Storm Interrogation

AWOC – Severe Track

IC3

Storm Interrogation Overview

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Layout of IC Severe 3

- 6 Topics with 26 lessons to choose from, NO Exam
- Your training facilitator will require you to take at least six based on what could most benefit you and your WFO
- The 6 Topics Are:

1. ICSvr-I: Updraft Location (Lessons 1-4)
2. ICSvr-II: Updraft Strength (Lessons 5-9)
3. ICSvr-III: Tornado Warning Guidance (Lessons 10-16)
4. ICSvr-IV: Flash Flood Warning Guidance (Lessons 17-19)
5. ICSvr-V: Large Hail Signatures (Lessons 20-23)
6. ICSvr-VI: Damaging Wind Signatures (Lessons 24-26)

You can take as many lessons as you desire: your facilitator will only require a minimum of 6.

IC Severe 3 Performance Objective

- The participant will demonstrate selection of products and proper procedures for effective data analysis in completing storm interrogation strategies for tornadoes, hail, flash flooding, and severe straight line winds.

Lesson 1: Weakly sheared updraft location

- Objective:
  - Determine where to look for severe pulse storm updraft signatures based on the stage in its lifecycle.

This module shows several examples of where the updraft is most likely to be located depending on where in the storm is in its lifecycle.

Not only clues in reflectivity and velocity can help us discriminate between updraft and downdraft within the mid- to upper-level of a convective

cell but also at the source level of initiation, a level which is often overlooked during the cell's initial stages.

Lesson 1 Summary: Pulse storm updraft location

- Reflectivity
  - Updraft is colocated with cores at these locations
    - Under and within new elevate cores
    - Within the top of strong growing echoes (e.g., top of the 55 dBZ echo)
    - In growing strong echoes at temperatures < -10° C
  - Updraft is not colocated with these cores
    - descending high reflectivity cores
    - High reflectivity cores (growing or not) at temperatures > -10° C

Summarizing, Reflectivity

Updraft is colocated with cores at these locations

Under and within new elevate cores

Within the top of strong growing echoes (e.g., top of the 55 dBZ echo)

In growing strong echoes at temperatures < -10° C (this height rises though, in the late lifecycle of a pulse storm)

Updraft is not colocated with these cores

descending high reflectivity cores

High reflectivity cores (growing or not) at temperatures > -10° C

Lesson 1 Summary: Pulse storm updraft location

- Velocity
  - Updraft is located
    - Above the zone of maximum low-level convergence in a developing storm
      - Low-level convergence difficult to spot without gustfronts
    - Between the maximum midlevel convergence and anvil-level divergence in a mature storm
    - From the low-level gustfront convergence sloped to the core's periphery at midlevels for a mature storm

Velocity

Updraft is located (Remember this is most likely located)

Above the zone of maximum low-level convergence in a developing storm

Low-level convergence difficult to spot without gustfronts

Between the maximum midlevel convergence and anvil-level divergence in a mature storm

From the low-level gustfront convergence sloped to the core's periphery at midlevels for a mature storm

For all of these pieces of evidence, none of them are direct measurements of vertical velocity. Also, as a cold pool

spreads out from its axis upon the core reaching the ground, updrafts may grow on a preferred flank of the parent cell,

resulting in a sloped updraft appearance. It is too simplistic really to show a time height diagram of maximum reflectivity and

convergence and say specifically that the entire core is either updraft or downdraft. The flanks of a midlevel core can certainly

be occupied by updraft while its center, downdraft. This is certainly true during the mature stages of a cell. Within the core, what

I can say is that it is likely the core is dominated by either updraft or downdraft.

Lesson 2: Sheared storm updraft shape and location

- Objective: Determine where and what shape the updraft is in a sheared convective cell
  - Specifically, locate the part of the Weak Echo Region occupied by updraft
  - How to determine if a WER exists in fast moving storm

This module builds on the one in which we determine the location of updrafts in pulse storms. Locating the updraft in sheared storms is something that is frequently done by warning forecasters. In this session, we show a methodology that may help your skills in discriminating the updraft size and shape at different altitudes. In addition, we discuss what a real echo overhang and underlying weak echo region is from that which is artificially generated by the volume scan with a moving storm.

Then we show a case emphasizing where in a weak echo region may lie the main updraft of a sheared cell.

Lesson 2 Summary: Sheared storm Updraft location

- Low-levels
  - Facing low-level SR flow side
  - Tight reflectivity gradient
  - Concave shape reflectivity gradient
  - Enhanced velocity convergence
  - WER
- High levels
  - Intense echo overhang (>45 dBZ)
  - On inflow side to mesocyclone
  - Storm summit divergence and echo center
  - BWER core
  - Low spectrum width

To summarize, the updraft location in a sheared storm is more likely than not to tilt with height. Therefore, look for reflectivity and velocity signatures at both low and high altitudes to gain a better understanding of the nature of particular storm's tilt.

At low-levels, you want to look for the updraft on the side roughly facing the low-level storm-relative inflow where there is a tight reflectivity gradient, preferably in a concave shape. You should see enhanced velocity convergence if your lower slices are below 4 to 5000 feet AGL. This area may lie in a weak echo region capped by intense reflectivity overhang. Recall that the echo overhang is not entirely occupied by low-level updraft. But the coincidence of more pieces of evidence at any point, does lead to higher confidence that the echo overhang is updraft.

At higher levels, the intense echo overhang, below an upper-level reflectivity maxima, under the region of strongest storm summit divergence gives you most of what you need to call the area an updraft. Your confidence increases if this area is in a BWER overlaid by high reflectivities, and in the vicinity of a mesocyclone. Remember that mature mesocyclones are partiall occupied by rear flank downdraft, even at high altitudes.

Lesson 3: The nature of the WER

- Objective:
  - Understand the characteristics of a WER
    - Specifically, determine the relationship between the WER and the updraft shape and location
- Motivation: The WER is a critical feature for
  - Determining updraft location
  - Estimating updraft severity

The Weak Echo Region is a storm signature commonly used to assess the severity of and to locate a convective updraft. But exploring the nature of the WER is the objective to be satisfied in this lesson. And specifically, what is the updraft shape and location with respect to the WER?

Lesson 3: WER Summary

- In moderate to strong shear, the WER is partly due to
  - intense storm summit divergence
  - And the updraft itself
- More is needed to locate the updraft in sheared convection

Jim: In moderate to strong shear, the WER is partly due to strong storm summit divergence advecting hydrometeors horizontally into the anvil canopy, and it is partly due to the updraft suspending hydrometeors above the ground. However, in order to locate the updraft itself, we have to do more than solely identifying the WER location. Other sessions in storm interrogation focus more detail on updraft location.

Lesson 4: Sheared storm updraft location via satellite

- Objective
  - As a compliment to, or without radar data, use satellite data to locate an updraft to deep, moist convection in a sheared environment
    - Be able to use satellite data during the day or night

This lesson looks at how to interpret storm top brightness temperature information from GOES to locate the storm top in an environment with significant vertical wind shear. This process may seem straightforward if there is a unique relationship between storm height and brightness temperature. However, that is often not the case. We will look at how you can locate a storm top even if cloud height and brightness temperature are not colocated.

Lesson 4 Summary: Sheared updraft detection by satellite

- Positive lapse rate above EL
  - Updraft summit height and IR brightness temperature well related
- Negative lapse rate above EL (inversion)
  - Updraft summit height and IR brightness temperature may **not** be well related
- Small overshooting tops will be poorly resolved by 4km GOES IR
- Parallax correction needed

When there are positive lapse rates above the EL, there is good agreement between updraft summit height and IR Tb.

When the lapse rates become negative (inversion), the Tb minimum gets displaced upwind. In some cases, there might not be a Tb minimum.

Small overshooting tops are likely to be unresolved by satellite and therefore, you need to look at the upwind side of the anvil relative to the storm-relative anvil layer flow.

Lesson 5: Upper-level Z core height and intensity

- Objective
  - Provide guidance on assessing the potential for an updraft to produce severe weather based on the height and intensity of the upper-level reflectivity core

The primary objective of this lesson is to provide you guidance on assessing whether an updraft may lead to severe weather based on the height and intensity of the upper-level reflectivity core.

Much of the guidance will be based on the same principles on which the Hail Detection Algorithm or HDA, is based. I believe you will find this useful since this technique uses the height and intensity of the reflectivity core above the 0° and -20° C levels, and therefore helps to account for widely varying severe weather scenarios.

As a companion to this lesson, we have provided you a tool in which you can enter in your own reflectivity values, the heights of those values, the 0° and -20° C heights, and the height of your radar so that you can use this tool to help determine how to apply this lesson to real world examples in your CWA.

Lesson 5: Summary

- Updraft intensity likely stronger as the height of 50, 55 dBZ core increases.
  - Warning performance (CSI) peaks at a certain altitude
  - That altitude depends on your thermal profile
- Presence of > 60 dBZ above the freezing level give strong likelihood of some type of severe
- Use the HDA worksheet to account for
  - different thermal profiles
  - Storm updraft dominant phase

To summarize, we've seen strong evidence of how strong the relationship between severe weather likelihood and the height of the upper level reflectivity core can be. We've also seen a case where a strongly initiating storm results in a large hail indication as a function of its intense upper-level reflectivity core and yet VIL density understates the storms intensity. Conversely, we've seen a storm with a high hail signal but where the reflectivity profile falls off in the sub -20° C air resulting in a low VIL density, and perhaps correctly.

In either case, a strong updraft should contain strong reflectivities, and those reflectivities should extend well into the sub -20° C air and close to the equilibrium level.

Lesson 5: Summary cont'd

- Updraft intensity that governs potential for severe
  - Hail size through lofting larger hailstones
  - For severe winds, precipitation loading
- Updraft intensity not the only factor
  - Hail size also a function of updraft width, trajectory paths
  - Severe microbursts a function of DCAPE even more than CAPE

Updraft intensity increases the odds of severe weather as it is capable of lofting larger hailstones, and increasing downdraft intensity through heavy precipitation loading.

Remember that updrafts evolve through time and looking at storm trends to discern when the maximum updraft intensity is the most important consideration. Also note that hail takes time to grow, and in the process traverse through complicated 4 dimensional paths, something that the HDA or these techniques do not consider. And remember that downdraft and outflow intensity is not solely a function of updraft intensity.

Lesson 6: Updraft strength– Low-level convergence

- Objective
  - Understand the contribution of low-level convergence to CAPE on updraft intensity

At the end of this presentation, you should understand the contribution of low-level convergence to CAPE on updraft intensity

You may not be able to provide specific values on how strong an updraft is likely to be, but you will have gained an appreciation in how updraft strength can be significantly enhanced beyond what the theoretical CAPE can provide in certain situations.

Lesson 6 Summary: Pulse storm updraft

- Convergence adds vertical velocity to the peak updraft expected from buoyancy alone
- Convergence depth and magnitude modulate the strength of the updraft
- Caveats
  - Updraft must reside over convergence to realize its vertical velocity
  - That means boundary-relative storm motion needs to be small

To summarize this event, the boundary collision may have added up to 8 kts of vertical velocity to the base of the convective updrafts. In addition, large plumes of moisture have been advected upward to produce a much stronger base for buoyancy to continue the initiation process. The result was a more intense set of thunderstorm updrafts than the initial storms that created the original cold pool boundaries in the first place.

There are some caveats to everything. First, the convective layer steering flow must be such as to minimize boundary-relative storm motion in order to generate the strongest, deepest updraft possible. Deep layer shear should be optimally balanced with the motion of the gust front to generate a deep overturning convective current. In this event, shear is not a consideration in the environment, storm motion was small, and the updraft generated by the boundary collision was likely upright and deep.

Lesson 6 Summary: Strong shear severe storm

- Updraft strength profile is maximized due to
  - Strong convergence (ΔV>50 kts over a few km)
  - Deep convergence (>3 km or 10 kft)
  - Low boundary-relative storm motion
    - Storm matching cold pool speed

Summarizing, this boundary moving at 50kts resulted in some incredible convergence, especially considering that the ground-relative low-level inflow was out of the southeast. This convergence was also deep (3 km) and the matching vertical velocity was calculated at 30 m/s at 3 km. The convective layer storm motion allowed the deep updraft to maintain its footing close to the vertical velocity generated by the convergence zone and the result was a deep overturning updraft capable of generating all the features associated with a high end severe squall line including tornadoes, severe low-level winds and excessive rainfall rates. Very severe hail was not something found in this event for many reasons. One of them may be that squall line updrafts tend to flatten out at lower altitudes than for more isolated modes of convection in similar environments.

Lesson 7: Severe updraft structural signatures

- Objective: Understand how the following signatures are an indication of, or contribute to severe updrafts in convection
  - WERs
  - BWERs
  - Stormscale velocity

This session adds onto the session on the height of reflectivity profiles. For sheared storms, however, signatures appear that are unique to this class of convection. The objective in this lesson is to understand the signatures in reflectivity and velocity that indicate a severe updraft is in progress. Again, what is meant by severe updraft is one that is often accompanied by large hail, severe straight line winds. As a performance objective, you should understand how Weak Echo Regions, Bounded Weak Echo Regions and stormscale velocity patterns contribute to recognizing a severe storm.

Lesson 7 Summary: Severe updraft signatures

- severe updraft signatures common to all storms in order of most severe first
  - BWER
  - WER
  - Intense reflectivity core, and deep relative to the –20° C level
  - Storm top displaced over WER
  - Deep convergence zone

Summary: Severe Updraft Signatures

The most severe updraft signatures tend to have these features common, even for linear systems.

- BWER
- WER
- Deep, intense reflectivity cores * *Severe linear updrafts tend to have somewhat shallower cores than discrete severe updrafts
- A storm top displaced over the WER
- A deep convergence zone** **This is a weak requirement as many discrete severe updrafts may not exhibit this. For example, classic or Low Precipitation (LP) supercells mostly fail to show any deep convergence and yet have extremelyi ntense updrafts.

Lesson 8: Estimating updraft intensity with satellite: part 1

- Objective
  - Use satellite data to qualitatively estimate updraft strength in the absence of radar data based on
    - Cloud top growth rates determined from temperature and the D2D cloud height estimation tool
    - Temperature and height of the storm equilibrium level

As a motivation for this lesson, there have been times when offices are stripped of radar data for various reasons. Satellite data can provide a useful backup, or as a tool of confirmation.

The objective of this lesson is to qualitatively estimate updraft strength from satellite based on two major parameters that you have the capability to evaluate

1. The cloud top growth rate in terms of time trends of cloud top temperature and height.
2. Temperature and height of the storm Equilibrium Level (EL)

Both of these parameters, you can evaluate for yourself using the D2D cloud height estimation tool.

We will discuss this more later in this lesson.

Lesson 8: cloud top cooling rates

- The peak cloud top cooling and ascent rate for the storm should be used
- Different criteria before and after storm produces an anvil

Storm B went on to produce 70 mph winds and 1” hail. No reports came in for Storm A, although I caution that storm A originated over relatively unpopulated territory and there may have been unreported severe weather at the surface.

Note that we used the peak cooling rates prior and after anvilgenesis for the lifetime of a particular single or multicell event.

Remember that cooling rates pre- and post-anvil are distinct and should be treated separately.

Lesson 8: cloud top cooling rates (contd)

- Cooling rates are dependent on image temporal frequency
  - Faster scans usually result in higher growth rates
  - Really need 30 second scanning to capture individual updraft growth spurts
- Best to make relative comparisons
- Another technique next

There are real problems using this technique, the worst of them is the uncertain image time interval. Cooling rates can be more a function of image frequency than anything real. A good check

The optimal frequency should be 30 seconds, which the GOES satellites have done under research operations.

Probably the best way to assess cooling rate is to compare cooling rates between storms in a similar environment.

The next satellite-based updraft intensity technique may help a bit to account for image frequency problems.

Lesson 8: Anvil T_{eql}

- Strengths –
  - Allows you to approximate the theta-E the updraft is realizing.
  - Relative strengths between storms
- Limitations
  - Required anvil exposure to undisturbed environment
    - Storm complexes push the equilibrium level higher
  - T_{eql} and height ambiguity in isothermal layers and inversions at the equilibrium level

To summarize, assessing the satellite based EL temperature can give you clues as to the θ_e in the updraft column, and therefore how well the storm is utilizing the θ_e found in its environment. Use this technique to assess relative updraft strengths between adjacent storms. But be careful. The storm anvil should be exposed to undisturbed environment free of pre-existing anvils. Equilibrium temperatures may also lose their relation to anvil height where isothermal layers or inversions exist across the EL.

Lesson 9: Estimating updraft intensity with satellite: part 2

- Objective
  - Utilize the following satellite signatures to assist radar in estimating updraft strength and severe storm potential
    - overshooting top characteristics,
    - presence of an enhanced-V,
    - anvil shape vs. storm-relative anvil-layer flow,
    - and anvil top temperatures.

This objective uses a case to highlight how the following signatures can be used to assist radar in estimating updraft strength and severe storm potential. We will mention:

•Overshooting top characteristics,

•enhanced-V signatures,

•anvil shape vs. storm-relative anvil-layer flow,

•and Anvil top temperatures.

We will also look at the radar presentation of this storm and some near storm environmental information.

Lesson 10 TWG: mesocyclones

- Objectives
  - Interpret mesocyclones and how they fit into providing the necessary tornado ingredients given radar sampling limitations
  - Know how the overall tornado warning skill scores may be related to mesocyclone strengths
  - Understand the impacts of radar sampling on mesocyclone strength and strength trends

The main objectives center primarily on how mesocyclones fit into satisfying the ingredients for tornadogenesis, what the most effective parameter is, and how effective it is at discriminating tornadic from nontornadic mesocyclones, and how sampling affects its strength and when to know If a trend in rotational velocity is real.

Lesson 10 Summary: Mesocyclone sampling

- Radar observed mesocyclone rotational velocity decreases as range of a constant intensity mesocyclone increases
- Uncertainty of trends in rotational velocity increases with increasing range
- However, the best warning performance using thresholds of rotational velocity seem to peak at 51-100km (30-65 mi) range.

In summary, radar observed mesocyclonic V_r decreases with range.

Uncertainty in V_r trends increases with range as the angular separation becomes more important.

Tornado discrimination potential of low-level V_r represented by the Heidke Skill Score, HSS peaks at 51 to 100 km in range.

It is important to know what is a real change in mesocyclone strength trend and what is a spurious artifcact of radar sampling.

Remember though that the mesocyclone diameter also can change with time and this fact will influence further what a real trend may be. Meoscyclones often contract prior to and during tornado time. The impact on sampling may result in the appearance of a mesocyclone weakening or going through more volatile trends during this contraction. Be mindful of this when it does happen.

Level 11: Storm scale signatures considered in tornado warnings

- Objectives
  - This lesson is intended to be an overview of common storm scale signatures associated with tornadogenesis. In particular:
    1. Discuss the ingredients for tornadogenesis
    2. Determine the range of low-level velocity difference that leads to good tornado discrimination in a TVS signature

This is intended to be a review of tornado precursor signatures for the most part. As a first objective this lesson presents the signatures and how they relate to the ingredients for tornadogenesis. In some contexts, the storm scale signatures we can detect are directly related to the ingredients for tornadogenesis. In other contexts, the role of these same signatures in contributing to the ingredients for tornadogenesis are still in the realm of the unknown.

As a second objective, this lesson covers the range of low-level velocity difference that lead to good tornado discrimination in a TVS signature based on the Tornado Warning Guidance (TWG) project conducted by the National Severe Storms Laboratory (NSSL) in 2001 and 2002. The results for the TVS velocity attributes were also extended to mesocyclone signatures, and near storm environment parameters. This lesson also mentions the ability of mesocyclone rotational velocity to discriminate tornadic from nontornadic storms. However, another lesson in IC3 delves into mesocyclone signatures and sampling in more detail.

Lesson 11: Storm scale signatures considered in tornado warnings

- Objectives (cont'd)
  3. Determining the relationship between the TVS and the tornado cyclone
  4. Recognize signatures conducive to vortex stretching
  5. Recognize common storm interactions observed with tornadogenesis in the past
  6. Understand what is not known in the relationships between the storm scale signatures in this lesson and ingredients for tornadogenesis

This talk also covers the relationship between the TVS signature and the tornado cyclone, and recognizes the signatures conducive to vortex stretching (e.g., updraft signatures). I devote some discussion to a topic of growing interest amongst researchers: the role interstorm interactions have on tornadogenesis.

Finally, we will discuss what we do not know about storm scale and near storm environmental signatures in regards to how the contribute to the tornado ingredients at the end of the lesson.

Lesson 11: Strong Updraft Signatures

- Strong signals favoring low-level vortex stretching
  i. Locally sharp concave reflectivity gradient facing the inflow
  ii. Inflow notch
  iii. Mesocyclone
  iv. WER
  v. BWER
  vi. Low-level velocity convergence and accelerated low-level inflow

A lot of the same signatures from which the presence of low-level vorticity can be inferred can also infer the presence of strong updrafts. In addition, there are other velocity and reflectivity signatures to infer strong updraft forcing and vortex stretching potential.

Lesson 11 Summary: Tornado signatures

- Storm scale
  - Interstorm interactions
  - Relationship between radar observed signatures and tornado ingredients
    - Mesocyclone
    - TVS
    - BWER
- Near storm environment
  (Covered in storm interrogation, IC2)
  - Low-level (0-1 km) shear
  - Deep layer shear
  - Pre-existing vertical vorticity
  - CAPE
  - CIN
  - Boundary layer humidity

To summarize, we discussed the relationship between radar observed signatures and the two tornado ingredients: low-level vorticity supply and vortex stretching potential. We also discussed the interstorm interactions and the most commonly observed ones related to initiating tornadoes.

Keep in mind that we did not cover the near storm environment and the relation between the most common parameters and tornado ingredients, except for the presence of low-level vertical vorticity.

Lesson 12: Stormscale enhancement to SRH

- Objective
  - Determine the likelihood that a storm is enhancing low-level SRH in its inflow
- Motivation
  - Some storms enhance SRH more than others from the base state environment

The objective of this lesson is to provide you considerations on how a potentially tornadic supercell may enhance Storm-Relative Helicities (SRH) in its stormscale environment. These considerations are based on results from recent project VORTEX experiments and other studies.

It is important to know which storms enhance SRH more than others due to factors that you cannot detect on the mesoscales.

Some storms may modify their local environment more than others and it is important to determine which ones may do so.

Lesson 12 Summary: Low-level SRH enhancement

- Close to radar, can detect
  - Forward flank outflow boundaries in velocity
  - Storm-induced inflow acceleration in velocity
- Far from the radar, must infer
  - FFD boundary right of the reflectivity core
  - Adequately high dewpoint depressions
- Anvil baroclinicity
  - Anvil must extend ahead of anticipated storm motion
  - Adequate solar heating right of anvil edge

Low-level SRH enhancement can be detected close to the radar in the form of forward flank outflow boundaries, and storm-induced inflow acceleration.

Far from the radar, your information content goes down and the need for inference and intuition go up. FFD boundaries are most likely to become prominent when supercells produce long forward flank cores and there are adequately high dewpoint depressions in the boundary layer.

Another, less tested consideration, is the anvil baroclinicity. Look for this where the anvil extends ahead of the anticipated storm motion and there is solar insolation outside the anvil shadow.

Lesson 13: Part 1--Near range tornadogenesis signatures

- Objectives
  - Recognize how tornado precursor signatures such as the mesocyclone and TVS appear in ranges less than 50 km
  - Interpret favorable signatures indicating a likely tornado that can only be detected at close ranges

The appearances of the classic mesocyclone and TVS are quite different when these features become large relative to the beam width. As we will see, the TVS may not represent the entire tornado cyclone, but perhaps an increasingly small part of it. The mesocyclone may not even look like a coherent rotational structure when smaller velocity structures within can be resolved.

On the other hand, it is these close ranges where radar data becomes by far the most useful tool because of the extreme detail it can portray.

There are two objectives in Part 1:

1. Recognize how tornado precursor signatures such as the mesocyclone and TVS appear in ranges less than 50 km
2. Interpret tornado signatures that can only be detected at close ranges.

Lesson 13 Summary: Close range rotation signatures

- More complexity of rotation
  - TVS is the detection of the tornado cyclone
  - Mesocyclone scale shows less symmetry
    - strongest velocities are located at midlevels on the right flank of the updraft for cyclonically rotating mesocyclones
    - Difficult to discern mesocyclone rotation at low-levels

To summarize, close range rotation signatures are more complex in scales.

At close ranges, the TVS is the manifestation of the tornado cyclone.

The mesocyclone does not appear as symmetric as before, with most of the strong velocities displaced to the right side of the updraft for cyclonically rotating storms. At low-levels, the mesocyclone may not appear at all.

Lesson 13 Summary: Close range tornadogenesis signatures

- Lowest level velocity signatures
  - RFD surge
  - strong convergence under higher level rotation and other updraft signatures
  - Increase in convergence with time
  - Rotation onset at tornado time
- hook echo
  - Rapid extension associated with RFD surge
  - Perhaps an elevated descent of reflectivity core into back side
  - Occasionally an anticyclonically shaped flare south of the hook

Remember that these signatures apply best to mesocyclone induced tornadoes.

Tornadogenesis signatures appear at low-levels as the RFD begins to develop. Convergence increases dramatically at low-levels and should appear under a midlevel mesocyclone and other strong updraft signatures. Only immediately before tornado formation is there any appearance of a tornado cyclone at low-levels. The convergence signature gives you on the order of 5 to 10 minutes of lead time. The onset of an intense tornado cyclone may only appear within a minute of tornadogenesis.

The hook echo may appear to extend in length and definition as the RFD develops. More recent research work has suggested that a descending ‘blob’ of reflectivity on the back side of the storm may contribute to RFD genesis.

As the RFD matures and begins to develop low-level rotation, an anticyclonic flare echo may be detected right of the main hook echo. Anticyclonic tornadoes are most likely if this anticyclonic flare coincides with the gust front underneath strong updraft.

Lesson 13 Summary: Close range mature tornado signatures

- Lowest level velocity signatures
  - TVS likely, sometimes not visible as a gate to gate signature – too close for a TVS
  - RFD gust front with other vortices along interface
- Reflectivity
  - Debris appears as a ball of very high reflectivity

Close range radar signatures of a mature tornado include good sampling of the tornado cyclone. Sometimes, the sampling is such that no gate to gate TVS strength signature appears in the tornado cyclone. The RFD gust front appears well defined, and there may be other vortices appearing along its interface.

If the tornado is ejecting large debris (e.g., tree branches, building parts), a reflectivity debris ball may appear as a small region of very high reflectivities extending upward several thousand feet or more.

Lesson 14: Part 2--Near range TDWR tornadogenesis signatures

- Objectives
  - Familiarize yourself with the applications and weaknesses of using Terminal Doppler Weather Radar (TDWR) for analyzing close range tornadogenesis signatures
  - Be familiar with the characteristics of the TDWR

As objectives, you should familiarize yourself with the applications and weaknesses of using the TDWR for analyzing close range tornadogenesis signatures. The same applications and weaknesses should apply to the interrogation of many meteorological features.

This lesson will also help you become more familiar with the characteristics of the TDWR.

At this point, development is underway to send TDWR data to WFOs on an operational basis. Thus for any site that has a TDWR in your CWA, this lesson will have more relevance to you.

Lesson 14: Summarizing TDWR vs. WSR-88D in near range tornadoes

- WSR-88D
  - Poorer resolution
  - Good unambiguous velocities
  - Poor temporal frequency
  - Low attenuation
  - Good coverage
  - Poor siting on mountain tops
  - NWS control
- TDWR
  - Better resolution
  - Poor unambiguous velocities
  - Good temporal frequency
  - High attenuation
  - Poor coverage (20 cities)
  - None sited on mountain tops
  - FAA control

The TDWR offers you excellent resolution and temporal frequency. However, given other factors favoring the WSR-88D, the TDWR will serve as an enhancement to the current network, and certainly not a replacement. Note the strengths of each radar are colored in yellow. The WSR-88D's advantages lie in its coverage, high

It is not known at this time how the TDWR data will be made operational to the NWS forecasters. Work will need to be done that will be defined during the course of AWOC delivery. As the details are worked out on delivering the data to the field, WDTB will provide more training on the use of TDWR data.

Lesson 15: Nonmesocyclonic tornadoes

- Objectives
  1. Given the example, show the conditions where pre-existing vertical vorticity is a significant tornado ingredient
  2. Determine the timing of greatest tornado threat given the superposition of
     - vertical vorticity and prestorm misocyclones
     - incipient updrafts
     - boundary intersections and/or collisions

The objectives of this lesson are two fold:

1. Show where pre-existing vorticity should be a significant tornado ingredient. This goes far beyond the analysis that is often shown in the SPC mesoanalysis web page using an objective analysis. Here, we go to the boundary scale using radar data, make some assumptions as to the nature of the wind field right up to the edge of either side of the boundary, then use the boundary width as a baseline from which to make an estimate of the background vorticity supply. This is probably as close as we can get to estimating what is really out there. However, note that boundary widths seem to decrease every time a newer higher resolution dataset becomes available.
2. Determine the timing of the greatest tornado threat given the superposition of vertical vorticity, perhaps prestorm misocyclones, incipient storm updrafts, and boundary intersections and/or collisions. Again, anticipating nonmesocyclonic tornadogenesis is very difficult when no significant rotational signatures appear on radar in advance of the event. Timing the convergence the tornado ingredients, vertical vorticity, vertical vortex stretching potential, based on what is detected by radar may help, along with spotter data, to provide some lead time.

Lesson 15 Summary

- Nonmesocyclonic tornadoes favored with
  - near zero CIN, steep lapse rates ground to cloud
  - Sharp boundary of 1 nm width or less
  - Prestorm vertical vorticity > .01s-1
    - vorticity sheet often rolls up into misocyclones
  - Superposition of strong developing updraft over low-level vertical vorticity
  - Often need a boost of vorticity and/or convergence from multiple boundary interaction
  - Prefers low boundary-relative cell motion

Nonmesocyclonic tornadoes are favored by:

near zero CIN, steep lapse rates ground to cloud

Sharp boundary of 1 nm width or less

Prestorm vertical vorticity > .01s-1

vorticity sheet often rolls up into misocyclones

Superposition of strong developing updraft over low-level vertical vorticity

Often need a boost of vorticity and/or convergence from multiple boundary interaction

Prefers low boundary-relative cell motion

None of this will give me an adequate false alarm or POD. These conditions can occur many times before there is a hit. But the increased awareness, and time to solicit for spotter reports may help in getting a warning out in time.

Lesson 16: Quasi Linear Squall Line (QLCS) tornadoes

- Objectives
  1. Recognize reflectivity/velocity precursor signatures to QLCS tornadoes
  2. Understand the importance of QLCS intersections with boundaries in regards to locating and timing the greatest tornado potential
  3. Understand the time-height evolution of a typical QLCS vortex
  4. What is the strength of of low-level rotation between tornadic and nontornadic vortices
  5. Familiarization with the theory of low-level QLCS vortex production by Trapp and Weisman (2003)

There are five objectives in this lesson. First, recognize the precursor signature in reflectivity and velocity most commonly observed with QLCS tornadoes. Second, learn how important QLCS intersections with boundaries are with regards to locating the greatest tornado threat. Third, learn the differences of the time-height evolution of a typical QLCS vortex and that of an isolated storm. Finally, this lesson will familiarize yourself with a theory of QLCS low-level vortex formation proposed by Trapp and Weisman (2003).

Lesson 16 Summary

- QLCS tornadoes favored
  - In regions with strong 0-1km shear, 0-3 km (≥ 15 m/s), 0-5 km (≥ 18 m/s) shear, similar to supercell tornado parameter space
  - At or left of intersections with
    - quasi-stationary fronts
    - outflow boundaries
- QLCS vortices may develop from the tilting of horizontal vortex lines within the cold pool and then enhanced by the coriolis force

QLCS tornadoes are favored in regions of strong 0-1 km shear and 0-6 km shear, a very similar setup to that of more isolated mesocyclonic tornadoes. As with isolated mesocyclonic tornadoes, QLCS tornadoes tend to be favored at and just north of a boundary external to the QLCS event.

QLCS vortices may develop from the downward tilting of horizontal vortex lines within the cold pool and then enhanced by the coriolis force. The coriolis force seems to act fairly quickly, within an hour, to enhance the cyclonic vortex and weaken the anticyclonic vortex to its north. Again, this theory has yet to have observational support since there has been no anticyclonic vortex observed immediately left of the cyclonic one.

Lesson 16 Summary (contd)

- QLCS tornado signatures
  - Near front inflow notch
  - In region of strong vertical vorticity along boundary
    - especially a low-level vortex
  - At or north of the initial bowing apex
- QLCS vortex time trends
  - mostly nondescending
  - typically larger and shallower than supercell mesocyclones
  - weaker rotational velocities than supercell mesos

QLCS tornadoes appear to be associated with a front inflow reflectivity notch in a region of strong low-level vertical vorticity just left of a region of a convex bow in the gust front. Look for a rear inflow notch to the right of the front inflow notch and behind the convex curve of the gust front as another indication that tornadogenesis probabilities increase.

QLCS vortices tend to be nondescending in nature. They are larger in diameter than traditional supercell mesocyclones but have weaker rotational velocities.

Lesson 17: FFG Modification

Objective:

- Understand the drawbacks of FFG, and recognize regions and times when modifying FFG would be very beneficial to detecting flash flooding

Bob Davis, forecaster at WFO Pittsburgh, presents this lesson on modifying FFG to better represent more accurate hydrological conditions

Lesson 17: Summary

- Reducing FFG for predefined basin conditions can improve FFMP detection capability and increase warning lead time.
- The use of FFGMOD factor for rainfall since data cutoff may aid in the updating of FFG between RFC issuance times.
- The use of FFGMOD may aid in the update of soil moisture conditions in small basins.

•This is especially true in highly urbanized areas

•FFGMOD may replace the “ratio” column in the FFMP threat table

Lesson 18: Effective Use of FFMP

Objectives:

- Understand how to best use FFMP, including Rate and Diff products
- Understand the radar limitations for rainfall estimation that directly affect FFMP and thus flash flood detection

Lesson 18 Summary

- FFMP is by far the best tool for flash flood detection
- FFMP *RATE* and *DIFF* products should be closely monitored
- Limitations of radar rainfall estimation affect FFMP greatly, especially hail contamination, distance from radar, and Z/R relationships

Lesson 19: Radar Rainfall Estimation

Objectives:

- Understand how inaccurate Z/R relationships can result in a missed flash flood detection
- Know how to anticipate warm rain processes

Lesson 19 Summary

- Radar rainfall estimation has errors that affect FFMP
- Failing to quickly and properly anticipate warm rain processes and then switch to tropical Z/R can result in failure to detect a flash flood

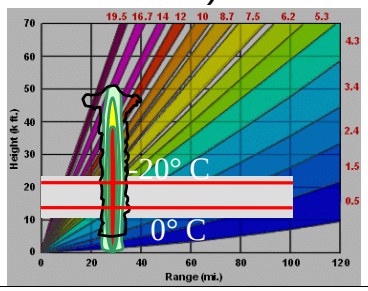
Lesson 20: Three Body Scatter Spike (Hail Spike)

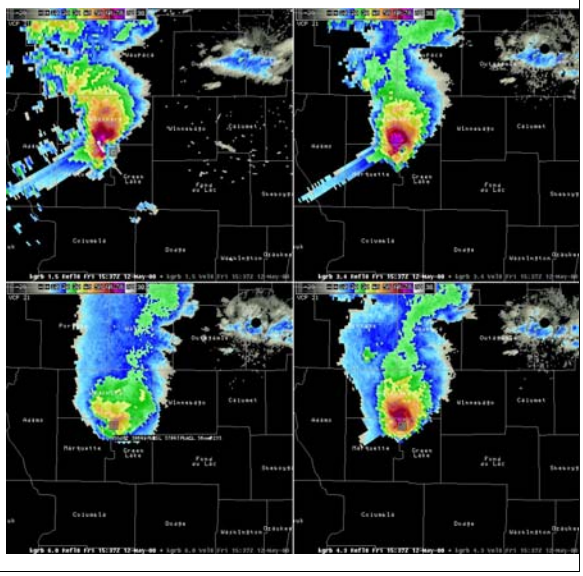
Objective:

- Understand what causes a three body scatter spike, what it signifies, and how it may contaminate velocity data

Lesson 20 Summary

- "storms producing the artifact, will or are now, *with absolute certainty*, producing very large hail" (Lemon 1998)





Another important point Lemon brings up in his paper is the additional threat of severe winds. With large hail and/or large quantities of wet hail, downburst potential is very high due to precipitation drag, and thus storms with hail spikes ALSO are likely to contain severe damaging winds, as is the case with this storm.

Lesson 21: VIL and VIL Density

Objective:

- Understand how VIL is calculated
- Recognize that VIL and VIL density are not good indicators of severe hail

Lesson 21: VIL / VIL Density Summary

- These products are not very useful in the context of hail detection when compared to base data and the HDA
- Understand VIL/VIL density limitations: distance to radar, environment, resolution, storm motion
- VIL of the Day? No way

VIL of the day struggles in that VIL is still used with it's many drawbacks, and then add to the fact that different environments can and typically do exist within the same radar umbrella on the same day

Lesson 22: The HDA

Objectives:

- Understand how the HDA produces severe hail probabilities and sizes
- Know how to best utilize the HDA, including ways to improve upon it

SCIT looks at the height and maximum reflectivity for each slice (top portion of the figure), stacks these regions of maximum reflectivity, giving a 3D depiction of an identificed storm (bottom portion). This 3D depiction is input into the HDA

Lesson 22: How to “beat” HDA

- Anytime SCIT misidentifies the vertical structure of a storm (strongly tilted)
- Knowledge of storm structure (meso, divergence, convergence, etc.)
- HDA needs a full volume scan of data before computing statistics
- When thermo. Environment characteristics change quickly or vary widely across radar umbrella

The HDA does not directly handle melting, which we showed in Severe IC1 that smaller sizes are highly affected by melting. Thus in areas with very moist environments HDA will overpredict sizes and POSH

•You can write a warning and send it out after viewing the bottom 2 radar scans in the time it takes the HDA to produce statistics from that volume scan

•Of course, with VCP 12 that time is decreased to about 4 minutes now.

•Knowing that a storm has rotation (HDA can’t account for that), BWER, other supercell characteristics is useful, especially in the early going before the hail cores really develop

Lesson 23: Hailstorm Characteristics

Objective:

- Recognize the following radar signatures of severe hailstorms and understand the limitations of the data.
  - Reflectivity height
  - Convergence/Divergence
  - Storm structure

Lesson 23 Summary: Large Hail Radar Interpretation

- At long range from the radar certain updraft characteristics may not be well resolved
- Understand data limitations, especially far from radar and/or with fast moving systems
- Usage of velocity signatures depend on range from radar and on viewing angle

Lesson 24: Hybrid/wet microburst detection

- Objective
  - Determine which microburst precursor signatures give
    - The most lead time
    - The highest probability of detection
- Motivation
  - Need to limit initial missed detections

The one objective of this lesson is to show which stormscale precursor signatures give you the most lead time and the highest probability of detection of wet and hybrid microbursts. The motivation for this session is to limit missed detections of the first microburst producing storm of the day and then increase the leadtime of all following microburst events.

We will limit ourselves to mostly stormscale signatures within the context of the environmental sounding.

Lesson 24 Summary: Hybrid/Wet downbursts

Precursor signatures

Signature	FAR	leadtime
1 Large enough CAPE to produce significant precipitation loading	high	Day 1
2 Significant DCAPE – evaporational cooling	high	Day 1
3 Strong initiation with high reflectivities (see updraft strength sessions)	med	15 min
4 Descent of high reflectivity core	med	5-10 min
5 Onset of midlevel convergence	med	0-10 min
6 Midlevel convergence (ΔV) > 50 kts	low	0 - 5 min

In summary, I present a table of microburst precursor signatures ordered with respect to the lead time each one offers.

The environment makes up for the most lead time but individual storm behavior precludes using the environment as a sole warning tool for every storm and thus the FAR is potentially high.

The best set of parameters to view in conjunction with the environment is to watch for the storms with rapid initiation capable of sending high reflectivities to greater altitudes than other adjacent storm. The descent of the high reflectivity core results in lower lead time but is usually when a warning is sent out since the descending core occurs rather rapidly. It is usually when the reflectivity core descends that the onset of midlevel convergence occurs. Don't wait for the midlevel convergence to reach some large value since large values of midlevel convergence and the period of strongest outflow occur nearly simultaneously.

In this session, I have not mentioned situations of weak shear convection embedded in strong horizontal winds. There have been many events where even weak showers have been able to initiate downdrafts bringing the high horizontal winds to the surface.

I encourage the use of DCAPE more than other parameters, because it accounts for downdraft forcing by lateral and sub cloud base dry air entrainment for a wider variety of situations. The method shown in this lesson is something that can be applied relatively quickly on the day of an

Lesson 25: MARC Signatures

- Objective
  - Be able to identify MARC signatures in radar data, and understand the characteristics of a signature associated with an impending severe wind event

The learning objective for this lesson.

Lesson 25 Summary: MARC signature

1. Look for $\Delta V \geq 25$ m/s in a small region (typically 15 by 7 km) embedded in larger scale convergence
2. Usually prior to formation of bows, line end vortices, low-level vortices within intense, deep reflectivity core
3. Found at midlevels of 4 – 5 km (13-16.5 kft)
4. Difficult to discern when line is parallel to the radials

To summarize, look for velocity differences > 25 m/s in a small region, typically 15 by 7 km and embedded in a larger convergent region at midlevels

The MARC signatures occur prior to the formation of bows, line-end vortices and low-level vortices within the intense deep reflectivity core.

Look to the midlevels, approximately 4 – 5 km AG for the MARC signature.

One final note, if the radials of your radar are roughly parallel to the line axis, you will have a difficult time detecting the MARC signature since most of the air flow is tangential and not radial.

Lesson 25 Summary: MARC signature (contd)

5. Environment favors these events in regions where surface-based CIN is not large
   - Downdrafts have increasing difficulty penetrating to the surface if cool, stable layer exceeds 2 km
   - Damaging wind potential thus mitigated in areas deep in the cool side of a polar front or ourflow boundary

Finally, the environment in which the MARC signature is embedded. The optimal situation for severe surface winds in the vicinity of a MARC is one in which the pre-storm CIN is low and there is no shallow layer. However, damaging winds have been observed in elevated MCSs where the stable layer can reach 2 km, even a bit more. Do not be surprised when a seemingly deep stable layer is insufficient to prevent damaging surface winds in an organized system. These kinds of events are not understood as well as we would like them to be. However, the probability of such an occurrence is still low.

Lesson 26: Extreme Non-Tornadic Wind Damage Events

- Objective
  - Identify characteristics of extreme non-tornadic wind events, and understand how to best observe and forecast their occurrence

The learning objective for this lesson.

Lesson 26: Unique? Characteristics of XDW Events

1) Quite long in duration at any one location along the path (10-20 minutes - or longer in extreme supercell/mesovortex events vs. a few minutes or less for bow echoes)
2) Very tight damage gradients along the periphery of XDW area
3) Supercell events have a much higher probability of being accompanied by large hail (> 4cm)

Much more research needs to be done, including obtaining data from new cases as they occur, to ascertain whether these XDW characteristics are generally the case with all XDW events. However, these characteristics were common in most cases examined thus far.

Lesson 26: Operational Considerations

- Supercells *within* a derecho producing MCS can be associated with an enhanced threat for XDW
- In *many* high-end derecho events - the most extreme damage is associated with supercells/mesovotices
- Supercell/Mesovortex XDW events *may* have somewhat different characteristics than “traditional” Bow Echo XDW events
- Events often move/evolve rapidly → timely flow of accurate information becomes *very* challenging
- Even high resolution surface mesonetwork observations may not be dense enough to completely capture storm-scale extreme wind events

The bullets presented here generally need little additional explanation. All are important things to remember when working an XDW event operationally. AWIPS and other operational procedures should be optimized to maintain maximum situation awareness during the event.

Lesson selection strategies

- Two – Part 1,2 lessons
  - ICSvr3-II-D and ICSvr3-II-E
    - Satellite detection of severe storms
  - ICSvr3-III-D and ICSvr3-III-E
    - Close range detection of tornadic storms
  - Suggest that both be taken
  - Part 2 lessons have part 1 as a prerequisite
  - Taking part 1 and 2 counts as two of the minimum of six lessons required for IC Svr 3

If you or your student picks either ICSvr3-II-D and/or ICSvr3-III-D, remind them that these are part 1 of a 2 part lesson, namely ICSvr3-II-E and ICSvr3-III-E. I encourage them to view both lessons. I consider the part 1 lessons to be prerequisites of the part 2 lessons because the part 2 versions contain extensions of the material in part 1 but not the introductions or the explanations. If a student wants to view a part 2 lesson, have them add the part 1. The students will be credited for taking 2 of the minimum of 6 lessons in IC Svr 3.

Lesson Selection Strategies

- Six lessons from six topics
  - Would cover one lesson from
    - updraft strength,
    - updraft location,
    - tornado,
    - flood,
    - wind and
    - hail interrogation
  - For a broad exposure to all topics
  - or

If you wanted a student to cover all storm interrogation topics here, one lesson from each topic will do the job. This would satisfy an environment where all convective and flash flood warning events are possible.

Lesson Selection Strategies

- For offices with high flash flood threat
  - Have the student concentrate on
    - updraft strength,
    - flood,
    - wind and
    - hail interrogation
  - For a broad exposure to all topics
  - or

If you wanted a student to cover all storm interrogation topics here, one lesson from each topic will do the job. This would satisfy an environment where all convective and flash flood warning events are possible.