Storm Interrogation

AWOC Severe Track

IC3-III-A

Tornado Warning Guidance – Mesocyclone analysis and sampling

Welcome to AWOC Severe Track

IC3-III-A

Tornado Warning Guidance – Mesocyclone analysis and sampling

It is about 18 slides long and should take 20 minutes to complete

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.

TWG: mesocyclones

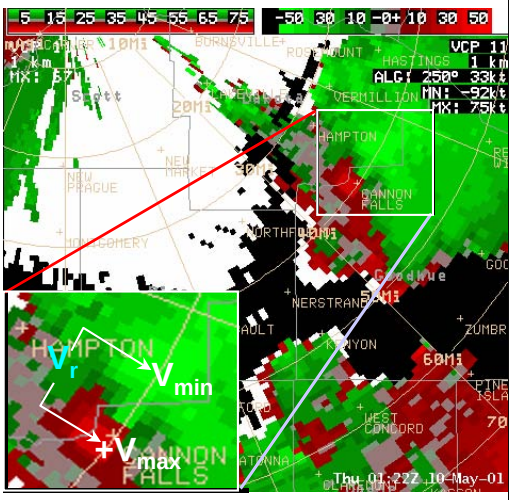
- Motivation
  - Weakening mesocyclones may just be a radar artifact
  - The impact of range on tornado warning performance based solely on mesocyclone low-level rotational velocity is not as simple as previously thought

All too often I am tempted at discontinuing a tornado warning when a mesocyclone begins to weaken. Is the mesocyclone truly weakening or is it a radar artifact? This session may help you in your decision.

A second motivation puts into light the difference that range from radar has on mesocyclone rotational velocity and tornado discrimination performance. They do not necessarily coincide and we show you how they differ.

Mesocyclone - review

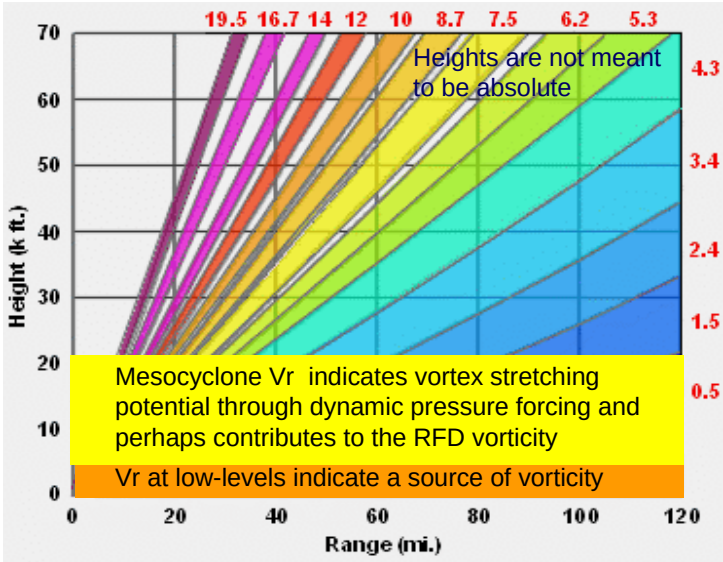
- Core diameter from **V_{min} to V_{max}** should not exceed 5 nm
- Rotational Velocity $V_r = (|\mathbf{V_{min}}| + |\mathbf{V_{max}}|)/2$ exceeds user thresholds
- Vertical continuity above the low levels adds confidence mesocyclone has some correlation with an updraft



As a refresher, when we define rotational velocity (V_r), it is the average of the absolute magnitudes of the maximum and minimum velocities found at some distance from the center of rotation. A mesocyclone contains azimuthal runs of continuously increasing velocity between the peak minimum and peak maximum velocities. Sometimes that run of adjacent range gates with increasing velocity is very short, especially when the mesocyclone is not much larger than the widths of the individual gates. This is where sampling issues come in when measuring V_r .

A mesocyclone should have vertical continuity and this leads to a mesocyclone having V_r measured at multiple elevations. The lowest elevation V_r is the one we will measure most often when assessing its potential for tornadogenesis.

Mesocyclones and tornado ingredients



This is what we do know:

Mesocyclones depicted on radar contribute to the ingredients for tornadogenesis either by showing the source of low-level vorticity available for stretching into tornadic scales or by showing where nondynamic pressure deficits act to enhance upward parcel accelerations, and vortex stretching below the mesocyclone detection level. This level may be very low.

What we do not know:

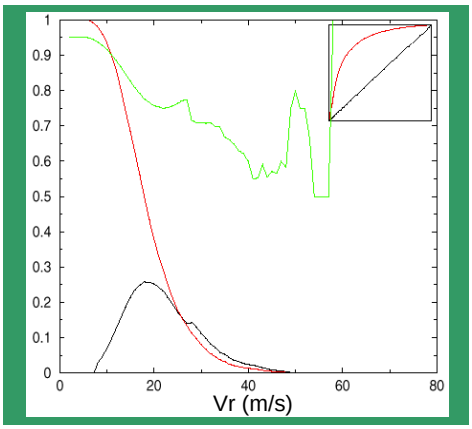
How does the mesocyclone serve the Rear Flank Downdraft (RFD) in vorticity transport? We know the RFD is rich in horizontal vorticity which then tilts into the vertical as it reaches ground. But the evolution of the vorticity from the front flank of the updraft, tilted into the mesocyclone and then its possible contribution to the RFD is unknown at this point.

Mesocyclone best predictor

MDA = Mesocyclone Detection Algorithm available in AWIPS OB4

This parameter is testable by user

MDA low-level rotational velocity: V_r (m/s)



FAR = green line
POD = red line
HSS = black line

Inset = POD vs FAR

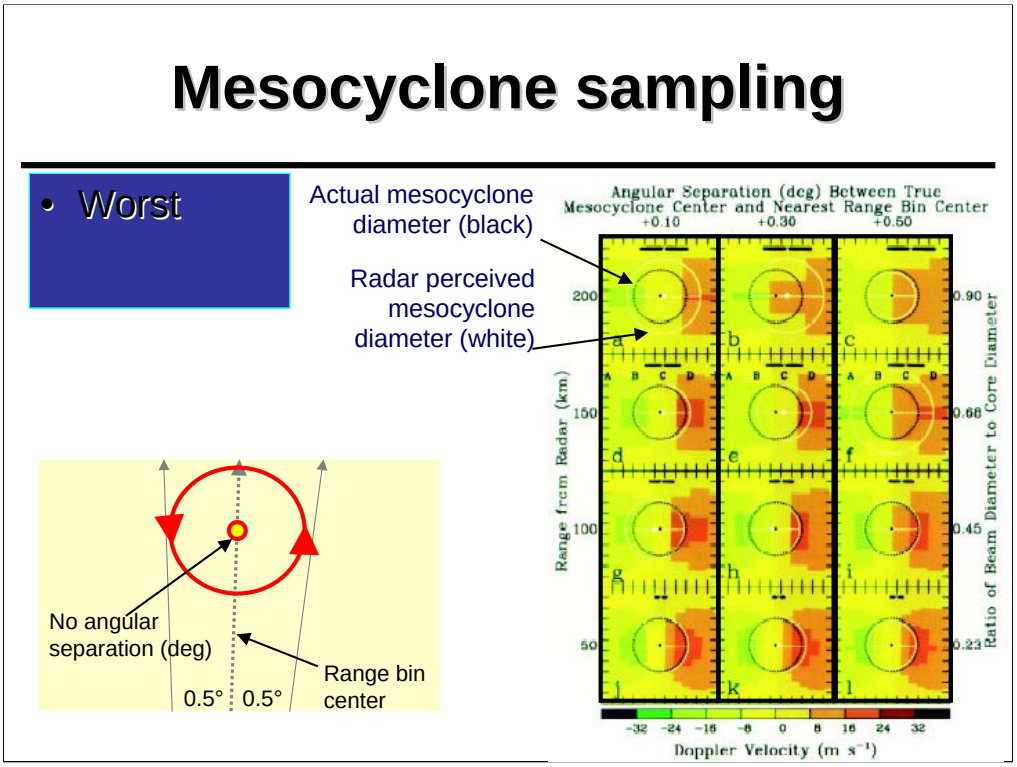
http://www.wdtb.noaa.gov/resources/PAPERS/twg02/index.html

A project between NSSL and WDTB was conducted in 1999 and 2002 to determine the skill scores of multiple radar and near storm environment parameters in discriminating tornadic and nontornadic radar detected mesocyclones and Tornado Vortex Signatures (TVS). The scope of the study went on to generate a neural network incorporating hundreds of parameters describing the mesocyclones and TVSs and near storm environment data. Results were mixed, however several important findings came out of the study.

For radar-based parameters describing mesocyclones, one of the best tornado discriminators wound up being low-level V_r. Using low-level Vr as a threshold and varying that threshold incrementally, we generated a graph of its skill in tornado discrimination. For example, at time T, the low-level Vr was evaluated by the mesocyclone detection algorithm (MDA). If the mesocyclone was within T-20 minutes to T+5 minutes of a tornado, that particular measurement of low-level Vr would be considered a hit. Otherwise, it would be a miss. After thousands of detections from many years spanning the country, statistics were created for low-level Vr, amongst hundreds of other parameters.

Note that the FAR remains high, never falling below 60%, and staying above 70% for most values of Vr. The POD drops off considerably as low-level Vr increases beyond 15 m/s (30kts). The black curve represents the Heidke Skill Score (HSS), a better skill score than Critical Success Index (CSI). The HSS accounts for correct null decisions (forecast of no and none observed) which the CSI does not. Note that the HSS peaks at roughly 20 m/s (40kts). However, there is a broad range of good HSS skill scores. If you waited till the Vr reached 20 m/s before issuing a tornado warning, your skill scores would be maximized. Just remember though that these skill scores don't have to answer to asymmetric penalty ratios, or take into account different environments with different sized mesocyclones. All mesocyclones of all sizes in all environments were lumped into these results.

I mention that low-level Vr is one of many parameters describing a mesocyclone. In actuality, there are other parameters that are slightly more skillful than this one. These include ones such as integrated rotational velocity, and mesocyclone strength rank. Both of these parameters cannot be easily evaluated by manual inspection of base data. They are available, however, in the MDA. The MDA will replace the current mesocyclone algorithm by AWIPS OB4.



Any mesocyclone velocity-based parameter suffers from sampling limitations owing to:

1. the ratio between the mesocyclone diameter and the beam width,
2. and the location of the mesocyclone center with respect to the beam center (measured by angular separation).

Note that the angular separation is zero when the mesocyclone center is located on the beam centerline, and rises to 0.5° when the mesocyclone straddles the edge of a beam. A mesocyclone is optimally sampled if the angular separation is 0.5°, or when none of the beams samples both sides of a mesocyclone and average out its velocities. Meanwhile the mesocyclone is large compared to the beam width when the ratio of beam diameter to mesocyclone core diameter is small. Look on the vertical axis to the right of the 12 panel and you will see this ratio appear small when the mesocyclone is large compared to the beamwidth and is well sampled. The smaller this ratio is, the less important angular separation becomes since a smaller portion of the mesocyclone velocities are affected by angular separation.

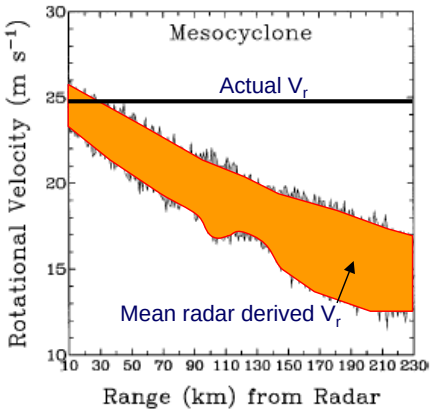
Results from a sampling study conducted by Wood and Brown (1997) show how these two considerations interact to reduce the maximum velocities and change the appearance of a mesocyclone. The 12 panel image on the right shows how a theoretical mesocyclone with a diameter described by the black circle and a Vr of 25 m/s changes according to angular separation and distance from the radar. The theoretical mesocyclone is 3.5 nm in diameter. But note that the radar's interpretation of the mesocyclone diameter (white circle) starts to change as the mesocyclone becomes smaller relative to beam width.

Look at the top row (range=200 km) where the mesocyclone diameter is just a little larger than the beam width. Three scenarios are presented:

1. An okay angular separation of 0.3° leads to a gate-to-gate signature similar to that of a TVS but the mesocyclone diameter is too high (see white circle) and a little off center.
2. The next slide shows the best condition where there is no angular separation and the mesocyclone is seen by the radar to be in the correct place and size. Vr is a little low since the maximum velocities exist in an area too small for adequate resolution.
3. Now, if the mesocyclone is sampled by the next volume scan with an angular separation of 0.5°, the velocity minima and maxima are averaged out to reveal near zero velocities. The adjacent beams can only pick out the weakening velocities outside the mesocyclone diameter. The mesocyclone will have appeared to weaken.

Mesocyclone sampling vs trends

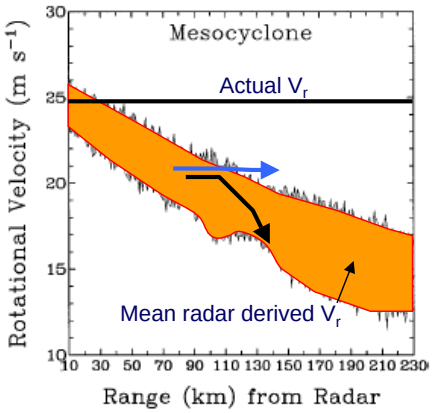
- Vary the angular separation between beam centerpoint and meso center
- Add radar data uncertainty
- Do this for all ranges
- Result is uncertainty for Vr for a 3.5 nm wide mesocyclone for all ranges
- Suspect any trends that fail to exceed the uncertainty envelope



Wood and Brown (1997) incremented the angular separation enough to graph the Vr in 50 steps for each range from the radar. Instrument noise was added to better simulate the velocity returns from the WSR-88D. The result is a picture of the uncertainty of how the WSR-88D depicts a true mesocyclone of 3.5 nm in diameter and a Vr=25m/s. Note that the uncertainty increases with range around a slowly diminishing average Vr depicted by the radar.

Mesocyclone sampling vs trends

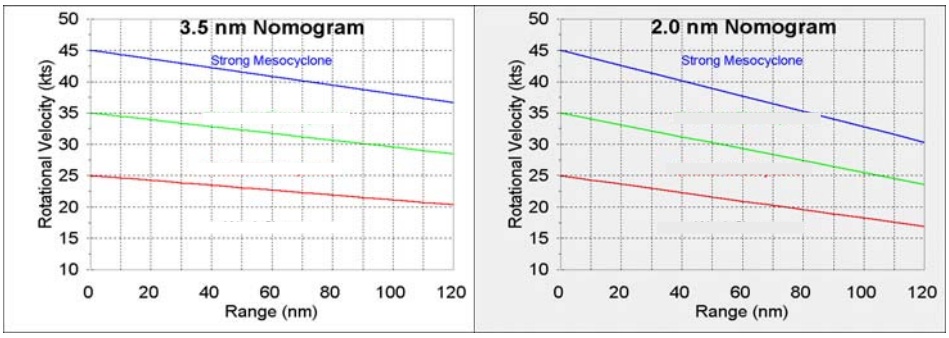
- The V_r trend in black is not strong enough to rule out radar sampling
- The V_r trend in blue, may indicate actual meso is intensifying
  - If the mesocyclone has moved away from the radar the same distance indicated here



When thinking about radar uncertainty and Vr degradation with respect to range, you may have a good picture of what kinds of mesocyclone trends may be real. Remember that this plot was created with a true mesocyclone Vr of 25 m/s across 3.5 nm. The range degradation of Vr would be sharper for smaller diameter mesocylones. A mesocyclone appearing to have constant Vr but is increasing in range is probably actually intensifying like the trend in the blue line. A mesocyclone appearing to be abruptly weakening by 3 m/s (6kts) while also increasing in range with time might not actually be weakening (black line).

Mesocyclone sampling effects with range

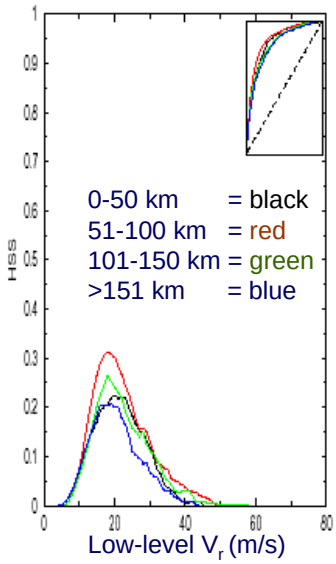
- Wood and Brown's results agree with the trends of V_r with range shown here.
- However…



The Wood and Brown (1997) results show the same Vr degradation with range as the classic mesocyclone nomograms we have preached to use for many years. There is one issue. What is a strong mesocyclone, a moderate, a weak mesocyclone with respect to its potential for a tornado discriminator? The HSS plot of low-level Vr suggests that tornado warning skill does not linearly increase with increasing Vr. There is a peak, after which the chances of missing tornadoes increases. How do the skill scores change with increasing range? The results are in the next page.

Mesocyclone low-level rotational velocity vs. range

- Heidke skill score shows the highest performance of low-level V_r at 51-100 km range
- Overall degredation in performance is not consistent with range



http://www.wdtb.noaa.gov/resources/PAPERS/twg02/index.html

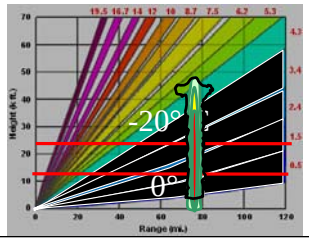
The TWG study broke all parameters that are radar range dependent into 50 km bins and recalculated their tornado discrimination potential. Note that for the low-level Vr, the best skills in HSS are achieved at an intermediate range of 51-100 km (27 – 53 nm).

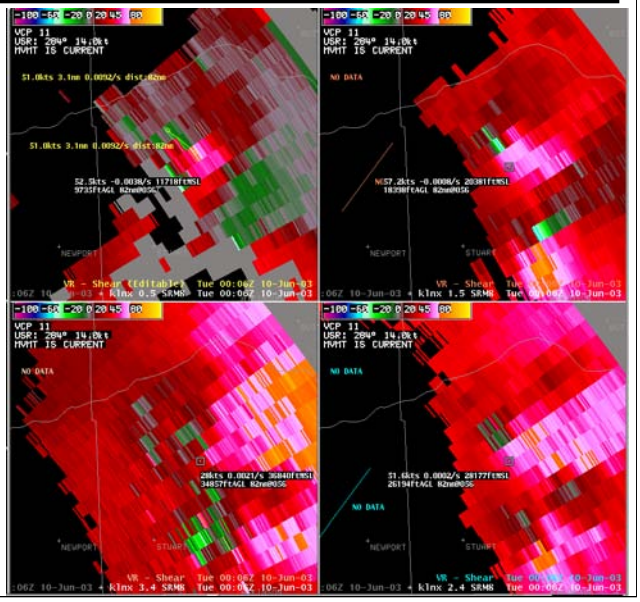
Then the HSS decreases somewhat at higher ranges. Note though that the HSS never drops drastically, even for ranges greater than 80 nm. The small changes in range probably represent the large compilation of all types of mesocyclones and that many are of fairly normal size (diameter=3.5 nm).

The low HSS skill scores of low-level Vr at the closest ranges <51 km, may be a result showing that many mesocyclones are strongly convergent at low-levels and therefore, have a lower rotational component to their total velocity. This is mostly speculation at this point. We do have a lesson on close range tornado warning guidance.

Example: Classic distant meso

- Typical size supercell at 78 mi
- Some uncertainty about measuring the same mesocyclone as its Vr increases and onset of gate-to-gate shear





Now to some examples.

The first one goes back to the 09 June 2003 northern Nebraska storm. It is a standard size supercell, and has the unusually low reflectivity values as of 2345 UTC. See the lesson on updraft strength from radar and satellite IC3-II-E. The storm continued to intensify and the reflectivities increased to more “normally” what is expected.

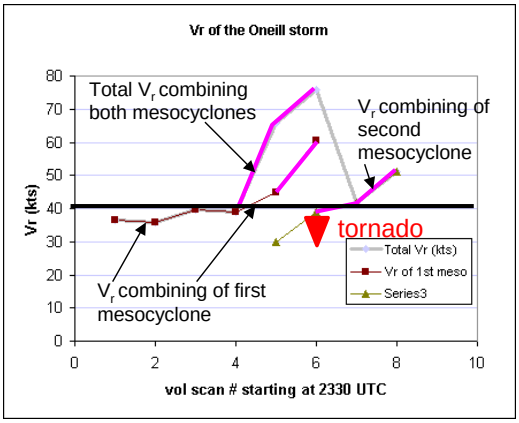
This four panel velocity loop extends into 0005 UTC the next day.

At 2335 UTC, there are huge outbounds on the north side of the mesocyclone. Is this velocity dealiasing? Yes, most likely

At 2350 UTC, I move the 4 panel further east and at the same time, the Vr increases abruptly. However, it is not clear whether or not I may be sampling inbounds of one mesocyclone and outbounds of another further southeast. My uncertainty remains until I see a more coherent velocity structure at the end of the loop. Vr values are very strong for this range and the mesocyclone is a bit larger than 3.5 nm. I will plot my total Vr assuming this is one mesocyclone we are tracking but I will also split the Vr into what I think may be two mesocyclones as well.

Vr trends

- From the Vr uncertainty chart, and the distance of 78 nm, I estimate a 5 m/s (10 kt) uncertainty in any trend



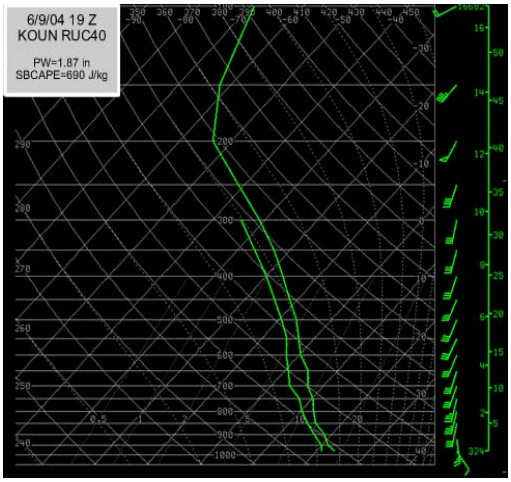
The purple line segments indicate increase in V_r above my 10kt uncertainty using the start points as my initial strength.
The black line indicates optimal Vr for best tornado warning skill based on TWG results.

Both the total Vr of what may be two mesocyclones are plotted. But with my uncertainty about whether I am seeing one or two mesocyclones, I will make my best guess as to the Vr for each one. Either way, note that there are fluctuations in low-level Vr but I am not calling these fluctuations real until I see a change of at least 10 kts from the start time of this loop. If I look at the Vr of the first mesocyclone only, not the combined ones, I get a one volume scan leadtime before the reported tornado. It is most likely the tornado came from the smaller velocity gradient on the northwest mesocyclone, or the northwest side of the combined mesocyclone.

If my uncertainty confuses you, it should given that this mesocyclone is at 80 nm and at that range, poor velocity sampling could inadvertently lead you to accidentally combine two mesocyclones into one.

2nd Example: Mini supercell

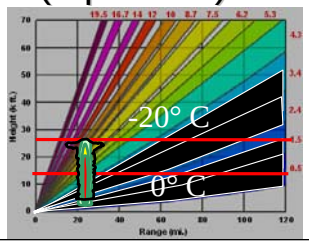
- Shallow CAPE
- Good low-level curvature
- Typical of tropical storm environments but with a subtropical system

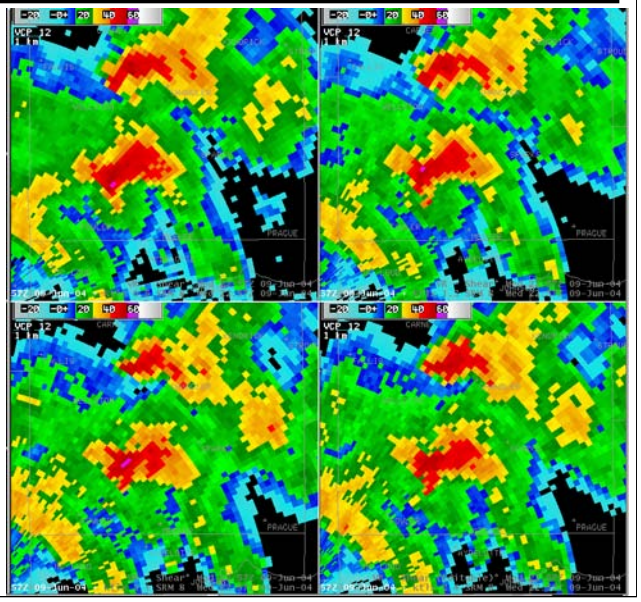


This case is not like the last one in that we are looking at a shallow CAPE, tropical type environment. There is good low-level turning below 2 km AGL and not much speed shear above that. Given my nearly saturated environment, and good 0-3 km CAPE, I might expect some minisupercells and a small tornado potential. At the time of this event and without 20/20 hindsight, this day presented itself as a challenging situation given the initially widespread areas of heavy rain, eventually breaking up into isolated modes of convection.

2nd example

- Close range, starting at 13nm and ending at 27 nm
- Tornado time is at 2257 UTC west of Chandler (top storm)

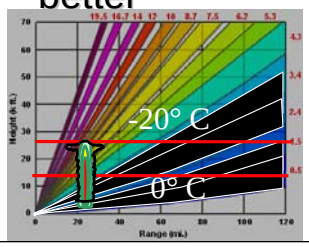


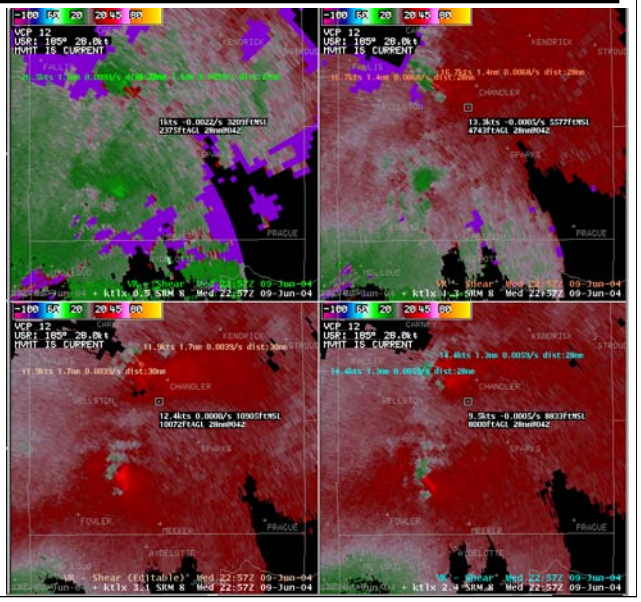


From a close range averaging 20 nm, the radar in VCP 12 shows two minisupercells. This 4-panel is zoomed to the same scale as the one in the previous case. Note in the VCP chart, the large separation between the 0 and –20 C levels indicating a weak lapse rate. The storm top barely made it to –20 C. None of these storms produced hail, however the rainfall rates were extremely high.

2nd example

- Small mesocyclone (2nm)
- Yet still smaller V_r than the Oneill storm
- Sampling much better



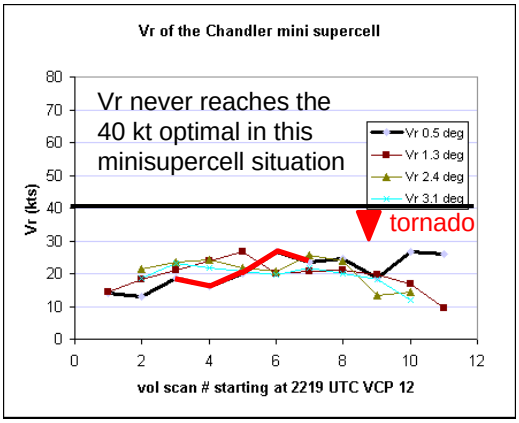


This 8 bit SRM imagery shows the mesocyclones on the same zoom level as the previous example. I am tracking the northern supercell mesocyclone. Despite the small size of the mesocyclone (<2nm in diameter), the close proximity to the radar allowed for good sampling. We should not have the same problems with angular separation as with the previous case.

Note in the first few frames of the loop, the lowest slice (upper left) mesocyclone structure is mostly convergent and experiences a lower Vr than even the very next slice, only 1500 ft higher. This is an example where the near range low-level Vr may be reduced since most of the velocities are convergent instead of rotational. The mesocyclone appears to shrink later in the loop and although the 0.5° slice shows more rotation, the Vr remains small. The tornado was reported in the last frame in the loop, or at 2257 UTC.

Vr trends

- From the Vr uncertainty chart, and the distance of 20 nm, I estimate around 3 m/s (6 kt) uncertainty in any trend
- Owing to good sampling, the velocity uncertainty is small



The red line segments indicate increase in the 0.5° V_r above my 6 kt uncertainty using the start points as my initial strength.
The black line indicates V_r for best tornado warning skill based on TWG results.

Starting with the Vr time trend from the previous caes, I add the current case and overlay the Vr at which the TWG study's HSS skill score peaks for low-level Vr. The minisupercell Vr never reaches close to that level.

I plotted the Vr time trend of all slices at once. The dark black trend represents the low-level Vr. Here with my decent mesocyclone sampling, I allow myself a lower threshold of velocity change in time before calling it a legitimate trend. The thick red line represents where that trend has occurred relative to the beginning of this trend. Note that the values increase, then level off and actually decrease a bit before the tornado report.

Summ: 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.