Storm Interrogation

AWOC Severe Track

IC3-II-D

Estimating updraft intensity with satellite: part 1

Slide 1: Storm Interrogation - Estimating updraft intensity by satellite - part 1

This presentation is 23 slides long and should take 20 minutes to complete.

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.

Estimating updraft intensity with satellite: part 1

- Possible methods
  - Cloud Top Temp (CTT) cooling rates pre-anvilgenesis
  - CTT cooling rates post-anvilgenesis
  - Cloud top growth rate using the cloud height tool in AWIPS
  - Anvil equilibrium level temperature/height

There are many methods for evaluating storm intensity from satellite:

1. Cloud top cooling rates prior to anvilgenesis.
2. Cloud top cooling rates after anvilgenesis. Now we are talking about the cooling rate of the overshooting top
3. Cloud top growth rate using the cloud height tool in AWIPS. This technique simply converts cloud top temperature to height. Otherwise, the physical basis remains the same as 1 and 2.
4. Anvil equilibrium level temperature and/or height. In many ways, this technique is better to use than cloud top growth rates

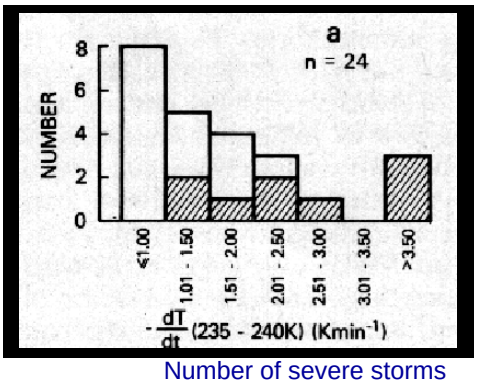
Estimating updraft intensity with satellite: part 1

- Recommended Prerequisite
  - Be familiar with the Interactive cloud height algorithm in D2D
  - Training is available at
    - http://www.cira.colostate.edu/ramm/visit/cldhgt.html

I mentioned that the D2D cloud top height tool is used in evaluating some of these techniques. This tool was developed by the Aviation Weather Center to help forecasters write convective sigmets around the world. Now that this technique is available to all, this tool should help you out in convective forecasting. The VISIT program has developed a training session for the general use of this tool at http://www.cira.colostate.edu/ramm/visit/cldhgt.html. The session is generic in the use of this tool. Here we provide some specific potential applications.

CTT cooling rate pre-anvil

- Note that cooling rates are ≳2° K/min for most severe storms based on limited samples
  - Prior to anvilgenesis
  - 2° K/min corresponds to only 4 m/s of updraft



Number of severe storms are shaded.

From Adler et. Al 1985

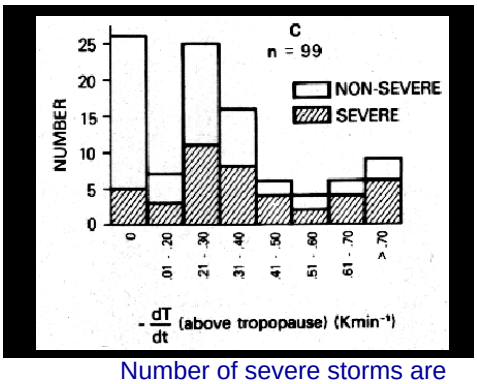
Satellite-based severe thunderstorm analysis research peaked in the mid 1980's prior to the advent of the WSR-88D because of the incentive to provide more information than the old radar system could provide. Some of the results from that time are still relevant today but there are caveats since we are now talking about higher resolution satellite imagery. Nevertheless, I present some of the techniques devised then in our current framework.

Adler et al 1985 approached discriminating severe from nonsevere storms using the cloud top cooling rate determined from rapid scan GOES imagery. After several severe storm outbreaks, they found a fairly good relationship between cooling rate and eventual severe weather reports.

This bar chart shows the maximum cooling rate found in a storm before it had a chance to produce an anvil. Note that the storms that went on to produce severe weather (gray shaded bars) tend to dominate when the cooling rates exceeded 2 degrees/minute. This only corresponds to a 4 m/s updraft. Poor resolution was blamed for the low values. GOES IR imagers before the advent of GOES 8 had a 4X8 km field of view at nadir (below the satellite). Now we have routine 2X4km imagery. Today's cooling rates are higher as a result and so this graph's purpose is to highlight the relationship, rather than specific thresholds.

CTT cooling rate post-anvil

- After anvilgenesis, overshooting top cooling rates are much smaller.
- If the cooling rates > 0.4° K/min severe storms were more likely in this dataset.



Number of severe storms are shaded.

Sampled from typical mid-western severe events

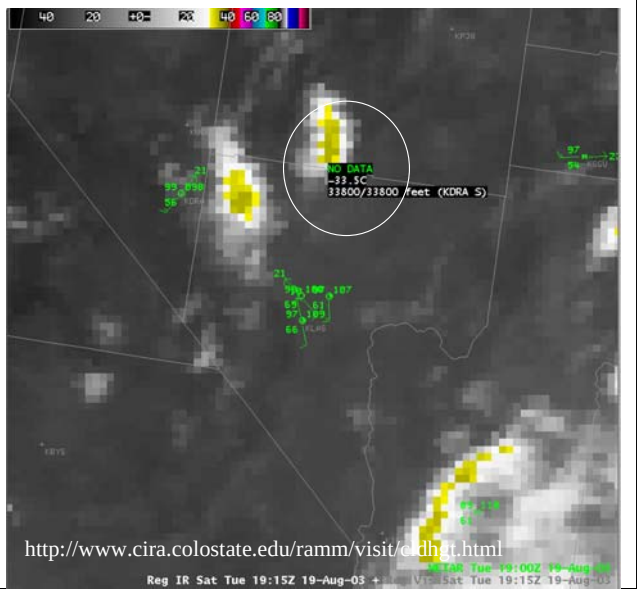
From Adler et. Al 1985

As the storm creates an anvil, and the overshooting top begins to extend above it, the cooling rate typically slows down. Following updraft surges also have slower cooling rates. The reason is that the overshooting top growth is in a region of negative buoyancy. Adler et al 1985 reflects this with much smaller cooling rates. Instead of 2 deg/min, now we are talking 0.4 deg/min as a strong severe/nonsevere thunderstorm discriminator. Again, these cooling rates reflect the maximum cooling rate found in the overshooting top prior to the severe report.

Another word of caution, their database was limited to major spring severe storm outbreaks with strong vertical windshear. We will look at multiple events as examples later.

Cloud top cooling rates example Storm A

- Initiation in pre-anvil stage north of LSV (Storm A)
- Use the cloud height algorithm to track cooling rate and cloud top growth



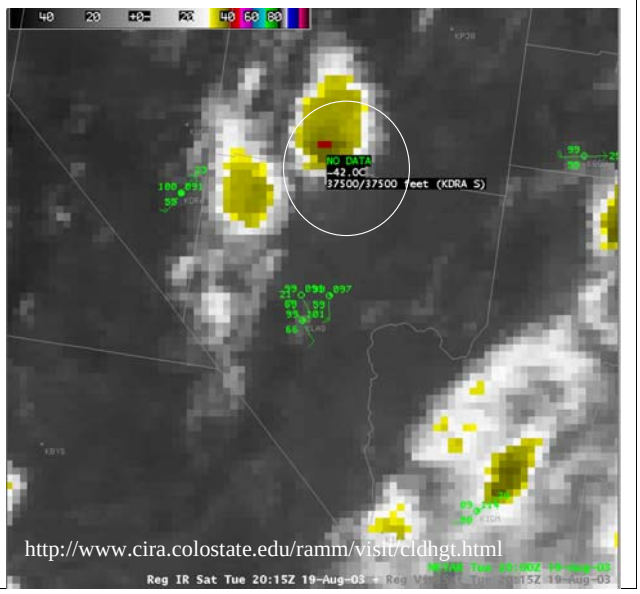
This storm is embedded in a monsoon environment with a shortwave trough moving northwest through AZ. It is generating off some high terrain north of LAS.
GOES-10 is in normal scan mode and the D2D cloud height algorithm is basing the cloud top height on the KDRA sounding at 12 UTC. It may be a bit on the dry side but should be fairly relevant when trending the cloud height and temperature.
Right away, notice the 6 deg temperature drop in the overshooting top in 15 minutes.

This is the pre-anvil growth stage of this storm.

See http://www.cira.colostate.edu/ramm/visit/cldhgt.html for the training on the AWIPS cloud height algorithm.

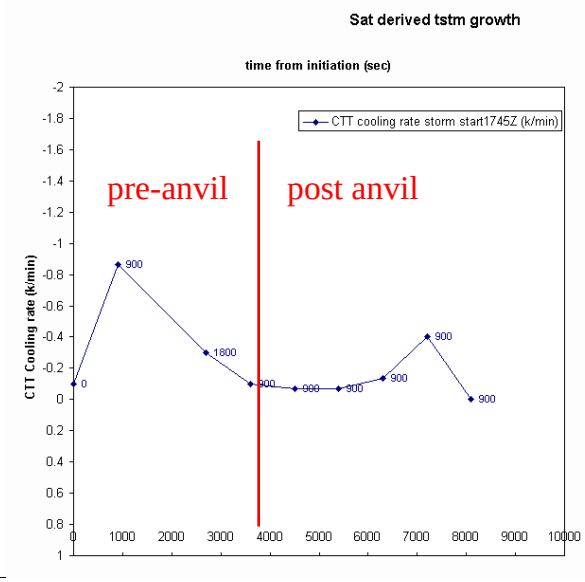
Cloud top cooling rates example Storm A

- post-anvil stage north of LSV (Storm A)
- Use the cloud height algorithm to track cooling rate and cloud top growth



In these three frames of this loop, this storm is now creating an anvil and any growth rate during this part of the storm growth can only be compared to the growth rates of storms after their respective anvils have formed.

Cloud top cooling rates example Storm A



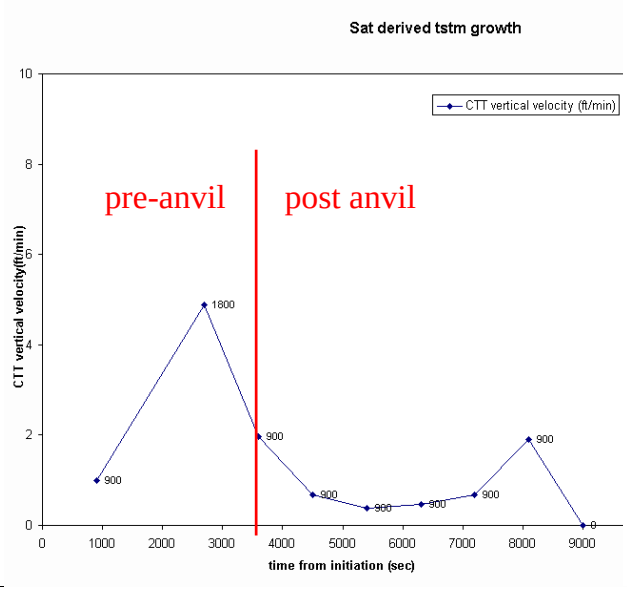
- Peak Pre-anvil cooling peaks at -0.9° C/min
- Peak post-anvil cooling = -0.4 C/min
- This is 15 minute data
- Adler's used 5 minute data

Time trends of temperature were taken of this storm from first cumulus to reveal this graph. Note there are large temporal gaps in the imagery which tend to overlook rapid growth spurts (see between 1000 and 2500 seconds). Still, the maximum temperature rate of –0.9 K/sec occurs in the first stages of the towering cumulus.

After anvilgenesis the peak cooling occurs as a followup updraft surge cools the overshooting top by 0.4 K/sec at 7200 seconds after initiation.

These rates are small compared to Adler's work. Adler et. al 1985 used 5 minute data, and if we had access to such, we would get higher rates. However, our higher resolution imagery should produce higher rates than Adler et. al 1985. Do the competing differences cancel each other? We don't know.

Cloud top vertical velocity example Storm A

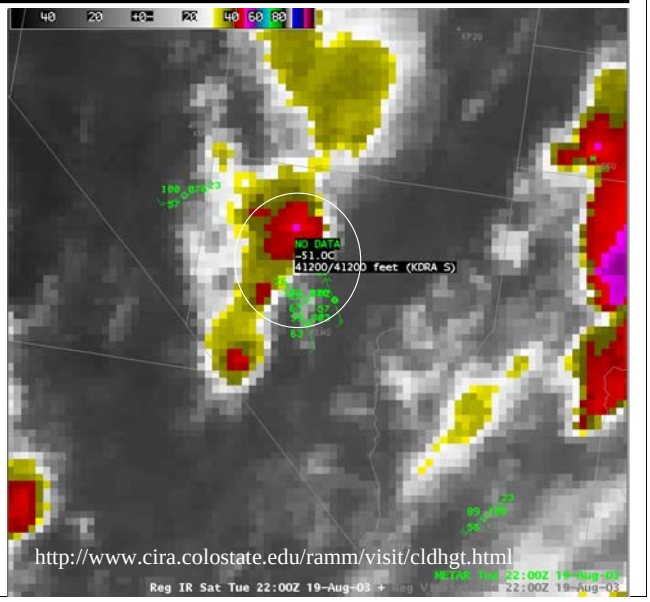


- Peak Pre-anvil cloud top vertical velocity = 5 mph
- Peak post-anvil cloud top vertical velocity = 2 mph

Converting temperature rate to growth rate of storm top height gives us maximum vertical motions of 5 (2) mph for the pre- (post) anvil stage respectively. To create this graph, I simply read off the maximum cloud height found nearby the cursor using the D2D cloud height algorithm (see the altitude on the right in the cursor readout) These results agree with Adler's results very nicely. We'll compare this storm with another one that formed closer to Las Vegas.

Cloud top cooling rates example Storm B

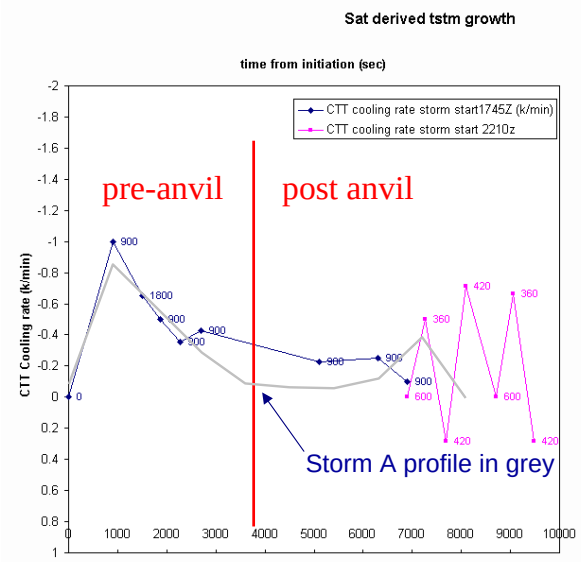
- Storm B initiates on high terrain and outflow from the west
- Let's compare with storm A



Storm B initiates on the high terrain northwest of the city's northern Suburbs near an implied outflow boundary (inside the white circle). Now we have RSO operations going on GOES-10. I cannot emphasize enough the importance of having RSO imagery should you try any of these techniques. Note the cloud tops are taller with this storm.
There are two separate updraft surges within this multicell. This loop shows only the first surge, mostly prior to anvil production.

See http://www.cira.colostate.edu/ramm/visit/cldhgt.html for training on the AWIPS cloud height algorithm

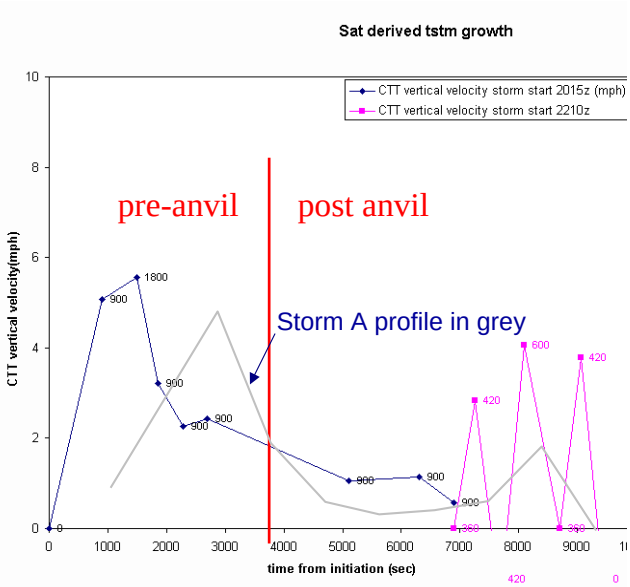
Cloud top cooling rates example Storm A



- Peak Pre-anvil cooling peaks at –1.0° C/min
- Peak post-anvil cooling = -0.7 C/min
- RSO begins at the purple time trend for the 2nd updraft surge

This graph compares storm A and storm B, where the storm A profile is set in a grey background. Both have also been set so that the timeline is time from initiation for both storms. Note that both of them exhibit a rapid growth but that storm B is a little more rapid than storm A, given the same image frequency. Storm B continues to show the same or more rapid cooling through its pre-anvil stage. During the post-anvil stage, the overshooting top is also more rapid than storm A. A second updraft surge, shown in purple, exhibits wild fluctuations in cooling rate but that the highest values are higher than with storm A.

Cloud top vertical velocity example Storm B



- Peak Pre-anvil cloud top vertical velocity = 5.7 mph
- Peak post-anvil cloud top vertical velocity = 4 mph for secondary pulse (purple)

Similarly, using the AWIPS cloud height estimator, peak updraft speeds are up to 5.7 (4) mph prior (after) to anvilgenesis.

Actual updrafts are much higher given:

1. that the satellite field of view is larger than individual updraft pulses,
2. that the IR imager only senses cloud edge in the zone of mixing, and not parcel core temperature
3. After anvilgenesis, updraft strength converts mainly to anvil-level divergence owing to adverse buoyancy gradients

Therefore 5.7 mph, or 501 ft/min is a significant number in the towering cumulus stage, and 4 mph or 352 ft/min is quite big.

Interim summary: cloud top cooling rates

- Storm B produced 1.25” hail and 70mph winds over LSV
- Storm A had no reported severe weather
  - Low population density
- 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.

Interim summary: 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

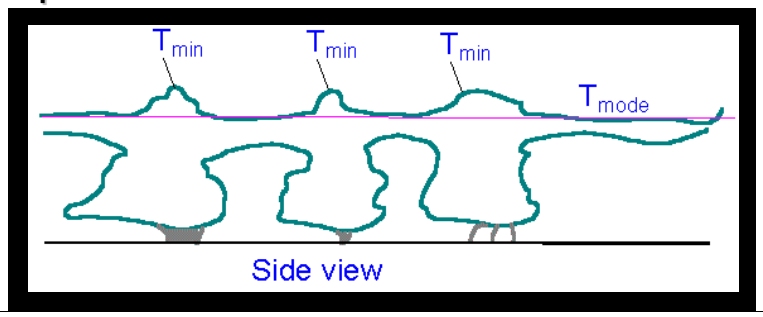
The optimal frequency should be 30 seconds, which the GOES satellites have done under research operations.

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.

Anvil equilibrium temperatures

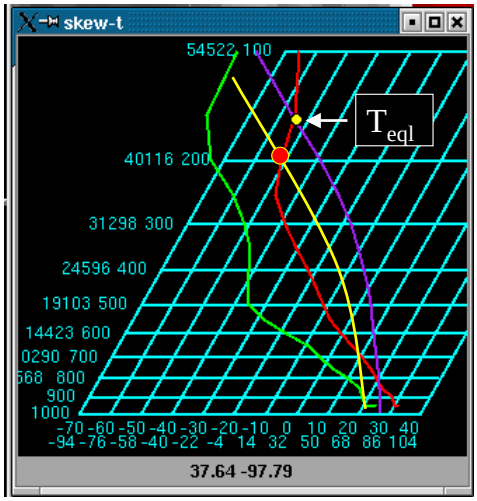
- Each convective cell has its own equilibrium level height which is visualized on satellite data as relatively flat areas of anvil.
- Represented by the mode of the brightness temp



When a thunderstorm updraft does reach its own equilibrium level (EL), anvil material spreads out to form a relatively flat region around the updraft overshooting top. This flat region is relatively large, larger than the field of view of the GOES imagery, and therefore, its temperature is easily resolved by the imager. Quantitatively, the mode of the brightness temperature reveals the flat region of the anvil.

Anvil equilibrium temperatures

- The standard parcel theta-E (purple) gives an equilibrium temperature (T_{eql}) of -55° C
- However, if the storm is entraining dry air, or is elevated, the actual theta-E realized (yellow) may give a warmer T_{eql}



Every convective cell has its own equilibrium level, quite distinct from what your RAOB or model sounding may tell you.

There are a million reasons for this to happen, the most frequent may have to do with dry air entrainment with updraft parcels. Another reason may be that the parcel originated at a level or incorporated air at different levels than the chosen method of deriving the theoretical parcel.

As a forecaster, you can sample the brightness temperature of areas that appear flat around the overshooting domes. The equilibrium level brightness temperature can be theoretically converted to the updraft parcel θ_e for the storm by looking on the sounding to where the EL . Then comparing θ_e based off the satellite EL to that of a representative sounding should provide an impression as to how close to the sounding θ_e the storm in question realized. A storm that is utilizing all of the potential θ_e shown in the sounding should have an EL brightness temperature close to the EL temperature in the sounding (purple curve with yellow EL). Storms experiencing loss of updraft θ_e through dry air entrainment, or a different level or parcel origin should show a warmer EL brightness temperature than the sounding suggests (yellow curve with red EL).

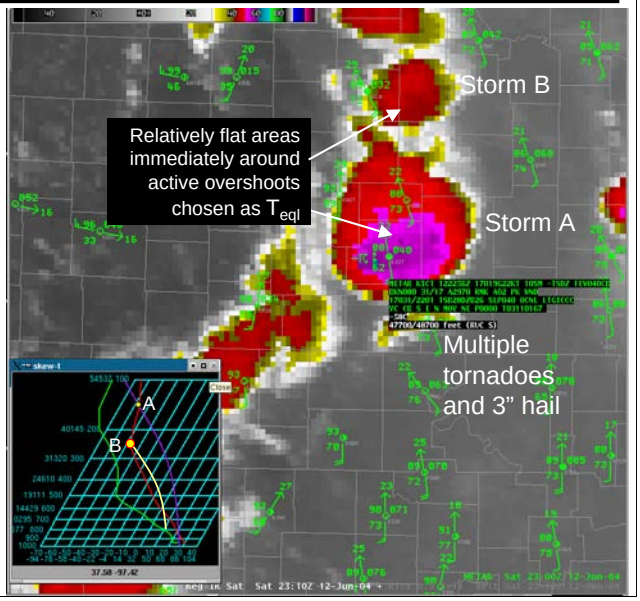
In theory, this technique appears straightforward but there are complications as follows:

1. The comparison environmental sounding is wrong
2. Storm anvils modify the upper-level temperature environment and change your sounding. Anvils warm the environment at their bottoms and cool the environment at the top. Large contiguous anvils push the tropopause upward and cool it down so that subsequent updrafts are able to reach cooler brightness temperatures without necessarily being more intense.
3. An inversion at the EL may complicate the relationship between cloud height and brightness temperature. As stronger updraft pulses create a higher EL, the brightness temperature may not change or even show warmer values.

Overall, this technique should be better than attempting to find the height of an overshooting top and comparing that to the sounding. The reason is that resolution, and cloud edge

T_{eql} example

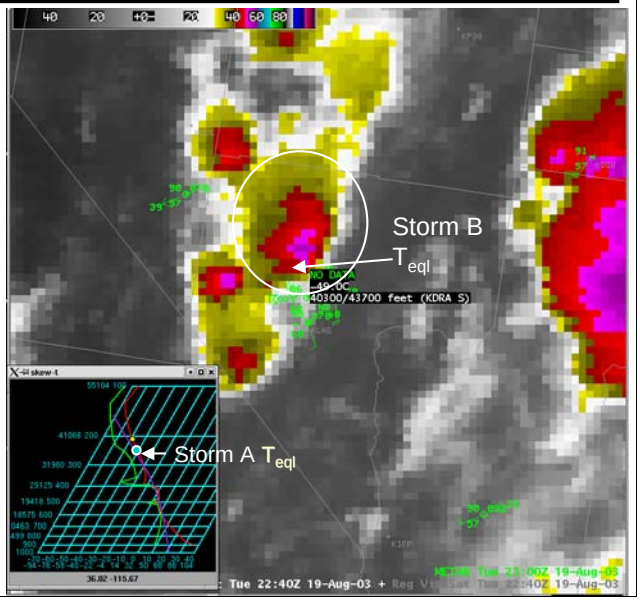
- 12 June 2004
- Storm A appears to be realizing all available SBCAPE
- Storm B is **not** realizing the available SBCAPE



A good example of the application of this technique is to examine storm behavior in a comparitive sense. On 12 June 2004, two storms in Kansas formed along a dryline. Given similar surface dewpoints, storm B looks relatively anemic vs. Storm A. Investigating the areas of relatively flat brightness temperature around the overshooting gives me an idea that the two storms have highly different EL temperatures. Storm A appears to be realizing all the SBCAPE found in the RUC model data in its proximity (see "RUC" in the AWIPS cloud height cursor readout). Storm B appears to be grossly underutilizing the SBCAPE available to it, and therefore realizes a much smaller θ_e . Storm B eventually dissipated while A went on to produce all sorts of severe weather.

T_{eql} example 2

- Back to LSV
- Storm B T_{eql} is colder than Storm A.
- Storm B is likely accessing higher theta-E air from near LSV

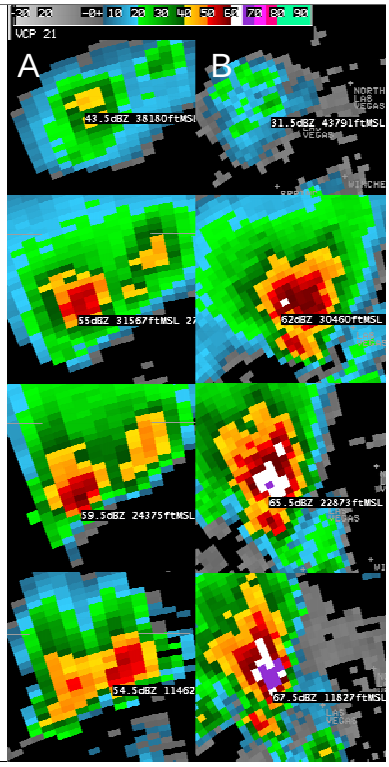


Going back to the LSV example, storm B is the storm that struck LSV with hail, strong winds, and flooding. Note that Storm A has a much lower EL temperature than Storm B. It is likely that Storm B is accessing higher θ_e air from the Colorado River Valley than Storm A. Or Storm A never realized the low-level θ_e air available to it. Either way, storm A likely has a weaker updraft than B.

http://www.cira.colostate.edu/ramm/visit/cldhgt.html

T_{eql} example 2

- Compare the storm A (left) and B (right) to note the relatively larger and more intense core that corresponds to the higher anvil equilibrium level



We can add evidence to the conclusion by noting that Storm B (right column) has a much stronger core with higher reflectivities.

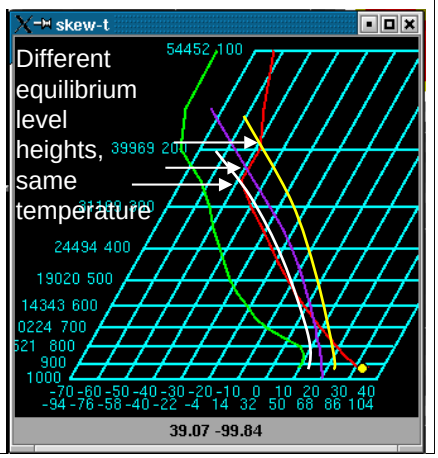
Interim summary: Anvil T_{eql}

- 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.

Interim summary contd: Anvil T_{eql}

- Limitations: T_{eql} and height ambiguity contd.
  - Isothermal layer on right may result in ambiguity of equilibrium level height



This is an example of the EL temperature and height ambiguity in an isothermal layer. All three parcel θ_e profiles give out the same EL temperature. I'm sure the updraft strengths would not be the same, however.

Other satellite-based severe convection training materials

- Enhanced-V's and what they mean
  - http://www.cira.colostate.edu/ramm/visit/ev.html
- More on how Enhanced-Vs are formed:
  - http://www.nssl.noaa.gov/istpds/icu624/
- Interpreting Rapid Scan Operations data
  - http://www.cira.colostate.edu/ramm/visit/rso3.html
  - http://www.cira.colostate.edu/ramm/visit/newrso.html

Here are some extra satellite-based training sessions that address severe storms detection. There is another session centered on a case that illustrates the supporting role of satellite data while interrogating storm structure.

Contact info

- If you have questions write to this group e-mail to ensure a quick response
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