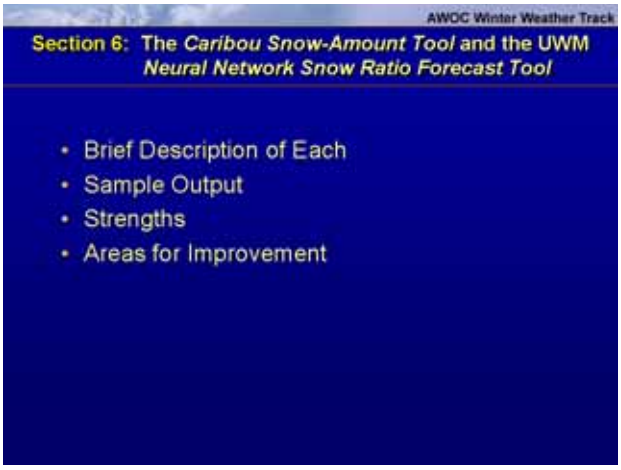
Instructor Notes: Here is an interactive quiz.

Student Notes:

27. Section 6: The Caribou Snow-Amount Tool and the UWM Neural Network Snow Ratio Forecast Tool

Instructor Notes: Now we're going to cover two tools which can be used to assist in the determination of snow to liquid ratios, the Caribou Snow Amount Tool and the UWM Neural Network Snow Ratio Tool. We'll describe each tool and show outputs, strengths, and areas for improvement.

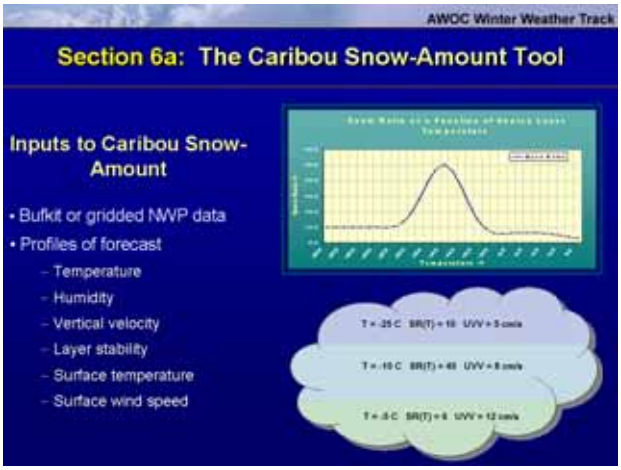
Student Notes:



28. Section 6a: The Caribou Snow-Amount Tool

Instructor Notes: The Caribou snow amount tool predicts snow ratios by reviewing forecast vertical profiles of temperature, humidity, and vertical motion And determining snow ratios over time intervals during each storm. The snow ratios are then multiplied by the QPFs for each interval and summed to yield a storm-total snowfall. The forecast inputs are shown on the left. On the upper right is a graph showing the assigned snow ratios according to the layer temperature. The lower right illustrates how snow ratios are calculated over multiple layers of the sounding, with the final ratio determined using a weighted average. The algorithm takes into account whether the vertical velocity maximum overlays the highest relative humidity and temperatures of the dendritic growth zone, and adjusts for compaction due to surface temperatures and wind.

Student Notes:

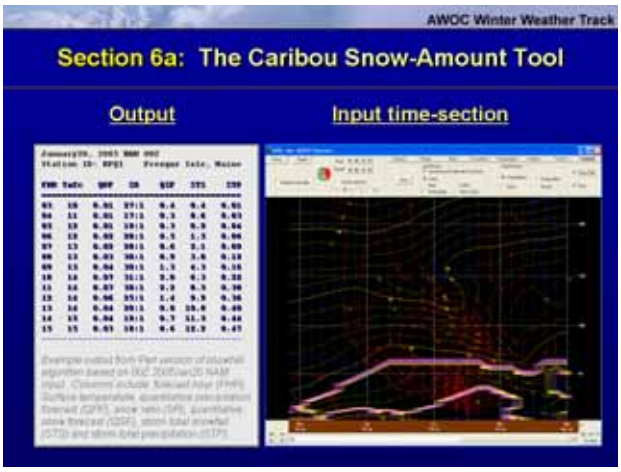


29. Section 6a: The Caribou Snow-Amount Tool

Instructor Notes: You can see a sample of The Perl version of the Caribou Snow Amount tool on the left. The program uses model soundings from the NAM, GFS, or WorkStation version of the Eta that are processed for use in the BUFKIT software. This

version of the program also uses precipitation type logic to improve on its snow ratio and snowfall calculations. BUFKIT sounding data are advantageous because they have the full native model vertical resolution, as well as very high temporal resolution (hourly for the NAM and Workstation Eta, 3-hourly for the GFS), yielding the best estimate of forecast snow ratio and potential snow accumulation at a given point. It also allows a forecaster to evaluate the snow ratio through visual inspection of the model data using the BUFKIT, such as the time section on the right. This GFE “Smart Tool” has the advantage of producing areal distributions of snow ratio and snowfall. This allows the forecaster to deliver more robust gridded forecasts of snowfall.

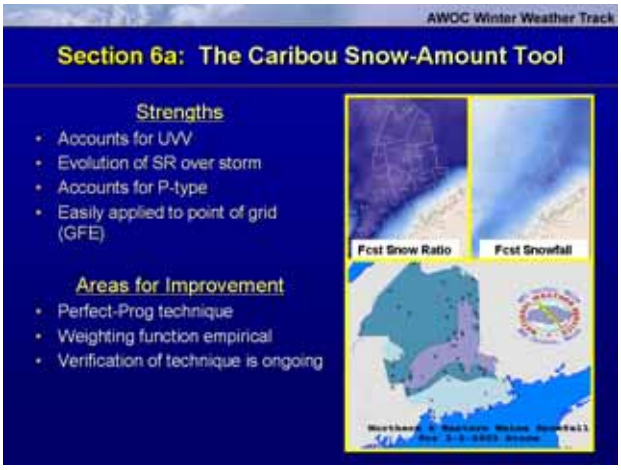
Student Notes:



30. Section 6a: The Caribou Snow-Amount Tool

Instructor Notes: We'll review the algorithm output in the right graphic. The upper left graphic shows output on information on the changes in snow ratio which occur during each event, and the upper right graphic shows output snowfall totals in the Graphical Forecast Editor. The bottom graphic shows observed amounts during an event, which you can compare to those forecast in the upper right panel. The strength of the Caribou snow amount tool is it accounts for the vertical velocity distribution, the evolution of snow ratios as profiles of vertical velocity, temperature, and relative humidity change during an event, and accounts for precipitation type. The areas for improvement would be to conduct a bias adjustment to the model profiles of temperature, relative humidity, vertical velocity, etc. which lead to errors in the algorithm performance. Potential improvements could also come from a study which provides a more robust statistical analysis showing more precisely how vertical velocities impact snow density. A comprehensive verification needs to be looked at to fully validate the utility of the algorithm. The current plan is for algorithm testing to continue.

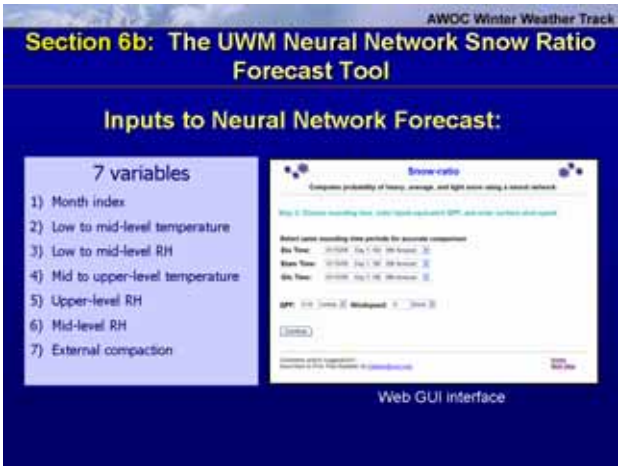
Student Notes:



31. Section 6b: The UWM Neural Network Snow Ratio Forecast Tool

Instructor Notes: The neural network ingests model forecast soundings (obtained from the NAM/Eta, the MesoEta and the GFS) and determines the likelihood that the snow will fall into one of three density classes (heavy, with ratios up to 9:1; average, with ratios from 9:1 up to 15:1; light, with ratios exceeding 15:1). The Roebber et al (2003) study indicated the most critical inputs for determining snow ratio are related to the month, temperature, and external compaction, so these are the inputs into the neural network forecasts. (Additional notes: Ten members with different weighting of each variable are run, and the outputs from these runs are then used to determine the probability of snow ratio class for each event. The authors have indicated that the highest probability of each class leads to an increasing probability of an extreme event. If a high probability occurs for the light class (low probabilities for the average and light categories), then the resultant snow ratio would likely be at the higher end of the range of snow ratios, instead of barely above the average range.)

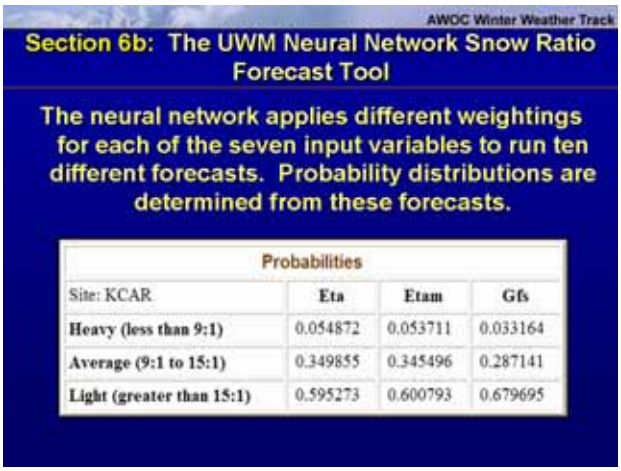
Student Notes:



32. Section 6b: The UWM Neural Network Snow Ratio Forecast Tool

Instructor Notes: The neural network applies different weightings for each of the seven input variables to run ten different forecasts. Probability distributions are determined from these forecasts. The predicted snowfall probabilities are shown for the table below for each range of snow ratio. When the probability in the light category is high (greater than 15:1 snow/liquid equivalent ratio), such as > 67%, then very high snow ratios are likely. When the probability for the heavy snow category is high (less than 9:1 snow/liquid equivalent ratio) then low snow ratios are likely. So the highest probabilities placed in either the light and heavy categories indicate when extreme events are likely. The Roebber web site http://sanders.math.uwm.edu/cgi-bin-snowratio/sr_intro.pl provides more background and specifics of the technique, plus the interface to choose the locations and provide forecast input to receive diagnosed snow to liquid equivalent ratios for each of the categories shown above. See Roebber et al (2003) and Ware et al (2006, accepted for publication in Weather and Forecasting) for background on the data, techniques, and elucidation of the dependence of snow ratio on temperature, month, relative humidity, and compaction due to liquid equivalent precipitation and wind speed.

Student Notes:



Probabilities

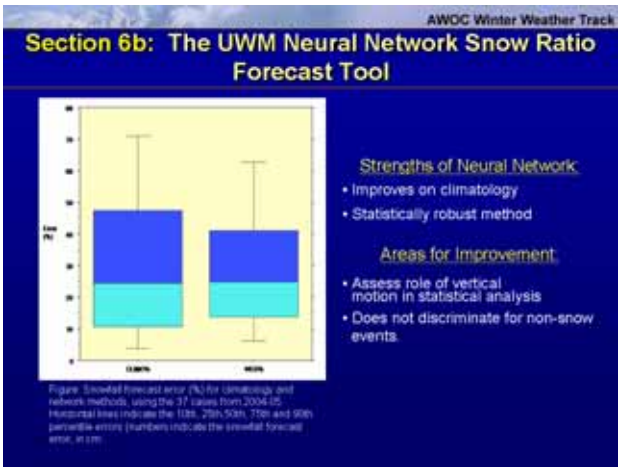
Site: KCAR	Eta	Etam	Gfs
Heavy (less than 9:1)	0.054872	0.053711	0.033164
Average (9:1 to 15:1)	0.349855	0.345496	0.287141
Light (greater than 15:1)	0.595273	0.600793	0.679695

33. Section 6b: The UWM Neural Network Snow Ratio Forecast Tool

Instructor Notes: The neural network forecast results show improvement over climatological snow to liquid ratios (60.4% correct determination of snow category vs. 41.7% for climatology). As you can see in the lower left, there are lower rms errors plus the neural net narrows the range of the most likely snow-liquid ratios (see verification graphic). The neural net weightings were calculated using 1650 events over a large portion of the country, so it is statistically robust. One possible area of improvement would be to see if a neural net could determine the contribution of vertical motion to snow-liquid ratios and factor in forecast vertical velocities. Another area would be to conduct a bias correction

for the forecast inputs, temperature and relative humidity inputs, and then use these bias adjusted forecasts as inputs into the algorithm. The neural net also needs to discriminate to not assign a snow ratio if the precipitation type is not forecast to be snow.

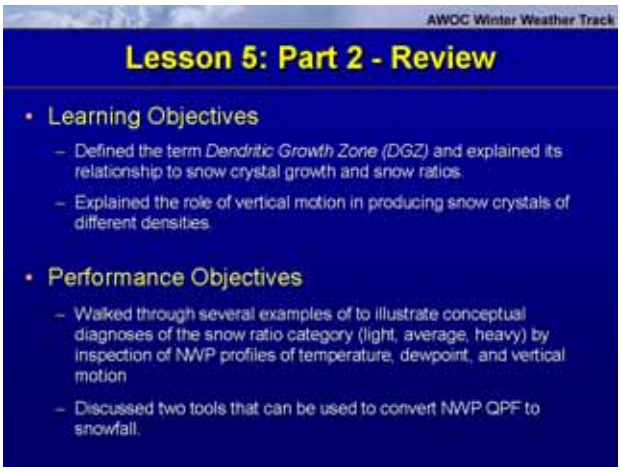
Student Notes:



34. Lesson 5: Part 2 - Review

Instructor Notes: For our learning objectives, We've covered the importance of the dendritic growth zone and the overlap with vertical motions and their implications for snow growth and snow density. For our performance objectives, we applied these concepts by showing how to analyze soundings to determine whether snowfalls will have average, light, or heavy density, and discussed the Caribou and neural net forecast tools which provide calculations of snow density which you can use to determine snowfall accumulations. The sounding analysis and quantitative forecast tools can be combined to provide improved snowfall accumulation forecasts.

Student Notes:



35. The End

Instructor Notes: This concludes the lesson on determining snow ratios-we hope it was interesting and we look forward to receiving your feedback.

Student Notes:

36. Recommended Web-Based References

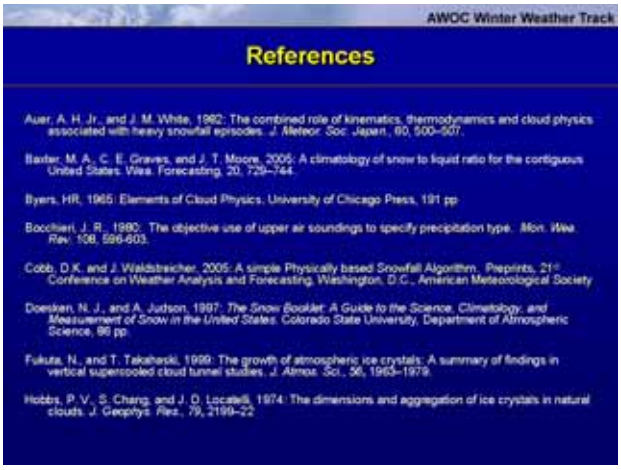
Instructor Notes: This is the first of three slides providing the references cited in this lesson.

Student Notes:

37. References

Instructor Notes: This is the second of three slides providing the references cited in this lesson.

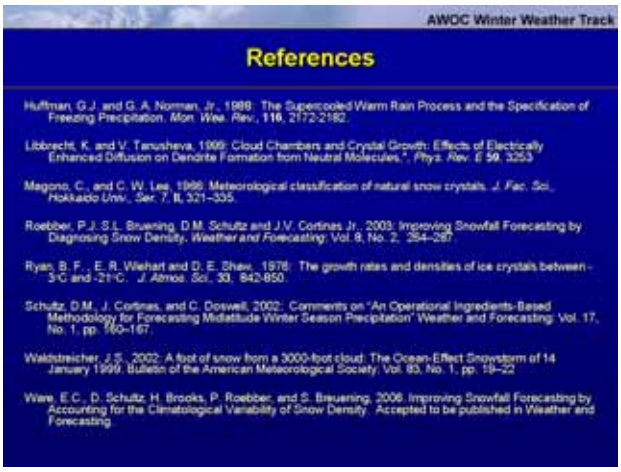
Student Notes:



38. References

Instructor Notes: This is the last of three slides providing the references cited in this lesson.

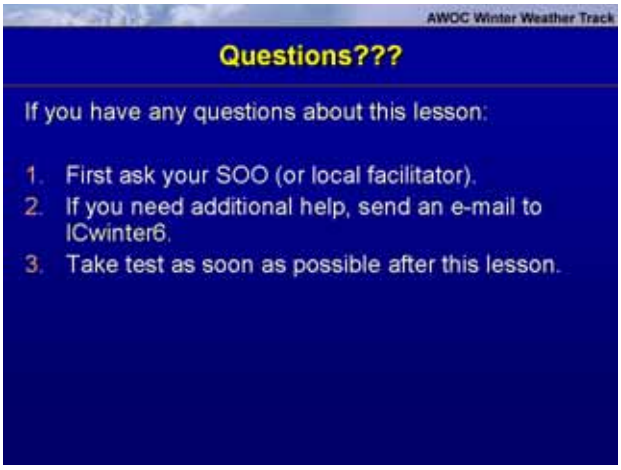
Student Notes:



39. Questions???

Instructor Notes: After going through this lesson if you have any questions, first ask your SOO. Your SOO is your local facilitator and should be able to help answer many questions. If you need additional info from what your SOO provided, send an E-mail to the address on the slide. This address sends the message to all the instructors involved with this IC. Our answer will be CC'd to your SOO so that they can answer any similar questions that come up in the future. We may also consider the question and answer for our FAQ page. Thanks for your time and good luck on the exam!"

Student Notes:



IC6.5: Optional Job Sheet

Snowfall Forecasting

Objective: Utilize BUFKIT and the internet to assess potential snow ratios using the techniques discussed in the Winter Weather AWOC IC 6 Lesson 5 modules.

Data: BUFKIT Workstation Eta profiles from 11/20/00 Buffalo, NY and 12/10/00 Peoria, IL.

Instructions:
Install the latest version of BUFKIT (version 4.71) from the CD provided by WDTB. If you already have it installed, skip ahead to #5. If you don't have the CD and want to install BUFKIT and the WW AWOC data on your personal PC, you can go to http://www.wdtb.noaa.gov/tools/BUFKIT.
Unzip the file into a temporary directory.
Run the program "setup.exe"
This setup program will install Bufkit and all the needed support and data files.
To begin, go to the Windows start button, click "programs" → BUFKIT Winter Weather AWOC, then click on the icon corresponding to BUFKIT Winter Weather AWOC.

Data Analysis--Sounding #1
With the Winter Weather AWOC BUFKIT loaded on the profile screen, select the model by clicking on the radio button: **EtaW**
Select the site by clicking in the drop down menu at the top, and choose **PIA**
Click the "Controls" button on the lower left, and turn on the omega field. Scroll ahead to the 24hr forecast valid at 7 AM on December 11th.
What type of snow ratio might you expect from this type of sounding-- **Heavy**, **Average**, or **Light** (circle one)? Explain your reasoning, being sure to discuss the effects from surface temperature, low-level winds, RH profile, and omega fields.

Click on the "Overview" button on the top right. A time-height plot will load, with forecast time increasing right to left. Click the reset button. Click on the box for "omega", then click on "snow growth".

When will the heaviest snow fall based on the Dendritic Growth Zone (DGZ) and upward velocities method discussed in the lesson?

Between _____ Z on _____ through _____Z on _____.

How strong are the vertical velocities in the DGZ during that time?

-____ µb/sec
Where is the core of the strongest vertical velocities located relative to the DGZ--**above**, **below**, **within** (circle one)?

In the time-height window, click on the “Precip” button, then click both the “snowfall” and “snow ratio” buttons near the top right of the screen. By default, the snowfall technique radio button should be **DGZ x Omega**. This is the Caribou Snow Amount Technique discussed in the IC 6 Lesson 5 module.
Based on this technique, what is the range of the expected snow ratio throughout the event?
~ ____:1 - ____:1
Did this agree with your reasoning in the previous question (C #1)? If not, why not?

How much snow is expected from this event based on this technique? (to integrate totals, hold down the right click button and drag left to right across snowfall bar graph)

_____Inches
Based on what you see, explain why the snow ratio (and thus snow fall amount) from this technique is so low.

Click the radio button in the snowfall techniques window such that **max temp in profile** technique is used for snow ratio and accumulation.
How much snow is expected from this event based on this technique?

_____Inches

Why is the snow ratio so much higher with this technique compared to the Caribou Method?

Click the radio button in the snowfall techniques window for **surface temp**.
How much snow is expected from this event based on this technique?

_____Inches
Finally, click the radio button for a standard 10:1 ratio.
How much snow is expected from this event based on this technique?

_____Inches
Data Analysis--Sounding #2
Switch to the BUF sounding by selecting it from the drop down menu from the profile window. Click the "Controls" button on the lower left, and turn on the omega field. Scroll ahead to the 24hr forecast valid at 7 AM on December 11th.
What type of snow ratio might you expect from this type of sounding-- **Heavy**, **Average**, or **Light** (circle one)? Explain your reasoning, and be sure to discuss the effects from surface temperature, low-level winds, RH profile, and omega fields.

Click on the "Overview" button on the top right. A time-height plot will load, with forecast time increasing right to left. Click the reset button. Click on the box for "omega", then click on "snow growth".
When will the heaviest snow fall based on the Dendritic Growth Zone (DGZ) and upward velocities method discussed in the lesson?

Between _____ Z on _____ through _____Z on _____.
How strong are the vertical velocities in the DGZ during that time?

-____ µb/sec
Where is the core of the strongest vertical velocities located relative to the DGZ--**above**, **below**, **within** (circle one)?

In the time-height window, click on the "Precip" button, then click both the "snowfall" and "snow ratio" buttons near the top right of the screen. By default, the snowfall technique radio button should be DGZ x Omega. This is the Caribou Snow Amount Technique discussed in the IC 6 Lesson 5 module.

Based on this technique, what is the range of the expected snow ratio throughout the event?
~ ____:1 - ____:1
Did this agree with your reasoning in the previous question (#13)? If not, why not?

How much snow is expected from this event based on this technique? (to integrate totals, hold right click and drag left to right across snowfall bar graph)
_____Inches
Based on what you see, explain why the snow ratio (and thus snow fall amounts) from this technique is so high.

Click the radio button in the snowfall techniques window such that **max temp in profile** technique is used for snow ratio and accumulation.
How much snow is expected from this event based on this technique?

_____Inches
Why is the snow ratio so much lower with this technique compared to the Caribou Method?

Click the radio button in the snowfall techniques window for **surface temp**.
How much snow is expected from this event based on this technique?

_____Inches
Finally, click the radio button for a standard 10:1 ratio.
How much snow is expected from this event based on this technique?

_____Inches

Using the UWM Neural Network for Snow Ratio

Go to this website: http://sanders.math.uwm.edu/cgi-bin-snowratio/sr_intro.pl This portion of the job sheet is only intended to allow you to become acquainted with a snow ratio neural network website should you want to use it during Winter Weather forecasting shifts. Read through the intro page and when ready, click the “begin forecast”. Play

around with this tool for your CWA if you wish. If there is no threat of snow in your CWA in real-time, consider picking Point Barrow, AK, (PABR) where it can snow year round and thus you'll get more realistic snow ratio statistics.

An answer key is available for this job sheet. Please see your local AWOC Winter Weather facilitator to obtain a copy.

IC6: References

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Penn, S., 1957: The prediction of snow versus rain. Forecasting Guide No. 2, U.S. Weather Bureau, 29 pp

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Lesson 2:

Baldwin, M., R. Treadon, and S. Contorno, 1994: Precipitation type prediction using a decision tree approach with NMCs mesoscale eta model. Preprints, 10th Conf. On Numerical Weather Prediction, Portland, OR, AMS 30–31.

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Lesson 3:

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Lesson 4:

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Wetzel, S.W., and J.E. Martin, 2001: An Operational Ingredients-Based Methodology For Forecasting Midlatitude Winter Season Precipitation. Wea. Forecasting, 16, 156-167.

Lesson 5:

Web-Based References:

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Cobb, D.K., A simple physically based snowfall algorithm http://ams.confex.com/ams/WAFNWP34BC/techprogram/paper_94815.htm

Libbrecht, K. G., A Snowflake Primer. http://www.its.caltech.edu/~atomic/snowcrystals/primer/primer.htm

Roebber, P., The University of Wisconsin - Milwaukee (UWM) Real time snow ratio forecast page http://sanders.math.uwm.edu/cgi-bin-snowratio/sr_intro.pl

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IC Winter 7: Monitoring System Evolution

1. IC7.1: Monitoring Model Accuracy

Instructor Notes: Welcome to Winter AWOC Instructional Component 7, Lesson 1.

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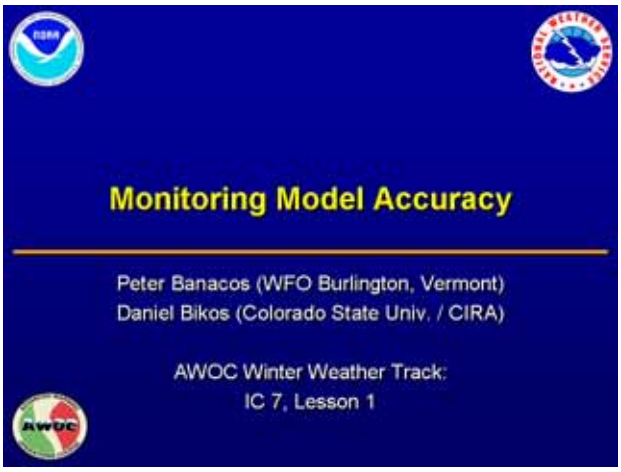

2. Outline

Instructor Notes: In this presentation, we'll discuss the benefits of diagnosis in improving upon model forecasts, especially in the short-range (24 hrs. or less). We'll show case examples of potential problem areas in numerical model forecasts pertinent to winter weather forecasting. Lastly, we'll provide basic guidelines for taking corrective action(s) in the official forecast.

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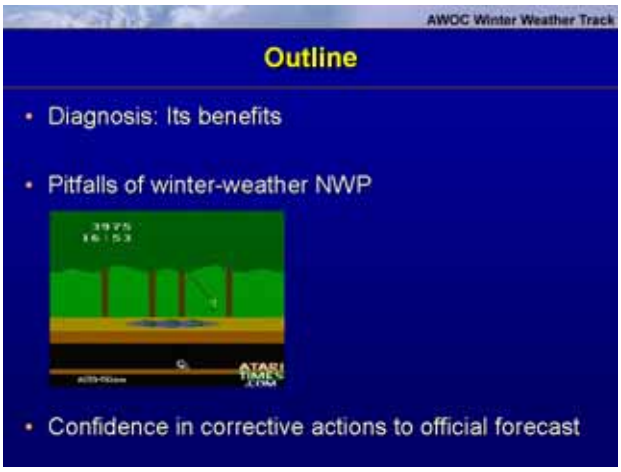

3. Learning Objectives

Instructor Notes: What tangible aspects of the model forecast are often critical to winter weather forecasting? The goal of this talk is to focus on those facets of the models that typically have the most problems, and yield the greatest impact upon sensible winter

weather elements (i.e., surface winds, P-type, QPF). A primary objective of this talk is to "survey" these NWP problem areas and provide a framework for recognizing them, especially within the realm of short-term forecasting. Fundamentally, this requires physical understanding of the process(es) involved and application of good diagnostic skills on the forecast desk.

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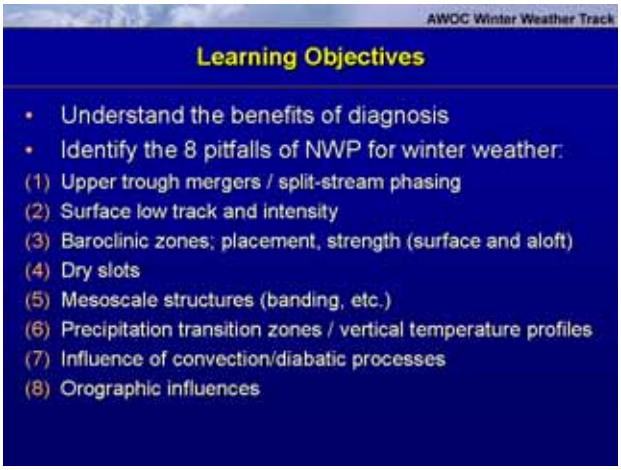

4. Performance Objectives

Instructor Notes: For each of the eight pitfalls of NWP, you will be able to demonstrate: an understanding the impact, how to assess the pitfall, knowing when and what corrective action is needed, understanding how hazards change, and awareness of false indications.

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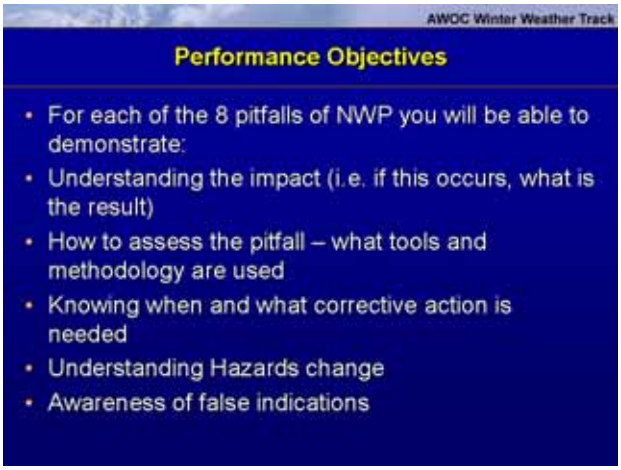

5. NWP Shapes our Expectations

Instructor Notes: Output from numerical models is one of the cornerstones of modern meteorology. Numerical models largely establish our expectations for how an event will unfold. However, models will never be able to represent the atmosphere perfectly, for

some of the reasons listed here. It is up to the forecaster to interpret the output and make adjustments/improvements to the guidance where possible. We have the ability to improve upon them if we understand their potential shortcomings (e.g., model physics), properly diagnose observational trends in the short-term, and apply our conceptual understanding of the atmosphere to the various forecast challenges we encounter.

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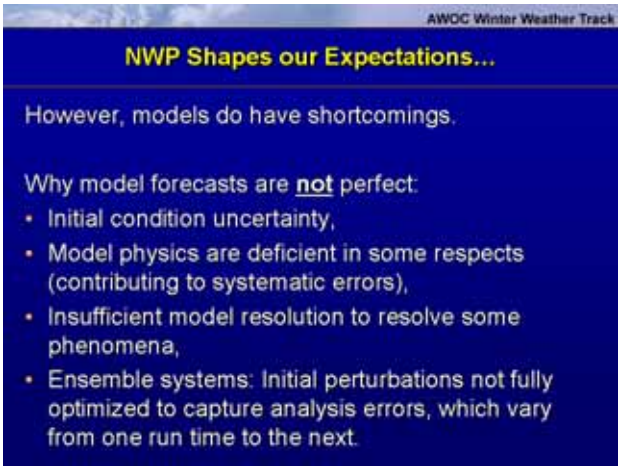

6. Mindset

Instructor Notes: Our ability to improve on “the models”, especially for short-term forecasts, depends critically on our diligence and ability in interpreting observational data, in fitting our physical and conceptual understanding to the observational trends, combining that with our understanding of the particular model’s physics and biases, and then making adjustments accordingly to produce the best short-term forecast possible. Our mindset at the forecast desk should be one that incorporates all of these areas for winter weather forecasting, as it is for forecasting non-winter weather related events.

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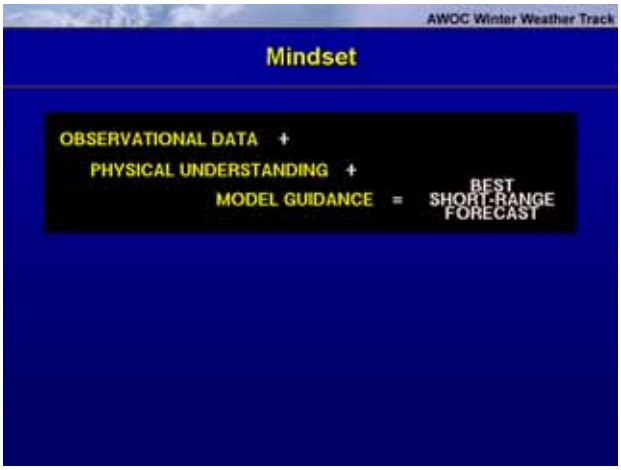

7. Integration of Data for Short-Term Forecasts

Instructor Notes: Potentially useful information comes to the forecaster from many disparate sources. It may be a spotter report in the field, ACARS data, some aspect of imagery interpretation, etc. When we talk specifically about short-term forecasting, the useful information coming into the forecast office often exceeds what can be assimilated objectively by a numerical modeling system. We will often see mesoscale details emerge which are unresolvable by the models, but can be a source of “value added” information provided by the human forecaster. Thus, the forecaster engrossed in doing good diagnostic work can often see trends that are not apparent or included in the model’s view of the situation. This situation is particularly true for mesoscale, convective, or boundary layer processes. The key is in the forecaster maintaining a high level of situational awareness through “cross utilization” of information from as many sources as possible, in conjunction with their knowledge of the models (e.g., physics, biases, etc.) and atmospheric processes.

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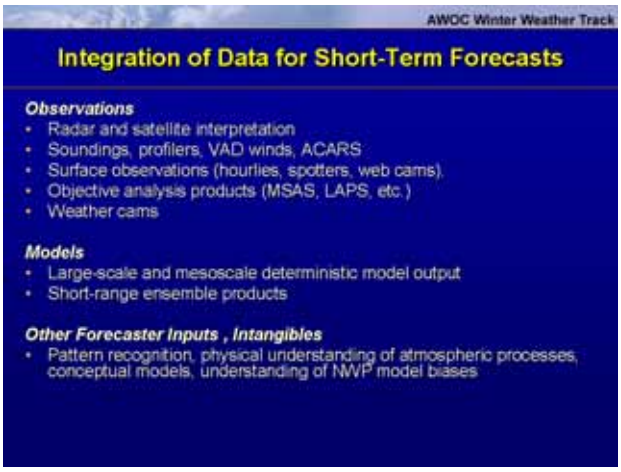

8. Utilization of Observations

Instructor Notes: This quote boils down the importance of gathering meteorological information from disparate sources. The fact that this quote is as relevant now as it was 20+ years ago suggests that humans will be an integral component in the short-term forecast process for many years to come.

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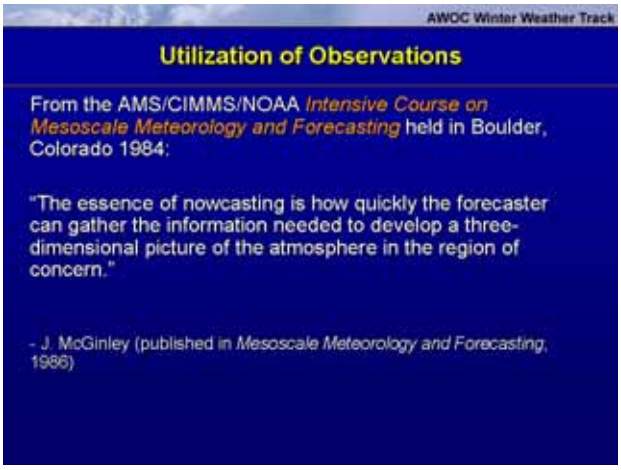

9. Relative Value of Model vs. Observational Data

Instructor Notes: At long time ranges, much of the forecast process involves analysis of various model solutions and interpretation of ensemble products. As we move closer to an "event", however, the value of using observational data increases relative to the models. In the nowcast time range, the observations hold more relative value than the models in terms of providing forecast information to the user community (e.g. "A mesoscale snow band producing 1-2"/hr. snowfall will migrate from line A at 12z, to line B at 15z."). We need to interpret observational trends to maximize mesoscale forecast details. It is critical that forecasters increasingly shift their attention to observational trends as important events approach (less than 24 hrs., especially less than 12 hrs.) to determine the mesoscale details and things the models may not be picking up on. This is one area where the human forecaster can contribute considerable value to the forecast.

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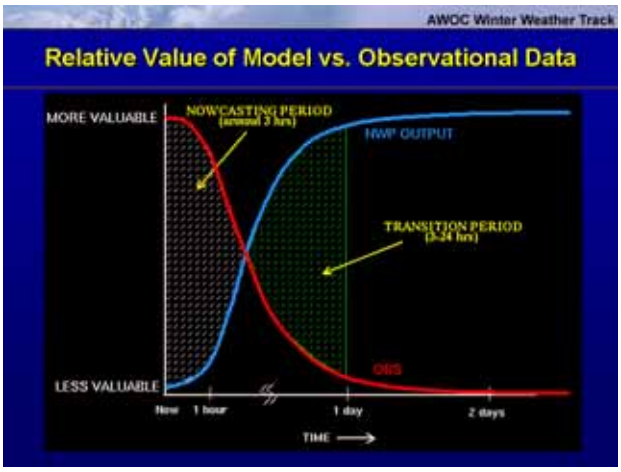


10. Upper Trough Mergers, Phasing

Instructor Notes: We transition now to discuss the 8 pitfalls of winter weather NWP, beginning with synoptic-scale aspects. For the most part, NWP does well with synoptic-

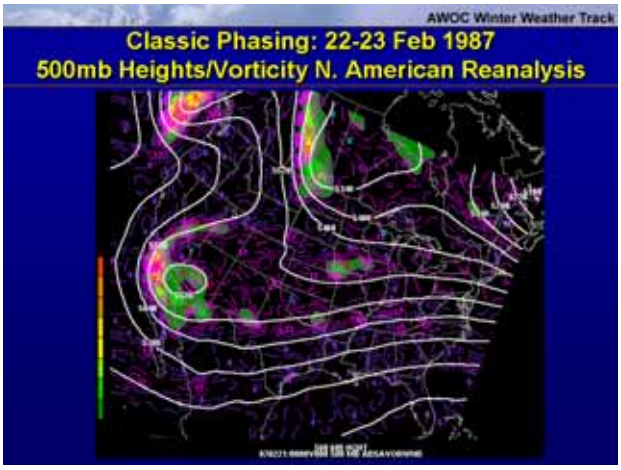
scale systems. However, an exception exists for split flow situations in which the amplification of a full latitude feature depends critically on the timing of features merging from two separate branches in the mid-tropospheric flow. In the short-term, one valuable method for assessment is to overlay water vapor (WV) imagery on 500-300mb height and vorticity information from the model of interest, to see how well the model appears to be handling large-scale features evident in WV imagery. Such a comparison may add or decrease confidence in the model solution indicating a potential merger. Such an analysis might then form the basis for the need to modify an existing forecast. Note: Mergers occur within the same branch of jet. (The Colorado Blizzard is such an example, show later under the orographic section). Phasing occurs between branches which are initially split (see example on the next slide).

Student Notes:

11. Classic Phasing: 22-23 Feb. 1987 500mb Heights/ Vorticity N. American Reanalysis

Instructor Notes: In the North American reanalysis data, we can see an example of classic phasing of two shortwave troughs in the northern and southern streams. In this loop, the troughs phase to produce one continuous filament of 500 mb vorticity extending from the Great Lakes southward to the central Gulf Coast states. Subsequent surface cyclogenesis was quite focused and strong (not shown).

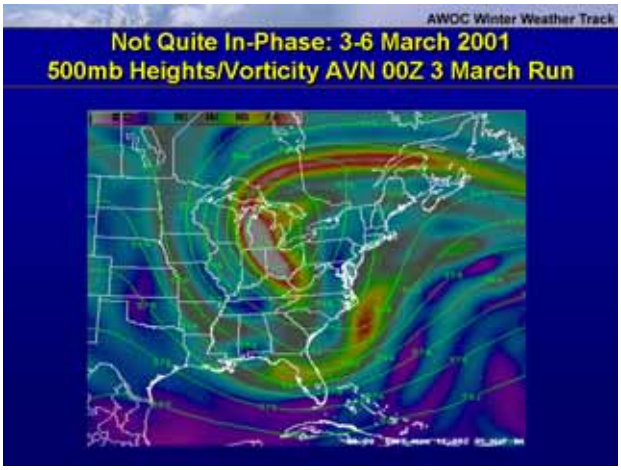
Student Notes:



12. Not Quite In-Phase: 3-6 March 2001 500mb Heights/Vorticity AVN 00Z 3 March Run

Instructor Notes: In a classic “near miss” event, the models had difficulty determining if a closed low over the Great Lakes region would fully phase with a slow moving trough moving into the Southeastern U.S. This particular solution from the AVN (00z/3rd) shows considerable interaction between the two features in question, although phasing is not complete. Such situations should always be viewed with caution, and with a lower degree of forecaster confidence than usual. This situation might imply being somewhat more reserved on forecasting “specifics” (p-type, snow amounts). This is especially true when various model runs show different solutions, and/or if the run-to-run continuity is lacking. Because the timing of the two separate features is so critical to the outcome, the lack of run-to-run continuity is often the case. This uncertainty would also manifest itself in ensemble solutions with large standard deviations in, say, the 500mb height forecasts among the ensemble members (or more visually through the so-called “spaghetti” plots). Ensembles are valuable in determining whether a consensus exists, or if a particular NAM or GFS run happens to be an outlier.

Student Notes:



13. Not Quite In-Phase: 3-6 March 2001 WV Imagery

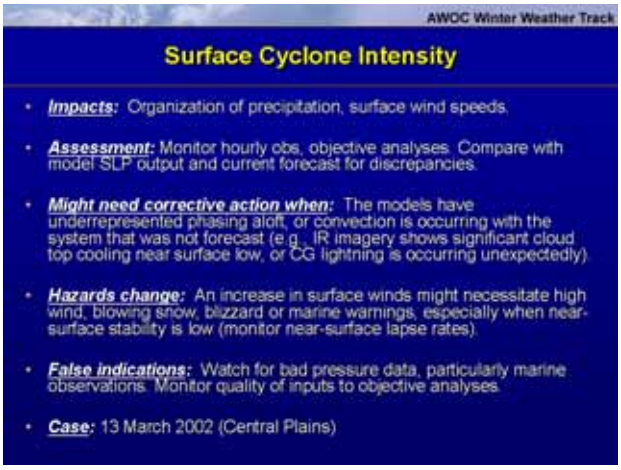
Instructor Notes: The water vapor imagery for the forecast period of interest shows that the two main features remain distinct from one another (i.e., phasing does not occur). In fact, the features are more distinct than was suggested by the 00z 03 March run of the AVN. The lack of phasing resulted in a significant snow event over interior New England and New York, but not for the cities of Boston, New York, or Philadelphia, as was suggested by some model solutions. The main point to remember is to view potential phasing events in split-flow with a lower degree of confidence than you might otherwise. Also, at short time-scales, use WV imagery to see any significant departures in how the features/phasing is progressing relative to a particular model solution. ***Note:*** In the online presentation a quiz question is available under the “Show URL” button for this slide.

Student Notes:

14. Surface Cyclone Intensity

Instructor Notes: Departures in surface cyclone intensity have large implications upon the wind field and amount/distribution of QPF. Comparisons between subjectively or objectively analyzed surface maps for isobars, isallobars, and frontal positions, can often yield valuable information and give a sense of how the models are trending versus reality. Any unexpected “bursts” in cloud top cooling or CG lightning activity (signifying convection) can also act as indications that the models may not be handling the thermodynamic or dynamic structure of the cyclone properly. This should act as a cue for the forecaster to scrutinize as much available information in imagery, (e.g., ACARS) to get a better sense for the underlying processes.

Student Notes:



15. Surface Cyclone Intensity13-14 March 2002

Instructor Notes: Here, the Eta is too slow in deepening the surface low over southeast Colorado. By 3z/14th, the observed central pressure (per MSAS) is 5 mb lower than the Eta forecast, and by 09z, we see that the Eta is too quick to eject the low-pressure center eastward away from the immediate lee of the Rockies. This situation results in significant errors in the surface wind and temperature fields late in the forecast period. The baroclinic zone in the ETA is displaced too far south (i.e., low-levels are colder than observed in METARs). Wind directions and magnitudes are also “off” in vicinity of the frontal zone. This demonstrates the importance of keeping up with observational trends to determine if the model forecast might be in error.

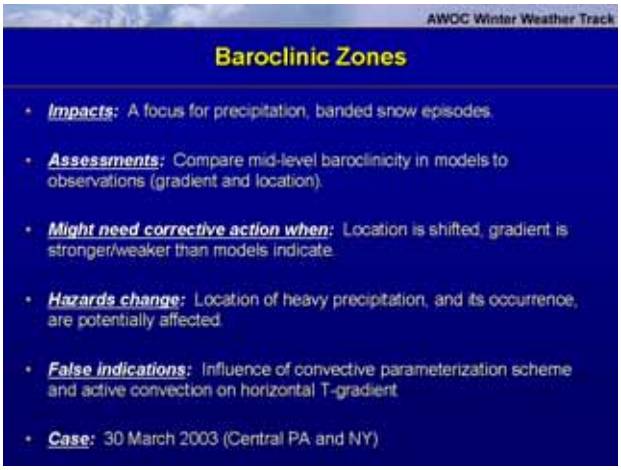
Student Notes:

16. Baroclinic Zones

Instructor Notes: The positioning and intensity of low- to midlevel baroclinic zones play an instrumental role in the potential for banded precipitation and in the surface cyclogenesis process. It is of utmost importance, therefore, to ensure that the models are adequately initializing the position and strength of any areas of enhanced midlevel

baroclinicity, especially if precipitation is expected. Since the spacing between rawinsondes is relatively large, and because the models rely in part on a first-guess field from the previous run cycle, it is possible for the model to initialize midlevel frontal zones erroneously. Also, the impact of the model convective parameterization scheme can significantly alter the character of the quasi-horizontal temperature field aloft near convection.

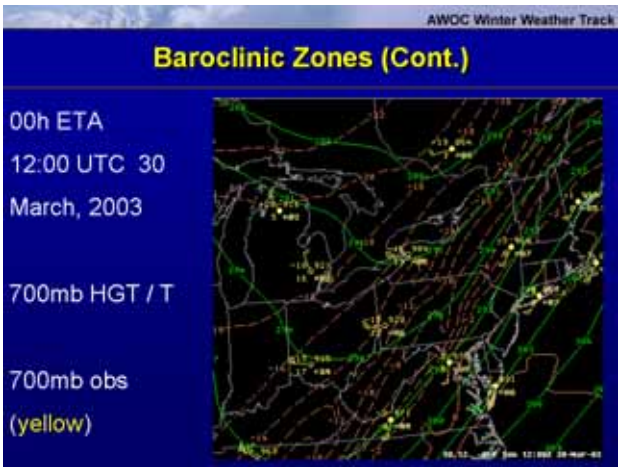
Student Notes:



17. Baroclinic Zones (Cont.)

Instructor Notes: Here we see an example where the Eta model analysis (0 hr. forecast) has underrepresented the magnitude of the southeast/northeast oriented baroclinic zone in vicinity of the central Appalachians. Comparing the 700mb analysis to the temperature data from the 12 UTC rawinsondes, we see that Pittsburgh, PA (PIT) has an observed temperature of –15 degrees C instead of about –13 degrees C in the analysis. Also, Dulles International in far northern Virginia (IAD) has an observed temperature of +1 degrees C though the Eta analysis shows about –2 degrees C. This combined with quasi-horizontal convergence at this time suggests that frontogenesis was underdone in the model within the baroclinic zone.

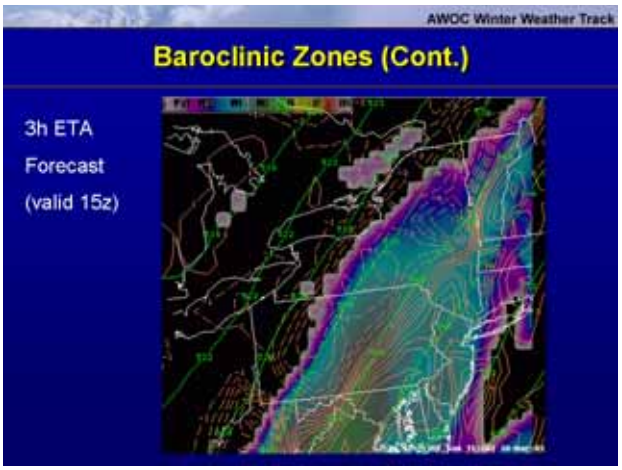
Student Notes:



18. Baroclinic Zones (Cont.)

Instructor Notes: The maximum upward vertical motion and QPF is displaced eastward from where it was observed (shown on following slide).

Student Notes:



19. Baroclinic Zones (Cont.)

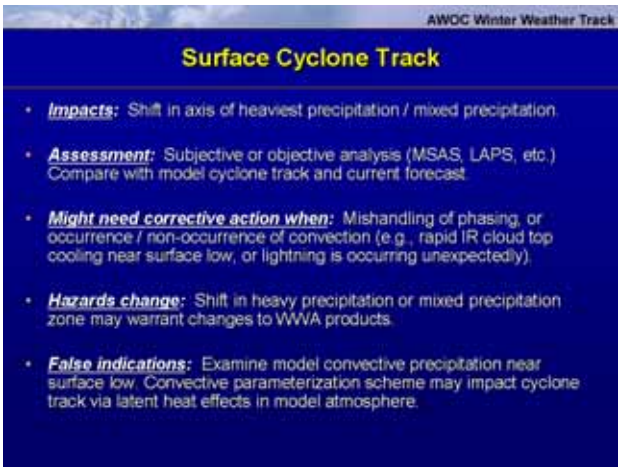
Instructor Notes: The Eta model QPF and UVV fields did not suggest a mesoscale snow band, as was observed in the mosaic radar imagery. The band also appears to be displaced westward from where the Eta suggested the heaviest precipitation would occur. These shortcomings are due, in part, to the inadequate initialization of the mid-level baroclinic zone as shown in the earlier slide. Identification of this type of error can help the forecaster better anticipate mesoscale banding potential not shown when the model is under representing a baroclinic zone. Also, it provides a physical basis (i.e., the resultant frontogenesis was likely stronger than progged) for believing the QPF amount and distribution is not correct in the numerical model.

Student Notes:

20. Surface Cyclone Track

Instructor Notes: The surface cyclone track is widely recognized as being critical to the outcome of precipitation amounts and precipitation type. For short-term purposes, analysis of satellite imagery and examination of hourly surface analyses remain among the best ways to monitor model accuracy in this regard.

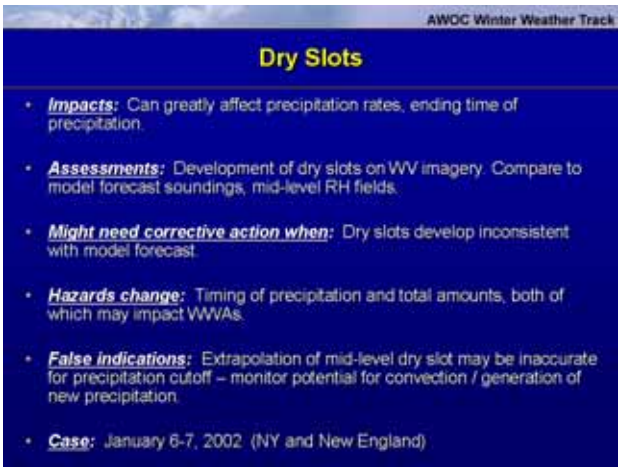
Student Notes:



21. Dry Slots

Instructor Notes: The unexpected rapid evolution of a midlevel dry slot associated with a synoptic-scale cyclone, can significantly alter expected winter precipitation duration and intensity. These details are not always handled well by the numerical models, and it is important to analyze observational data (e.g., surface observations, WV imagery) to monitor these trends and take corrective action(s) as appropriate.

Student Notes:



22. Dry Slots (Cont.): 6-7 January 2002

Instructor Notes: Loop of Eta model output, which is used to compare to reality in the next 2 slides.

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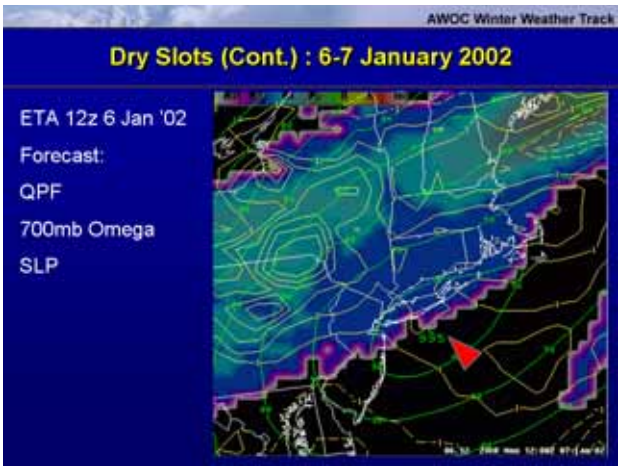

23. Dry Slots (Cont.): 6-7 January 2002

Instructor Notes: Water vapor imagery indicates that the dry slot moves north-north-eastward across southern New England much faster than was suggested in the Eta UVV/QPF fields.

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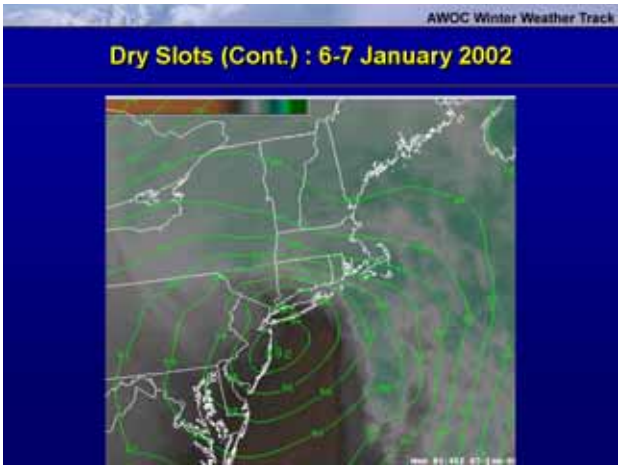

24. Dry Slots (Cont.): 6-7 January 2002

Instructor Notes: This radar mosaic imagery also bares out that the precipitation moves northward through southern New England faster than was suggested by the Eta, with the precipitation ending early due to the dry slot.

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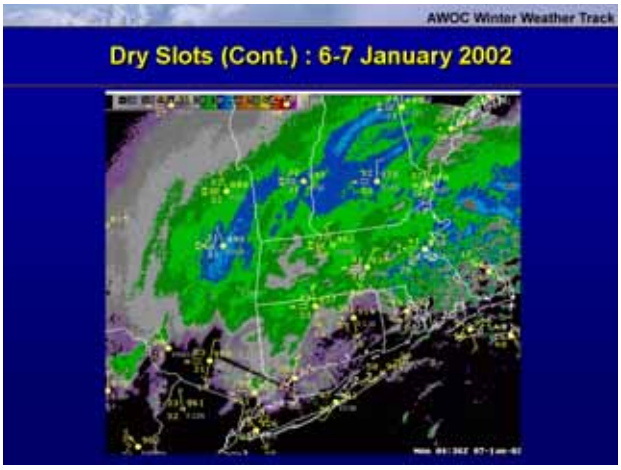
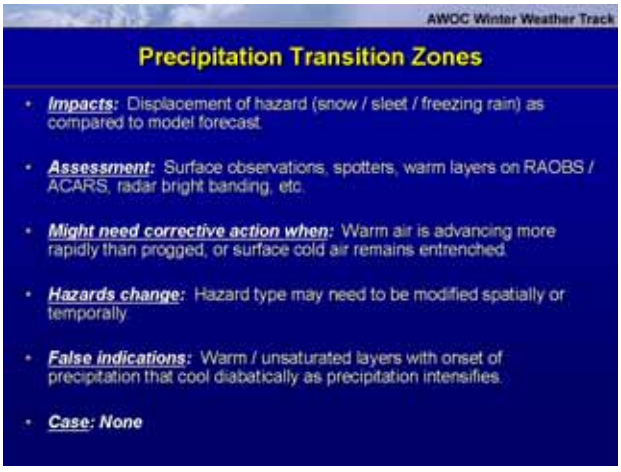


25. Precipitation Transition Zones

Instructor Notes: Precipitation type (P-type) and the spatial placement of P-type transition zones can have a significant impact on the forecast and can be a source of error in the models depending upon how well boundary layer temperatures, temperature advection, and any diabatic effects are being handled. The quality of the initialization of these factors is also crucial to the accuracy of the spatial distribution of various precipitation types in any numerical modeling system. There is no case study included for this type of error.

Student Notes:



26. Mesoscale Banding

Instructor Notes: Mesoscale snow bands represent a significant winter weather hazard and can be associated with intense snowfall rates well in excess of 1”/hr. The current generation of numerical models is not always able to resolve the spatially narrow vertical motion axis and band of relatively high precipitation amounts associated with mesoscale bands. Mesoscale bands can manifest themselves in several different ways. Axes of quasi-stationary frontogenesis and deformation, or translation of these fields along the

long axis of the mesoscale band, will often result in prolonged heavy precipitation in one location and locally heavy snow accumulations. The physics of these bands have been covered in an earlier IC.

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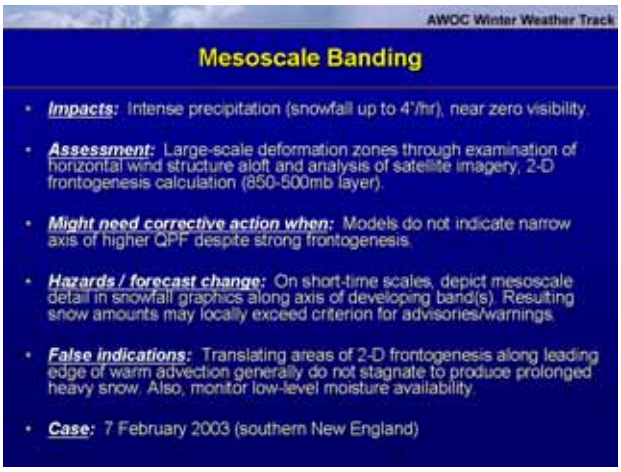
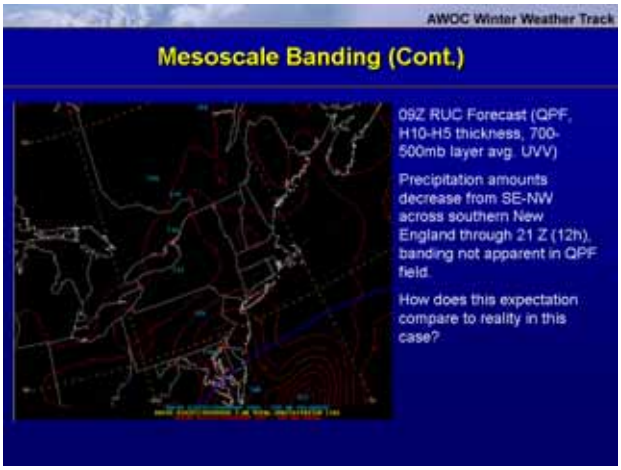


27. Mesoscale Banding (Cont.)

Instructor Notes: For this coastal cyclone case, the RUC upward vertical motion and QPF field suggests that maximum precipitation will occur near or just offshore of the southeastern Massachusetts coast, with precipitation amounts gradually tapering off to the north and west. The model QPF/UVV forecast does not hint at any banded precipitation structure during the forecast. This RUC forecast is also representative of the Eta's handling of the situation.

Student Notes:



28. Mesoscale Banding (Cont.)

Instructor Notes: The observed radar mosaic loop overlaid with the 700 mb frontogenesis field from the same RUC run indicates a frontogenetically forced band of moderate to heavy precipitation occurring north and west of the precipitation maximum indicated in

the model QPF/UVV output (previous slide). Some of this discrepancy is a function of insufficient horizontal resolution in the model. However, the point is that it often benefits the forecast to examine the model frontogenesis field specifically to correct for the lack of frontal scale detail in the UVV/QPF output. This also contributes to a better understanding of how important mesoscale dynamics are unfolding in the model, and how that will relate to the mesoscale organization as might appear on radar.

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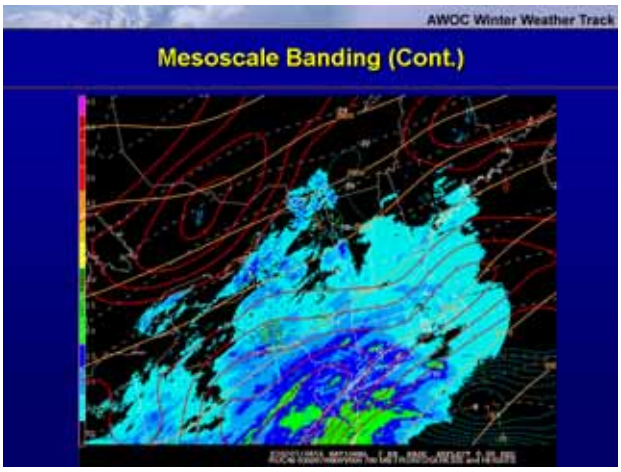
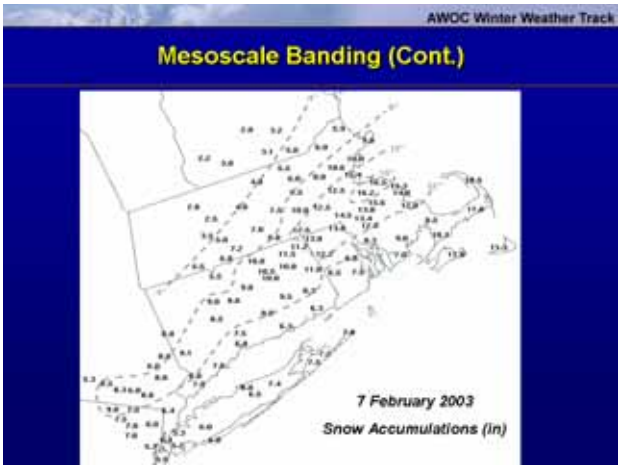


29. Mesoscale Banding (Cont.)

Instructor Notes: Resulting snow accumulations reflect the mesoscale structure apparent on radar but not in model QPF field. We find that this mesoscale band produced significant snowfall to the tune of 12-16” over Boston and its southern suburbs. Snowfall rates at BOS reached 2”/hr. for four consecutive hours from 16-20 UTC, and were 1”/hr. or greater for seven consecutive hours. Beware the model that depicts strong frontogenesis and has precipitation but does not show an axis of higher precipitation. The resolution of the model may be inadequate to show the mesoscale circulation associated with some bands (Note: very high resolution models such as workstation Eta and WRF may better resolve narrow bands). ***Note:*** In the online presentation a quiz question is available under the “Show URL” button for this slide.

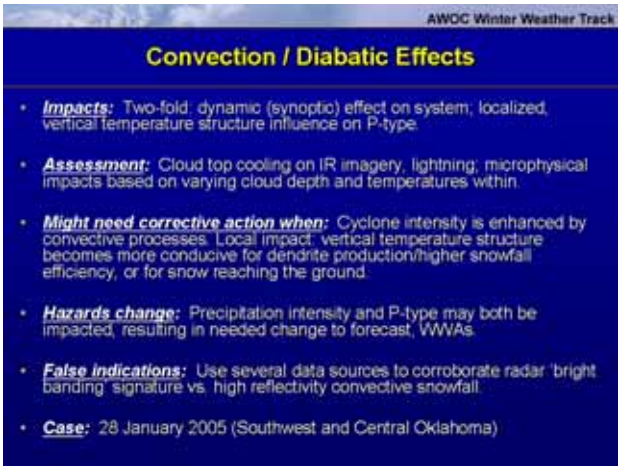
Student Notes:



30. Convection/Diabatic Effects

Instructor Notes: Convection can wreck havoc on the models. It is difficult to decipher what effects are real and what might be a function of the model itself (e.g., a function of the convective parameterization scheme). The influence of convection can impact a wide range of spatial scales. The enhanced magnitude of convective motions can impact local vertical temperature profiles and effect precipitation type. On the synoptic-scale, convection can enhance the surface cyclogenesis process, especially over relatively warm water such as the Gulf Stream. When convection is active, our confidence in the model's ability to handle the details accurately is generally going to be lower than otherwise, and our situational awareness needs to be high to counteract these potential deficiencies.

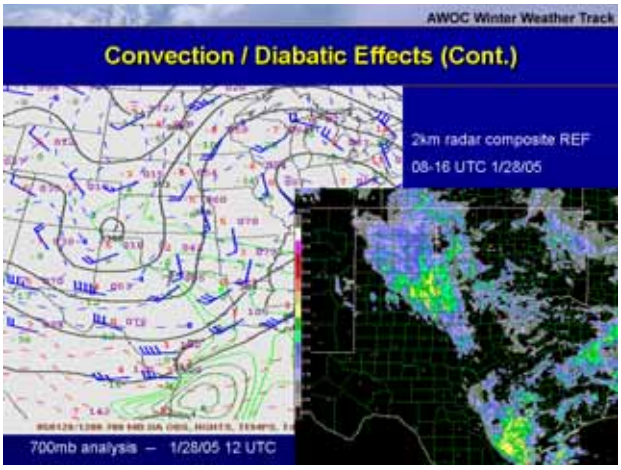
Student Notes:



31. Convection/Diabatic Effects (Cont.)

Instructor Notes: On January 28, 2005, a rather sharp shortwave trough was located over the southern High Plains. The 700mb analysis at 12z indicates minimal cold temperature advection across Central OK. A band of precipitation, driven by midlevel differential vorticity advection (not shown), was moving from southwest to northeast between 08-16 Z, with embedded high reflectivity elements in the radar mosaic. The models generally indicated a thermodynamic structure supportive of rain (not shown).

Student Notes:



32. Convection/Diabatic Effects (Cont.)

Instructor Notes: The observed soundings from Fort Sill (FSI, in SW Oklahoma) and Norman (OUN, in central OK) are juxtaposed on a skew-T. First note that the low-level wind profile shows veering with height, a general sign of horizontal warm advection from the SFC through 700mb at FSI. Secondly, both the FSI and OUN soundings show saturated conditions in the 850-700mb layer. The layer temperature is above 0 degrees C in the OUN sounding. However, where the moderate to heavy convective precipitation is occurring at FSI, the sounding has locally cooled and become isothermal near 0 degrees C. This is likely a result of latent heat of melting, associated with a large amount of falling snowflakes. Eventually, the latent/diabatic cooling is sufficient to eliminate the warm nose in the sounding, and the falling snowflakes no longer melt aloft but now reach the ground. Since substantial (i.e., very heavy) precipitation is necessary to make this effect appreciable, the snowfall rates are often heavy for short periods of time, and can substantially impact travel conditions. The narrowly focused axis of upward vertical motion caused the heavy snow to be of short duration (a few hours) before ending.

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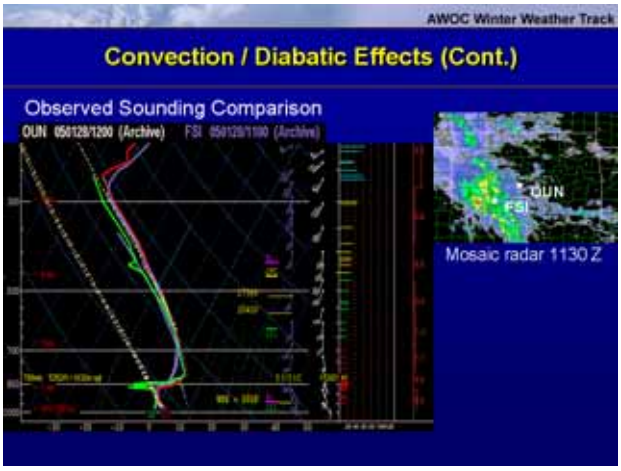
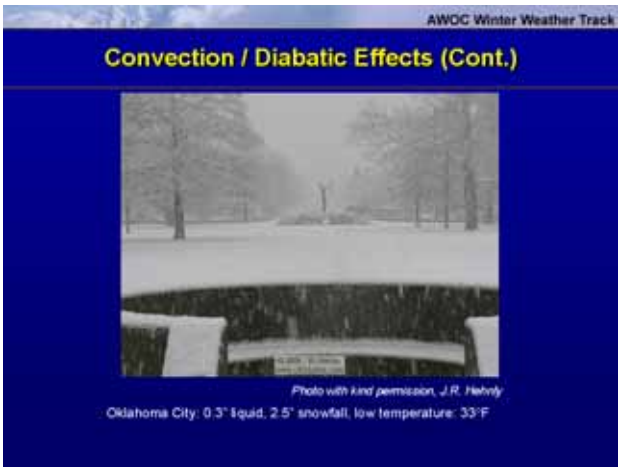


33. Convection/Diabatic Effects (Cont.)

Instructor Notes: In Oklahoma City, where these diabatic effects were later felt, 2.5 inches of snow fell in a short period of time, even though the surface temperature never fell below 33 degrees F. Liquid equivalent precipitation was 0.3” (liquid equivalent ratio of 8.3 to 1).

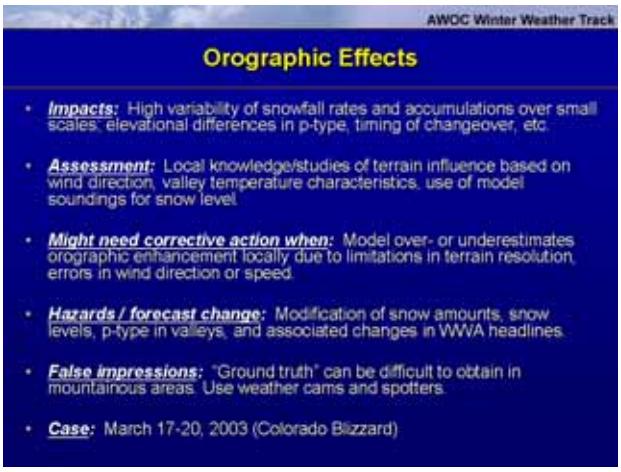
Student Notes:



34. Orographic Effects

Instructor Notes: Orographic effects are an area in which local human expertise at the WFO level can result in improvement over NWP guidance.

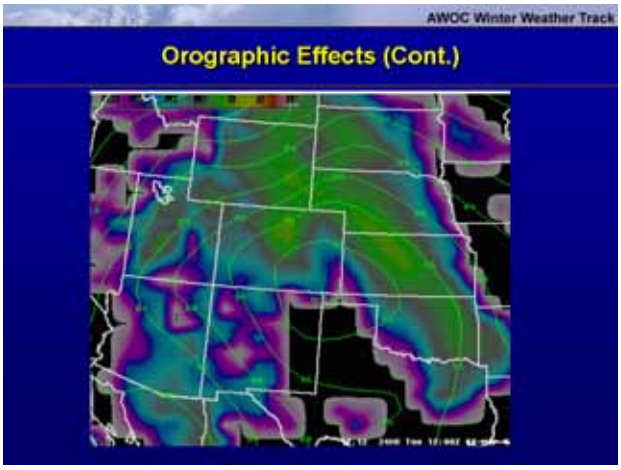
Student Notes:



35. Orographic Effects (Cont.)

Instructor Notes: The Eta model forecast from 12z 17 March 2003 shows a maximum in precipitation along the front range of Colorado and Wyoming through 30 hours.

Student Notes:



36. Orographic Effects (Cont.)

Instructor Notes: The upslope nature of the low-level easterly winds contributes to enhanced upward vertical motion and highest snow amounts along the eastern slopes of the Rockies in this case. As we'll see in the next slide, there was also an elevational dependency on precipitation type, with mostly rain out over the plains.

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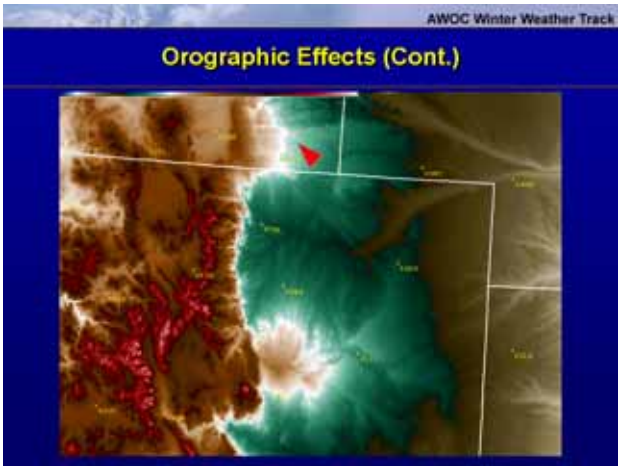
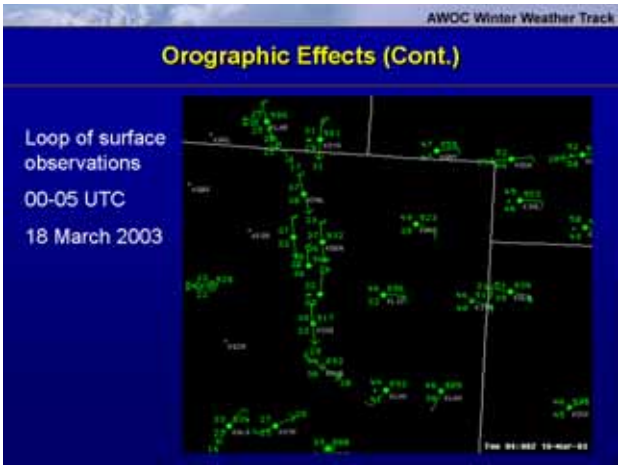


37. Orographic Effects (Cont.)

Instructor Notes: Marginal surface temperatures at the start of the event suggest elevation will play a role in precipitation type, in addition to the role of the orography in providing upslope enhancement to precipitation amounts.

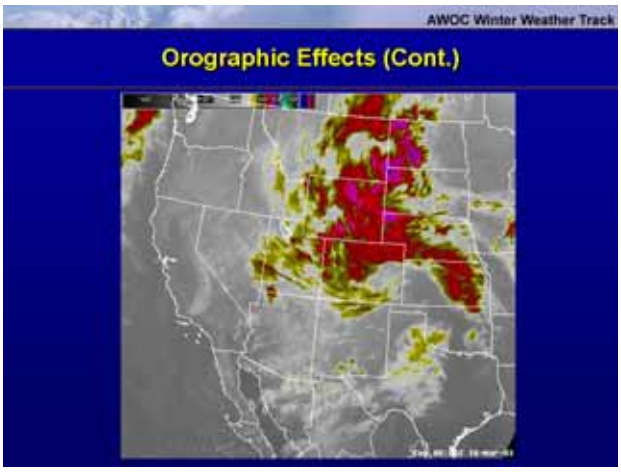
Student Notes:



38. Orographic Effects (Cont.)

Instructor Notes: Midlevel vorticity center is quasi-stationary across southeast Colorado, which allows for a prolonged period of easterly to southeasterly flow into central Colorado. Trajectories from the east and southeast allow for ample low-level moisture advection. A shortwave trough rotates westward around the northern periphery of the trough into northeastern Colorado, and is associated with cloud top cooling and expansion of the upper-level cloud canopy. General enhancement/expansion of cold cloud tops north of the stationary midlevel vorticity center suggests favorable large-scale support for precipitation across northcentral CO.

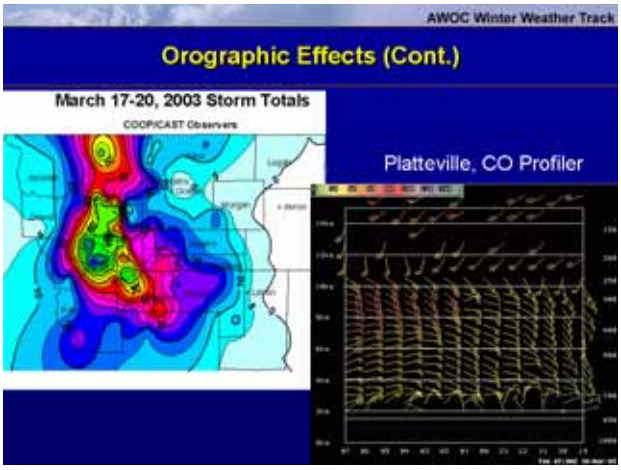
Student Notes:



39. Orographic Effects (Cont.)

Instructor Notes: The profiler time-height cross-section indicates a considerable increase in deep-layer easterly flow over time during the evening of March 18. The final snow accumulation map indicates snow confined to the higher elevations (the Palmer and Cheyenne ridges and adjacent mountains to the west, which receive the maximum benefit of the low-level upslope enhancement).

Student Notes:



40. Developing Confidence for Forecast Amendments

Instructor Notes: It is important to have solid reasoning when making adjustments to forecast products, particularly any watches, warning or advisory products which have greater public visibility and societal impact. This slide lists factors that contribute positively to our confidence in making changes to a weather forecast. For example, when the consensus opinion supports a forecast change, and when we have both solid evidence and physical rationale for making a change, we can have more confidence in making a change to the current forecast that will be for the better. We must always be aware that there exists a delicate balance between providing consistency in our products - which is also valued by customers - versus maximizing accuracy in light of ever present uncertainties. We should keep in mind that many customers value consistency in the product as much as accuracy. Therefore, so-called flip-flops should be minimized to the extent possible. ***Note:*** In the online presentation a quiz question is available under the “Show URL” button for this slide.

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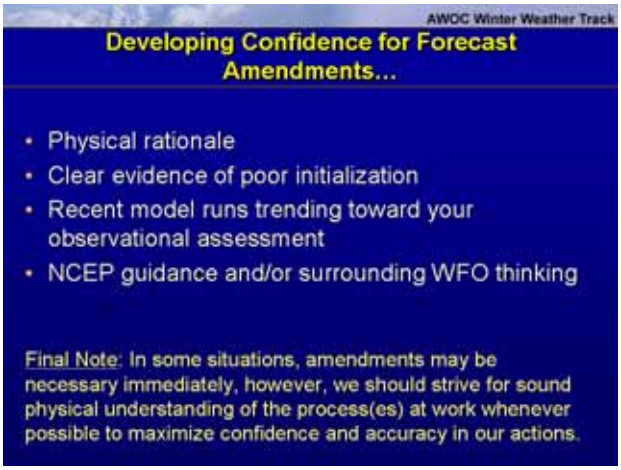

41. Basic Points to Remember

Instructor Notes: Quality short-term forecasting requires carefully analysis of observational trends and comparison to model output – we can become more efficient in the analysis process with practice, but there aren't any "shortcuts", per se. Good analysis skills of a wide array of data sources remains necessary. We must be able to gather the necessary information efficiently to develop a complete three-dimensional picture of the weather situation. The optimal mindset of short-term forecasting is one that integrates model output with observational data sources, and physical understanding of atmospheric processes relevant to the situation. By doing this, we are in an ideal position to make adjustments to the model forecasts and incorporate mesoscale details that may otherwise be missed.

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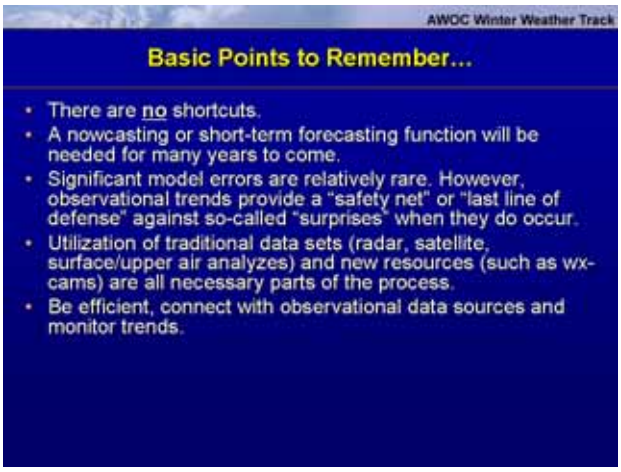
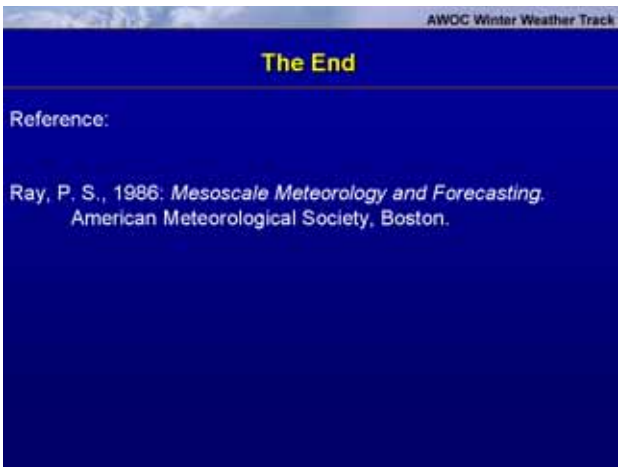


42. The End

Instructor Notes: Here is the complete reference cited earlier during the presentation.

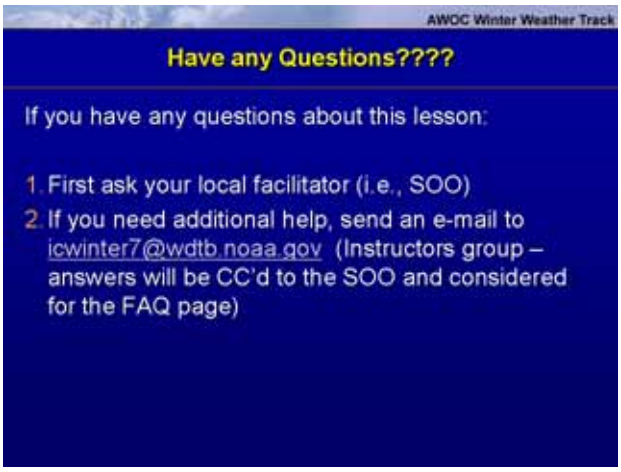
Student Notes:



43. Have any Questions????

Instructor Notes: If you have any questions about this lesson, first ask your local AWOC facilitator. If you need additional help, send an E-mail to the address provided. When we answer, we will CC your local facilitator and may consider your question for our FAQ page.

Student Notes:



IC7.1: Optional Job sheet

Monitoring Model Accuracy

Objective: Examine model data from a winter weather case to assess the pitfalls of numerical weather prediction as discussed in the winter weather AWOC IC 7 Lesson 1 training module.

Data: 15 March 2004 winter weather event across the Midwest. You will be using AWIPS D2D for this exercise.

Instructions:

1. Load the 15Mar2004 Winter Weather AWOC case on your WES machine in case review mode, using the DMX localization. Set clock to 13 UTC 15 March 2004.
2. Assessing Pitfall #1: Upper Trough merger, phasing
   - Overlay a water vapor loop with NAM 80 500 mb absolute vorticity and heights on the CONUS scale. Monitor the progression of short-wave troughs vs. model solution, especially in this split flow.
     1) Are there any short wave troughs in the model output that are merging or phasing with the deep long wave trough over the Great Lakes?
     2) Does the NAM have the short wave trough well analyzed?
3. Assessing Pitfalls #2, #3 and #7: Surface cyclone intensity and track, convection/ diabatic effects
   - Load and examine hourly obs and MSLP objective analyses (MSAS) with IR satellite over the last 24 hours (13 Z 14 March through 13 Z 15 March) on the regional scale. Overlay NAM 40 MSLP and 1-hour lightning. You are looking for unexpected lightning strikes and IR showing significant cloud top cooling near the surface low, or significant departures in the current data from the progged surface cyclone track or intensity.
     3) Is there any evidence that the surface cyclone is more intense or taking a different track than the models predicted? Explain your reasoning.
     4) Where is the convection located relative to the surface cyclone?

5) How might the convection affect the surface cyclone track or intensity?

4. Assessing Pitfall #4: Dry slot

- Load WV imagery on the regional scale, overlay the NAM 40 700-300 mb RH fields. Focus on the 12 hr NAM forecast valid at 12 UTC and the 12 UTC WV image by selecting “Prev Run” from the top left drop down menu in D2D before you load the product in the volume browser. In another pane, load the DDC, DVN, OMA, TOP Raobs and overlay corresponding NAM 40 model soundings at those same areas (i.e. load points over those cities, then use volume browser to load point soundings)

6) Where is the dry slot?

7) How did the NAM 40 12 hr forecast handle the location and movement of the dry slot?

5. Assessing Pitfall #5: Precip transition zones

- Examine the surface obs once again on the regional scale and overlay surface temperatures from the RUC and NAM 40

8) Where is the changeover to snow occurring over the last hour or two?

9) How are the models handling surface conditions? Too cold? Too warm? Bad timing?

- Load a NAM 40 model sounding in the changeover region somewhere near south-west Iowa. Overlay Omaha's sounding and then overlay an aircraft sounding from around 12 UTC (MDCRS in the volume browser, you will need to have "Inventory" selected in the main D2D window before loading the aircraft data, found under upper air menu and heading "Aircraft").What is the primary cause of the changeover to snow?

10) Will you have to worry about sleet or freezing rain anywhere across Nebraska or Iowa? Why or why not?

- Load a nearby lowest tilt radar reflectivity loop.

12) Where is the radar bright banding occurring, and at what height?

6. Assessing Pitfall #6: Mesoscale banding

- Swap panes and get to the state scale. In the volume browser, load the NAM 40 model run snow accumulation product, then overlay both KDMX and KOAX 0.5 reflectivity. (You will only be able to compare a few snowfall graphics to actual radar images because of the way AWIPS loads products)

13) Is the NAM accurately depicting the nature of the mesoscale snow band across Nebraska/Iowa? Be specific.

An answer key is available for this job sheet. Please see your local AWOC Winter Weather facilitator to obtain a copy.

1. IC7.2 Part 1: WSR-88D Winter Weather Precipitation Estimation

Instructor Notes: Welcome to lesson two in the winter AWOC 7th instructional component. We will be talking about winter weather precipitation estimation in relation to the WSR-88D. This lesson should last about 30 minutes. Part 2 of this lesson is an interactive exercise at the end of the lesson.

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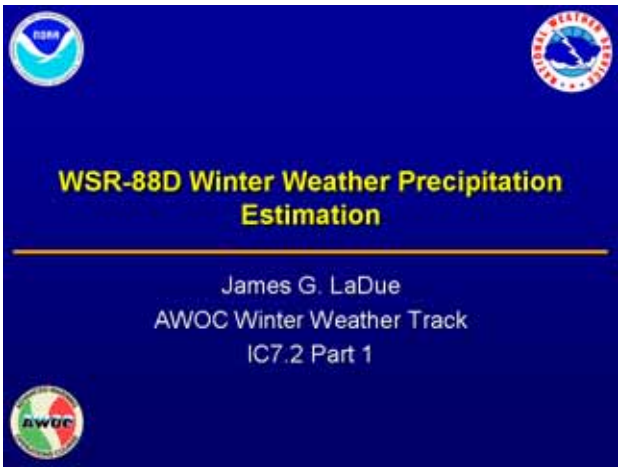
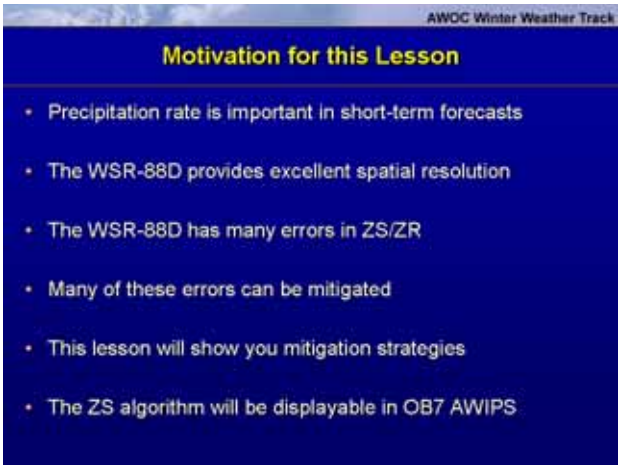


2. Motivation for This Lesson

Instructor Notes: This lesson fits well in the Instructional Component 7 because we will be talking about how well the WSR-88D estimates precipitation. In the short-range forecasting period, observational data of precipitation rate is the single most important data set. Gauge and spotters provide the best point by point reports of winter precipitation rate, but the WSR-88D provides the greatest spatial detail. But there are a lot of errors in relating radar reflectivity returns to actual snowfall rate. The good news is that most of these errors can be accounted for as long as you keep in mind a few strategies and considerations for detecting them. Pretty soon, the ZS algorithm will be viewable on AWIPS when you get OB7. There will be a lot of extra data like snow depth and snow water equivalent. This lesson will describe radar-based precipitation intensity issues with respect to the output of the ZS algorithm.

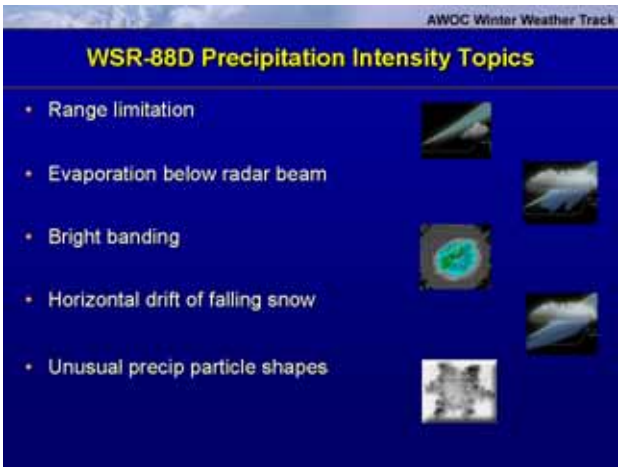
Student Notes:



3. WSR-88D Precipitation Intensity Topics

Instructor Notes: Five considerations adversely affect good precipitation estimates, and especially snowfall. Limited range becomes exacerbated in the winter when cold temperature microphysics routinely occur closer to ground. Bright banding becomes more of an issue as the freezing level is low enough to interfere with the hybrid scan selection. Evaporation below the lowest radar beam.

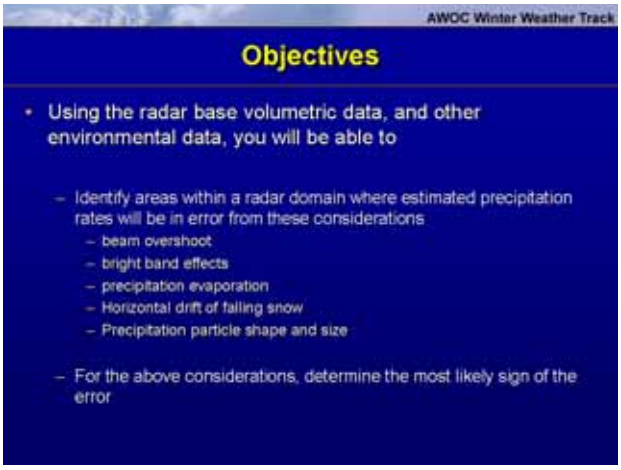
Student Notes:



4. Objectives

Instructor Notes: The objectives of this lesson are to identify areas on your radar domain where precipitation estimates are likely to be wrong. We will introduce the error sources that are most likely creating errors and then talk about ways to identify them and compensate for the errors. Some of these error sources are easier to account for than others. For example, bright banding is a source of error that typically results in overestimating precipitation while horizontal drift in falling snow may result in over- or underestimates of your precipitation estimations.

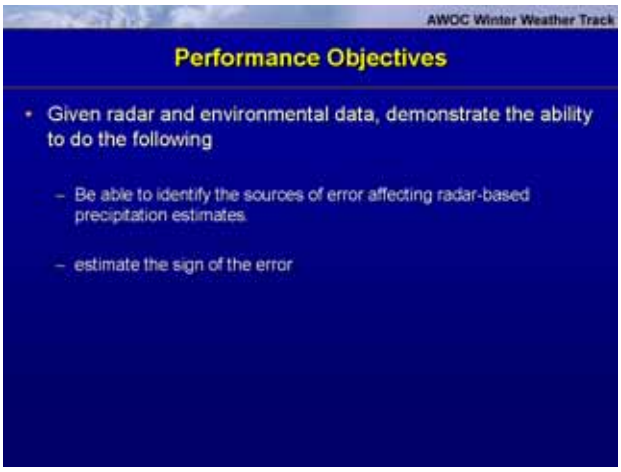
Student Notes:



5. Performance Objectives

Instructor Notes: This is one performance objective that you should be able to demonstrate at the end of the lesson. Given radar, surface, sounding and geographical data, you should be able to use the material this lesson presents to determine if the radar is most likely under or overestimating precipitation rate. You should also be able to determine one or more sources of error may exist.

Student Notes:

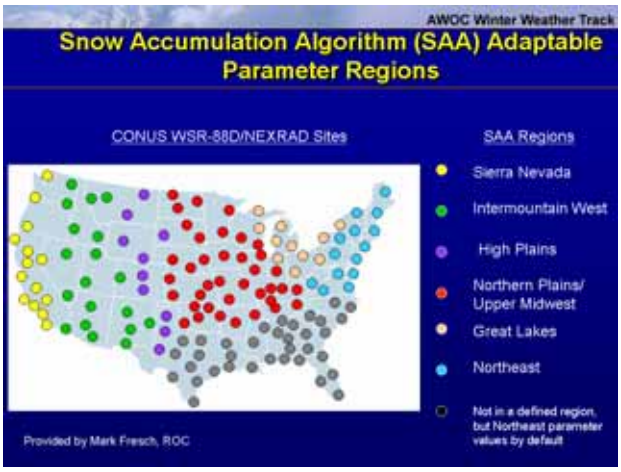


6. Snow Accumulation Algorithm (SAA) Adaptable Parameter Regions

Instructor Notes: The ZS algorithm, first deployed in the RPG in 2004, is now viewable in AWIPS. The Bureau of Land Management worked with the NWS to determine the most appropriate ZS algorithm for geographical regions. A representative office in each geographical region was the site of a one or more season's worth of high quality snow spotter data, where spotters not only sample snow depth but liquid equivalent too. After enough data has been collected, Super and Holroyd (1997) fixed the alpha and beta

coefficients to one value that represents the minimum error between radar snowfall estimates and ground truth. Adjacent offices are also assigned these same coefficients based on the assumption that similar climatic conditions as the focus office exist, too.

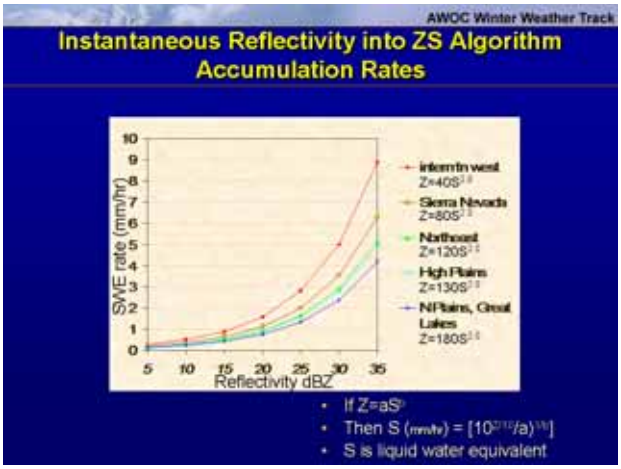
Student Notes:



7. Instantaneous Reflectivity into ZS Algorithm Accumulation Rates

Instructor Notes: The default output of the ZS algorithm is liquid water equivalent rate in mm/hr. However, the ZS algorithm output will provide accumulated products of both liquid water equivalent and snow depth, both in English units. By the way, the snow depth will be derived using a fixed snow-to-liquid ratio. The ZS algorithm results show an exponential increase in snowfall rates with reflectivity for any region. The default coefficients are fixed over regions, however the weather is not. Variations in many factors can cause deviations from your default ZS algorithm settings.

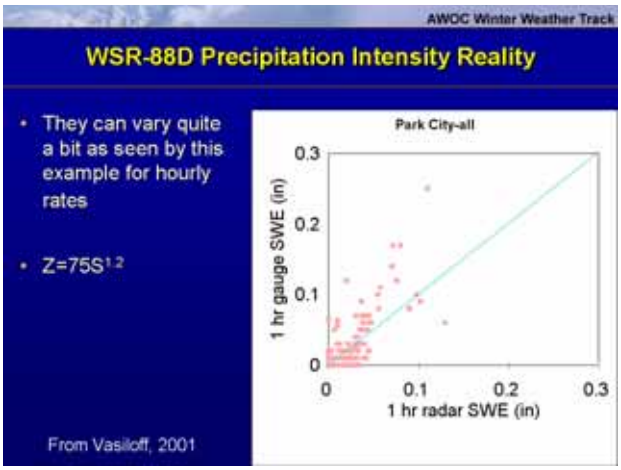
Student Notes:



8. WSR-88D Precipitation Intensity Reality

Instructor Notes: Prior to and during the winter Olympics in Salt Lake City, Steve Vasiloff compared radar-based snow depth and SWE accumulations on an hourly basis with that of good quality snow gauges. The scatter is pretty significant. Just to remind you, the KMTX radar is using the ZS algorithm here and that the lowest 'unblocked' elevation angle is 1.5 degrees. The ZS algorithm used is Z=75S1.2.

Student Notes:



9. WSR-88D Precipitation Intensity Topics

Instructor Notes: Now that we've seen the problems, let's go ahead and discuss some of the strategies to mitigate them. We'll start off with looking at range limitations from radar.

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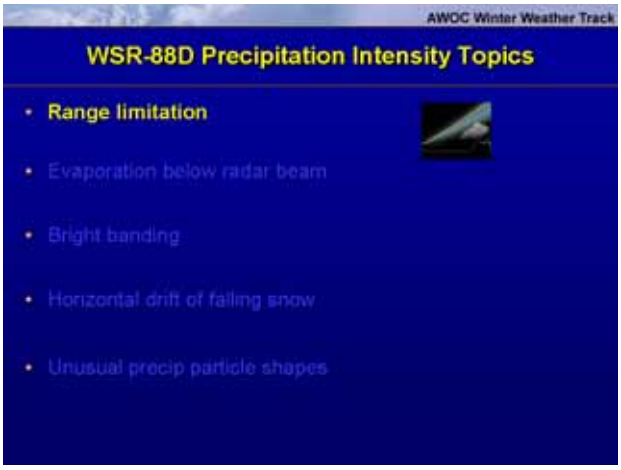
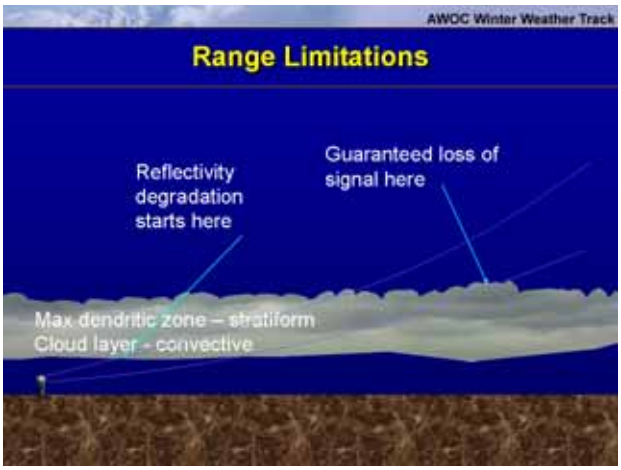


10. Range Limitations

Instructor Notes: Reflectivity begins to degrade once the top end of the radar beam climbs above the precipitation production layer. You're guaranteed to lose the signal once the bottom end of the beam departs the precipitation region. The precipitation generation region is difficult to quantify. One definite zone is the maximum growth layer for dendrites (e.g., the -12 to -18 degrees C layer). However, the presence of high cloud liquid water content in zones warmer than the dendritic growth layer but still below freezing can contribute significant amounts of riming and needles. In warmer saturated regimes, the collision-coalescence becomes active, too. Even the dendritic production layer can be fairly low in very cold weather, even near ground level. All of these precipitation production zones can be shallow and, therefore, cause reflectivity degradation at close ranges to the radar. As a side bar, orographic precipitation can occur very close to mountain sides. The WSR-88D has an exceedingly difficult time separating ground returns from real precipitation when both occur within a range gate. Clutter filtering can reduce or eliminate precipitation in range bins also containing clutter.

Student Notes:

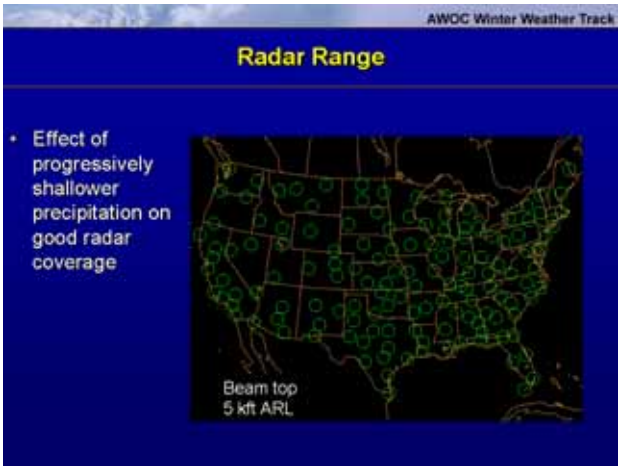


11. Radar Range

Instructor Notes: Here is the radar coverage for CONUS given that the dendrite production zone is relatively high, say > 22 kft. ARL. So for example, if there was a warm advection precipitation event where the dendrite production was the only layer producing precipitation, then expect good sampling by radar. Range limitations in this case are not a big problem. Now, the precipitating layer is lowering. Synoptic situations where this is common often occur in TROWALS, or along frontogenesis zones. Range degradation begins at a lower level and gaps in adequate coverage begins. Orographic clouds often hug the sides of mountains which can mean range is extremely limited. Also, in arctic outbreaks, shallow convection can result in significant snowfall rates, even with the precipitating layer at just 5 kft AGL. I have seen cases of power plant plumes and midwestern reservoirs producing significant snowfall whose cloud tops were only 1000'. Radar is

extremely limited in its usefulness. Here is the coverage of typical lake effect snow, and precipitating orographic clouds where the precipitating layer is 8.5 kft AGL.

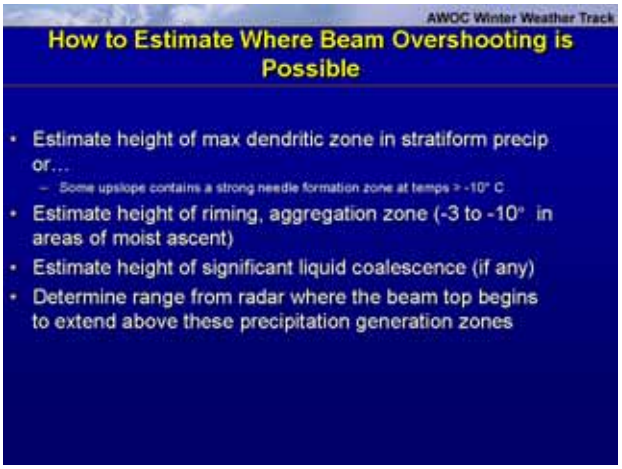
Student Notes:



12. How to Estimate Where Beam Overshooting is Possible

Instructor Notes: Here's the rule of thumb: watch out for favored regions where saturation and vertical motion are likely resulting in precipitation production. Your radar should at least sample the dendrite production zone adequately. But even if it does, watch out for feeder clouds that can enhance precipitation through riming, aggregation or coalescence. Even clouds not able to make it to the dendrite production layer can produce significant precipitation. Short distances can result in big changes in precipitation production layers. In convection, precipitation is being produced anywhere updraft is intersecting precipitation in warm layers and in subfreezing air. It is more likely you want to sample the warm cloud layer when the updraft is weak. Of all things to remember, do remember that the cursor readout you see is the beam center point. Reflectivity degradation begins when the beam top exits the precipitation layer.

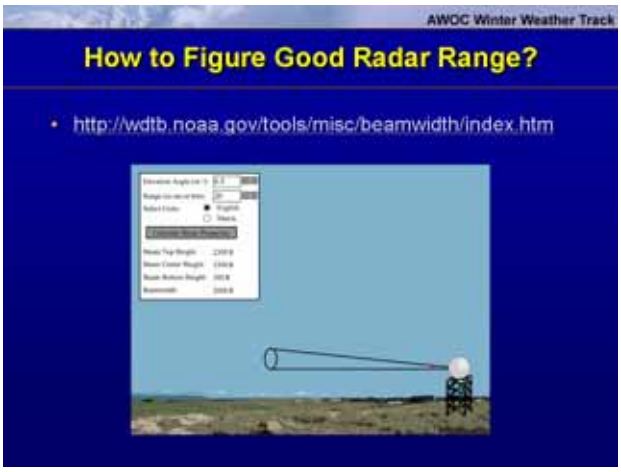
Student Notes:



13. How to Figure Good Radar Range?

Instructor Notes: This tool is available on our web site if you would like to use it. Enter in the range of your cursor and your elevation angle. Then calculate beam properties and you'll know the top of your beam. If the beam top is greater than where you believe precipitation is developing, then your radar will underestimate precipitation rate.

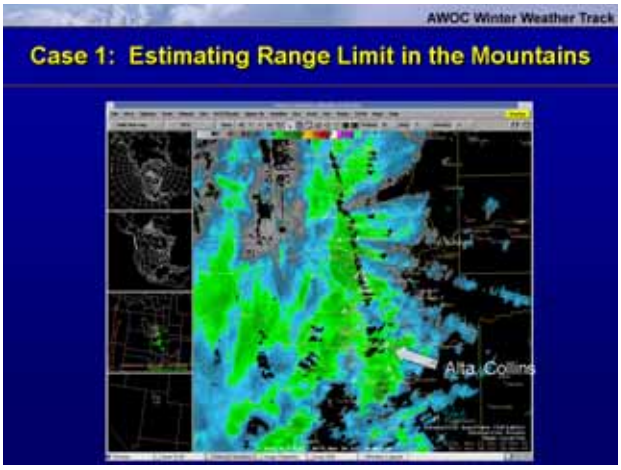
Student Notes:



14. Case 1: Estimating Range Limit in the Mountains

Instructor Notes: In this first example, we will look at the major considerations of whether or not you're sampling precipitation generation by looking at a specific site. Alta Collins is a small gauge site at Alta ski area (9662' MSL). The 1.5 degree beam reflectivities is followed by the 0.5 degree beam. Note that there's some beam blockage toward the radar but over the site there are reflectivity data. We will use the reflectivity for each elevation angle and convert it to liquid equivalent rate. There will be one for beam blockage and we'll talk more about that in the next slide.

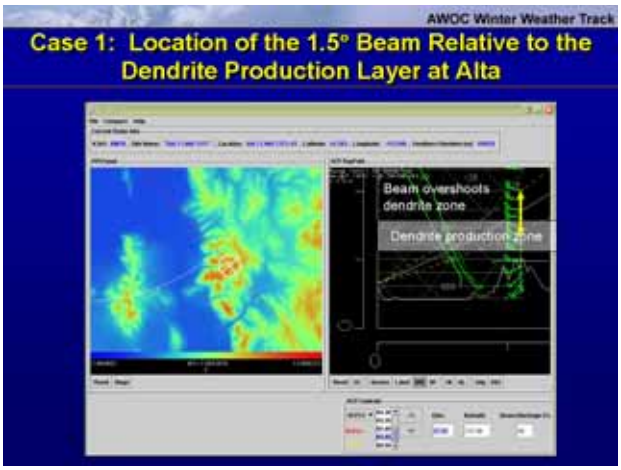
Student Notes:



15. Case 1: Location of the 1.5 Degree Beam Relative to the Dendrite Production Layer at Alta

Instructor Notes: Alta is located at the cross-hairs on the RHI scan. It's a high mountain location at the end of the valley that slopes up to the east. Overlaying the Eta12 18 UTC analysis sounding, the dendrite production layer lies just above the mountain ridge. Note the height of the 1.5 degree beam over Alta. Take a look at the beam height relative to the dendrite production layer (the -12 to -18 degree C layer). How do you think the radar would do in sampling the precipitation being caught at the Alta Collins gauge? Here is a scenario: If there were no gauge there, and the DOT requested an estimate of snowfall rates up the canyon leading to that gauge, what would you tell them?

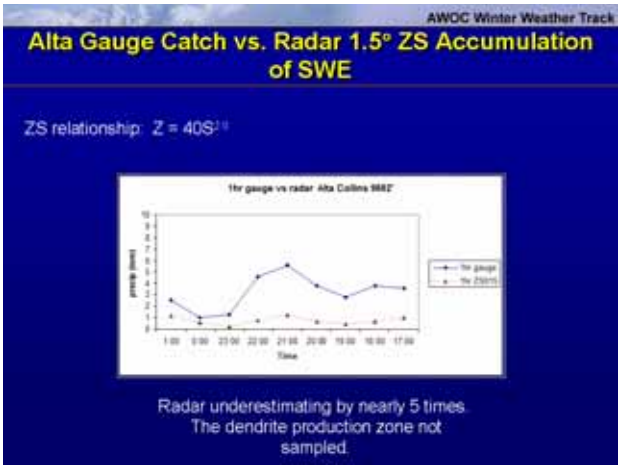
Student Notes:



16. Alta Gauge Catch vs. Radar 1.5 Degree ZS Accumulation of SWE

Instructor Notes: It is not surprising the radar is not sampling the production of snow in the -12 to -18 degree C layer when using the 1.5 degree elevation scan. Let me remind you ahead of time that I am using ZS coefficients that will be operationally in use for the same radar. I could simply adjust the coefficients to match the radar estimations to what we observe for any one time interval. However, look at the trends to show how different sampling errors come into play at different times. Any singular change to a ZS algorithm coefficient will simply change the whole time trend. With the 1.5 degree scan precipitation estimations, I could change the coefficient and lift the whole time trend up and attempt to minimize the error with the Alta gauge. It's important to note that I would not improve on changing the radar precipitation estimation errors over time. In other words, change the shape of the time trend to match the observations. Anyway, I haven't even tried using the 0.5 degree scan to see how it improve the radar estimates.

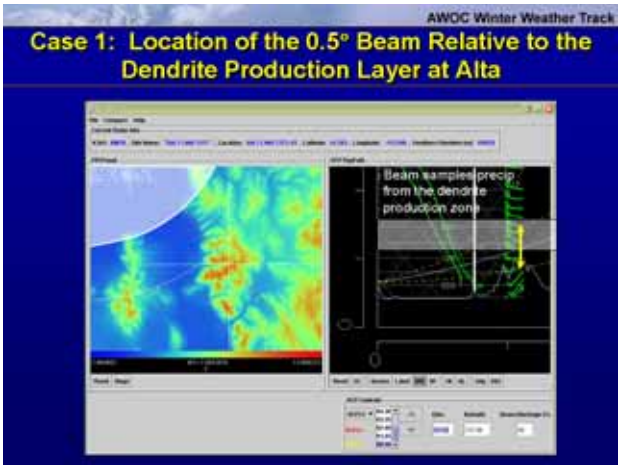
Student Notes:



17. Case 1: Location of the 0.5 Degree Beam Relative to the Dendrite Production Layer at Alta

Instructor Notes: How well do you believe the 0.5 degree elevation scan will improve the radar ZS estimates given the same ZS relationship? Do you think the radar is adequately sampling the snow that is falling into the Alta Collins gauge? Note here the relationship between the dendrite production layer (grey rectangle) vs. the vertical extent of the 0.5 degree beam over the Alta site (yellow arrow line segment). The vertical white line represents the approximate distance from the radar where the top of the 0.5 degree beam reaches the -12 degree C layer. Let's say that snowflakes grow rapidly within the dendrite production layer with a bottom at -12 degree C. Then we can say that reflectivity will definitely degrade as soon as the top of the beam enters into this layer. For this example, that's 37 nm away from the KMTX radar. Let's draw a ring around the radar marking 37 nm first on the plan view map on the left and then on a real image in the next page. I want to make you aware that as long as the air is saturated, and there is upward motion, needles can easily form at temperatures warmer than -12 degree C. So anywhere it's below freezing and these conditions are met, there will probably be snow fall production and an increase in reflectivity as you approach the ground. But at least we should catch most of the snow production in the dendrite production layer.

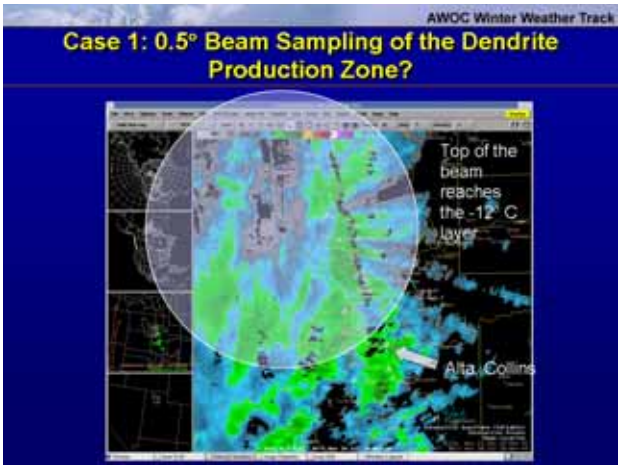
Student Notes:



18. Case 1: 0.5 Degree Beam Sampling of the Dendrite Production Zone?

Instructor Notes: In the white shaded area, the radar beam top is below -12 degree C. Whatever precipitation falls out of the dendrite production zone should be theoretically well sampled by the lowest elevation slice. As you can see, however, we've got beam blockage issues and inhomogeneities in the precipitation field that result in the appearance of reflectivity degradation with range east of the radar. Alta is outside the region where the 0.5 degree elevation slice remains entirely below the -12 degree C layer. Thus we can be almost sure of some reflectivity degradation and, therefore, the radar is likely underestimating the snowfall rates at the ground. As a caution, we have not considered precipitation evaporation between the radar beam and ground. While I stand by my claim above, I must consider if evaporation may prove me wrong. In this case, precipitation has been occurring for awhile and the atmosphere between the radar beam and Alta Collins is likely near saturation. I'll talk more about evaporation later.

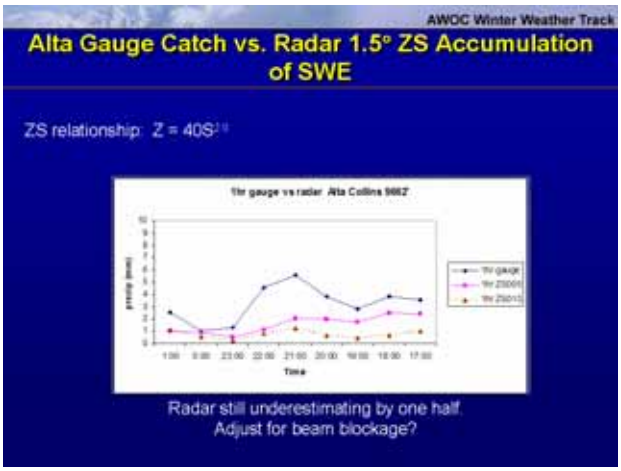
Student Notes:



19. Alta Gauge Catch vs. Radar 1.5 Degree ZS Accumulation of SWE

Instructor Notes: It is not surprising the radar is not sampling the production of snow in the -12 to -18 degree C layer when using the 1.5 degree elevation scan. What can the 0.5 degree scan do to improve the radar estimates? Well, there's an improvement. The radar is capturing more of the snow falling into the Alta Collins gauge but there's still a ways to go. The 0.5 degree scan is partially blocked by intervening terrain. The ZS algorithm will adjust for partial beam blockage. There's about 40% blockage here and so let's see if a +4 dB adjustment will close the gap.

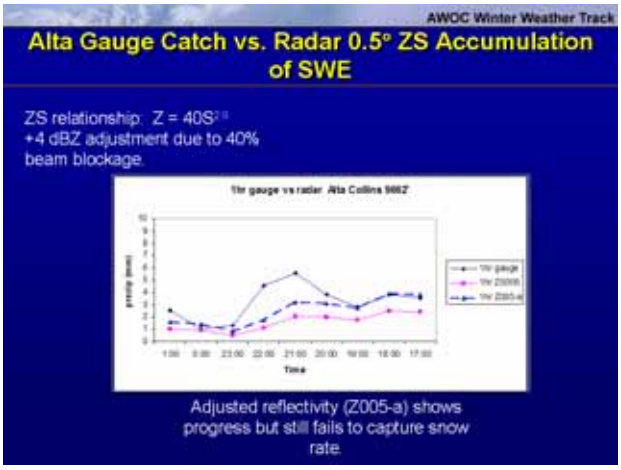
Student Notes:



20. Alta Gauge Catch vs. Radar 0.5 Degree ZS Accumulation of SWE

Instructor Notes: Even adding an adjustment to reflectivity from the 30-40% beam blockage, in a similar way to the ZS algorithm, the radar fails to capture the amounts at the Alta Collins gauge from 20-23 UTC. We could lower alpha in Z=alpha*S^{Beta} to 20 but that will increase the radar SWE estimates everywhere and overestimation would result on either side of 20-23 UTC. What is really happening is that most likely there is large amounts of aggregation and riming occurring close to the mountain sides as the upslope flow became more saturated below the dendrite production layer. The radar cannot easily discriminate between these situations because of the beam blockage. A static +4 dBZ adjustment is insufficient when the actual precipitation rate in the blocked area changes with time.

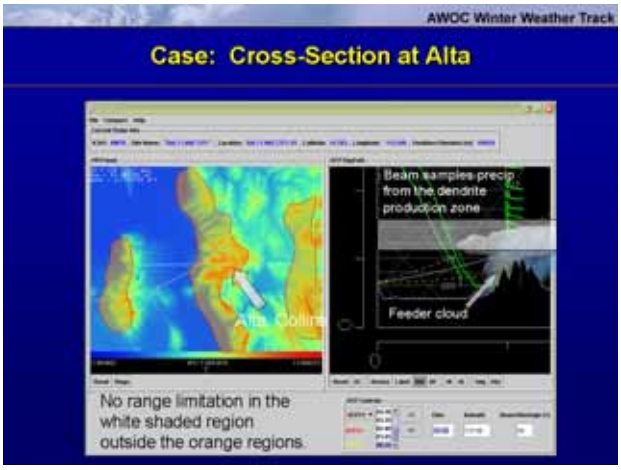
Student Notes:



21. Case: Cross-Section at Alta

Instructor Notes: While the beam is probably sampling the dendrite production zone adequately (even this is not 100% sampled), the enhanced upslope is likely causing strong lifting in the layer just below the maximum dendrite production zone. The result of this situation is stronger lift is quite possibly generating even more snow through needle formation, snow flake aggregation, and riming. For simplicity, we say that the dendrites falling into this layer from above is being fed by this lower-level updraft and so we call this cloud a feeder cloud. The sounding here suggests that this is quite likely. Unfortunately, the radar near Alta has no chance in adequately resolving this feeder cloud layer because of its shallow nature, this layer is rubbing against the terrain, and beam blockage is a constant problem. Anywhere there is cloud in temperatures warmer than -12 degree C, with moist ascent, expect to see continuous precipitation enhancement through ice multiplication, aggregation, riming, and liquid drop coalescence. I expect this problem to be most pronounced on the upslope sides of the mountains here. Assuming no beam blockage, then adequate radar sampling of feeder cloud requires that the top of the beam remain below the LCL. In this example, the LCL is roughly 7500’ MSL. The radar altitude is already > 5 kft MSL and so the top of the beam would hit the LCL just 20 miles away. Except for the terrain around Promontory point (upon which the radar is located), no adequate sampling of the LCL region exists and it is likely the radar will underestimate observed precipitation in any upslope region where cloud exists. I will paint these likely regions in orange.

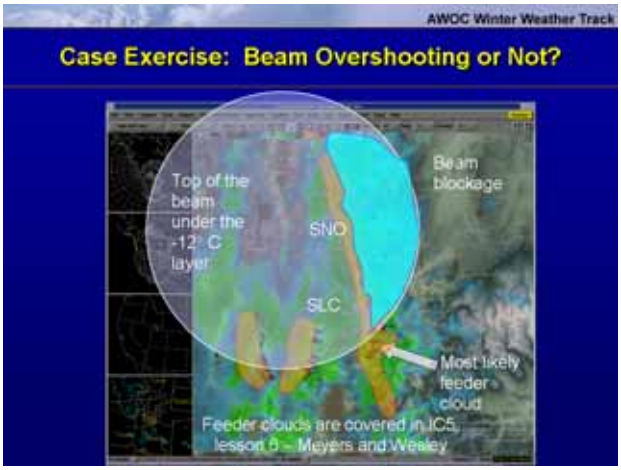
Student Notes:



22. Case Exercise: Beam Overshooting or Not?

Instructor Notes: Going back to the map, here is the 0.5 degree reflectivity image overlaid on the topography. I again overlay the region where the entire beam is below -12 degree C in the white shaded circle. However, beam blockage is limiting reflectivity in large regions east of the Wasatch as represented by the regions in blue. Anywhere with a strong upslope component has the highest probability of the seeder/feeder process and I overlay these in orange. The best range sampling is most likely in areas shaded in white but outside the orange feeder cloud areas and away from beam blockage. I remind you that feeder seeder processes are nicely covered in a lesson on topographic precipitation forcing in IC 5, lesson 6 authored by Mike Meyers of GJT and Doug Wesley of COMET.

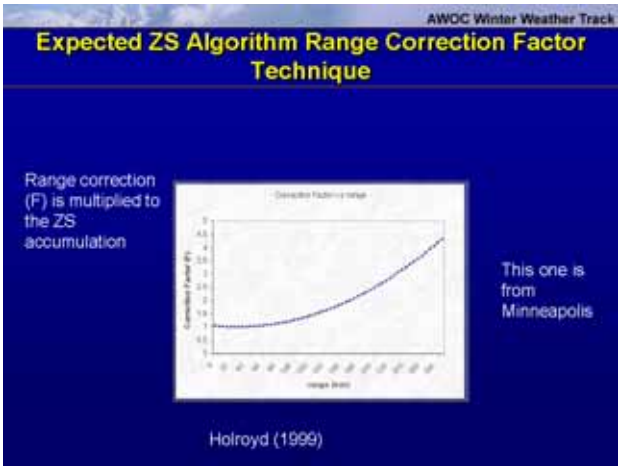
Student Notes:



23. Expected ZS Algorithm Range Correction Factor Technique

Instructor Notes: Note that in flat regions, there is a range correction required on a climatological basis. The Bureau of Land Management (Holroyd, 1999) found this adjustment factor to the radar estimated SWE for Minneapolis based on a winter's worth of snow events. Not much adjustment is needed close to the radar but increasing adjustment is required at larger ranges. In actuality, beyond 180 km or so, the lowest beam is overshooting so badly that no adjustment will give you an adequate estimate. This range correction will likely be applied to the ZS algorithm output once it is viewable on your AWIPS. This graph was based on a climatology of one winter. Range corrections would vary widely in very short time intervals, even minute by minute for certain events. And we've already seen how it will change when there's topography.

Student Notes:



24. Quiz item #1

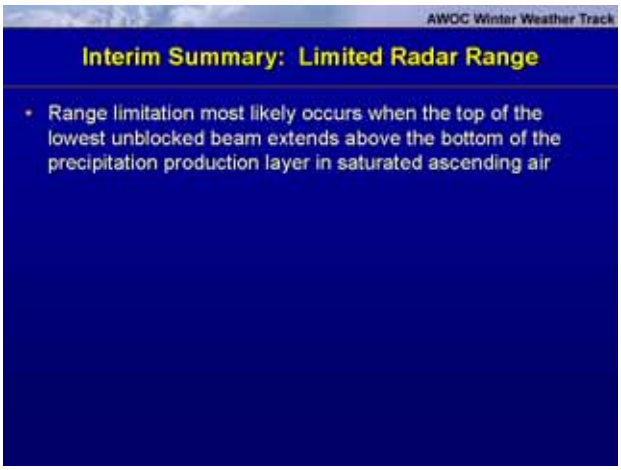
Instructor Notes: Take a moment to complete this interactive quiz.

Student Notes:

25. Interim Summary: Limited Radar Range

Instructor Notes: Range limitation most likely occurs when the top of the lowest unblocked beam extends above the bottom of the precipitation production layer in saturated ascending air. Is your lowest beam fully sampling feeder clouds? In the absence of feeder clouds, where is your beam relative to the dendrite production layer? Range is severely limited in topographic ascent, lake effect, and maritime warm clouds.

Student Notes:



26. WSR-88D Precipitation Intensity Topics

Instructor Notes: Let's talk about sub-beam evaporation of precipitation and where it affects radar precipitation estimates.

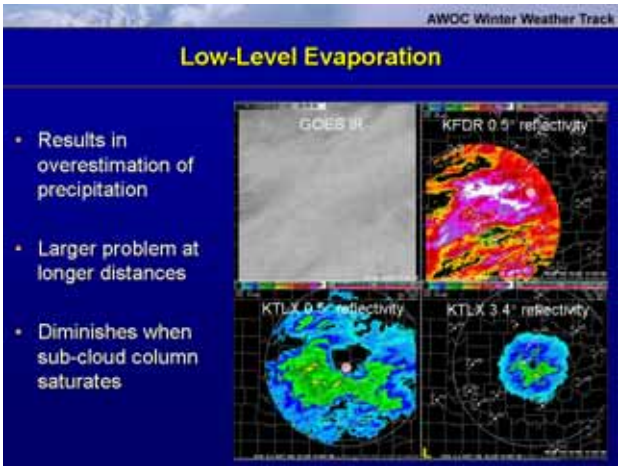
Student Notes:

27. Low-Level Evaporation

Instructor Notes: The overestimation problem increases with increasing range from the source radar. The KFDR radar in the upper-right shows precipitation over an area where

it is clearly virga, as viewed by the KTLX radar. If the environment saturates below the radar beam, this problem would diminish. The problem is if you don't have a nearby radar, how can you tell where the radar is overestimating precipitation rates. We'll look at reflectivity as a proxy for instantaneous precipitation rate and then look at some cases of hourly rates.

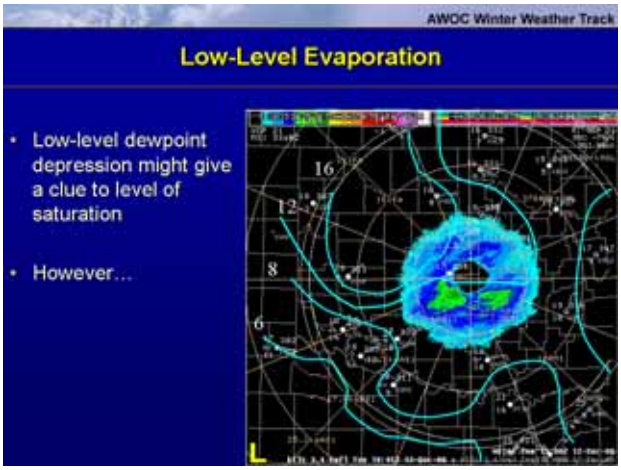
Student Notes:



28. Low-Level Evaporation

Instructor Notes: You can clue in on any subsaturated air by observing dewpoint depressions. Remember that these depressions are based on dewpoint, and not frost point. Thus if it's significantly below freezing, you probably will not see dewpoint depressions less than 5 degrees C.

Student Notes:



29. Low-Level Evaporation

Instructor Notes: Surface dewpoint depression in the last page was not entirely representative of the amount of total evaporation that a hydrometeor would experience on its

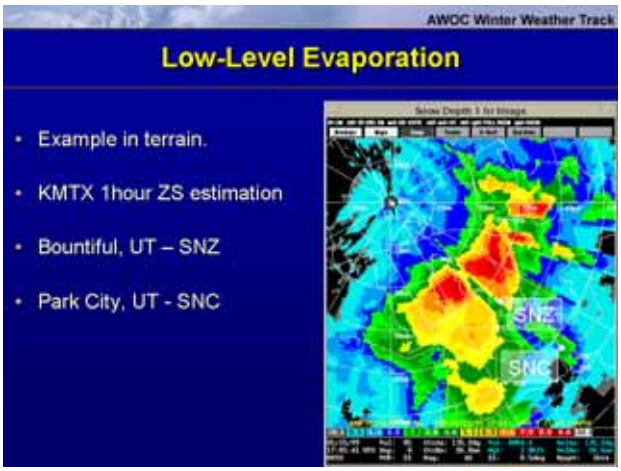
way to the surface. We still know that precipitation rate will be overestimated by distant radars.

Student Notes:

30. Low-Level Evaporation

Instructor Notes: In significant terrain, some areas routinely experience evaporating precipitation below the lowest scan from your nearest radar. I'll present to you a study comparing gauge catches vs. radar-derived precipitation estimates for several stations in the Salt Lake City area. Vasiloff (2001) studied precipitation rates in this area in preparation for the 2002 Winter Olympics. Here is an example of two stations, Bountiful and Park City, and how their elevations impact catchment. Bountiful (SNZ) is at 5000' MSL and west of the Wasatch mountains while Park City (SNC) is east of the Wasatch crest and at 7000' MSL. This one-hour accumulated snow depth map was created using a ZS relationship. Note that radar estimations over Bountiful were much higher than for Park City.

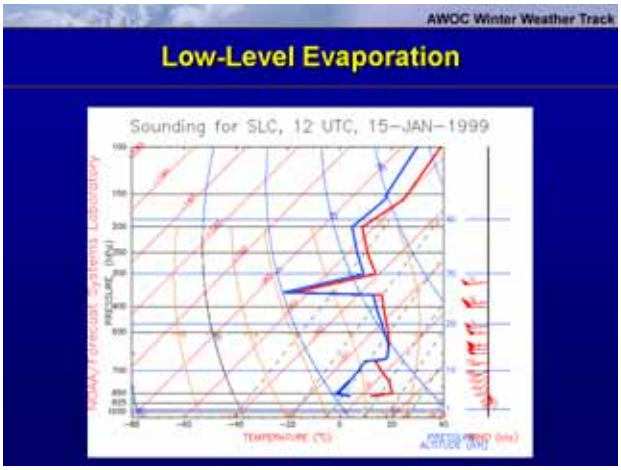
Student Notes:



31. Low-Level Evaporation

Instructor Notes: The sounding from Salt Lake City shows a dry layer extending up to 650 mb. Elevation is an important determinant regarding how much evaporation you will receive.

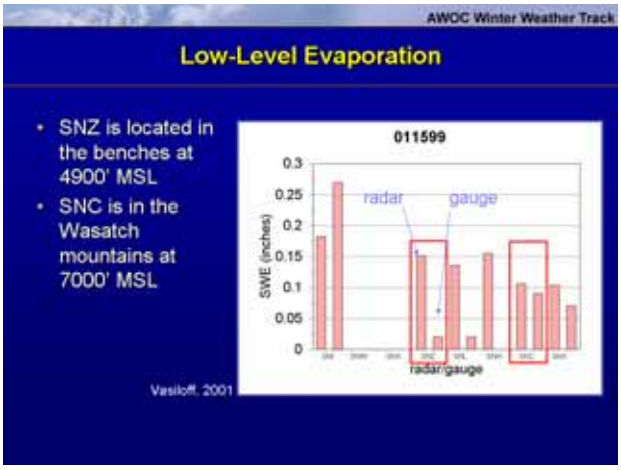
Student Notes:



32. Low-Level Evaporation

Instructor Notes: In the red square highlighting Bountiful's precipitation, note that the gauge recorded much less than the radar estimate. It is also not surprising here that Bountiful received much less precipitation than Park City given the evaporation problems. Meanwhile at Park City, the radar and gauge agree much more. Remember that this is one specific ZS relationship that was used.

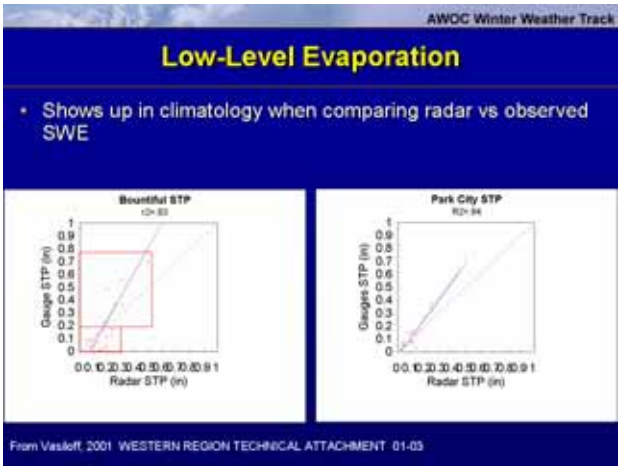
Student Notes:



33. Low-Level Evaporation

Instructor Notes: Here, I show you radar Storm Total Precipitation (STP) from the ZS algorithm vs. the gauge accumulations, both in liquid water equivalent. Over a period of storms, the climatology of evaporation starts to reveal itself. The radar consistently over-estimates the ground truth at Bountiful for light snow storms. Note for Park City that the gauge and radar agree much more readily for similarly light events. But for heavier snow storms, the radar actually underestimates precipitation ground truth, especially for Bountiful. Can you name a reason why that might be the case? Vasiloff created an adjustment to the ZS algorithm using the regression curve represented by the solid blue line. However, one has to wait until the snow event is done before the adjustment is made.

Student Notes:



34. Example 1: SLC Sounding

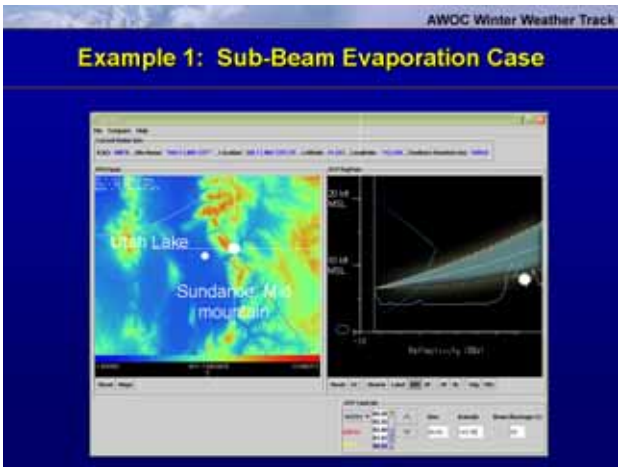
Instructor Notes: Let's take a look at a case from Salt Lake City. The sounding was taken 6 hours before and shows a typical pre-cold frontal environment with a substantial dry layer up to 550 mb.

Student Notes:

35. Example 1: Sub-Beam Evaporation Case

Instructor Notes: The Sundance Midmountain gauge is located just below the 0.5 degree beam from KMTX. There is a small amount of beam blockage from higher terrain to the northwest. As precipitation is beginning, we'll assume a vertical reflectivity profile such as the one shown on the cross-section to the right. Note that the reflectivity peaks at 30 dBZ just above mountain top and then trails off to 10 dBZ at the valley floor as sublimation takes its toll. If we assume the true vertical reflectivity profile is the same everywhere, then elevation has a controlling influence on the accuracy of the radar precipitation estimate. The closer you are to the maximum reflectivity, the more precipitation you will see. Let's see how elevation and location affect the accuracy of the storm total precipitation from the KMTX radar in the next page.

Student Notes:

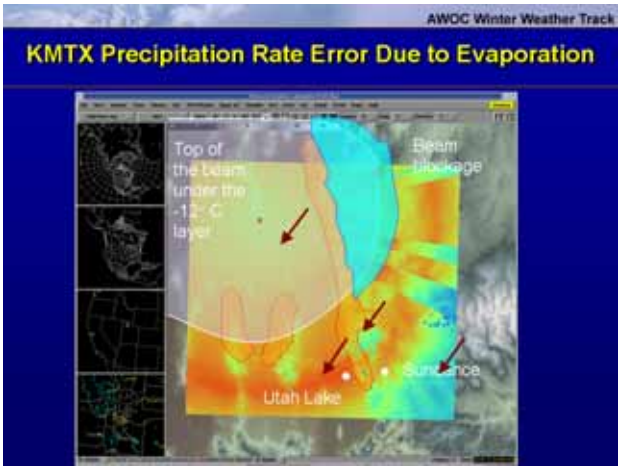


36. KMTX Precipitation Rate Error Due to Evaporation

Instructor Notes: We'll shortly see how low-level evaporation creates an elevation dependency on the accuracy of the precipitation algorithm. First, I left the zones that we talked about in part one showing where you need to be to adequately sample precipitation emanating from the dendrite production zone. Because it's so early in this event, there are probably not many feeder clouds so we'll take those out. Instead, let's overlay a precipitation rate difference product based on the precipitation algorithm. This adjustment is the difference between the official STP algorithm using the DHR and the true precipitation observed at the ground using the true reflectivity as it intersects the ground. Everywhere you see warm colors, the radar is overestimating precipitation. The further from the radar you go, the warmer the colors or the bigger the difference. But in the higher terrain, you have smaller differences as the terrain approaches the radar beam, and higher reflectivities. This simulates one reason why high terrain observes more precipitation. The green colors represent near zero error. Consider the following questions that you'll be asked in the next page: Is the radar over, under or properly estimating snowfall rate at Sundance? Assume the Z=70S1.4. The blue colors represent the radar underestimating the precipitation. Given the relatively low terrain well southeast of Sun-

dance, how can the radar underestimate precipitation given low-level evaporation issues?

Student Notes:



37. Quiz Item #2

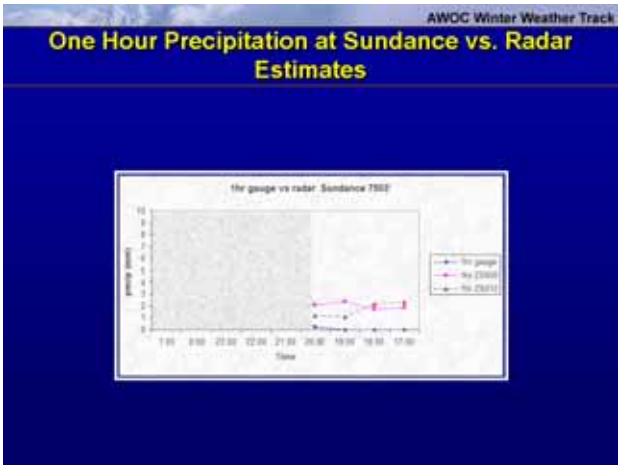
Instructor Notes: Take a moment to complete interactive quiz #2.

Student Notes:

38. One Hour Precipitation at Sundance vs. Radar Estimates

Instructor Notes: The answer is here. Over the period from 17-19 UTC, reflectivities remained high in the lowest two scan elevations but nothing appeared in the Sundance gauge. Evaporation is taking a toll. Finally at 20 UTC, some snowfall reaches the gauge.

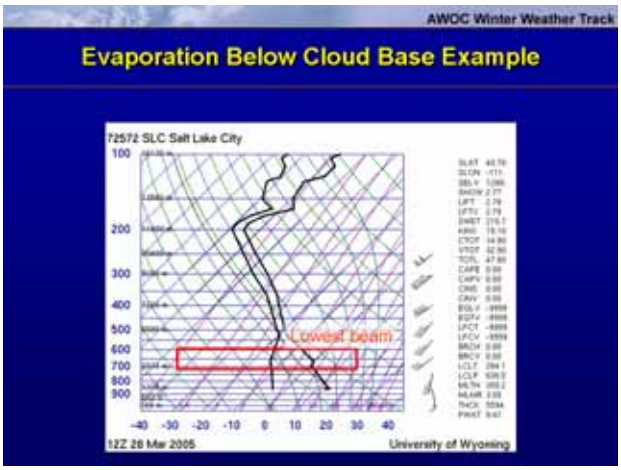
Student Notes:



39. Evaporation Below Cloud Base Example

Instructor Notes: 12 hours later, the cold front passes SLC, and the column is nearly saturated except for the lowest 50 mb. Sundance lies just below the lowest beam from KMTX.

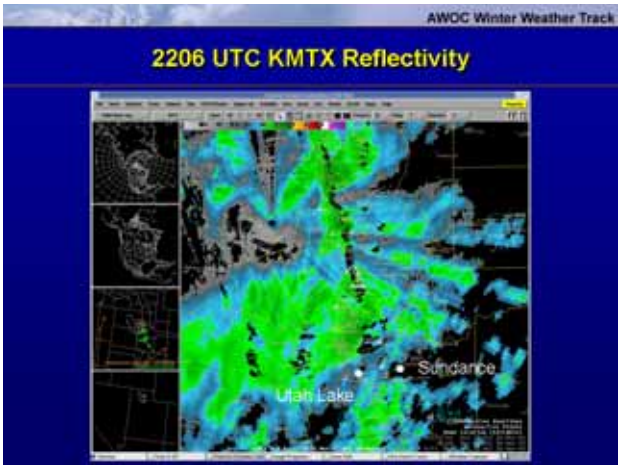
Student Notes:



40. 2206 UTC KMTX Reflectivity

Instructor Notes: Here is a 2206 UTC reflectivity image from KMTX. We'll estimate whether or not the radar will overestimate, underestimate, or be right on with its precipitation measurement. Note that when we do go from 1.5 degree to 0.5 degree, the reflectivity increases slightly over Sundance. Is the radar over, under or properly estimating snowfall rate at Sundance? Assume the Z=70S1.4.

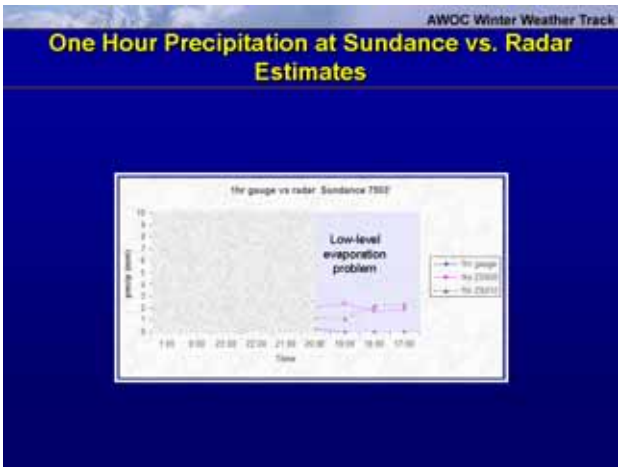
Student Notes:



41. One Hour Precipitation at Sundance vs. Radar Estimates

Instructor Notes: The gauge is now reporting slightly greater hourly totals than the radar estimate. It is likely now that feeder clouds have developed in the post-cold frontal air and that light seeder precipitation is being enhanced below the radar beam. What was a problem with low-level evaporation has perhaps become a problem of beam over-shooting.

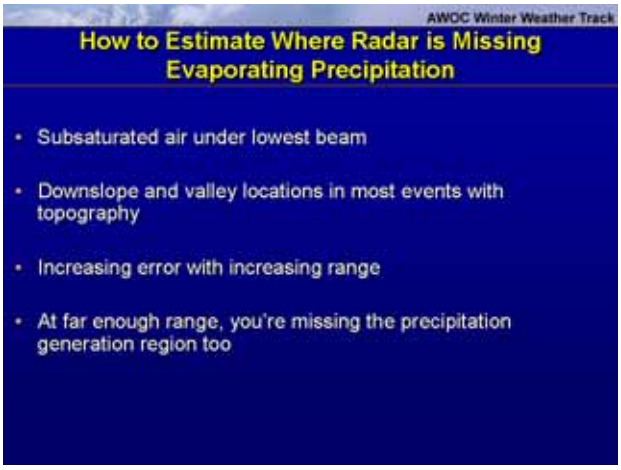
Student Notes:



42. How to Estimate Where Radar is Missing Evaporating Precipitation

Instructor Notes: Anytime there's subsaturated air, precipitation evaporates. And as long as this is occurring underneath the radar beam, you're going to run into potential precipitation overestimates. Most areas subjected to hours of virga without any compensating process to dry the air will saturate fairly quickly.

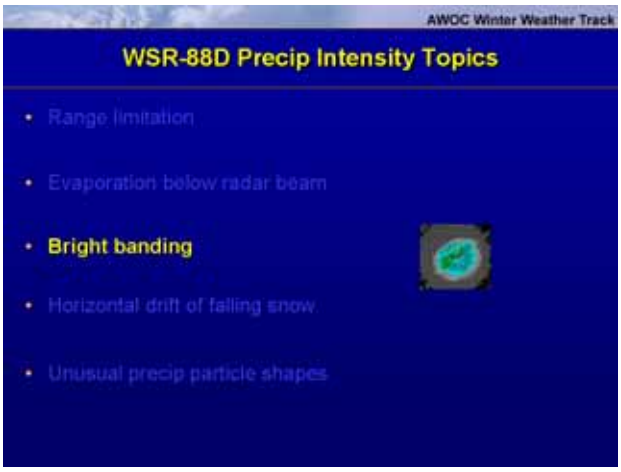
Student Notes:



43. WSR-88D Precip Intensity Topics

Instructor Notes: Five considerations adversely affect good precipitation estimates, especially snowfall. Limited range becomes exacerbated in the winter when cold temperature microphysics routinely occur closer to ground. Bright banding becomes more of an issue as the freezing level is low enough to interfere with the hybrid scan selection. Evaporation can also occur below the lowest radar beam.

Student Notes:



44. Bright Banding Reflectivity Factor

Instructor Notes: Let's break down the mechanisms behind the bright band you see on radar because there is more than one. As snow flakes fall through the melting layer, water begins to coat their ice surfaces. The increased water coating helps colliding ice particles to stick together and snow flakes begin to increase in size. Larger particles form and the radar reflectivity increases. The liquid water coating itself also helps to increase radar reflectivity because the dielectric constant increases as ice changes phase to liquid. An offset to the increasing reflectivity occurs when the terminal velocity of the precip-

itation particles increases as melting accelerates. Increasing terminal velocity increases the separation between hydrometeors and lowers the reflectivity.

Student Notes:

45. Quiz Item 3

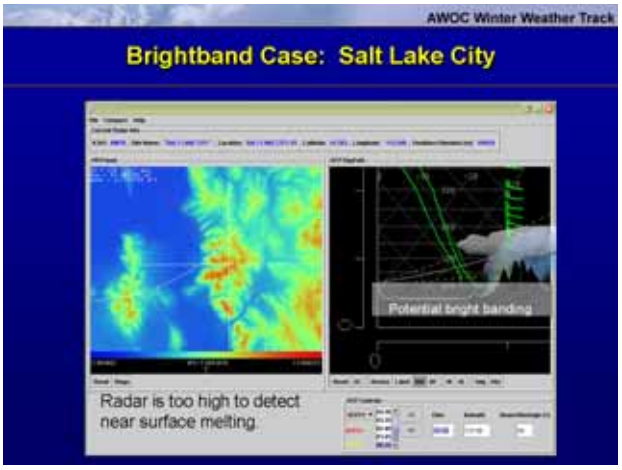
Instructor Notes: Take a moment to complete interactive quiz question #3.

Student Notes:

46. Brightband Case: Salt Lake City

Instructor Notes: In the Salt Lake area on this day, there may be sampling issues due to sub-beam evaporation and overshooting of upslope clouds. But there was no problem with bright banding even though there was a melting layer. The radar was simply too high. The radar location for once helps to eliminate one error source.

Student Notes:



47. WSR-88D Precipitation Intensity Topics

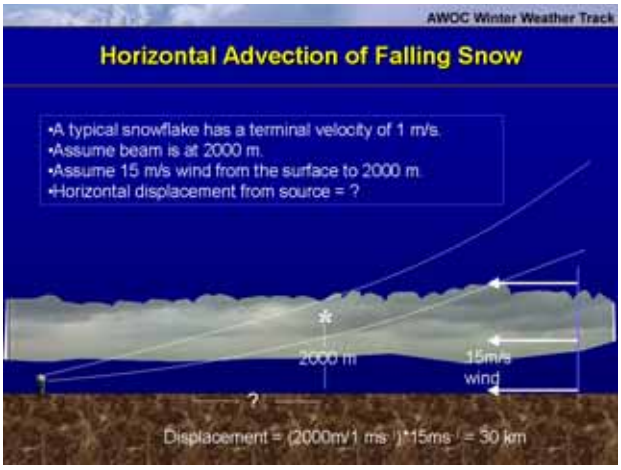
Instructor Notes: We will discuss precipitation errors coming from horizontal drift of falling snow.

Student Notes:

48. Horizontal Advection of Falling Snow

Instructor Notes: Let's assume a snowflake has a fall velocity of 1 m/s at an altitude of 2 km. If we're experiencing a 15 m/s wind, how far would that snowflake be horizontally displaced before reaching the ground? You may pause this presentation if you would like to figure out the answer. I'll pause a few seconds here. If you've come up with 30 km, you are right. That could be literally in the next county.

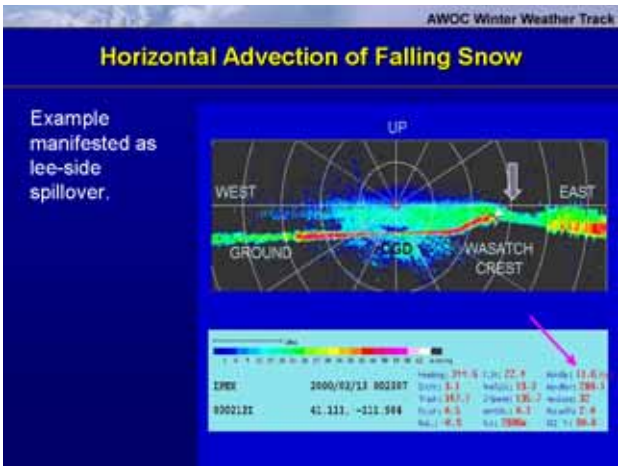
Student Notes:



49. Horizontal Advection of Falling Snow

Instructor Notes: An example of horizontal drift of falling snow is illustrated nicely here in this cross section taken from the P3 aircraft tail radar just west of the Wasatch mountains. Snow forming in the upslope drifts down the lee side of the crest for several miles. In this part of the country, the ‘spillover’ effect is a blessing for ski areas on the east side of the crest. In other parts of the country, this effect can occur if there is strong wind shear and rapidly moving transverse snowbands. If the location you’re monitoring is far enough from the radar when one of these bands pass overhead, you may not have snow fall under the band for quite some time. Fortunately, this is one error source that can be mitigated by knowing the vertical wind profile and the height of the beam. The BLM attempted to implement a correction for horizontal drift of falling snow into the ZS algorithm. The results showed no significant improvement to the algorithm, possibly because other errors were so large. The error we’ll talk about next is just one of those errors.

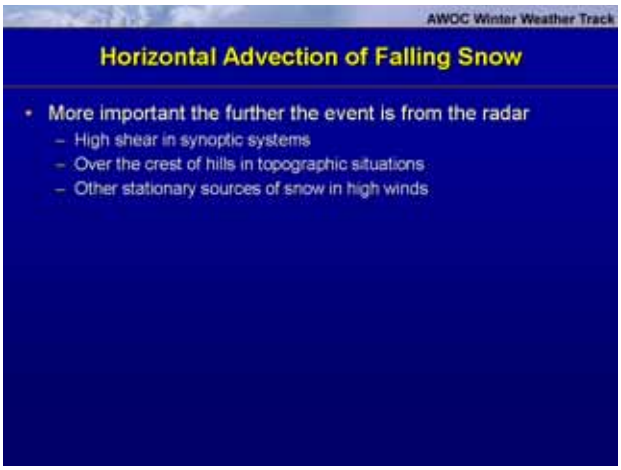
Student Notes:



50. Horizontal Advection of Falling Snow

Instructor Notes: What you want to look for are situations where either you have a situation where rapidly moving bands transverse to the mean flow exist in regions of high vertical wind shear or a stationary snow production source embedded in strong winds such as orographics. The high shear forces the snow to horizontally drift relative to the source of the snow. Lake effect is a stationary source of snow by relative standards but the snow often falls within the axis of the band, just downwind. There are times though at the end of a lake effect band where snow production is nonexistent and all the snow that is falling is simply drifting there from upwind.

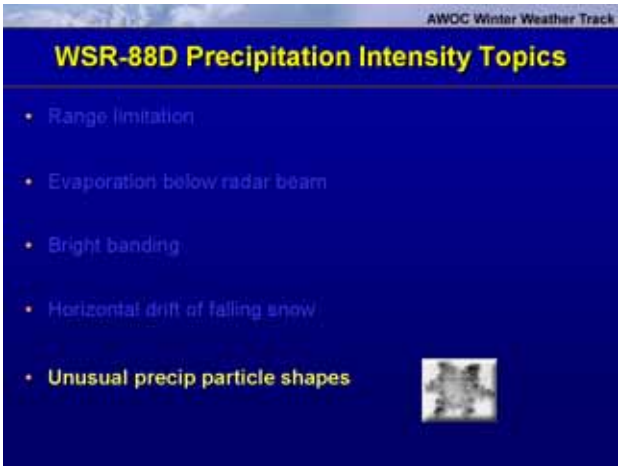
Student Notes:



51. WSR-88D Precipitation Intensity Topics

Instructor Notes: This final error source is probably the most intractable. Precipitation particle shape and size is something we'll talk about next.

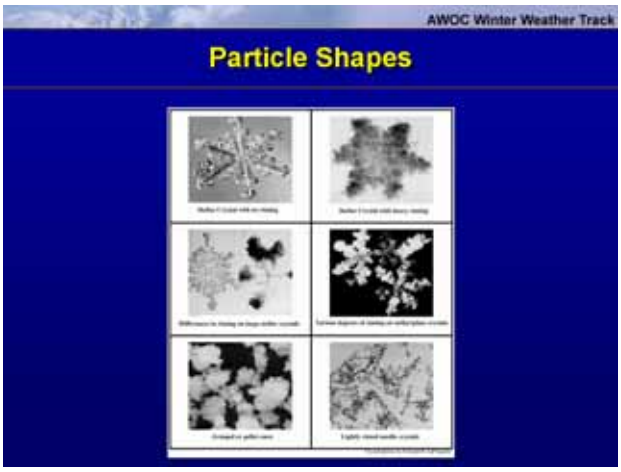
Student Notes:



52. Particle Shapes

Instructor Notes: Precipitation particle shape and size can significantly alter reflectivity without a corresponding increase in liquid equivalent precipitation rate. If you experience snow events, take a look at how the shapes and sizes of the snowflakes change over short periods of time. Many precipitation systems can contain a mixture of stratiform and convective elements with variations in vertical velocity profiles with respect to the thermal profile. The result is rapid changes in particle shapes. At this time, there is not much that can be done to adjust the ZS.

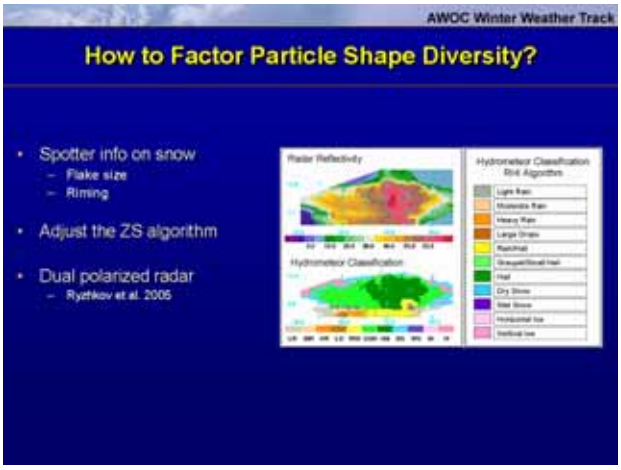
Student Notes:



53. How to Factor Particle Shape Diversity?

Instructor Notes: There are some tactics we could employ that would give us a handle on what direction the ZS algorithm error might be as a result of precipitation shape diversity. We could have spotters report to us flake size and type based on a template of images that we just saw in the last page. We could then adjust the ZS algorithm to help account for different precipitation particle shapes. However, once adjusted, it is adjusted for everyone in the radar domain and that's probably not a good solution. Really the best solution is one upon which the NWS is preparing to take, that is dual-polarized radar. Polarization diversity will allow us to detect different shapes and sizes of ice particles.

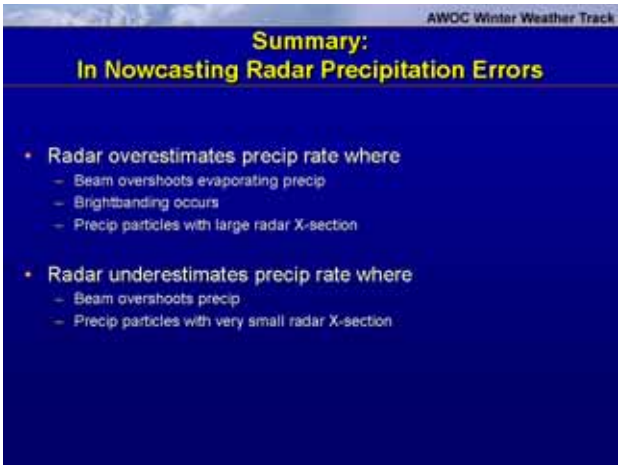
Student Notes:



54. Summary: In Nowcasting Radar Precipitation Errors

Instructor Notes: This slide summarizes the common reasons discussed in this lesson when radar algorithms overestimate or underestimate precipitation rate during snow events.

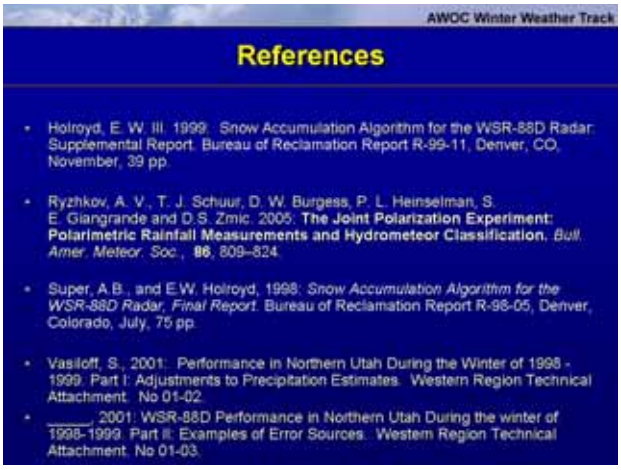
Student Notes:



55. References

Instructor Notes: This slide contains a list of all the references sited in this lesson.

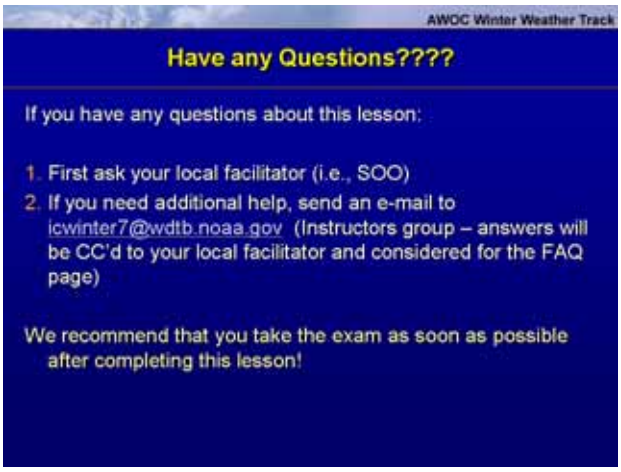
Student Notes:



56. Have any Questions????

Instructor Notes: If you have any questions about this lesson, first ask your local AWOC facilitator. If you need additional help, send an E-mail to the address provided. When we answer, we will CC your local facilitator and may consider your question for our FAQ page. We strongly recommend that you take the exam as soon as possible after completing this lesson.

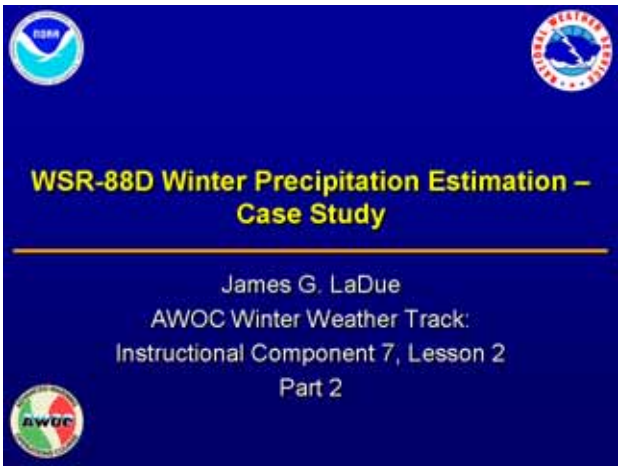
Student Notes:



1. IC7.2 Part 2: WSR-88D Winter Precipitation Estimation - Case Study

Instructor Notes: This is part 2 of a lesson on WSR-88D winter precipitation estimation. This is a case study of a New England snow event and should last about 20 minutes.

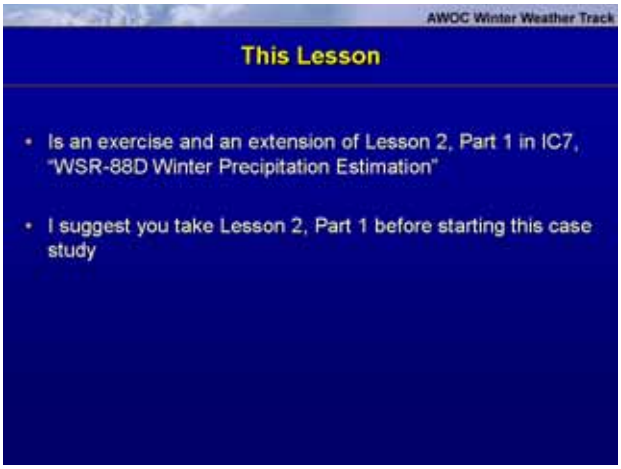
Student Notes:



2. This Lesson

Instructor Notes: This lesson is an exercise and an extension of Lesson 2, Part 1 in IC7, titled “WSR-88D Winter Precipitation Estimation”. I suggest you take lesson 2 part 1 before starting this case study.

Student Notes:

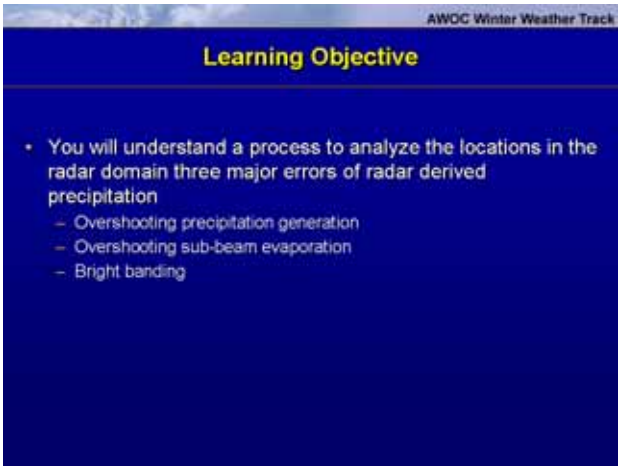


3. Learning Objective

Instructor Notes: By the end of this lesson, you will understand a process to analyze the locations in the radar domain three major errors of radar derived precipitation: over-

shooting precipitation generation, overshooting sub-beam evaporation, and bright banding.

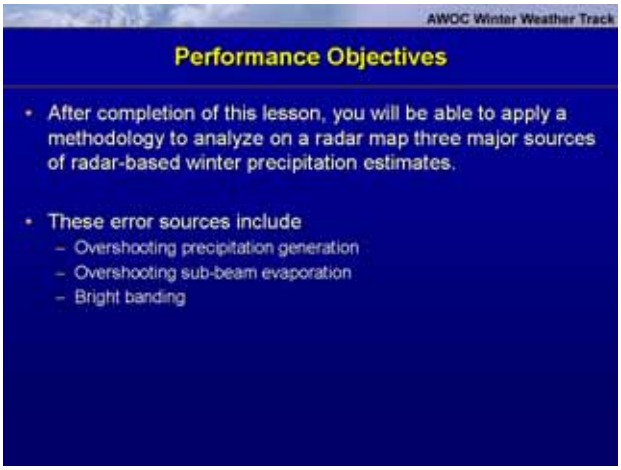
Student Notes:



4. Performance Objectives

Instructor Notes: After completion of this lesson, you will be able to apply a methodology to analyze on a radar map three major sources of radar-based winter precipitation estimates. These error sources include: overshooting precipitation generation, overshooting sub-beam evaporation, and bright banding.

Student Notes:

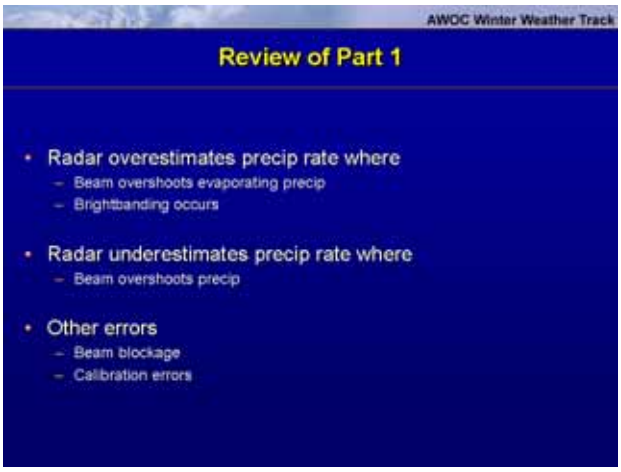


5. Review of Part 1

Instructor Notes: As a review of Part 1 of this lesson duo, remember that the radar overestimates precipitation rates where the beam overshoots evaporating precipitation and bright banding occurs. The radar underestimates precipitation where the beam overshoots precipitation production layers. There are system errors, too, that affect precipitation rate estimations such as beam blockage and calibration. You do have the option of adjusting the ZS algorithm coefficients but you would have to keep changing them over

small horizontal distances. We cannot adjust the ZS algorithm without an automated real-time correction scheme and good ground truth data. Instead we choose to draw areas where the precipitation will be over or underestimates of a fixed ZS relationship.

Student Notes:



6. Case: Range Limitations in New England

Instructor Notes: Let's try an example and take a look at how well the radar is estimating precipitation at Fitchburg, MA (in the circle). We ran the ZR algorithm using the default ZS coefficients that are planned for the Northeast U.S. and the minimum dBZ set to 10. However the results will not replicate the actual implementation of the ZS algorithm because there is no range correction applied here and a lower minimum dBZ setting. Given the criteria I set, do you think the precipitation is likely to be over or underestimated for Fitchburg?

Student Notes:

7. Surface Map – New England

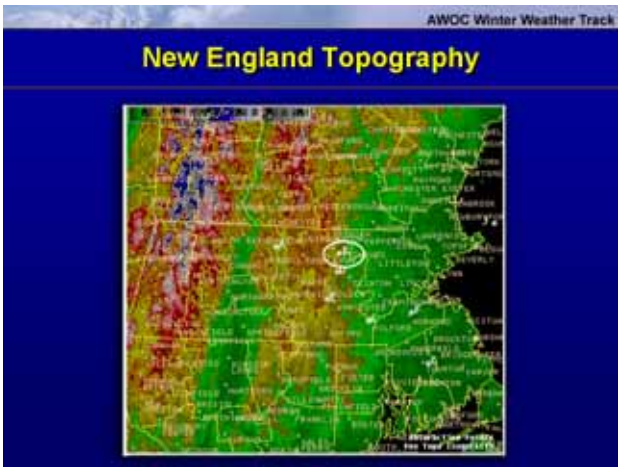
Instructor Notes: Fitchburg is well north of the rain snow line. The near saturation around the area also corresponds to relatively low cloud bases. Light winds in the area suggest that any bucket gauge should be able to be pretty efficient at capturing falling snow.

Student Notes:

8. New England Topography

Instructor Notes: Fitchburg is in an area of relatively high terrain (600’ MSL) and with the light easterly winds, there should be some upslope component to the flow. Upslope flow in subfreezing air means a greater possibility of low-level feeder clouds. Let’s see what the morning sounding on Cape Cod shows. Let’s see what you think about the sounding with the question coming up.

Student Notes:



9. Quiz 1

Instructor Notes:

Student Notes:

10. Eta Sounding New England Case

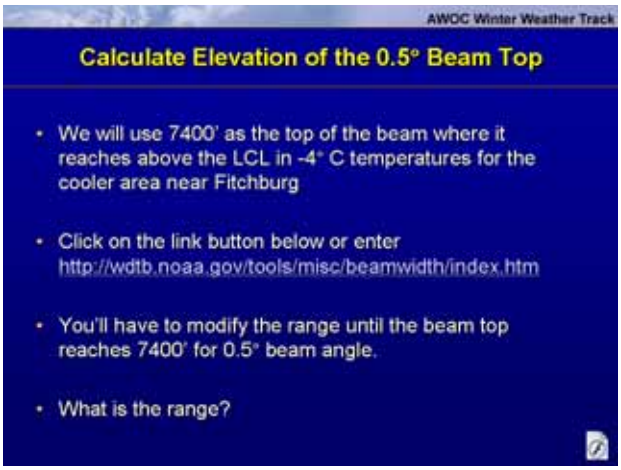
Instructor Notes: That was a tough question. Let's assume that we need to have the lowest beam entirely below the dendrite production layer. Well, that's below about 560 mb layer or 15 kft. MSL. But it's not sufficient to be below just the dendrite production layer. We need to capture ice multiplication, aggregation, riming and needle formation. Most of these processes occur at temperatures colder than -4 degrees C. You'll need to have the beam top below 10 kft MSL to capture most of those processes. Given the deep saturated layer below, there may still be some additional aggregation as snow flakes become coated with thin films of water and get "sticky". So, reflectivity may go up a bit more. As a word of caution, thin films of water also increase the dielectric constant; therefore, reflectivity increases with no corresponding increase in actual liquid precipitation rate. Also, this sounding is not quite as far north as Fitchburg so the cold precipitation generation layer may be a little bit lower.

Student Notes:

11. Calculate Elevation of the 0.5 Degree Beam Top

Instructor Notes: It is difficult to tell where in the sounding precipitation generation ceases and precipitation falls to the ground in its final form and intensity. We do know that below the dendrite production zone, frozen precipitation continues to develop. Even in warmer temperature you still have needle formation, riming and aggregation. We'll take temperatures warmer than -4 to -5 degrees C to be the point where most frozen precipitation growth will have already occurred. The soundings in the previous page show that temperature to be roughly 7400' MSL. We'll take that height and use the beamwidth tool.

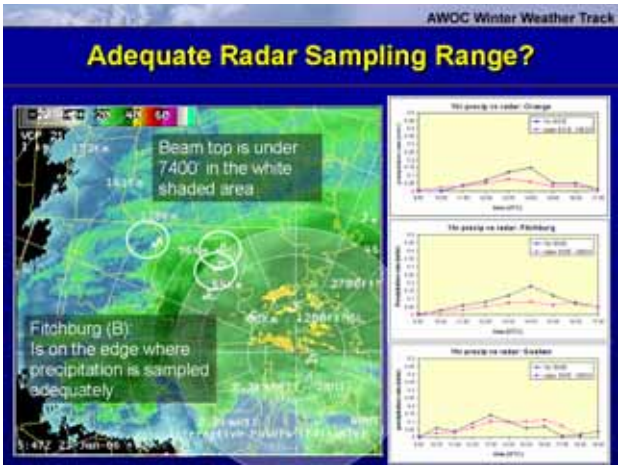
Student Notes:



12. Adequate Radar Sampling Range?

Instructor Notes: It would be ideal if the beam was hugging the ground and there was no ground interference. Instead, it appears that perhaps we can adequately sample most precipitation if the entire beam remained below 7400' AGL. The white shaded circle satisfying this condition extends out about 53 nm from the radar. The Fitchburg observation is right on the outer edge of good radar sampling. Is 7400' AGL enough or do we need to be lower? As it turns out, the Fitchburg ASOS is reporting higher hourly precipitation rates than the radar using the $Z=120S^{2.0}$ relationship. Going to the town of Orange, MA, which is further away, the same problem reveals itself. The radar is underestimating the hourly reports. Going a little closer to the town of Goshen, MA, the comparison is different. The radar is showing better agreement, perhaps even a bit of an overestimate. If we believe the surface COOP station, then the radar beam is more accurately sampling the precipitation at Goshen than at Fitchburg. That is quite possibly because the beam is extending above some significant precipitation generation as one goes to Fitchburg and points beyond relative to the radar. I could make the argument that the COOP station is underestimating its precipitation and that would be a valid argument. However, I will show later in this lesson that there is nothing indicating that there is enough instrument error to change the conclusions that the radar beam over Fitchburg and beyond is overshooting generating precipitation.

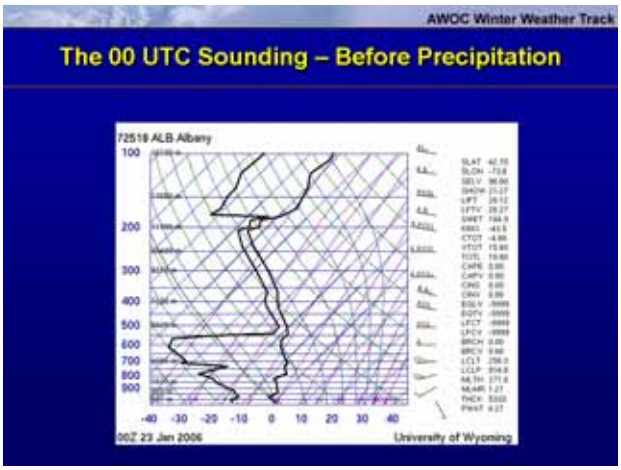
Student Notes:



13. The 00 UTC Sounding – Before Precipitation

Instructor Notes: At 00 UTC on the 23rd, the Albany, NY sounding showed a very dry airmass below the midlevel moisture streaming in ahead of a short-wave trough. Let's take a look at the radar 4-panel image next.

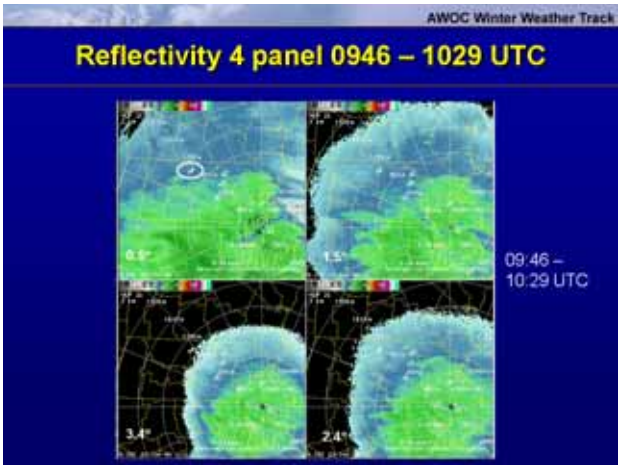
Student Notes:



14. Reflectivity 4 panel 0946 – 1029 UTC

Instructor Notes: Take a look at this loop and given the previous sounding and the nature of the reflectivity echoes, determine the type of radar-based precipitation error you may observe here. Orange, in the white oval, is reporting a 9 degree dewpoint depression. I'll pop up a quiz page next so you may answer.

Student Notes:



15. Quiz 2

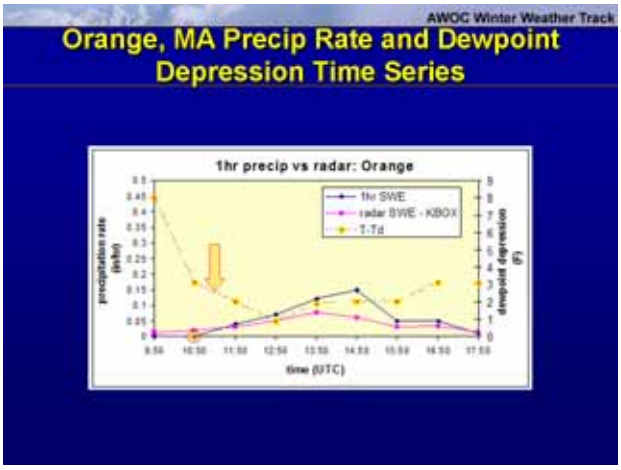
Instructor Notes:

Student Notes:

16. Orange, MA Precip Rate and Dewpoint Depression Time Series

Instructor Notes: When you look at the dewpoint depressions, the dewpoint depressions correlate well with the propensity of the KBOX radar to overestimate precipitation rate at Orange. We're using Z=200S2, but we could raise the coefficient to 220 or 230 and I bet that wouldn't help because no precipitation is being recorded at Orange. Even if there was, note how the errors switch signs later on. You'd have to adapt by changing the ZS coefficients again. The error sign flipped as a large flux in moisture from above quickly saturates the air at Orange. I believe this is a common evolution for many sites that are located well away from the nearest radar.

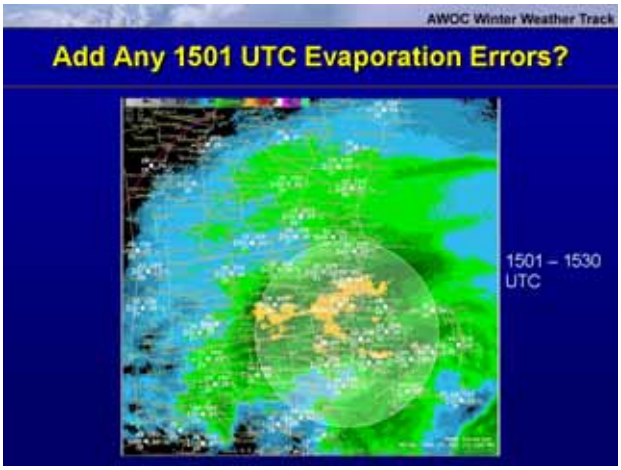
Student Notes:



17. Add Any 1501 UTC Evaporation Errors?

Instructor Notes: At this time, most everyone's saturated (at least with respect to ice). I doubt sub-beam evaporation is an issue now. Let's not include it in our considerations. So we still consider where the radar may overshoot precip outside the white shaded circle.

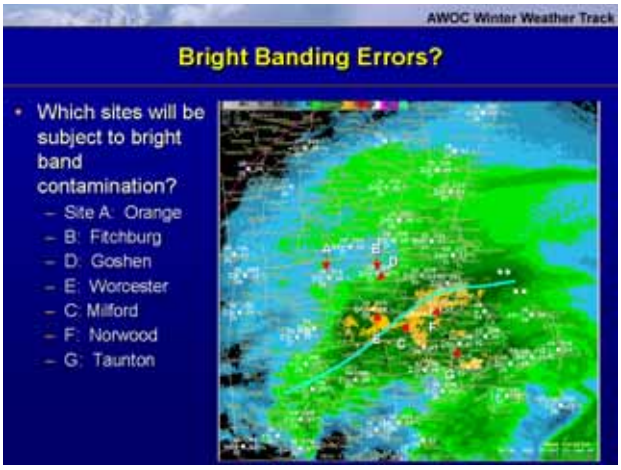
Student Notes:



18. Bright Banding Errors?

Instructor Notes: Let's try out your skill at locating bright band contamination. I have seven sites, some are ASOS, some are COOP sites. I am going to trust these sites as being relatively accurate. Understand that ASOS buckets are heated with poor shielding so some losses may occur due to evaporation and wind. Fortunately the wind is light and temperatures are fairly warm so it won't take much to melt snow into the bucket. The METARS tell me that the rain/snow line should be along the blue contour. The sites are, Orange, Fitchburg, Goshen, Worcester, Milford, Norwood, and Taunting. We'll go to a quiz.

Student Notes:



19. Quiz 3

Instructor Notes:

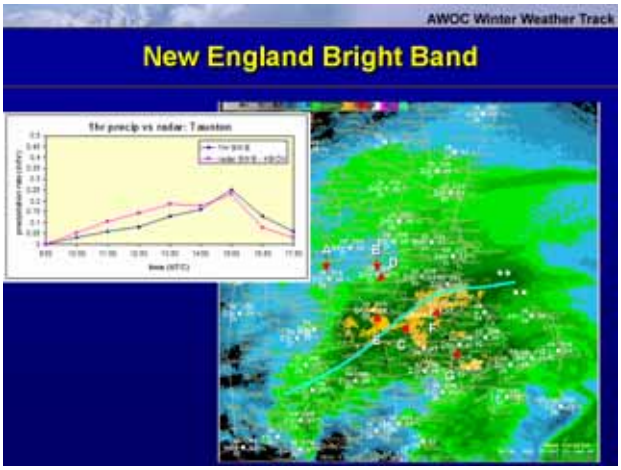
Student Notes:

20. New England Bright Band

Instructor Notes: Let's go through the answer to the last question. We start off with Orange (A) and see the problems with underestimation because of overshooting. The same goes with Fitchburg (B). When we get to Goshen (D) we see the radar transition from underestimate to overestimation around 15 UTC. It could be either wet snow, sub-beam evaporation, change in precipitation particle shapes, or an error with the gauge. If we just talk about adequate precipitation coverage, it is doubtful there is sub-beam evaporation given the saturated conditions. I suggest that we are looking at wet snow aggregates with a larger than normal reflectivity factor than the liquid equivalent present. In other words, perhaps some bright banding is beginning even though it is all snow. Going to Worcester (E), shows the same effect and here it is also snow. Recall from lesson 1 that snowflakes near freezing often have a thin film of liquid resident on the ice surfaces resulting in a high dielectric constant and a high radar reflectivity cross-section. Going to

Milford (C), and especially Norwood (F), we are looking at large waterlogged flakes with a huge reflectivity cross-section as the melting layer is fully sampled by KBOX. Finally, the radar is sampling completely melted precipitation at Taunton and there is better agreement there. Note, though, that earlier in the day there is some potential bright banding.

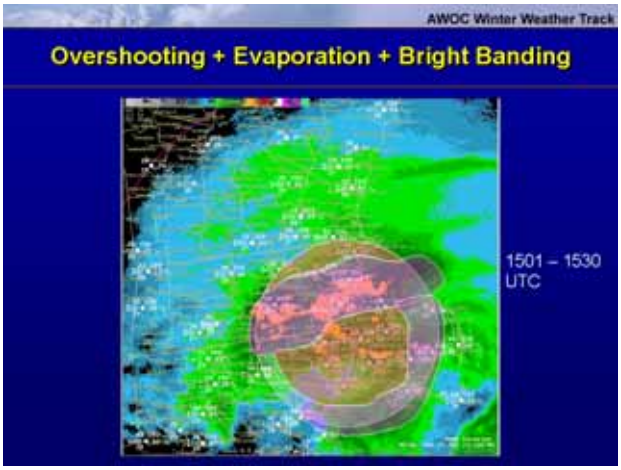
Student Notes:



21. Overshooting + Evaporation + Bright Banding

Instructor Notes: Beam overshooting problems exist outside the white shaded circle. There are likely no significant evaporation errors given the saturation across the radar domain. The most likely areas of bright banding appear in purple. The northern area is where the rain snow line exists at the surface but the errors leach into the wet snow areas to the north. Thus, the only areas of good precipitation sampling most likely exists in the orange areas. The northern orange area is the only area where snowfall is adequately sampled for the 15 UTC time frame.

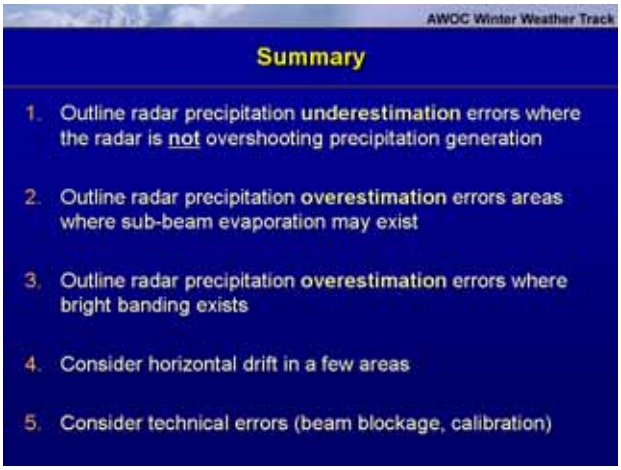
Student Notes:



22. Summary

Instructor Notes: Outline radar precipitation underestimation errors where the radar is not overshooting precipitation generation. Outline radar precipitation overestimation errors areas where sub-beam evaporation may exist. Outline radar precipitation overestimation errors where bright banding exists. Consider horizontal drift in a few areas. Consider technical errors (beam blockage, calibration). Precipitation particle shape and density is the final error source that cannot be directly accounted for except when after considering the first 5 errors. If there is a consistent bias in the precipitation where sampling is good, you may consider the ZS algorithm coefficient to be in error because of precipitation particle shape.

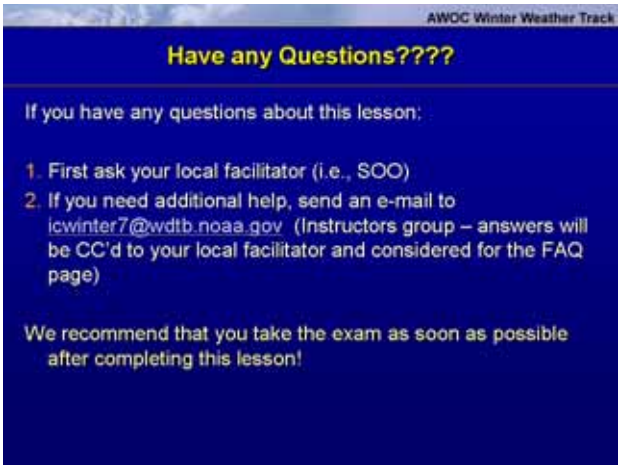
Student Notes:



23. Have any Questions????

Instructor Notes: If you have any questions about this lesson, first ask your local AWOC facilitator. If you need additional help, send an E-mail to the address provided. When we answer, we will CC your local facilitator and may consider your question for our FAQ page. We strongly recommend that you take the exam as soon as possible after completing this lesson.

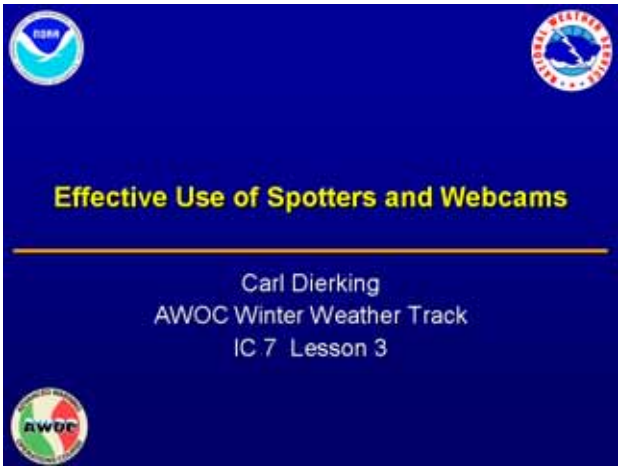
Student Notes:



1. IC7.3: Effective Use of Spotters and Webcams

Instructor Notes: Welcome to AWOC Winter Weather IC7 - Lesson 3 on the effective use of spotters and webcams. This lesson has 25 slides and should take about 15 minutes.

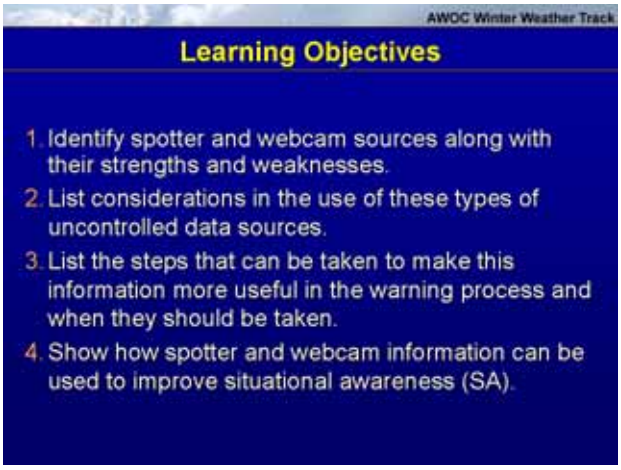
Student Notes:



2. Learning Objectives

Instructor Notes: There are four learning objectives for this lesson. First, we'll identify different sources of spotter and webcam information that can assist the forecast office in monitoring winter storm progress. Students should be able to identify the strengths and weaknesses of each source. Second, we will list some considerations in the use of these uncontrolled data sources and suggest ways to minimize error in interpretation. Third, we will show examples of what can be done to improve the value and usefulness of these types of data, and discuss when would be the best time to do it. Students should be able assess the information source and know what steps could be taken to extract more quantitative data from them. Lastly, this lesson will provide examples of how this information has been used to improve SA while monitoring the progress of a winter storm.

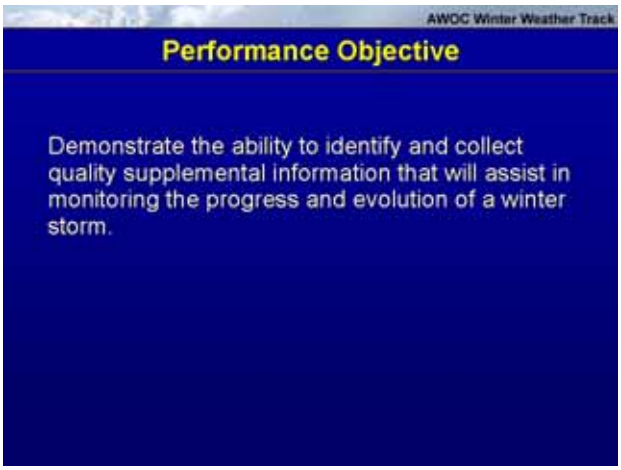
Student Notes:



3. Performance Objective

Instructor Notes: There is only one performance objective for this lesson and that is to demonstrate the ability to identify and collect quality supplemental information that will help you to monitor the progress and evolution of a winter storm. Not all of these sources of information will be of the same caliber, but when time is critical, it is important to recognize where there are deficiencies and what steps may be taken to minimize those deficiencies.

Student Notes:

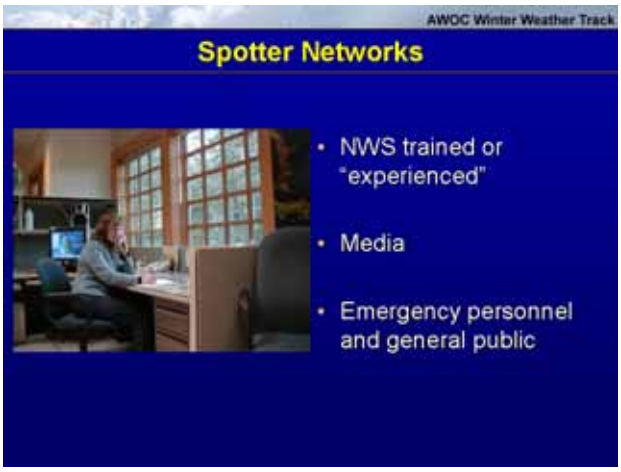


4. Spotter Networks

Instructor Notes: In this lesson, the term “Spotters” is applied broadly to include more than those individuals officially trained by the NWS. Certainly, the most reliable spotter reports generally come from locally-trained NWS spotters. However, often there are other sources of supplemental information. The media can be active participants in your overall spotter network in addition to their role in the dissemination process. Often members of the general public are concerned enough about evolving weather conditions to call a forecast office and relay information about an event. This group may include emer-

gency personnel or other first responders to a weather induced emergency. All of these different groups compose your spotter network that you can use to supplement an official observation database.

Student Notes:



5. Trained or Experienced Spotters

Instructor Notes: NWS trained spotters are usually the most knowledgeable and accurate providers of supplemental observations. They have been trained in the proper method of measuring winter weather elements, such as visibility, snow and ice accumulations, etc. They should know the critical thresholds and are encouraged to be "pro-active," promptly reporting when those thresholds are met. In addition, they often welcome requests for report updates. Recruiting and keeping good winter weather spotters requires a special outreach effort. Some offices maintain an extensive snow spotter networks, sending out mailings each year to recruit new volunteers and to confirm the status of their current network. It takes a lot of work, but it can be critical to operations that deal with mesoscale precipitation events.

Student Notes:

6. Media

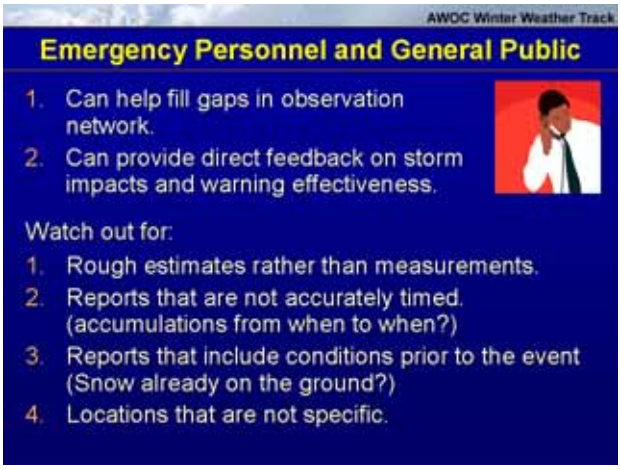
Instructor Notes: The media is a diverse group that disseminates information through a variety of means, including television, radio, newsprint, and the internet. They are valuable partners in the NWS effort to widely distribute weather forecasts and warnings to the public, but they can also be an important source of information about the progress of a serious event. Information that they collect is usually very timely and may be may be accompanied by video, photographs, or eyewitness interviews. They may have their own network of reporters or private spotters. Within their dissemination focus, they are an important distribution outlet. When evaluating media reports there are a few things to watch for: a tendency toward sensational numbers, or the perceived need to add attention grabbers to generate interest in the story; reports that are second-hand or relayed through reporters; reports that are not accurately timed; and limited areal coverage which may be biased toward population centers or the location of a customer base.

Student Notes:

7. Emergency Personnel and General Public

Instructor Notes: Reports from the general public are helpful to fill gaps in the observation network. Often individuals concerned enough to call for information about the event will also be able to relay local information about the impacts of the storm and effectiveness of the warning. It can be difficult to assess the accuracy of these reports, but there are some things to watch for, including: rough estimates rather than measurements (poor visibilities, drifting, and other factors can sometimes result in misleading conclusions); reports that are not accurately timed (i.e. start of snow accumulation); reports that include conditions prior to the event (i.e. snow already on the ground); and locations that are not specific.

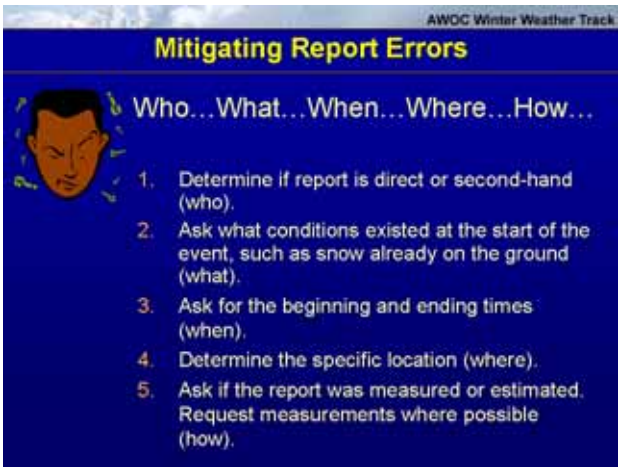
Student Notes:



8. Mitigating Report Errors

Instructor Notes: Whenever a report is received from an unknown source, try to glean as many of the important details as possible to mitigate errors in interpretation. Make sure you have the basic "Who…what…when…where…and how" of the report. Try to determine who took the report. Was it observed by the individual directly or was it second-hand? Ask what conditions existed at the start of the event (for example, was snow already on the ground? Determine when the event started and, if applicable, when it ended. Make sure the location is as specific as possible, and if in doubt ask where the report was taken. Ask if the report was measured or estimated. How was it determined?

Student Notes:



9. Response Question #1

Instructor Notes: Take a moment to complete this response question.

Student Notes:

10. Webcam Data Sources

Instructor Notes: A relatively new source of supplemental observations comes from the rapidly expanding network of internet web cameras. Webcam data can be provided by a variety of sources that include: NWS, other government agencies, commercial, and personal or privately-owned. Each source will have differences in accessibility, image quality, size, update frequency, and, of course, importance to the event.

Student Notes:

11. NWS Webcams

Instructor Notes: There are a few webcams owned, or maintained cooperatively, by the NWS. These are the most flexible cameras to work with since they can be configured to meet the needs of the forecast office. If necessary, the distribution of the images can be controlled. However, the sparsity of the network may not provide adequate coverage for an event.

Student Notes:

12. Other Government Webcams

Instructor Notes: A growing number of other government agencies at the national, state, and municipal level are offering internet webcam imagery. For example, National and State Parks often provide webcam views of some of their more popular scenic sites; the FAA in Alaska provides webcam images of airports and frequently navigated routes; Highway Departments provide views of important transportation routes; and cities may offer a webcam view of a well-known part of town to encourage visitors. Some of these sources may have restrictions on their use, and some may require agreements for special use of the images. However, most agencies are more than willing to cooperate with the NWS on the use of their data.

Student Notes:

13. Commercial/Personal Webcams

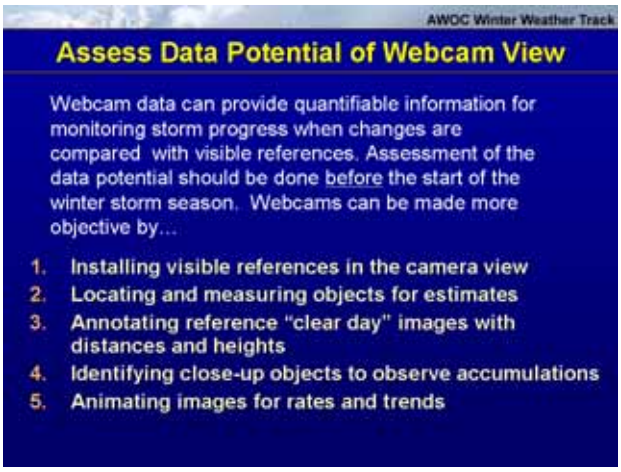
Instructor Notes: The most abundant source of webcam data comes from commercial or privately-owned sources. Some webcam providers may be willing to consider suggestions that would add value to their images and increase their popularity. Often, permission is required for special use of the images, or to get access to restricted images. In one example, WFO Juneau became aware of restricted webcam data that a cell provider had located on several mountain top cell towers. After being contacted, the company was more than happy to make these images available to the local office, and even installed snow stakes at some of the sites. Finally, be sure to credit the source whenever using an image publicly.

Student Notes:

14. Assess Data Potential of Webcam View

Instructor Notes: Webcam data can provide quantifiable information for monitoring storm progress when changes are compared with visible references. Make assessments of the data potential of each image source before the winter storm season begins. Webcams can be made more objective by: (1) installing visible references in the camera view; (2) locating and measuring permanent objects for estimates; (3) making reference images on a clear day with annotated distances and heights; (4) noting close-up objects that can be used to observe accumulations; and (5) animating images for rates and trends.

Student Notes:



15. Extracting Objective Data from Webcams

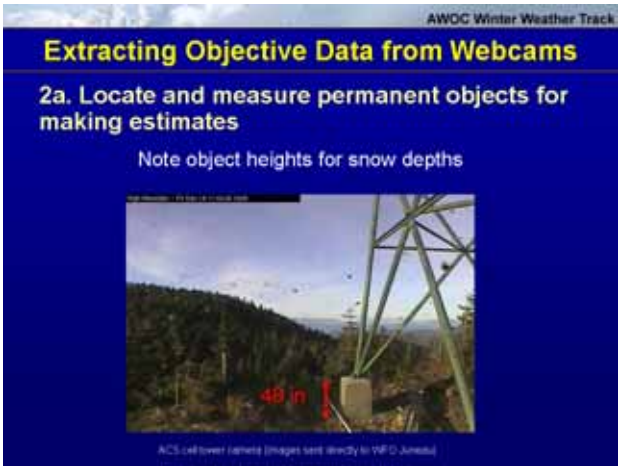
Instructor Notes: Whenever possible, in critical locations, install or note existing visual references that can be viewed in the image, such as snow stakes, windsocks, thermometers, etc. Often webcam owners will consider enhancements that would make their cameras more popular.

Student Notes:

16. Extracting Objective Data from Webcams

Instructor Notes: During a preseason assessment, locate and note permanent objects that could be used as references to estimate changes. For example, the height of prominent objects can provide information about snow depth. If possible, visit the site and make accurate measurements.

Student Notes:



17. Extracting Objective Data from Webcams

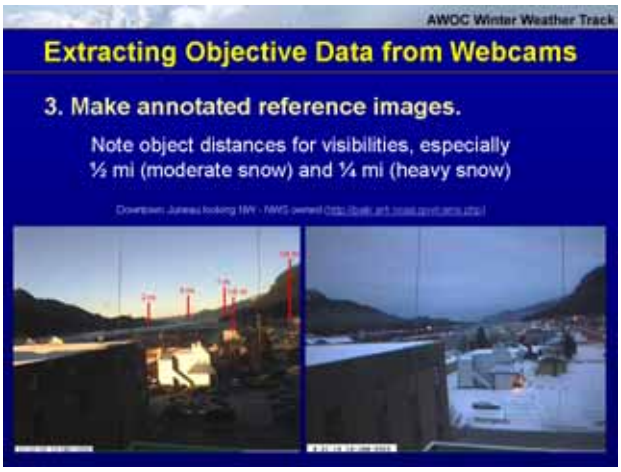
Instructor Notes: Where wind is a concern, look for moveable objects, such as flags, trees, or smoke, that can be used for estimating wind characteristics. Here is an example of a webcam in Rochester, NY that looks over Lake Ontario with a flag in the foreground. In one image it is possible to estimate wind and sea conditions. The Beaufort scale for land offers a helpful description of the amount of movement to expect at certain speeds, although some motion (such as moving tree branches) may require a fairly high sampling rate.

Student Notes:

18. Extracting Objective Data from Webcams

Instructor Notes: Save clear weather examples of each image and annotate object distances for estimating visibility or heights for estimating snow depths. Make sure these images are easy to access and compare with the real-time data. In this example, as snow moves into downtown Juneau, you can watch the visibility decrease to less than 1 mile and the snow intensity changes from light to moderate.

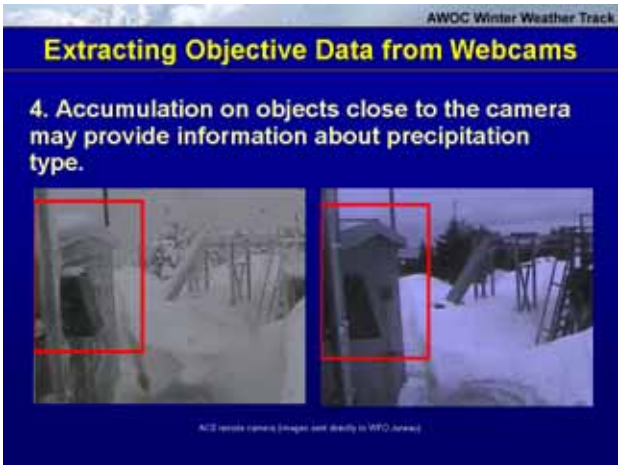
Student Notes:



19. Extracting Objective Data from Webcams

Instructor Notes: Examine exposed objects close to the camera which may provide clues about precipitation type. In this example, it is easy to conclude that the precipitation type had changed from snow on the left, to rain on the right, as the snow and ice disappears from nearby structures.

Student Notes:



20. Extracting Objective Data from Webcams

Instructor Notes: Animate or compare images over time to determine rates or trends. This comparison can also be very helpful in determining when conditions were the most significant. In this example, during a “lake effect” snow event in New York, notice how the snow depth increased over 6 inches in 3 hours, rising from 1.4 feet to over 2 feet between 2 and 5 pm.

Student Notes:

21. Response Question #2

Instructor Notes: Take a moment to complete this quiz question.

Student Notes:

22. Tools for Maintaining SA

Instructor Notes: There are a number of tools available that offer easy access to a webcam image network identified for your area of concern. Some are already being used at National Weather Service offices. This is one example of a web server based “image gallery” that helps maintain SA by collecting images and providing thumbnail overviews of the latest available. Quick access to animation or higher resolution images is available by clicking on the thumbnail or the image name.

Student Notes:

23. Tools for Maintaining SA

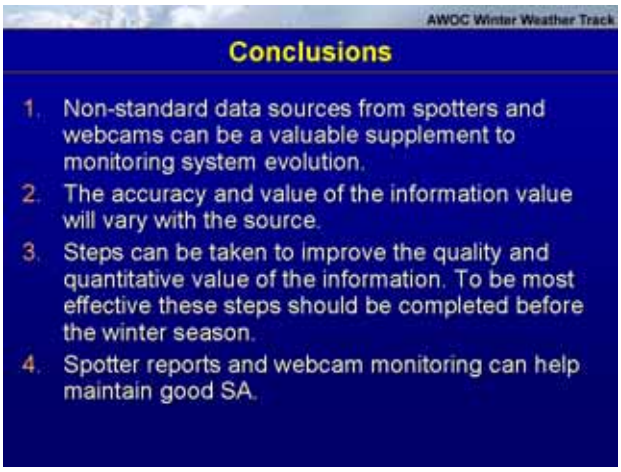
Instructor Notes: Another example of a tool for maintaining SA is the “Hunter/Gatherer” application which is designed to run on a PC. This tool will continually collect a set of images and sequentially display the most recent for each site in the large viewing window. Looping and archiving options are also available.

Student Notes:

24. Conclusions

Instructor Notes: In conclusion, these are the main points to take away from this presentaiton. 1. Non-standard data sources from spotters and webcams can be a valuable supplement to monitoring system evolution by filling the gaps in the operational observation network. 2. The accuracy and value of the information will vary with the source. 3. Steps can be taken to improve the quality and quantitative value of the information. To be most effective, these steps should be completed before the start of the winter season. 4. Spotter reports and webcam monitoring can help maintain good SA.

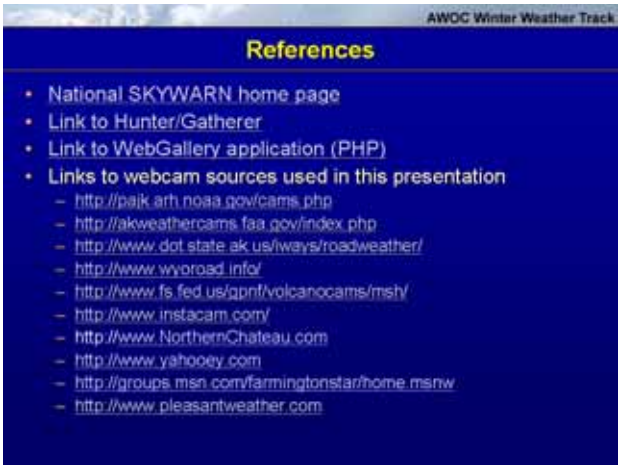
Student Notes:



25. References

Instructor Notes: Here is a list of references cited in this lesson.

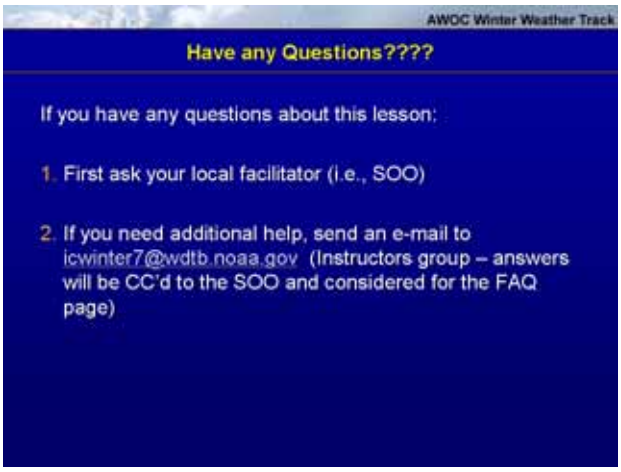
Student Notes:



26. Have any Questions????

Instructor Notes: If you have any questions about this lesson, first ask your local AWOC facilitator. If you need additional help, send an E-mail to the address provided. When we answer, we will CC your local facilitator and may consider your question for our FAQ page.

Student Notes:



IC7.3: Optional Job Sheet

Evaluating Web Cams in Your Area

Objectives:
1) become familiar with weather webcams in your area,
2) evaluate how you would use these webcams in forecasting/warning, and
3) provide a basis for planning future site visits.

Data: Internet

Instructions: Search for weather web cams in your area, and evaluate two of them using the form below. When you are done, give this sheet to your local AWOC facilitator.

1. Locate webcams that may be useful for your area. Conduct an internet search for *weather webcams* using state and/or particular city names (e.g. “weather webcams Alaska)”.

Webcams:_____

_____

_____

2. Pick two webcams that you might use in the future, and analyze their characteristics for potential use using the elements below (if available):

Webcam #1 Name:

Fixed view, controllable:_____

Update frequency:_____

Useful visibility landmarks (0-1/8 mi, 1/8-1 mi, 1+ mi):_____

_____

Trees, flags, smoke for wind estimates:_____

Snow depth:_____

Traffic Monitoring:_____

Other:_____

_____

<u>Webcam #2</u> Name:

Fixed view, controllable:_____

Update frequency:_____

Useful visibility landmarks (0-1/8 mi, 1/8-1 mi, 1+ mi):_____

_____

Trees, flags, smoke for wind estimates:_____

Snow depth:_____

Traffic Monitoring:_____

Other:_____

_____

3. In what ways could you foresee using the webcams in your forecasting and warning duties?

_____

_____

_____

_____

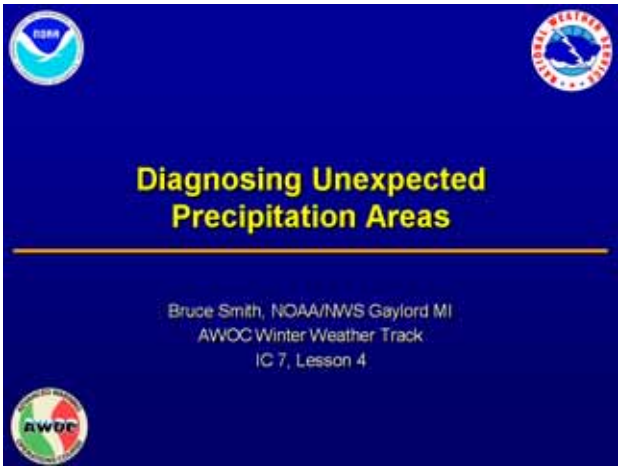
_____

_____

1. IC7.4: Diagnosing Unexpected Precipitation Areas

Instructor Notes: The title of this lesson is “Diagnosing Unexpected Precipitation Areas”. It will take approximately 30 minutes to complete. My name is Bruce Smith, Science and Operations Officer at Gaylord, Michigan.

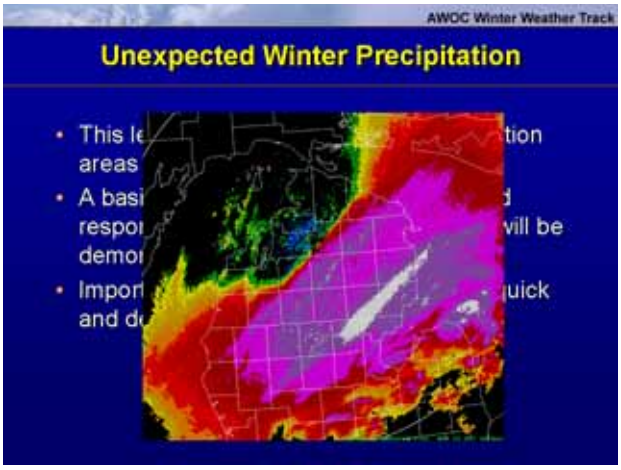
Student Notes:



2. Unexpected Winter Precipitation

Instructor Notes: When winter precipitation develops, or changes character and intensity in ways that differ from the current forecast, it is critical that forecasters work quickly to understand the reason the precipitation is occurring, and to determine how long it will persist, so that winter weather headlines can be accurately addressed. A methodology for dealing with unexpected winter precipitation is covered in this lesson. It is the 4th lesson of Instructional Component 7, “Monitoring System Evolution”. Through the use of a case study, a methodology will be demonstrated to recognize and respond to unexpected precipitation. The role of observational data, and the utilization of effective diagnosis and short term forecasting techniques will be emphasized. Every operational forecaster should be able to efficiently execute this methodology, so that quick and decisive action can be taken to improve the forecast.

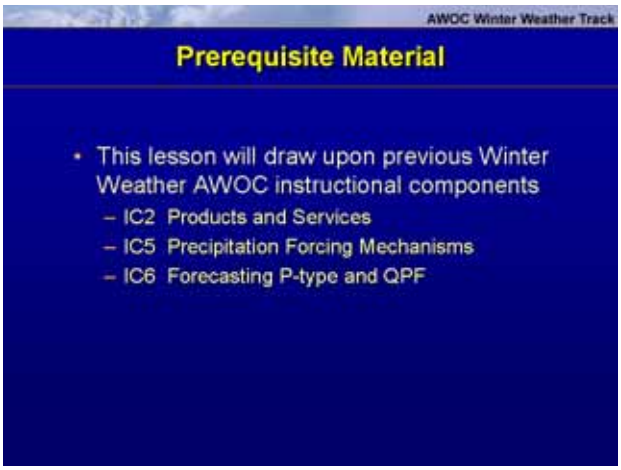
Student Notes:



3. Prerequisite Material

Instructor Notes: The following instructional material previously presented in the Winter Weather Advanced Warning Operations Course can be considered background material for this lesson.

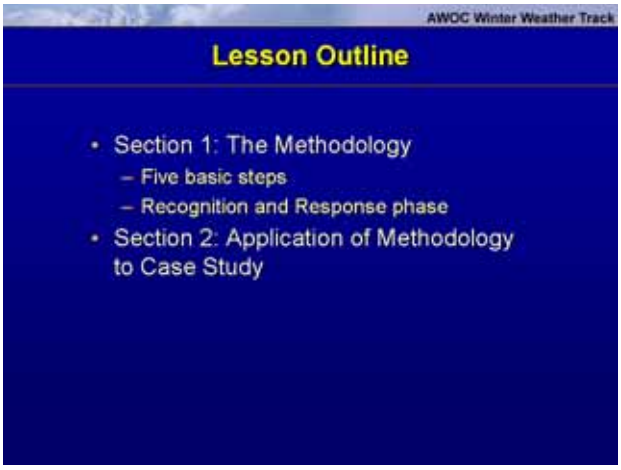
Student Notes:



4. Lesson Outline

Instructor Notes: This lesson will be broken down into two sections. In section one, a methodology for handling unexpected precipitation areas will be described. It is comprised of five basic steps. These steps make up the recognition phase and the response phase of the methodology. Finally, in section two of this lesson, the methodology will be applied to a short case study.

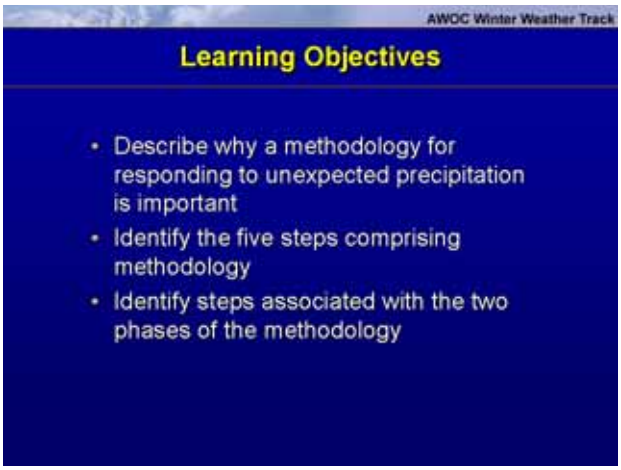
Student Notes:



5. Learning Objectives

Instructor Notes: At the end of this lesson, you will be able to accomplish the following learning objectives: First, you will be able to describe why a methodology for responding to unexpected precipitation is important. Next, you will be able to identify the steps comprising this methodology. Lastly, you will be able to identify which steps are associated with the recognition phase of the methodology, and which are associated with the response phase of the methodology.

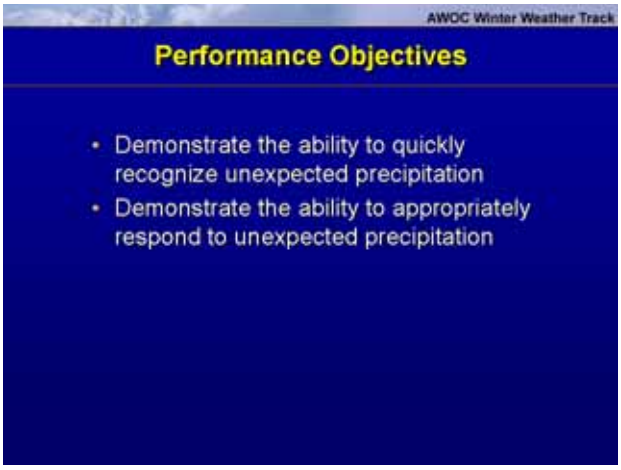
Student Notes:



6. Performance Objectives

Instructor Notes: There are two performance objectives. First, you should be able to demonstrate the ability to quickly recognize unexpected precipitation areas. And second, You should be able to demonstrate the ability to respond appropriately to unexpected precipitation areas.

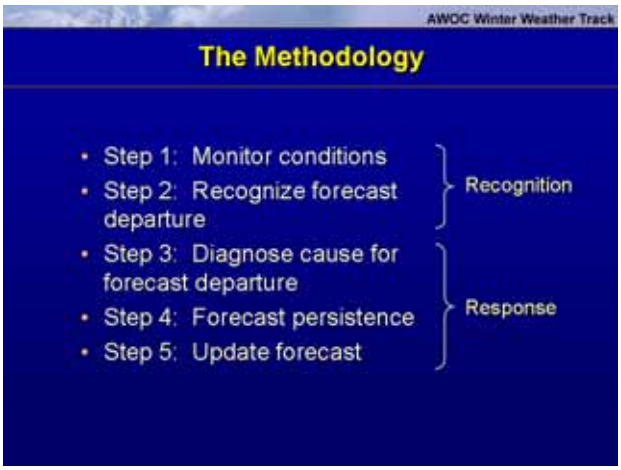
Student Notes:



7. The Methodology

Instructor Notes: As previously mentioned, the methodology is comprised of five elements (or steps). The first two – monitor conditions and recognize forecast departure – make up the recognition phase of the methodology. Forecasters need to recognize as early as possible when departures from the current forecast are occurring. The last three elements – diagnose cause for forecast departure, forecast persistence, and update forecast – represent the response phase of the methodology. Ultimately, the forecast update needs to be scientifically sound, decisive, and timely. Any operational forecaster who has responded to unexpected conditions -- in other words, every forecaster -- should find the methodology essentially review.

Student Notes:

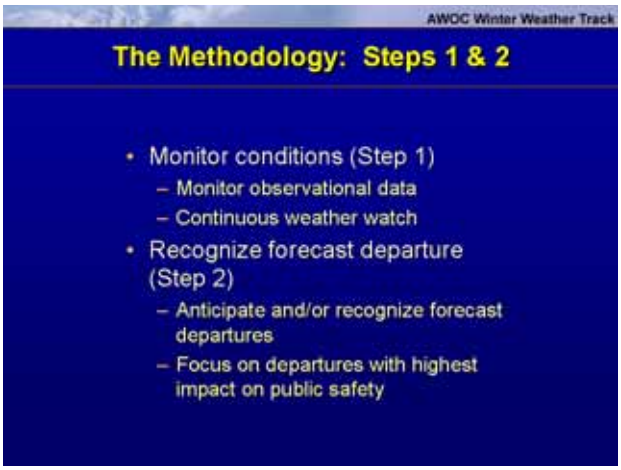


8. The Methodology: Steps 1 & 2

Instructor Notes: The first step of the methodology is to monitor conditions. Within the context of the current forecast, monitor all observational data, including: surface observations, upper air data, satellite data, profilers, webcams, and spotter reports. It is critical for forecasters to maintain a continuous weather watch so that trends in observational

data can be recognized and assessed. Step two is to recognize forecast departures. Ideally, forecasters will anticipate forecast departures prior to their occurrence. However, in other situations, forecast departures won't be recognized until they have already occurred. Examples might include surface reports of freezing rain or spotter reports of unexpectedly high snowfall amounts. Especially during complex weather situations, forecasters should initially focus on forecast departures that could potentially have the highest impact on public safety.

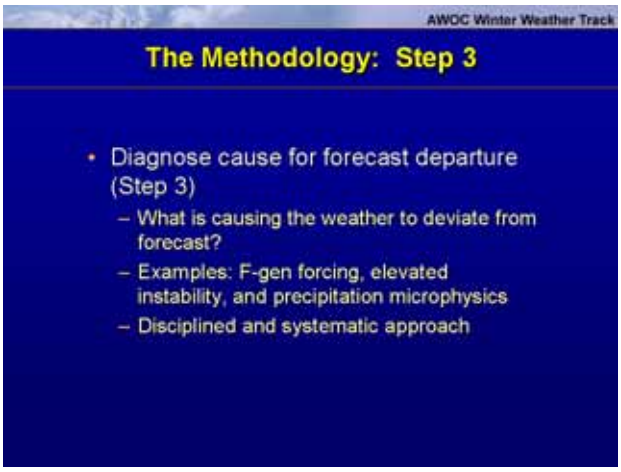
Student Notes:



9. The Methodology: Step 3

Instructor Notes: Step three of the methodology is to diagnose the cause for the forecast departure. In other words, what is causing the weather to deviate from earlier expectations? Banded precipitation associated with frontogenetical circulations, higher precipitation rates due to elevated instability, and unexpected precipitation microphysics are all examples of processes which can cause wintertime precipitation to change character or intensity. As with any diagnosis, forecasters need a disciplined and systematic approach when applying diagnostic tools, conceptual models, and their local knowledge.

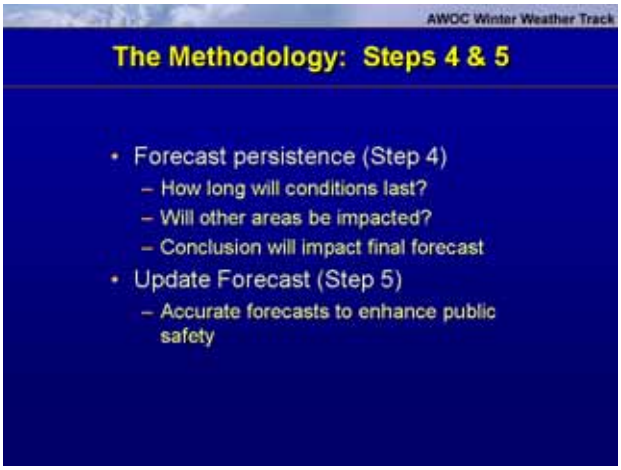
Student Notes:



10. The Methodology: Steps 4 & 5

Instructor Notes: Once the cause for the forecast departure has been accurately diagnosed, the next step (step four) is to forecast the persistence of those conditions. For example, if snow has unexpectedly changed to freezing drizzle due to the disruption of ice processes by midlevel drying, how long will the drying persist? 2 hours? 6 hours? Will the midlevel drying impact other areas? These are the types of questions forecasters need to ask, and to accurately assess, since the answers will impact how the forecast is updated. All of these questions brings us to step 5, updating the forecast. Our ultimate goal (of course) is to provide the most accurate forecasts to help enhance public safety. Steps 4 and 5 of the methodology are closely related, since an accurate assessment in step 4 will directly impact the final response forecasters make in step 5. And without an accurate assessment of the persistence, forecasters will often find themselves playing catch-up with multiple forecast updates.

Student Notes:



11. Question: Five steps of Methodology

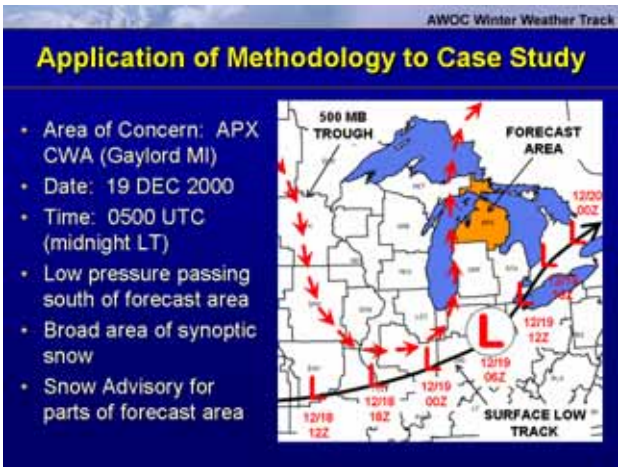
Instructor Notes: Take a moment to complete this interactive quiz question.

Student Notes:

12. Application of Methodology to Case Study

Instructor Notes: We'll now apply the methodology to a short case study. You're at the Gaylord, Michigan forecast office... it's December 19th... the present time is 05 Z, or midnight local time. As the event begins, a deepening 500 mb trough is located over the western Great Lakes, and a surface low (presently over northeast Indiana) is forecast to move across extreme western Lake Erie into southern Ontario. Broad synoptic snow is occurring across the region, and a Snow Advisory is in effect for parts of the forecast area.

Student Notes:

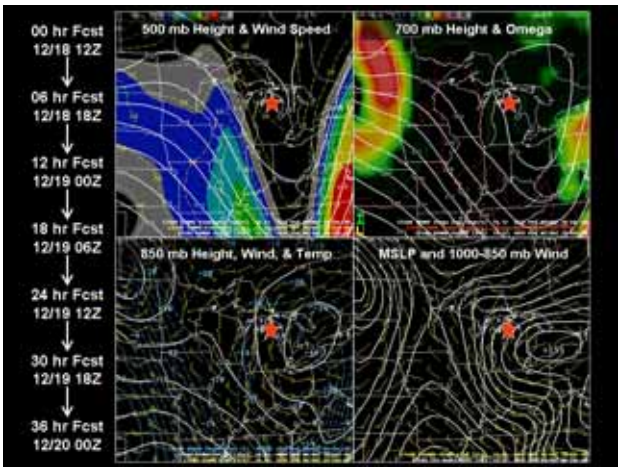


13. Synoptic Overview

Instructor Notes: We'll now step through a 4-panel display from the December 18 12 Z run of the Eta. The 4-panel depicts 500 mb height and wind (in the upper left); 700 mb height and omega (in the upper right); 850 mb height, wind, and temperature (in the lower left); and mean sea level pressure and 1000-850 mb wind (in the lower right). As a point of reference, the red star denotes your location within the Gaylord forecast area. As we move to 18Z December 18 (roughly 12 hours prior to the current time) we see the 500 mb trough deepening over the upper Mississippi Valley, with a 90 kt jet lifting northeast into the Ohio Valley. Similarly, a closed 700 mb low is positioned in the vicinity of Iowa, with an impressive area of 700 mb lift over the western Great Lakes. WAA is noted in advance of the 850 mb low, and the surface low at this time is located near St. Louis. By 00Z December 19, both the 500 and 700 mb lows continue to deepen. Meanwhile, the centers of circulation at 850 mb and the surface have moved into Illinois. By 06Z December 19 (close to the current time), we see the 500 and 700 mb lows near Chicago. Strong 700 mb ascent is noted across Lower Michigan and, not surprisingly, is coincident with the location of the left exit region of the 500 mb jet streak. 850 mb WAA continues to spread into Lower Michigan at this time, as easterly flow develops from the surface through 850 mb. Over Lake Huron, 850 mb temperatures are around -13 degrees C at this time, and with lake temperatures around +4 degrees C, lake enhancement is possible. By 12Z December 19, the 500 and 700 mb troughs are passing through the region,

as the 850 mb and surface lows move into extreme southeast Lower Michigan. The low level flow shifts from east at 12Z...to northeast by 18Z...and finally to north by 00Z as the system pushes steadily off to the east northeast.

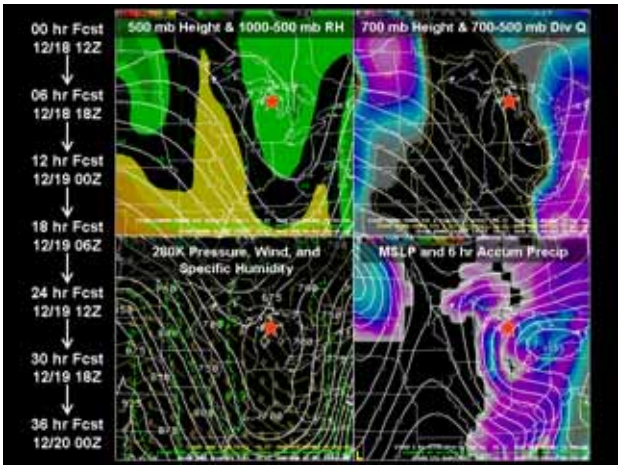
Student Notes:



14. Synoptic Overview

Instructor Notes: Here is another 4-panel display from the December 18 1200 Z run of the Eta. This 4-panel depicts 500 mb height and 1000-500 mb relative humidity (in the upper left); 700 mb height and 700-500 mb Layer Q-vector divergence (in the upper right); 280K Pressure, wind, and specific humidity (in the lower left); and mean sea level pressure and 6-hour precipitation accumulation (in the lower right). Consistent with the previous 4-panel, by 18Z December 18, we see an impressive area of QG forcing for ascent moving into the western Great Lakes, as deep layer (1000 to 500 mb) moisture gradually increases. By 00Z December 19, deep layer moisture and QG forcing for ascent both increase across Lower Michigan. Meanwhile, the 280K isentropic surface suggests isentropic plugged, with specific humidity (a measure of absolute moisture) of 1 to 1 ½ gm/kg at this level. By 06Z December 19 (close to the current time) forcing for ascent appears to be near it's maximum, with both the QG and the isentropic analysis plots supporting strong lift. It is interesting to note that while deep layer relative humidity values are high at this time (exceeding 80%), specific humidity values on the 280 K surface (located between 700 and 750 mb) are only 1 to 1 ½ gm/kg. By 12Z December 19, QG support for ascent is just beginning to shift off to the east, as closed circulations at both 500 and 700 mb move into Lower Michigan. The trend continues at 18Z December 19... QG support has pushed off the east. Similarly, the 280 K isentropic analysis shows that isentropic lift is about to end. And finally, by 00Z December 20, large-scale support for lift has entirely shifted to the east. Eta QPF fields support approximately one third of an inch water equivalent for the 12 hr. period ending 12Z December 19th...with another two tenths of an inch for the 12 hr. period ending 00Z December 20th.

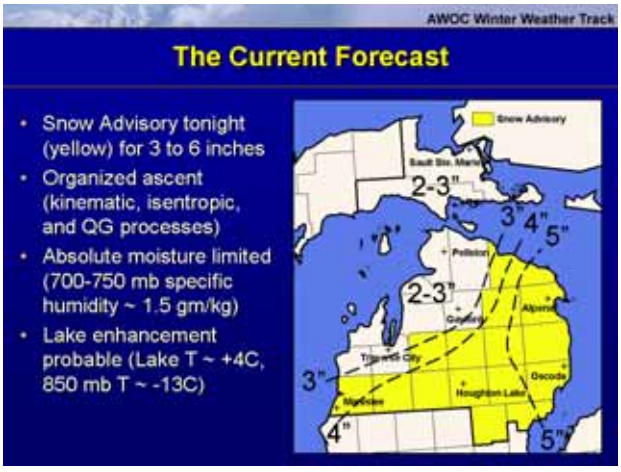
Student Notes:



15. The Current Forecast

Instructor Notes: The current forecast includes a snow advisory for the rest of tonight (depicted in yellow) for eastern and southern portions of the forecast area. Between 3 and 6 inches of snow are expected in this area. As previously noted, organized ascent will pass through the region the remainder of the night, and while deep layer relative humidity is high, specific humidity in the 700-750 mb layer is only approaching 1.5 gm/kg. Some lake enhancement is expected over eastern areas, thanks to easterly low level winds and lake to 850 mb temperature differentials of around 17 degrees C.

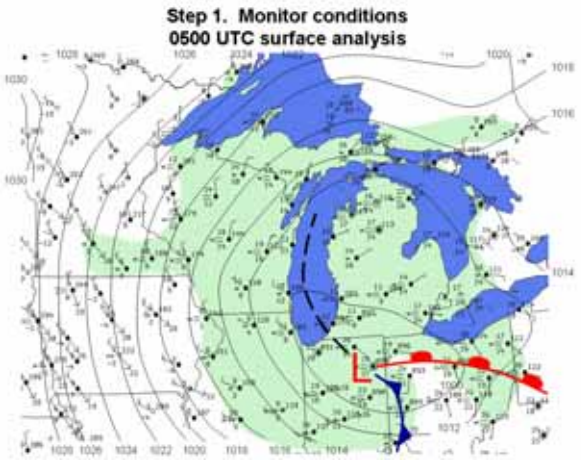
Student Notes:



16. Surface Analysis

Instructor Notes: Now that we have reviewed the current forecast, as well as the supporting model data, we will step through the methodology. As you recall, step one is “monitor conditions”. We begin by reviewing the 05Z surface analysis, which shows the surface low over northeast Indiana. Light to moderate snow is falling across much of Michigan and Wisconsin, as well as portions of Illinois, Indiana, and Ohio. With the exception of one freezing rain report in northern Ohio, all precipitation is falling as snow.

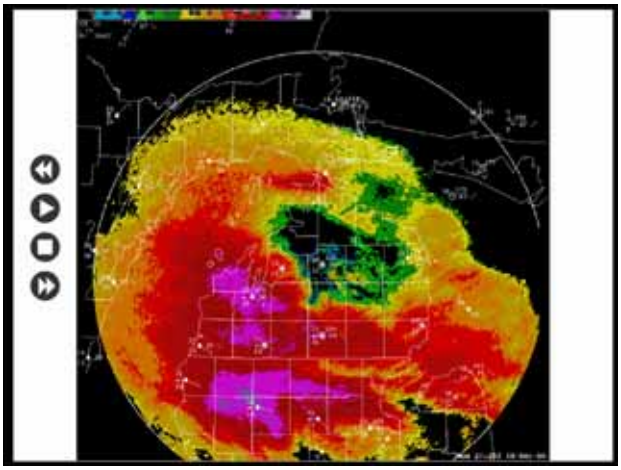
Student Notes:



17. Radar Loop

Instructor Notes: A loop of the Gaylord WSR-88D from roughly 2130 Z to the present time shows snow overspreading the region from southwest to northeast. During this time period, snowfall intensities from a radar perspective don't appear to be particularly high. For the most part, maximum reflectivities are in the 20 to 24 dBZ range.

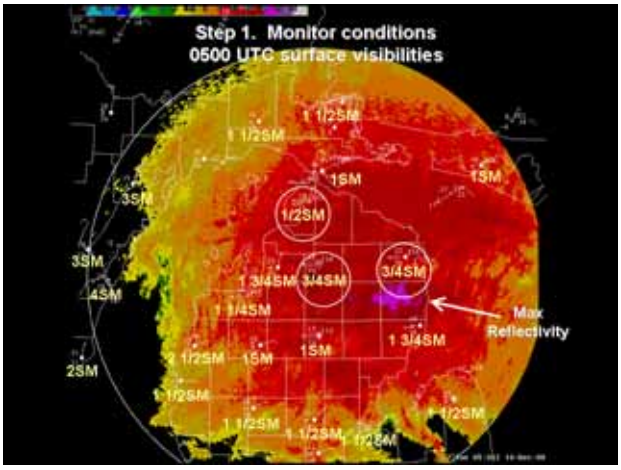
Student Notes:



18. Visibilities

Instructor Notes: Current surface visibilities generally range from 1 to 2 miles across the forecast area, indicative of light to moderate snow. The exceptions are Pellston, Gaylord, and Alpena – where visibilities range from ½ to ¾ mile. It's worth noting that only during the past hour have the visibilities at these locations fallen below 1 mile. At the present time, the highest radar reflectivities are located along the Lake Huron shoreline just south of Alpena.

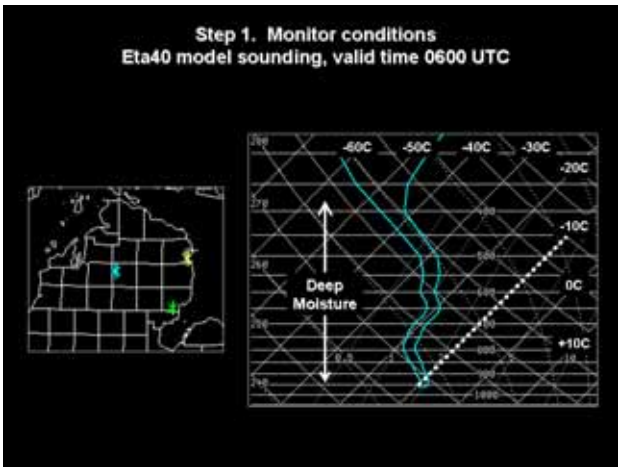
Student Notes:



19. Model Sounding

Instructor Notes: An Eta model sounding for a location near the center of the forecast area, valid at 06Z, shows moisture extending from the surface through approximately 400 mb. From a snow growth standpoint, it is worth noting that nearly the entire sounding is colder than -10 degrees C. This finding is consistent with our previous observation of the relatively cold 850 mb temperatures.

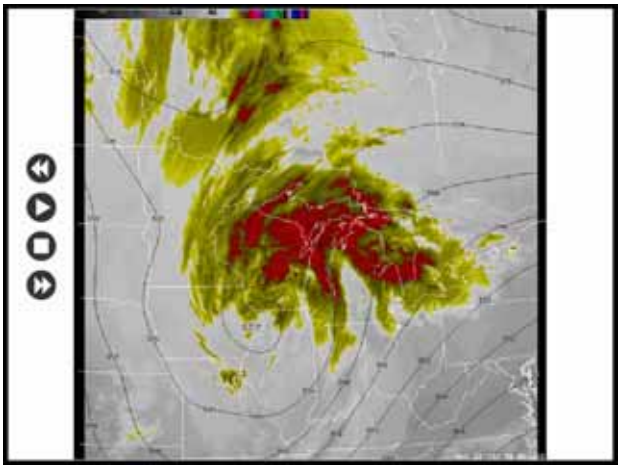
Student Notes:



20. IR Satellite Loop

Instructor Notes: Finally, we conclude step one (monitor conditions) by reviewing IR satellite data. This loop is valid from roughly 2230 Z to the present time. 500 mb heights are overlaid. The mid-tropospheric circulation center is clearly visible, and strong vertical ascent can be inferred from the expanding area of cold cloud tops across the northern Great Lakes.

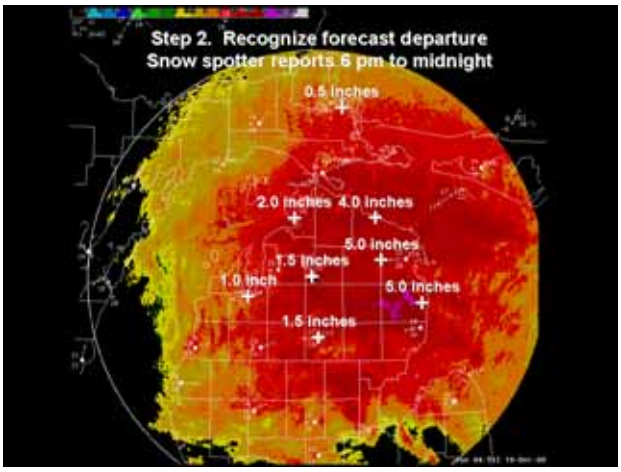
Student Notes:



21. Spotter Reports

Instructor Notes: Next, we move to step 2 -- Recognize forecast departures. While the observational data up to this point has supported widespread snow, nothing has stood out to suggest heavy snowfall. That is about to change as midnight spotter reports begin to arrive. Over central and western parts of the forecast area, spotter reports show up to two inches of snow during the past six hours. These reports are consistent with the current forecast. Over eastern areas, however, spotter reports are heavier. At Rogers City, 4 inches is reported, while 5 inches is reported by two spotters around Alpena. In this case, all spotter reports are considered to be very reliable. With 3 to 6 inches of snow forecast for tonight, and 5 inches having already fallen by midnight in some areas, it appears that forecast snowfall amounts may be underdone, and that warnings might be justified for some counties.

Student Notes:



22. Question: What comes next?

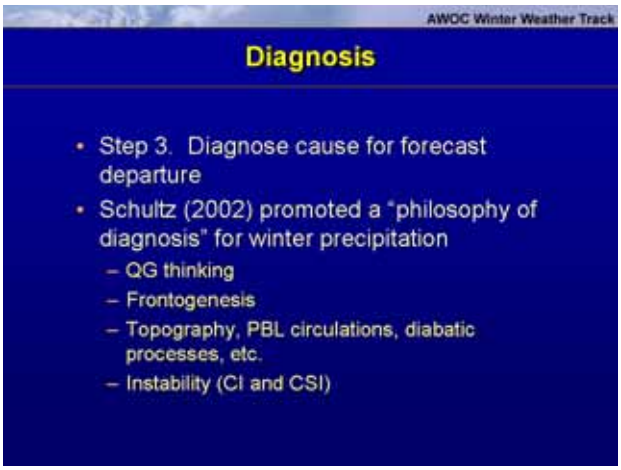
Instructor Notes: Take a moment to complete this quiz question.

Student Notes:

23. Diagnosis

Instructor Notes: In step three, we diagnose the cause for the forecast departure. Schultz (2002) promoted a “philosophy of diagnosis” for winter precipitation. It was suggested that if you see something on radar and you don’t know what is causing it, your first attempt to account for it should be QG thinking (in other words, DPVA and/or warm advection). If QG diagnostics don’t provide an answer, then try frontogenesis at different levels. If frontogenesis fails to account for the precipitation, then try other processes such as orographic lift, PBL circulations, and diabatic processes. The role of instability should also be considered, remembering that it’s affect is to modulate the response to the given forcing.

Student Notes:

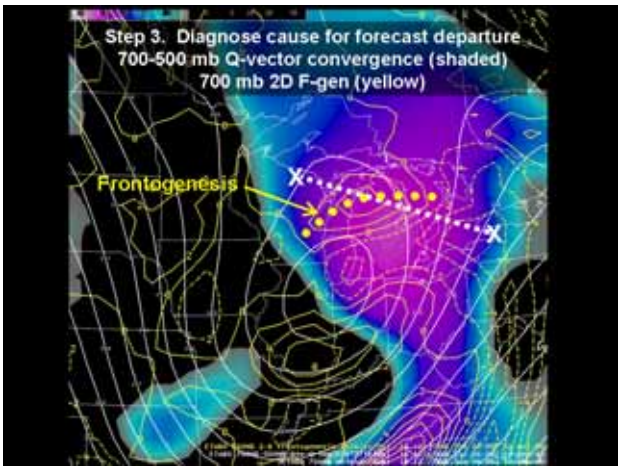


24. QG Forcing and Frontogenesis

Instructor Notes: We’ll now attempt to apply this philosophy of diagnosis to our case study. Shown on this image is 700 mb height contours, 700-500 mb layer Q-vector convergence, and 700 mb 2D frontogenesis – valid at 06 Z. As previously noted, strong QG support for ascent is occurring across the region. Also, note the band of positive Fronto-

genesis oriented west to east across Lower Michigan, in an area likely associated with 700 mb deformation. We'll now construct a cross-section through the area of frontogenesis so that we can better assess the associated forcing and thermodynamic regime. The cross-section will extend from northern Wisconsin to near Buffalo.

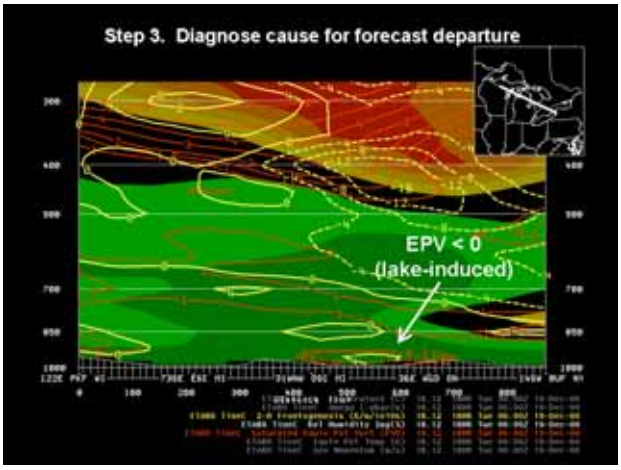
Student Notes:



25. Cross-Section

Instructor Notes: Initially plotted on the cross section is 2-D Frontogenesis (in yellow), and relative humidity (with values greater than 70% shaded green). Note the max in frontogenesis noted previously on the plan view. Model omega is now overlaid. A broad area of ascent is noted near the center of the cross section, with the max ascent (not surprisingly) located on the warm side of the 700 mb frontogenesis max. Model omega, relative humidity, and isotherms reveal an excellent thermodynamic regime for efficient snowflake growth near the center of the cross section (near Lake Huron). Note the juxtaposition of strong vertical motion, high relative humidity, and temperatures around -15 degrees C – consistent with the cross hair signature. A cursory look at equivalent potential temperature and geostrophic momentum shows relatively high static stability above the boundary layer. The relative stability aloft is supported by saturated equivalent potential vorticity (shown in red), which is overlaid with 2-D frontogenesis. Shallow lake-induced instability is noted in the vicinity of Lake Huron. Aloft, however, there is little evidence of instability aloft across northern Lower Michigan.

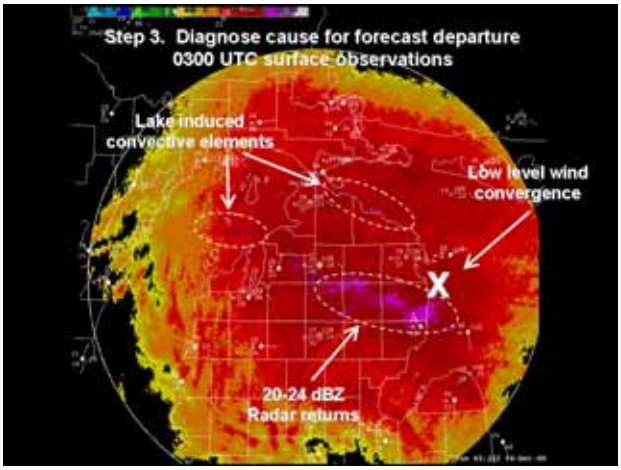
Student Notes:



26. Radar and Surface Data

Instructor Notes: Continuing with step 3 of the methodology we take a closer look at radar and surface observations from earlier in the evening (around 0330 Z). Three aspects of this image are worth noting. First, subtle convective elements can be seen in the radar data embedded within the synoptic snow over northern Lake Michigan and Lake Huron, though radar reflectivities are weak. Next, note the low level wind convergence in the vicinity of Alpena. In fact, the two coastal wind reports and the two Lake Huron ship reports support the existence of a circulation center southeast of Alpena. Lastly, higher radar returns are found south of Alpena, near the location of the spotter reports, and coincident with the cross hair signature previously noted in the cross section.

Student Notes:



27. Question: The critical observation...

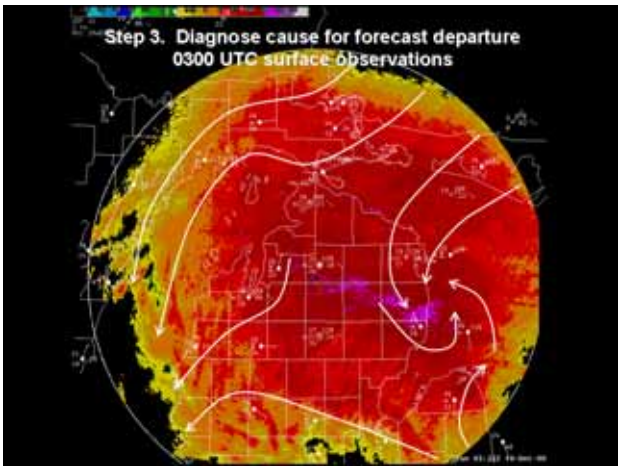
Instructor Notes: Take a moment to answer this question.

Student Notes:

28. Low Level Circulation

Instructor Notes: The low level circulation over western Lake Huron, as revealed by surface observations, is the most likely culprit for the locally heavy snowfall around Alpena. A subjective streamline analysis shows the apparent circulation. Note that the circulation is supported by both of the offshore ship reports, as well as the southerly flow shown in surface observations near the tip of Michigan's thumb.

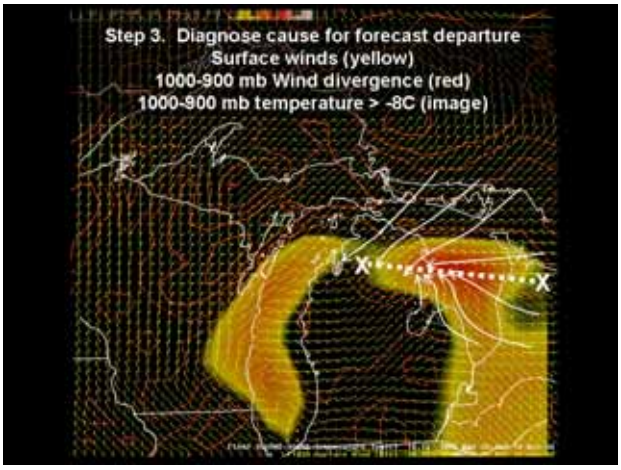
Student Notes:



29. Convergence Over Lake Huron

Instructor Notes: To examine the origin of this low level circulation, we next examine 40 km Eta output of surface wind (in yellow), 1000-900 mb wind divergence (in red – such that the dashed contours show boundary layer convergence), and 1000-900 mb temperature (with values warmer than -8 degrees C shown in shades of yellow and red). We start at 12 Z the morning prior to the event. Note the low level convergence and heat plume over eastern Lake Huron, associated with west to northwest winds over Lake Huron. Initially, the plume remains stationary and, in fact, intensifies. By 00z, as the synoptic low approaches from the southwest, winds become easterly. This causes the heat plume and area of low level convergence to get drawn back to the west across Lake Huron. By 03Z, the heat plume reaches northeast Lower Michigan, and by 06Z the convergence and heat plume are located near the location of the heavy snowfall. A subjective streamline analysis clearly shows the strong convergence coincident with the low level heat plume. We'll now construct another cross section. This time extending from north central lower Michigan across central Lake Huron, to just south of Georgian Bay.

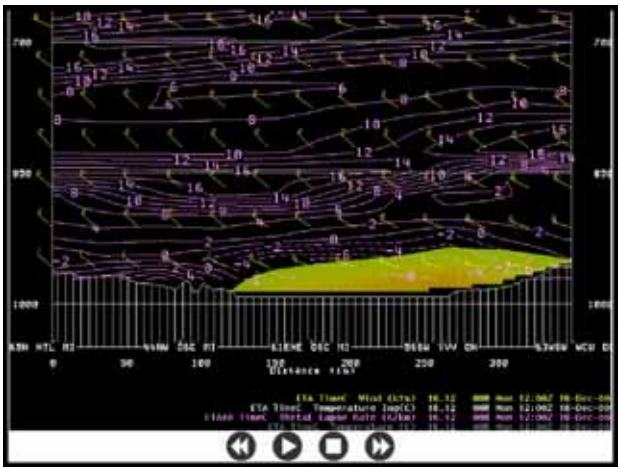
Student Notes:



30. Cross-Section Loop

Instructor Notes: Depicted on this cross-section loop over central Lake Huron are winds (in yellow), theta-e lapse rate (in purple), and temperature (with values warmer than -8 degrees C shown in shades of yellow and red). Lake Huron is at the center of the cross-section. Note that as boundary layer winds become east, the lake induced heat plume intensifies and moves to the west. As winds become north late in the loop, the heat plume shifts back to the east. Also, note the decrease in static stability over north-east Lower Michigan, as depicted by the theta-e lapse rate values. This occurs in response to both the lake induced heat plume, and the strong, synoptic scale ascent.

Student Notes:

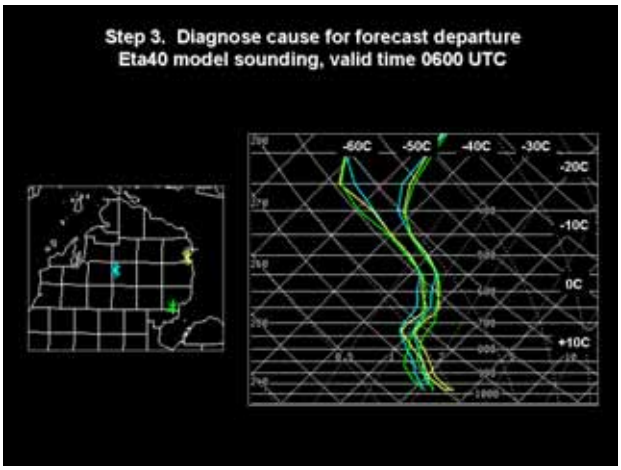


31. Model Soundings

Instructor Notes: We conclude our diagnosis in step 3 of the methodology by looking at three forecast model soundings, all valid at 06Z. The first sounding (in blue) is over the central portion of the forecast area (well inland from the Great Lakes). It shows deep moisture, but with very little of the moisture at temperatures warmer than -10 degrees C. The next sounding (in yellow) is along the Lake Huron shoreline about 60 miles south of

Alpena. It also shows deep moisture, but with a slightly deeper portion of the sounding warmer than -10 degrees C. The final sounding (in yellow) is near Alpena. It shows the boundary layer heat plume, abundant moisture below 800 mb, steeper lapse rates below 800 mb, and an approximately 3500 foot layer warmer than -10 degrees C. In other words, it indicates that in addition to the overlying synoptic moisture, lake-induced processes are also occurring. Compared to the other forecast model soundings, for the reasons just stated, this sounding should be a much better producer of heavy snowfall.

Student Notes:



32. Question: And the diagnosis is...

Instructor Notes: Take a moment to complete this question.

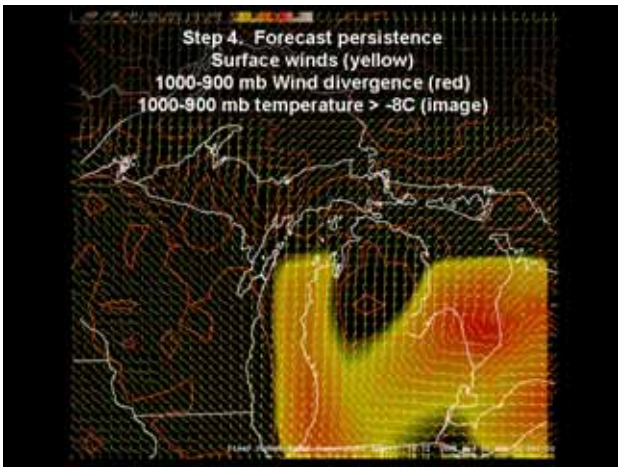
Student Notes:

33. Eta40 Loop

Instructor Notes: Now that we have diagnosed the lake-induced heat plume and convergence over Lake Huron as the main cause for the reports of heavier snowfall, let's move on to Step 4 – which is to forecast the persistence of convergence area. To do this, we'll once again examine 40 km Eta output of surface wind (in yellow), 1000-900 mb

wind divergence (in red – such that the dashed contours show boundary layer convergence), and 1000-900 mb temperature (with values warmer than -8 degrees C shown in shades of yellow and red). At 06Z, the previously noted heat plume and area of strong convergence can be seen just south of Alpena. Moving forward in time, we note that the heat plume remains over northeast lower Michigan, as the convergence slowly sags southward. By late afternoon (or roughly 21Z) the convergence area is forecasted to have weaken. Also, remember that during this time, synoptic lift associated with the large-scale system is pushing rapidly east of the area with the upper trough, so little in the way of large-scale ascent is occurring by afternoon.

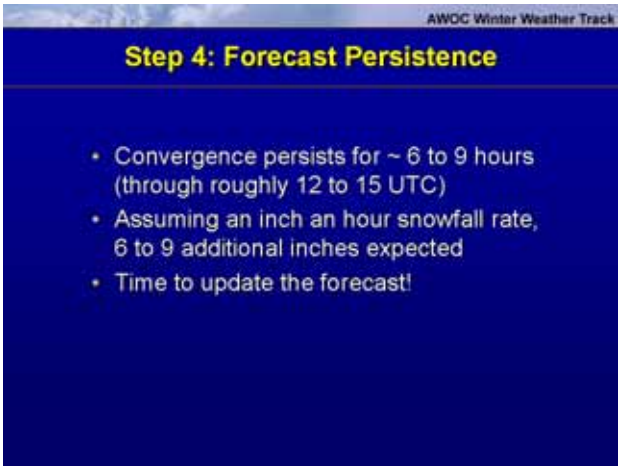
Student Notes:



34. Step 4: Forecast Persistence

Instructor Notes: Based on this very brief assessment, strong convergence and enhanced snowfall rates will likely persist over northeast Lower Michigan (near and south of Alpena) for the next 6 to 9 hours (until roughly 12 to 15Z). Assuming a conservative snowfall rate of an inch an hour...an additional 6 to 9 inches of accumulation can be anticipated near Lake Huron. And finally, the last step of the methodology (of course) is to update the forecast.

Student Notes:



35. Step 5. Update Forecast

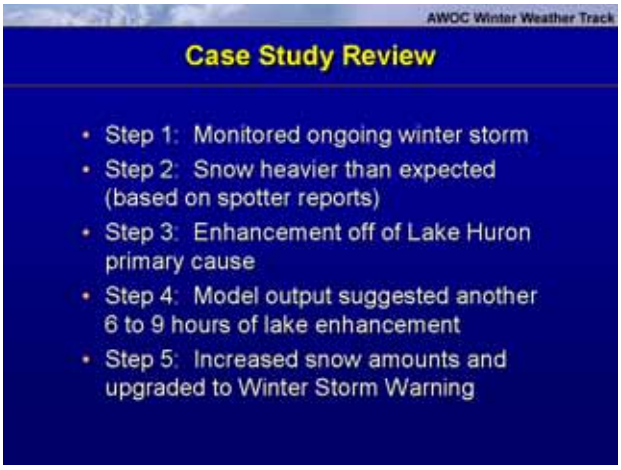
Instructor Notes: As you recall, the initial forecast called for 3 to 6 inches of snow over eastern and southern parts of the forecast, and a Snow Advisory was in effect. Based on the spotter reports and the subsequent assessment of the situation, total snow accumulations of around a foot are now expected by midday over northeast lower Michigan near Lake Huron. Consequently, the forecast will be updated for the higher snowfall amounts, and portions of the Snow Advisory will be upgraded to a Winter Storm Warning – that will extend through about noon.

Student Notes:

36. Case Study Review

Instructor Notes: Let's briefly review how we applied all five steps of the methodology to the case study. In step 1 we monitored conditions (this included surface observations, radar, satellite, and spotter reports). In step 2, based on several spotter reports, we noted that snow was falling heavier than originally anticipated. In step 3, we reviewed several meteorological aspects of the event, and concluded that the heavy snow was most likely being caused by enhancement off of Lake Huron. We determined in step 4 that the low level enhancement would likely persist for another 6 to 9 hours. And finally in step 5, we updated the forecast to increase snow amounts and to upgrade parts of the original snow advisory to a winter storm warning.

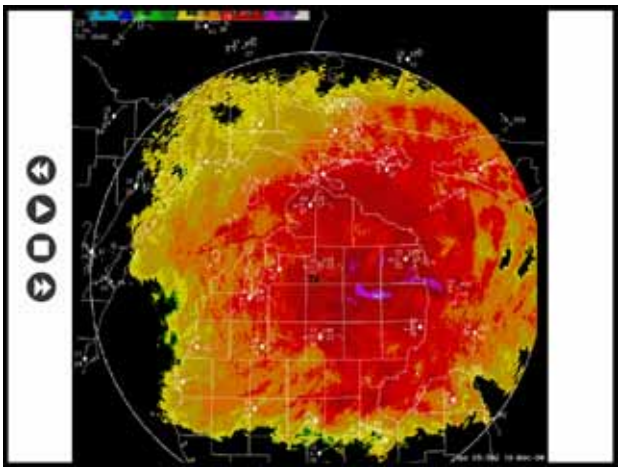
Student Notes:



37. What Happened?

Instructor Notes: You may be wondering what actually happened in this event? A loop of the Gaylord WSR-88D from roughly 06 UTC through 11 UTC reveals a few interesting things. First, note the persistent high radar returns streaming in from Lake Huron near and just south of Alpena. These higher returns coincide very nicely with the center of circulation noted in the surface observations and model data. In fact, by the end of this loop, at least one center of circulation (void of radar returns) can be seen south of Alpena. How intense was the convection? Well, the 09Z observation at Alpena indicated heavy snow with thunder.

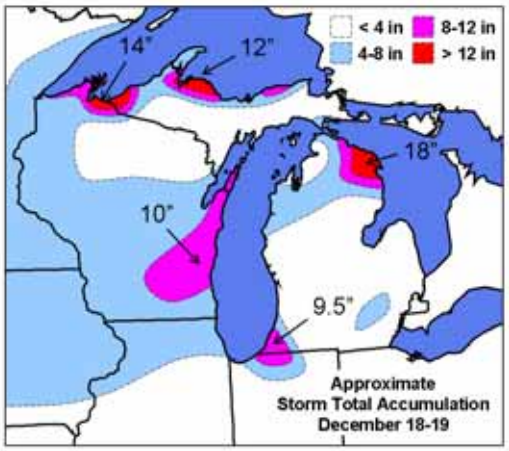
Student Notes:



38. Observed Snowfall

Instructor Notes: From 12 to locally 18 inches of snow during this event over northeast Lower Michigan. Clearly, other parts of the Great Lakes received locally heavy snowfall, as well. In all cases, the enhanced snow occurred downwind of the Great Lakes. Areas receiving heavy snowfall included: parts of Upper Michigan, northern and eastern Wisconsin, extreme southwest Lower Michigan, and northern Indiana.

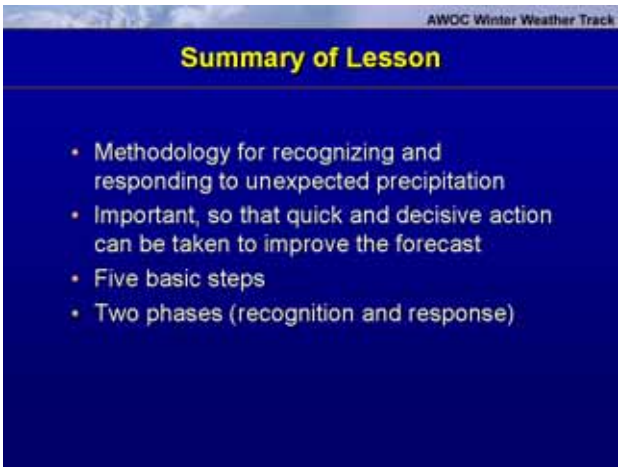
Student Notes:



39. Summary of Lesson

Instructor Notes: In this lesson, through the use of a short case study, we outlined a methodology for recognizing and responding to unexpected precipitation areas. While this methodology is likely intuitive to most forecasters, it is importance so that quick and decisive action can be taken to improve the forecast. As you recall, the methodology was comprised of five basic steps and two phases. The first two steps – monitor conditions and recognize forecast departure – made up the recognition phase of the methodology. The last three steps – diagnose cause for forecast departure, forecast persistence, and update forecast – represented the response phase of the methodology.

Student Notes:

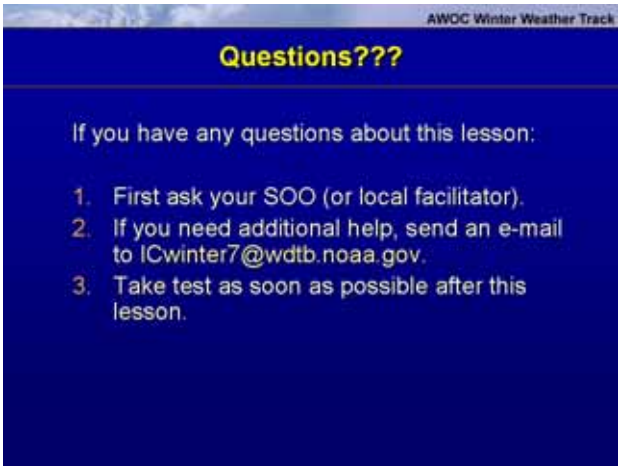


40. Questions???

Instructor Notes: After going through this lesson if you have any questions, first ask your SOO. Your SOO is your local facilitator and should be able to help answer many questions. If you need additional info from what your SOO provided, send an E-mail to the address on the slide. This address sends the message to all the instructors involved

with this IC. Our answer will be CC'd to your SOO so that they can answer any similar questions that come up in the future. Thanks for your time and good luck on the exam!

Student Notes:



IC7.4: Optional Job Sheet

Diagnosing Unexpected Precipitation Areas

Introduction:

Objective: Building off knowledge gained in the IC 7 Lesson 4 training module, examine a winter weather precipitation event and diagnose the reasons for higher than expected snowfall amounts.

Data: 13 February 2004 winter weather event across northwest Texas and southern Oklahoma. You will be using AWIPS D2D for this exercise. **Procedures are available with this case if you wish to use them.** All procedures will be listed in bold in the instructions of this jobsheet.

Instructions:

Load the 13Feb2004 Winter Weather AWOC case on your WES machine in case review mode, using the OUN localization. Set clock to 06 UTC 14 February 2004

Synoptic Overview and Review of Current Forecast:

Load the procedure set called **"IC7Lesson4"** and load in the first entry **"4panel Syn Overview"**. If you choose to load the products on your own, load the following into a 4-panel regional scale layout:

1. 500 mb height and winds;
2. 700 mb height and omega;
3. 850 mb height, wind, temp; and
4. mslp and surface winds.

In another pane, load the procedure from IC7Lesson4 called **"QG forcing Precip accum"** which loads in a 4-panel display:

1. NAM80 500 mb height and 1000-500 mb RH;
2. 700 mb height and 700-500 mb Div-Q;
3. Select isentropic surface that is just below or near 700mb, and load Pressure, Wind, and specific humidity on that isentropic surface; and
4. MSLP and 6 hr accumulated precip.

Question 1. Where is the strongest QG upward vertical forcing located over the next 24 hours (through 00 UTC on the 15th)?

The fictitious graphical snowfall advisory you inherited is shown in Figure 1, valid for 2 AM-6 PM local time (08-00 UTC). Warning criteria in this CWA is 4 inches in 12 hours, or 6 inches in 24 hours. The previous shift felt the snowfall would be just below this threshold, but could be close to exceeding 3 inches in 12 hrs across the extreme southern part of the CWA along the Red River counties.

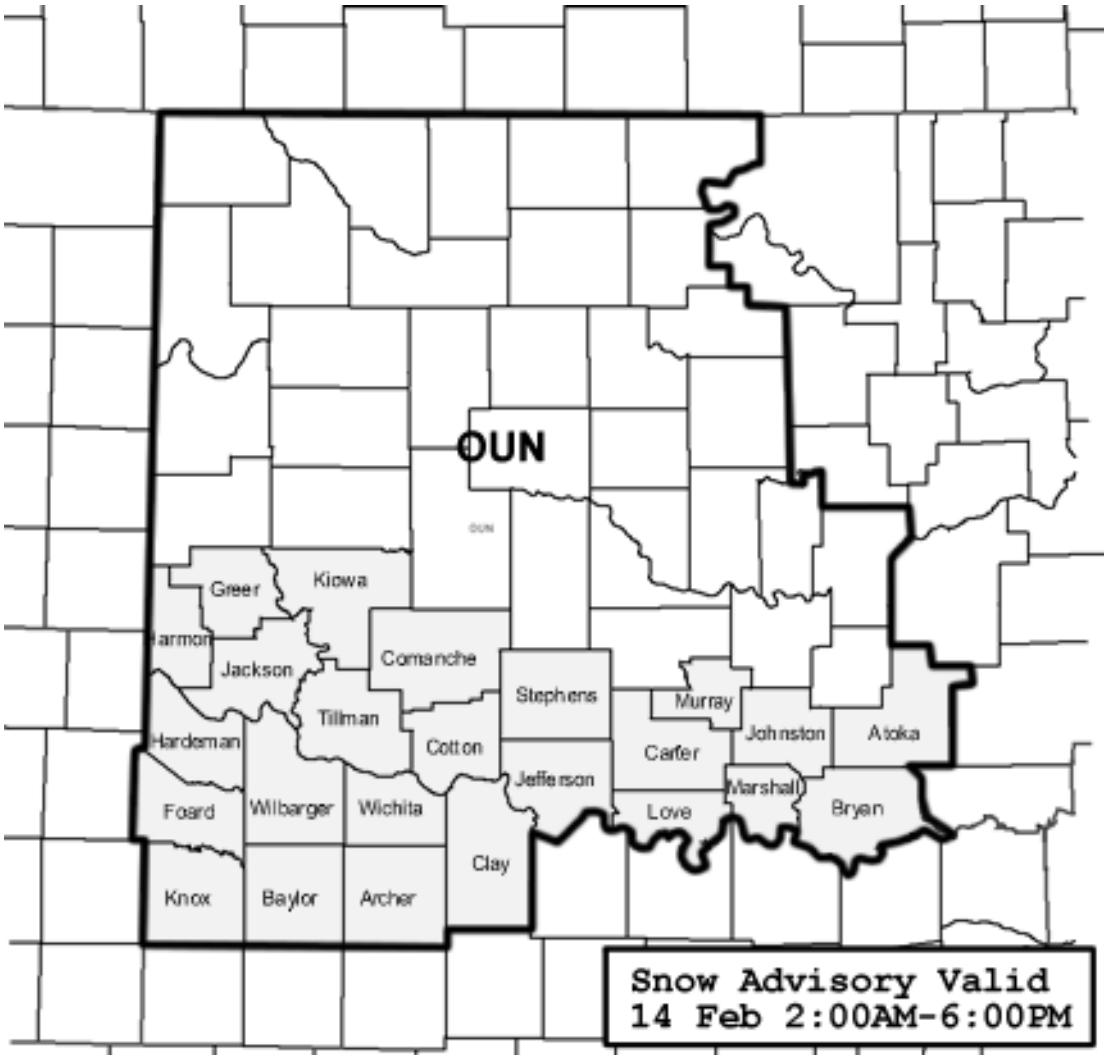


Figure 1. The snow advisory for the OUN CWA, valid 08-00 UTC on 15 February 2004.

Precipitation Diagnosis Methodology

Step 1: Monitor Surface Conditions

Following the methodology in the training module, you will move ahead to a time period during the snow advisory and evaluate the conditions to see if the snow advisory is still the proper product for this event. Set the clocks to 13 UTC 13 February 2004.

Load from the IC7Lesson4 procedure the set named **"NAM MSLP Metars"**, which loads in a single pane layout on the state(s) scale, load NAM40 MSLP and overlay metars.

Load from the IC7Lesson4 procedure the set named **"IR 500mb Heights"**, which loads IR satellite and overlay NAM40 500 mb heights.

Next, load from the IC7Lesson4 procedure the set named **"TLX, FDR and Metars"**, which loads 32-frame KFDR 0.5 reflectivity and toggled with KTWX 0.5 reflectivity and overlaid metars (since it was VCP32/31 with a 32 frame loop you can view ~5 hours of radar data). For a closer examination of the metars in hourly increments, load the set named **"METAR 6 radar frames"**. This loads metars first and overlays the reflectivity images in 1 hr increments.

Question 2. Does the location and intensity of the precip agree with what you saw in the 12 hr forecast from the NAM 80 in the previous step?

Step 2: Recognize Forecast Departure

Figure 2 shows the spotter reports that came in at 7:00 AM local time (also current D2D time), for snowfall totals since the current snowfall began overnight.

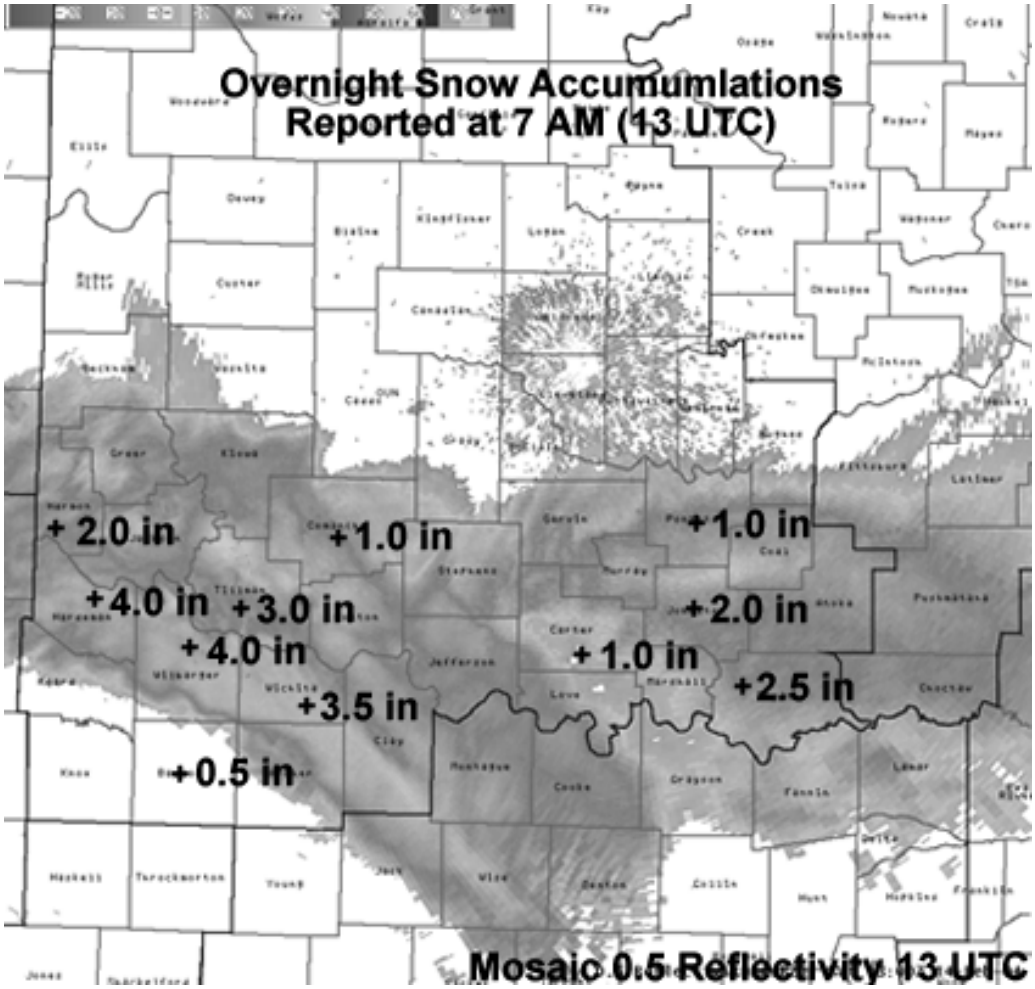


Figure 2. 14 February 2004 13 UTC 0.5 degree mosaic 8-bit reflectivity with overnight snow accumulations reported around 13 UTC overlaid.

Question 3. Are these snowfall totals consistent with the snow advisory currently in effect?

Question 4. Given current trends in radar, which counties will likely see additional snowfall exceed (or likely already has exceeded) warning levels?

Step 3: Diagnose Cause for Forecast Departure

Load from the IC7Lesson4 procedure the set named **"Meso Lift"**, which loads NAM 80 500 mb height, saturated EPV from 700-300 mb, 700-500 mb Div-Q, and 700 mb 2-D Frontogenesis in a state scale plan view window.

To aid in answering question #5 below, you may want to load in a separate window the same products but in a different manner, using the set named **"dprog-dt Meso Lift"**. This loads all available model runs valid at 12 UTC on 14 February 2004. The data are NAM 80 500 mb height, saturated EPV from 700-300 mb, Div-Q 700-500 mb and 2-D Frontogenesis at 700 mb just as you did in the step above.

Question 5. Where is strong QG forcing coupled with frontogenesis, and is it stronger and/or positioned differently than previous model runs?

Using baseline A, set up a cross section through the maximum frontogenesis and along the region of strongest Q-vector convergence, roughly from central Texas north to north central Oklahoma. Then you can load from the IC7Lesson4 procedure the set named **"Xsection Line A"**. This set will load NAM 80 geostrophic momentum, θ_e, saturated equivalent potential vorticity, RH, 2-D Frontogenesis, Omega, and temperature ***along Line A only***, thus the importance of positioning Line A where you want it. You'll have to toggle on and off combinations of products to answer the questions below.

Question 6. What do you notice about the location of the rising motion vs. area of frontogenesis?

Question 7. Is this cross section favorable for efficient snowgrowth in the dendritic growth zone? Where are these conditions most favorable?

Question 8. Is there any instability, and if so, is it favorably coupled with frontogenesis? Where is the instability greatest?

Step 4: Forecast Persistence

Using radar trends, metars, and the cross section analysis, analyze how long you expect the snow to continue across northwest Texas and southern Oklahoma, and which counties will be affected the most or longest. You'll need this information for the final step below.

Question 9. Snow likely to continue through _____UTC.

Step 5: Update forecast

On the original CWA Snow Advisory map provided, indicate where you would upgrade to a Heavy Snow Warning by drawing an **"X"** through the county. Then, draw total expected snow fall accumulation contours on the map. If you upgrade to a heavy snow warning, when will you set it to expire?

Question 10.HSW Expires at: _____ CST

IC7: References

IC7 Lesson 1

None

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IC7 Lesson 4

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