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Topic: Storm-Based Warning Fundamentals

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Welcome to the Storm-Based Warning Fundamentals lesson entitled “TOR for Isolated Tornado Threat.” The lesson is narrated by former instructor, Paul Schlatter. Since this module was part of the original storm-based warning course from 2011, there are occasional references to objective “T1” . Please disregard those verbal references .The purpose of this lesson is to show examples of possible ways to issue tornado warnings for individual and potentially tornadic supercells.

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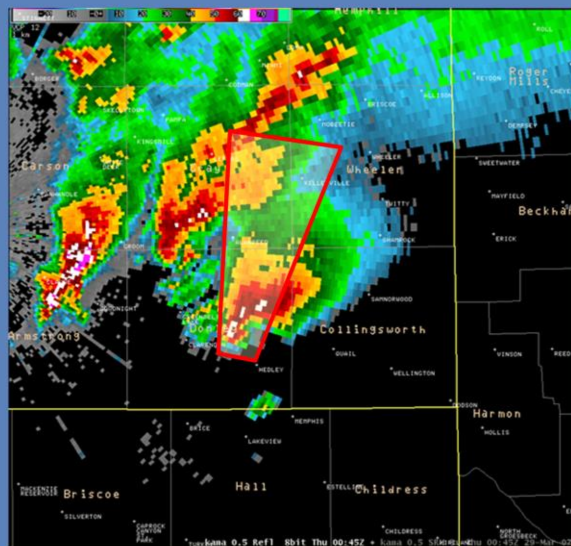
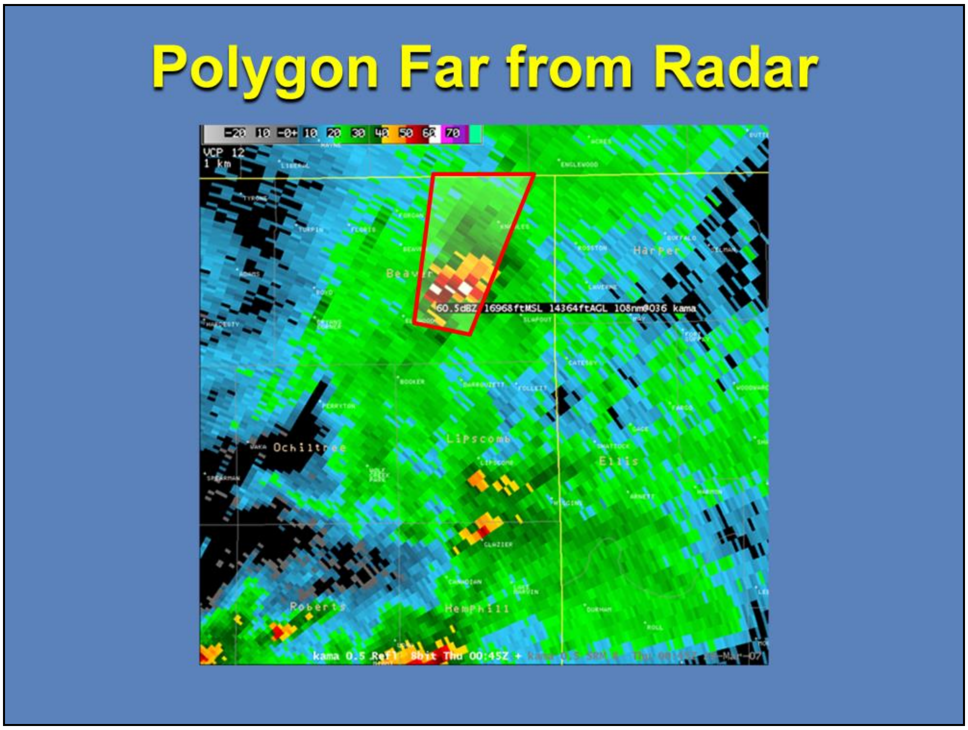
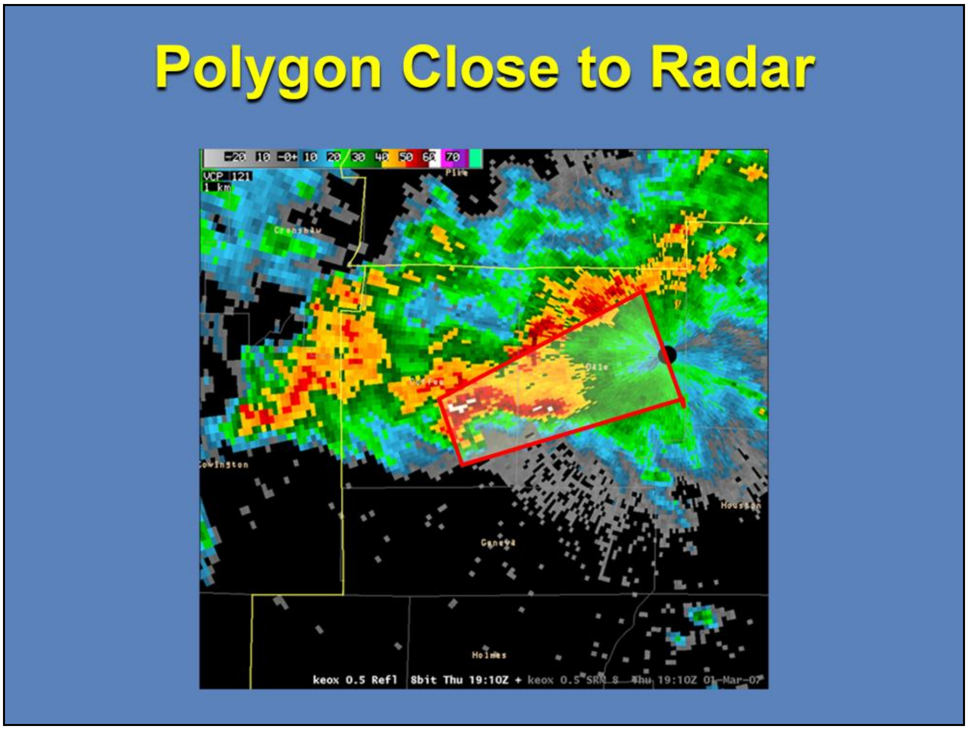
1st Example Polygon



This first example shows several supercells east of the Amarillo, Texas radar. Strongest reflectivity returns from the hail cores are moving from 200 degrees at 35 knots, as are the low-level circulations give or take a few degrees and knots. The furthest east supercell in Donley County has already produced significant tornadoes and shows no signs of weakening or even becoming less tornadic. A storm-based tornado warning for the next 40 minutes for this supercell may look like this, covering the area I feel is most at risk to experience a tornado based on near-storm environment and an analysis of all-tilts SRM. It's fairly narrow because of the steady-state behavior of the circulation and storm over the last couple of hours. Toggling over to reflectivity, the tornado warning includes just about all of the reflectivity and hail core to the north and west of the inflow notch but it may be a good idea to make the polygon a little wider to include the potential for hail since drawing a tiny severe thunderstorm warning on the fringes of the tornado warning is impractical and would be confusing to our customers for this storm. Thus, it would be a good idea to include expected hail size in the text part of the warning. Additionally, the south end of the polygon is south of the circulation to account for the potential for severe rear flank downdraft winds. It is a good idea to keep a buffer in the polygon to account for the potential of RFD winds.



Try this example far from the radar. A tornado warning polygon for this storm 100 nm from KAMA, which is also moving NNE at 35 knots, may look like this for a 30 minute warning. The polygon extends to the CWA border on the north and includes the impressive gate to gate signature. (Z toggle) This storm produced a significant tornado within this polygon and also includes all significant reflectivity associated with the hail core.



Another example, this time very close to the radar. We are looking at southeast Alabama and the KEOX radar, for the northeast part of the Tallahassee CWA. The low-level circulation is moving from about 230 degrees at 43 knots. Toggling over the reflectivity, we can see that the low-level mesocyclone is moving into an area of 60 dBZ to the east-northeast. There are also 60 dBZ returns just north of the circulation. Thus, a single storm based tornado warning for this event may look like this, for the next 30 minutes. This is the Enterprise, AL tornado so you know how strong and persistent the tornado from this point forward. Let me toggle back to SRM just to give you an idea of the amount of buffer included around and ahead of the circulation, given the uncertainty of the tornado track over the next 30 minutes.

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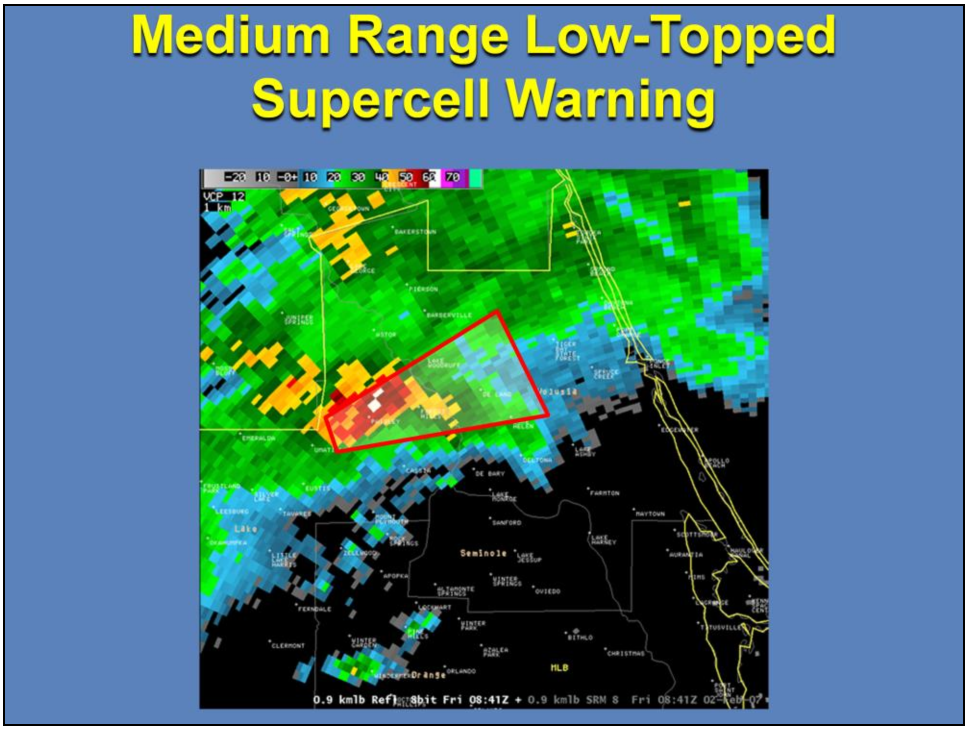

The next case is at a medium range from radar, about 70 nm, this is from KMLB and the storm is over eastern Lake County, Florida. I am showing the 0.9 degree tilt since the 0.5 tilt is contaminated by being right at the end of the first trip. This was a low-CAPE environment but contained off the wind charts shear. This supercell had been tornadic for over a half an hour by this time. A storm-based tornado warning may look something like this. I tracked the mesocyclone for storm motion, and it is moving out of the WSW at 46 knots. This is a 30 minute warning, taking the eastern edge of the polygon into central Volusia County. Toggling over to reflectivity…nearly all strong reflectivity is expected to remain within the tornado polygon.

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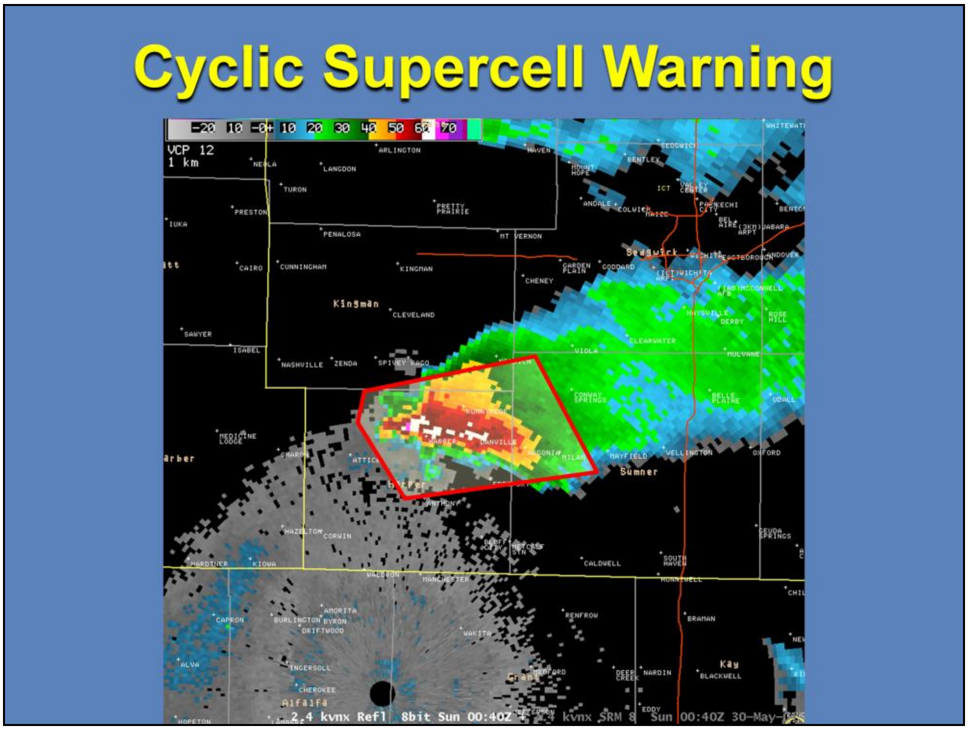

Let’s try a hindsight example to illustrate the need to NOT make warnings too narrow in the new storm based world. I say hindsight because I know the location and movement of the tornadoes from this radar image forward. Let’s look at a cyclic supercell in Southern Kansas. Often times, especially with cyclic supercells, older, occluded mesocyclones with or without tornadoes move well to the left of the parent storm track. In this image, the older mesocyclone is moving NNE as indicated by the white arrow, and in fact produced a tornado that persisted for over 15 minutes following this volume scan. The new mesocyclone, clearly dominant based on an all-tilts analysis, is shown here. The new mesocyclone track is indicated with the white arrow, and it went on to produce a strong, long track tornado from here into Sumner County. A narrow, storm-based tornado warning that would merely cover the southern flank of the storm and hook echo would not cut it with this storm, as a significant tornado would be missed, and possibly subsequent tornadoes. Here is the polygon I have drawn. It is pretty wide in the north/south direction to account for the older mesocyclone and the possibility that during this 30-min warning the new meso may also occlude and moves left of the storm track. With cyclic supercells, it’s a good idea to make the tornado polygon account for the possibility of tornadoes to the left of the storm track. Toggling to Z, we find that the polygon contains all of the RF gustfront and hail core so those threats should be covered in the text portion of the product. If you are unsure if a particular supercell is cyclic, it is probably better to play it safe and keep a nice buffer to the right and left of the rotational track for your tornado warning polygon.

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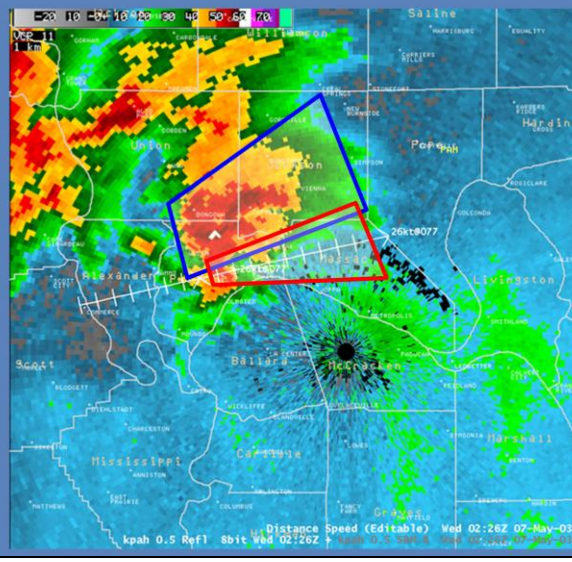
Unique/Rare Event: Separating TOR and SVR for Single Supercell



Here is a final example of a very rare storm, with which you could potentially split up the severe thunderstorm and tornado warnings. Recall from previous examples that given the high uncertainty of tornado location and movement, distance from radar, and/or the location and track of the tornado relative to hail core, issuing separate tornado and severe thunderstorm warnings wouldn't be a viable option. However, there are in fact a few storms where this may be done effectively. Here is one such storm from Paducah, Kentucky, with the track of the TVS indicated with the distance speed tool.

A few things are unique to this and other rarely seen tornadic supercells like it:

•Close to the radar

•Nearly Steady state, non-cyclic supercell

•Classic reflectivity structure with sufficient separation between hail core and tornado

•Tornado location and track not overlapping with hail core track

With these in mind, I first drew the tornado warning polygon based on all-tilts SRM for 30 minutes. There actually isn't much uncertainty with the location and movement of this tornado because the supercell has been nearly steady state and the TVS movement hasn't varied more than 5-10 degrees over it's already significant lifetime. Toggling over to reflectivity, clearly the hail core is not within the tornado polygon and is expected to track along and to the north of the northern edge of the polygon. Thus, a severe thunderstorm warning for hail up to the size of golfballs could be issued like this, based on storm history and an analysis of all tilts base reflectivity. This storm did produce severe hail and a long track F4 tornado over the next hour, cutting a swatch across Pulaski, Massac and Pope Counties. A bit of overlap is essential between the severe thunderstorm and tornado warnings.

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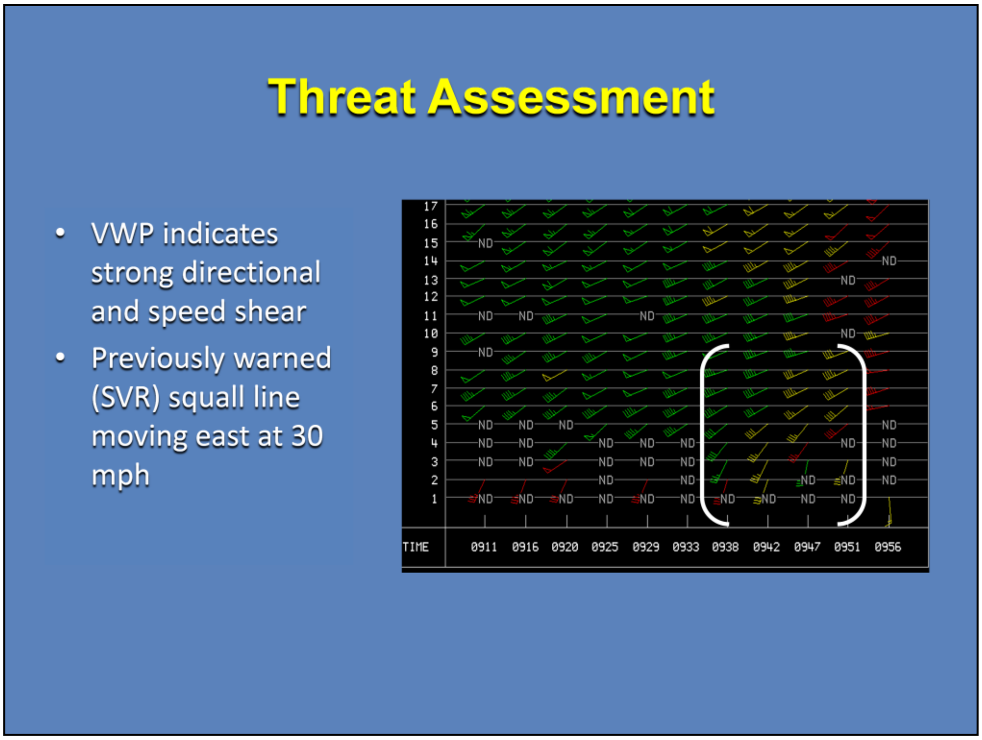
Lesson Summary

- Draw polygon based on analysis of SRM, level of uncertainty
- TOR/SVR: “To Split , or not to Split…”

Draw your storm-based tornado warning polygon for a supercell based on a thorough temporal and spatial analysis of all-tilts SRM, incorporating your uncertainty about the location and movement of the potential tornado. Be sure to include wind or hail threats in the text part of the product, as time permits. There are rare but high-end storm events where separating severe thunderstorm and tornado warnings is a viable option. A classic, steady state tornadic supercell close to the radar is a candidate for splitting up the warnings. The vast majority of tornadic supercells however would be well handled by a single storm-based tornado warning with a buffer around the low-level circulation to account for RFD winds to the right of the track, and hail or deviant tornado motions to the left of the circulation track. This concludes the presentation for objective T1, thanks for listening.

Welcome to the Storm-Based Warning Fundamentals lesson on Tornado Warnings for Quasi-Linear Convective System (QLCS) Tornado Threat. This lesson was used as a previous Objective T3 for the original Storm–Based Warning Course.



The environment for this event supported tornadic potential due to very strong directional and speed shear as you can see from the BMX VAD wind Profile (VWP). A squall line, which had a history of producing damaging winds and hail was moving eastward at around 30 miles per hour through central AL.

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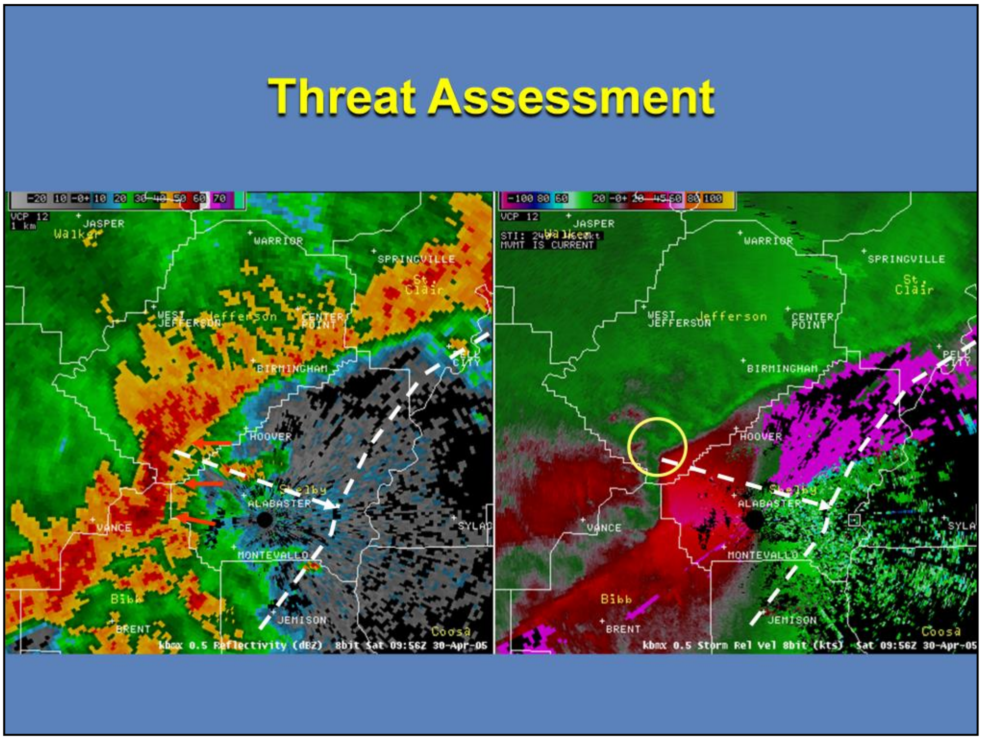

Along this squall line, you can see that there is bowing segment starting to develop just to the west of the radar. Also, inflow notches are becoming better defined along and just to the south of a kink in the squall line. The kink is a location for possible rapid, low-level mesocyclone development, which could lead to a squall line tornado. The location mentioned is in southern Jefferson County denoted by the yellow circle. So, how do we lay out the storm threat given the location of the potential tornado threat and additional severe thunderstorm threat (mainly high winds and hail) along the southern portion of the line? The 30 min projected squall line motion is denoted by the dashed white line.

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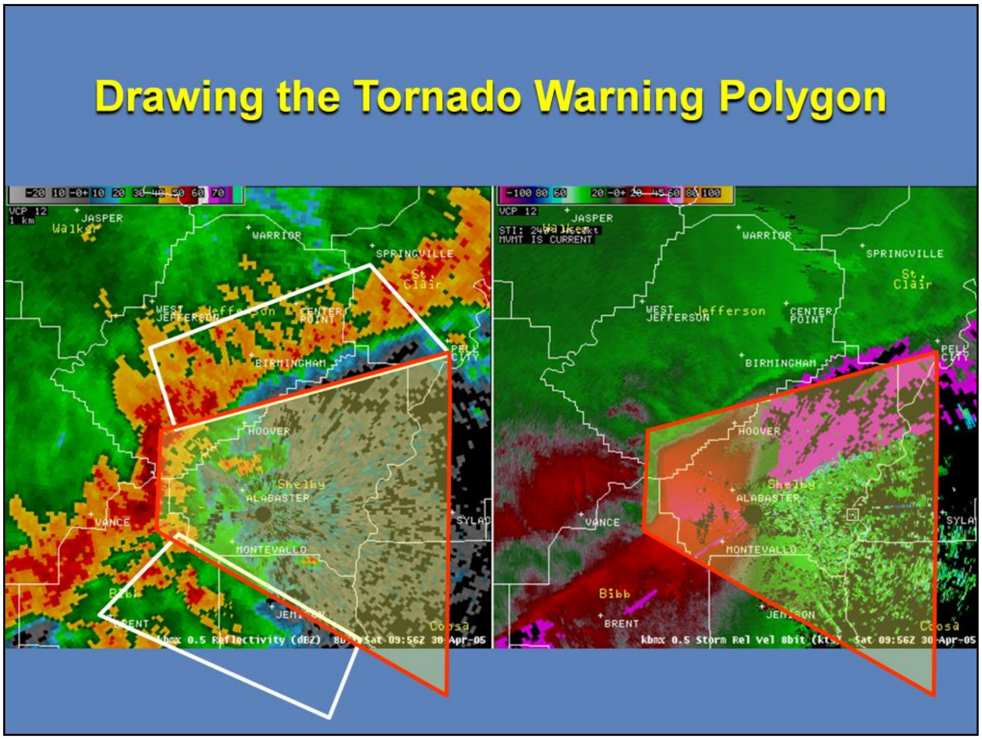

The red polygon is a potential tornado warning for 30 minutes for the squall line tornado threat area. You could also lay out separate severe thunderstorm warnings for adjacent line segments and storms developing along and ahead of the squall line. These severe areas are shown in white (note the slight overlap). For follow-up statements, as the line moves eastward, you would want to trim the back edges of the warnings but be mindful that new development could occur anywhere along the line.

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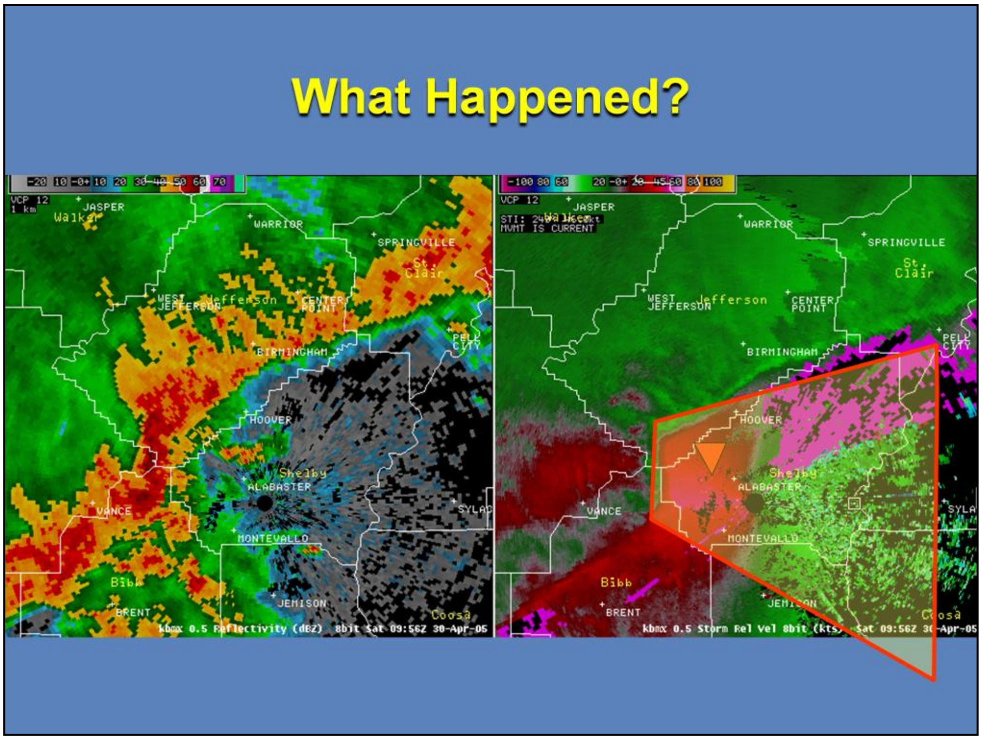
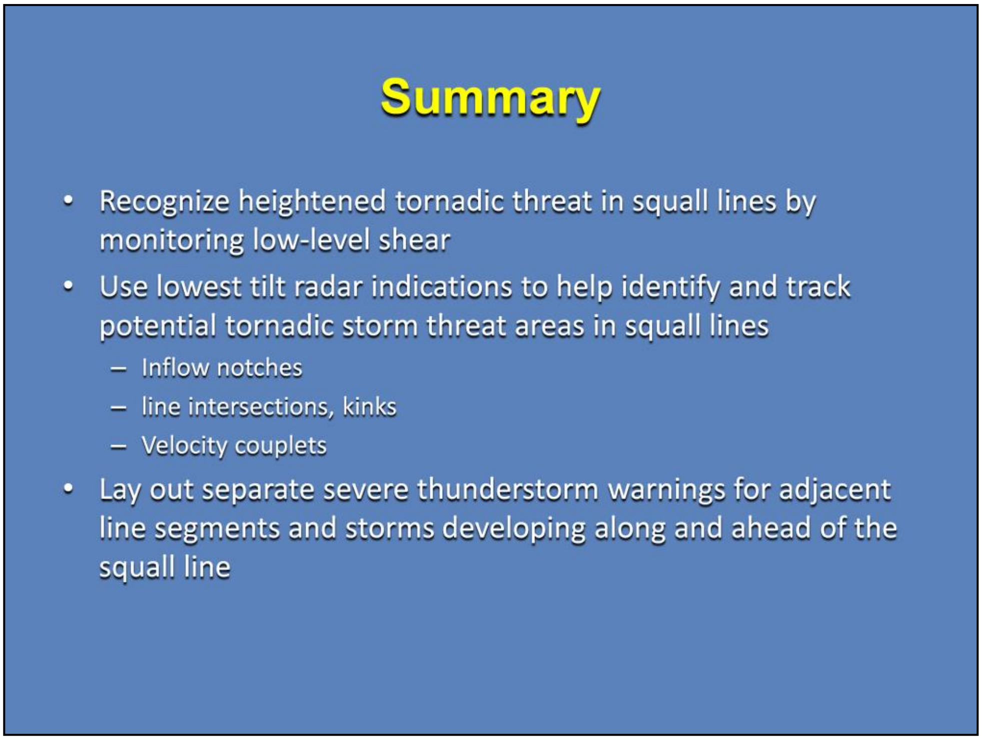


This storm was one of 9 tornadoes that occurred in Birmingham's CWA on April 30, 2005. This particular tornadic storm that affected the Helena, Alabaster, Pelham, and Chelsea areas was rated an F1 with winds estimated around 75 miles an hour. The tornado first touched down just west of County Road 93 near the Cahaba Wildlife Management Area in Helena. The tornado moved generally eastward and crossed County Road 17, County Road 58, US 31, Interstate 65 and County Road 11 before ending near County Road 39. The tornado damage path was approximately 11.6 miles long and 100 yards wide at its widest point. The tornado was on the ground from approximately 504 AM CDT to 518 AM CDT.



For squall line tornado SBWs, here are a couple of points to remember:

First, recognize tornadic threat in squall lines by evaluating environmental low-level shear, like from VAD wind profiler data. Use lowest tilt radar indications (Base data works best) to help identify and track potential tornadic storm threat areas in squall lines such as: inflow notches, line intersections, velocity couplets at kinks in line.

Lay out separate severe thunderstorm warnings (or tornado warnings) for adjacent line segments and storms developing along and ahead of the squall line.

This brief lesson will illustrate some of the issues involved with drawing storm-based warning polygons for storms training over the same region. The lesson will consist of an example of several storms whose individual motions will bring them over the same areas one after another. Additionally, there will be a summary slide with the key points to walk away with from this example.

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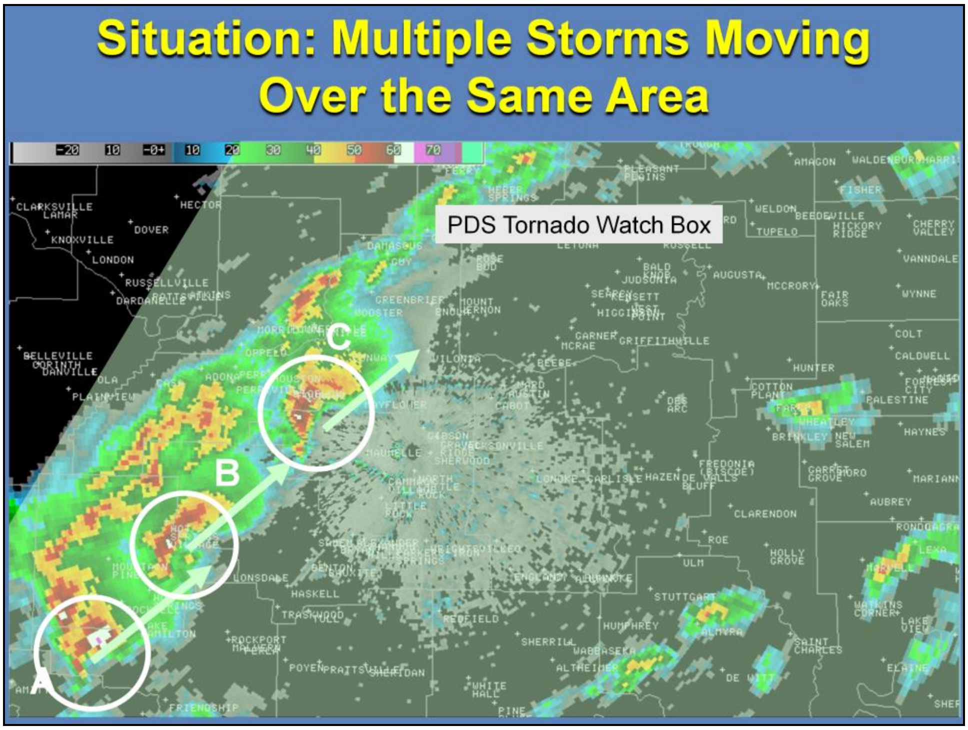

The next few slides will present a situation with potentially tornadic storms moving over the same areas. [A, B, & C labels appear] The discussion will focus on two storms, labeled Storm A and Storm B. Additionally, some mention will be made of a third storm, Storm C. [watch box graphic appears] All three storms are located in a High Risk area that is covered by a PDS Tornado Watch. [watch box graphic fades] …pause…

[circles and storm motion vectors for storms appear] In this case, all three storms are moving along in nearly the same direction with Storm A moving slightly faster than Storms B and C (green arrows indicate storm motion vector). All three storms have storm structure on radar indicative of supercells with the potential to produce tornadoes in the near future. While the near-storm environment is more supportive of tornadogenesis further to the north, the warning forecaster thinks that it would be prudent to issue a TOR for all three storms. [circles move forward to show future storm location] Looking forward in time, we can see approximately where the storms will be in the next 30 minutes or so. These future positions just highlight how difficult drawing polygons can be for this case.

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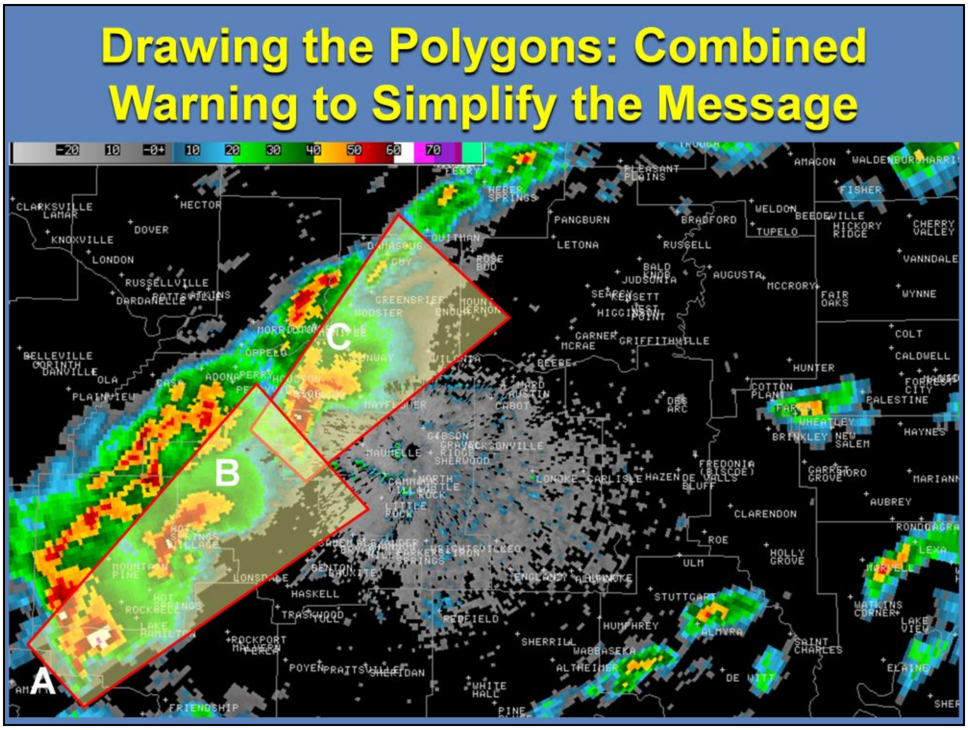

The primary warning issue is how to draw your polygons so that they minimize confusion from overlap. This example could produce several different polygon possibilities. [warning polygon appears] The solution presented here, with Storms A and B encompassed by one warning and Storm C covered by a separate warning, is a good one because it minimizes overlap. Additionally, this product combination would allow for some different wording for the different areas as Storms A and B are impacting more recreational and rural areas while the Storm C is impacting the suburbs of a large metro area.

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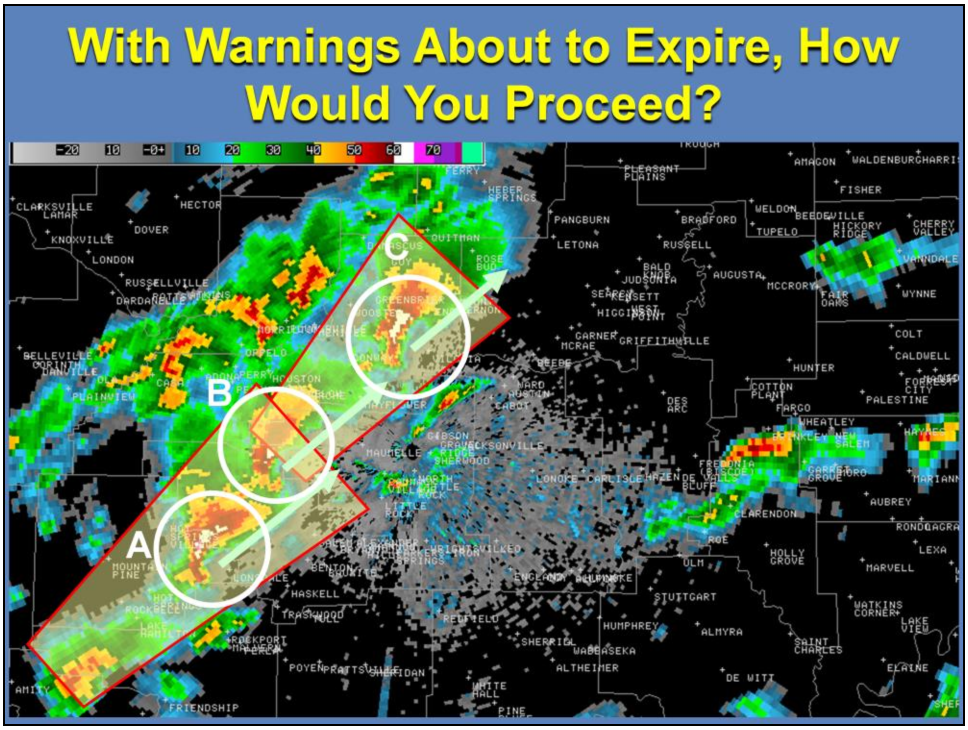
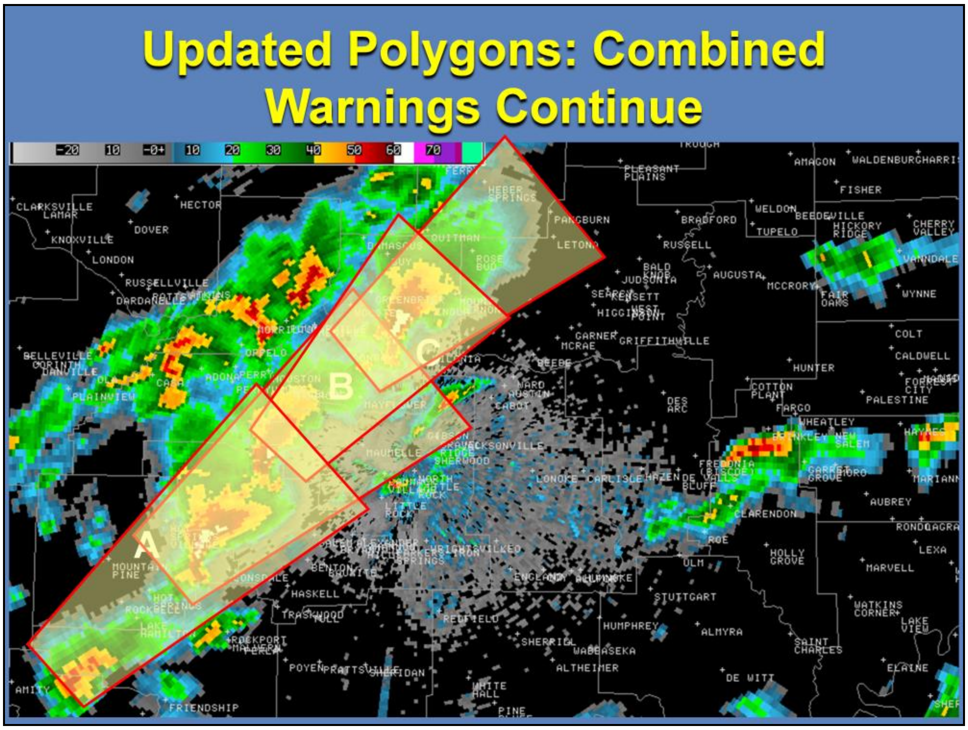


Moving ahead in time about a half-hour, it’s time to reissue our warnings. [warning polygons fade] During that time, the storms have continued to intensify with reports of tornadoes with Storm C. [circles & arrows for storms appear] The storm motion for these three storms continues to be roughly the same as it was earlier. While the decision to continue having all three storms covered by TORs is straight-forward, do you continue to use the same polygon strategy for these three storms? [circles move forward in time] Looking ahead in time, you can see the storms appear to being moving along the same paths still.



…pause… [fade warning polygons to dashed lines] In this example, the subsequent warning polygons that were drawn are similar to the original ones [new warning polygons appear] (with Storms A and B in one warning) as the previous warnings. That will not always be the case, however. If storm motions had changed significantly enough between the two storms, issuing separate polygons may have been prudent. This change in warning issuance would also have been necessary if the threat for either storm changed significantly (say if, in this case, only a SVR was warranted for one of these storms).

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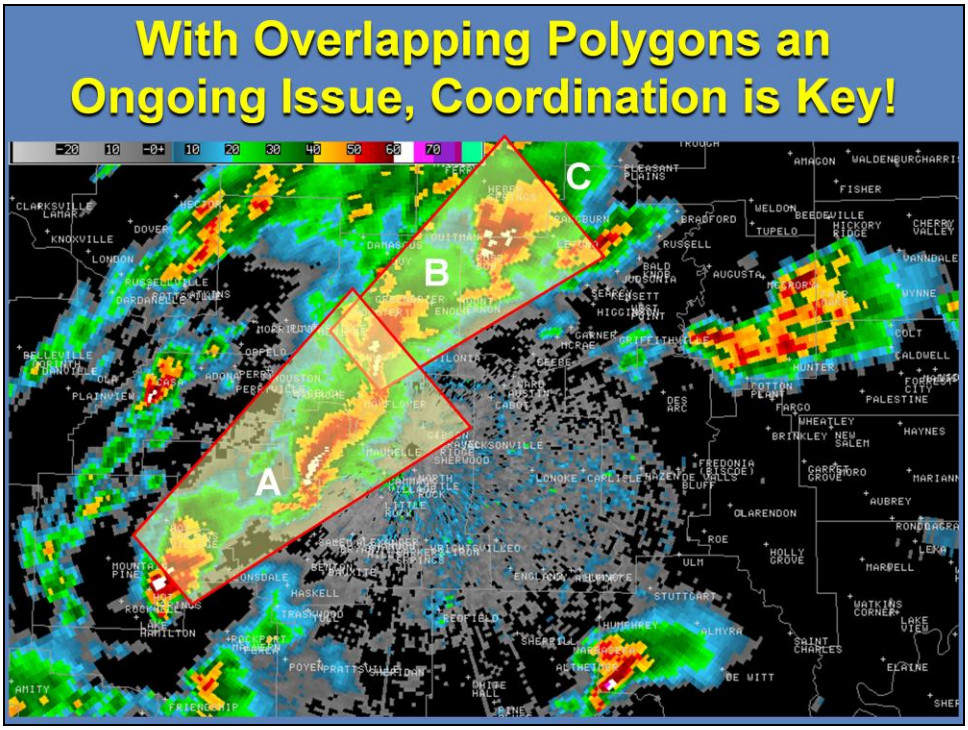

And here are Storms A, B, and C 30 minutes later. It appears in this image that these storms will continue to be a significant threat. Additionally, there is another storm further to the southwest along this same path to worry about. This is obviously an extreme example. However, one can see from such an example why intra-office coordination between warning forecasters is so important for these cases.

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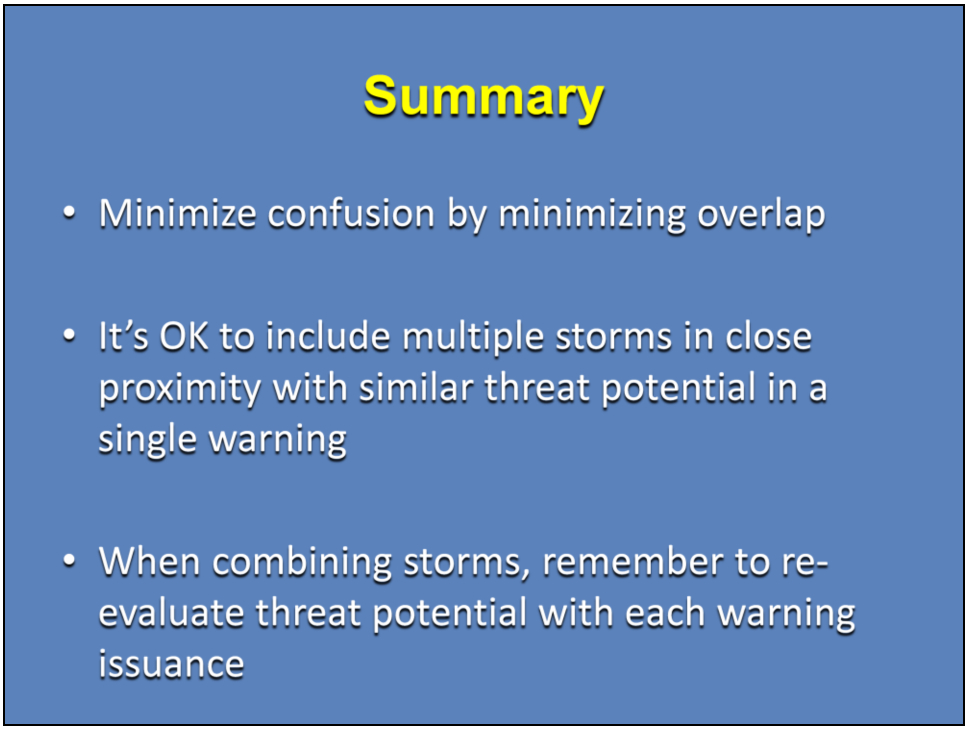

In summary, here are the key points from this example. [first bullet appears] With several storms training over the same area, it will often be confusing to our customers what warning covers what storm. One of the best ways to minimize confusion for them is to minimize the overlap in our warning polygons. [second bullet appears] Even though we are putting a lot of emphasis on these warnings being "storm-based", they are still threat based as well. When multiple storms are in close proximity to each other with similar threats, it's acceptable (if not sometimes preferable) to include them in a single warning polygon. [third bullet appears] When you do combine storms in a single polygon, you need to remember to continually re-evaluate the threat potential of the storms during each warning cycle.

This is a storm-based warning lesson where we discuss what to do for low shear pulse severe storms. I thank Gary Woodall MIC, Phoenix for reviewing this module.

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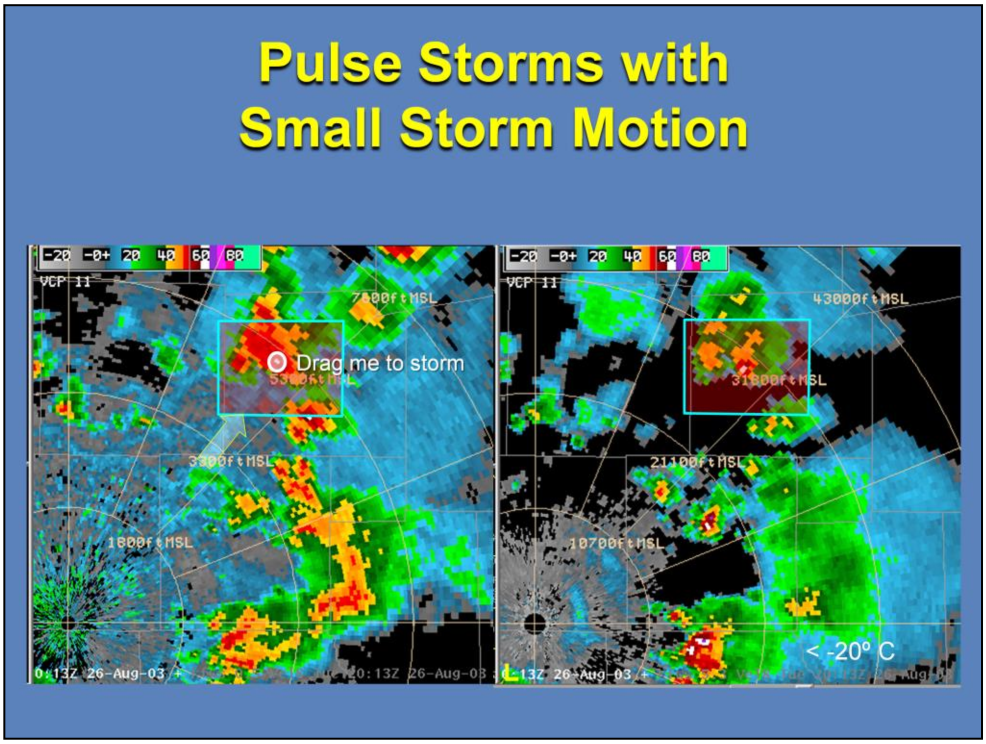

This is a pulse severe thunderstorm environment with little wind shear and weak steering layer flow. The individual cell lifecycle will be dominated by buoyancy process and thus will be relatively short-lived. I have a two panel display, one showing low-level reflectivity (left) and the other showing reflectivity above the -20º C level (right). The storm in question is located northeast of the radar. By the second scan, an updraft pulse develops >60 dBZ reflectivity in the right panel. You may consider issuing a warning at this time assuming that the subsequent downburst expands equally outward in all directions. You draft a warning polygon by taking the 'drag me to storm' icon over the center of the reflectivity core. Adding zero storm motion yields a square box. Your warning's in draft mode pending further consideration. You've got a minute to consider more issues.

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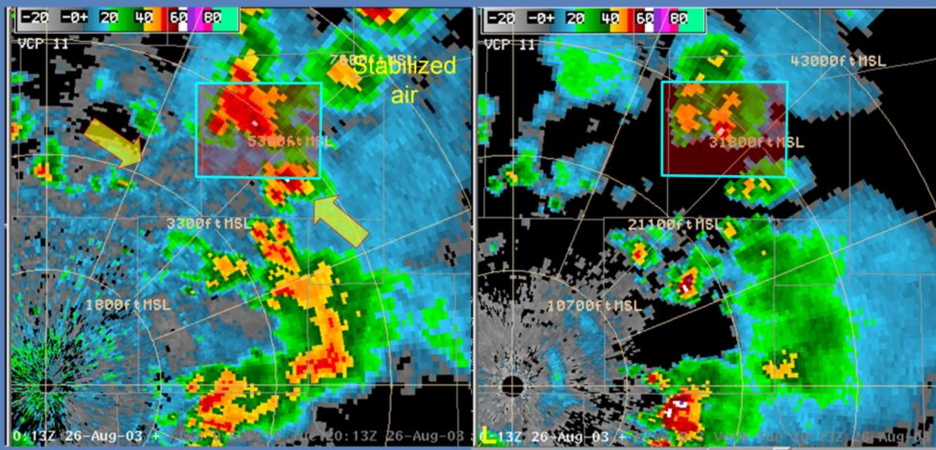
Anticipating Future Initiation



Upon closer inspection, you notice that previous convection is stabilizing the air northeast of your storm. At the same time, there’s another cell to the southeast moving to the northwest. There may be a cell merger. Also, you noticed a boundary collision to the southwest of your storm. Boundary collisions would be prime areas for new convective initiation.

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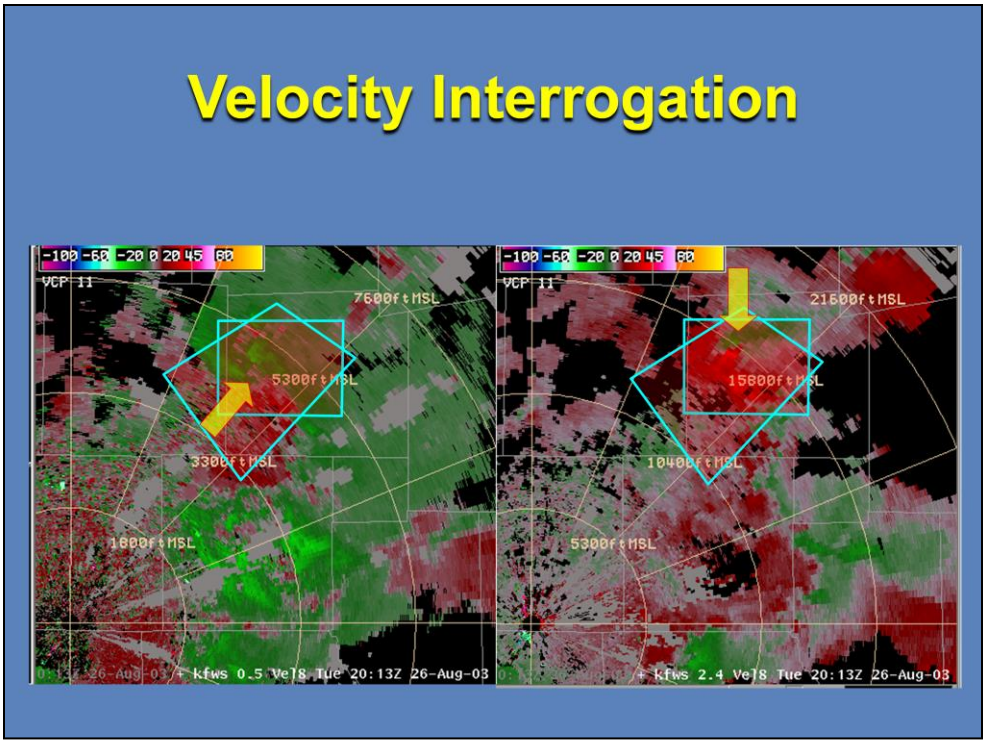

You look at the velocity data and by 2013 UTC you see a MARC signature in the right panel; right above and behind where you see low-level convergence. The MARC starts showing up at the same time as the 60dBZ at 30 kft ARL. There are also indications of a gust front associated with the low-level convergence moving to the southwest. Perhaps it may be necessary to redraw the polygon to reflect the possibility that new cell initiation and subsequent downburst may occur to the southwest and during your warning. You expand the width of the severe thunderstorm polygon on the southwestward end to reflect the greater uncertainty of where that new cell and downburst may occur.

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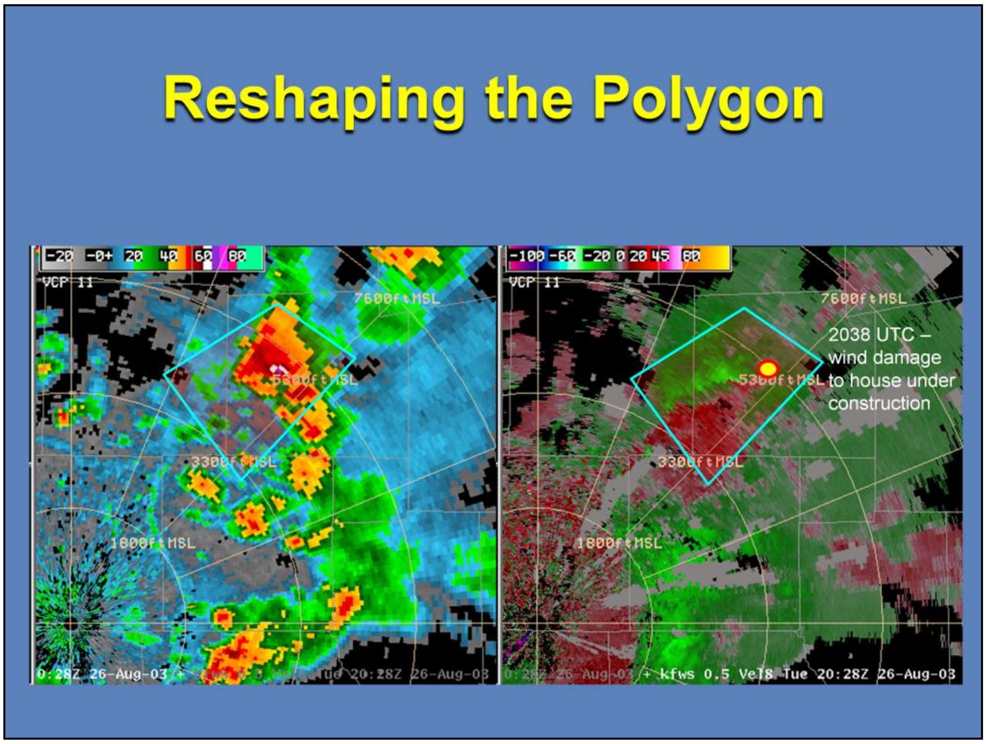
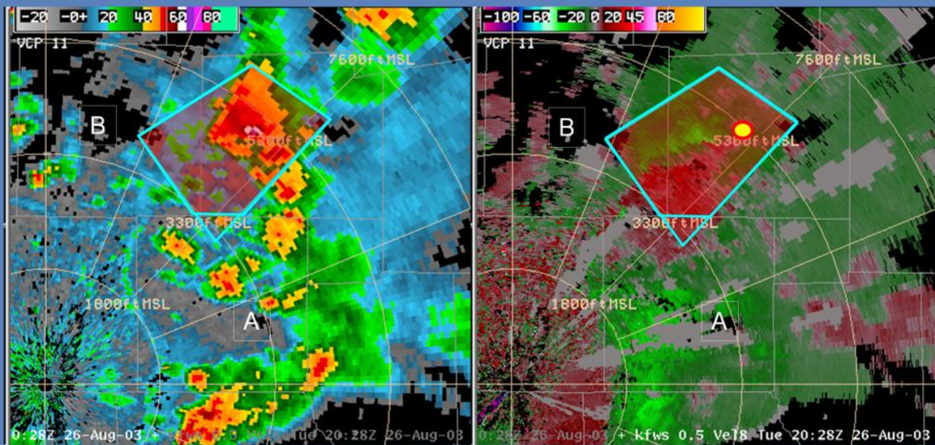


The precursor signatures that we saw of a severe microburst in this case included the rapid upward growth of high reflectivities followed by a MARC signature. The downburst did strike ground starting near the 2028 UTC volume scan and spread mainly to the southwest. Damage was reported to a house under construction at 2038 UTC. The northeast part of the warning polygon verified, however the rest of the polygon warning covered the area most likely for subsequent initiation along the colliding boundaries to the southwest of the original storm. A storm can easily undergo initiation and produce another severe downburst within the warning polygon verification time.

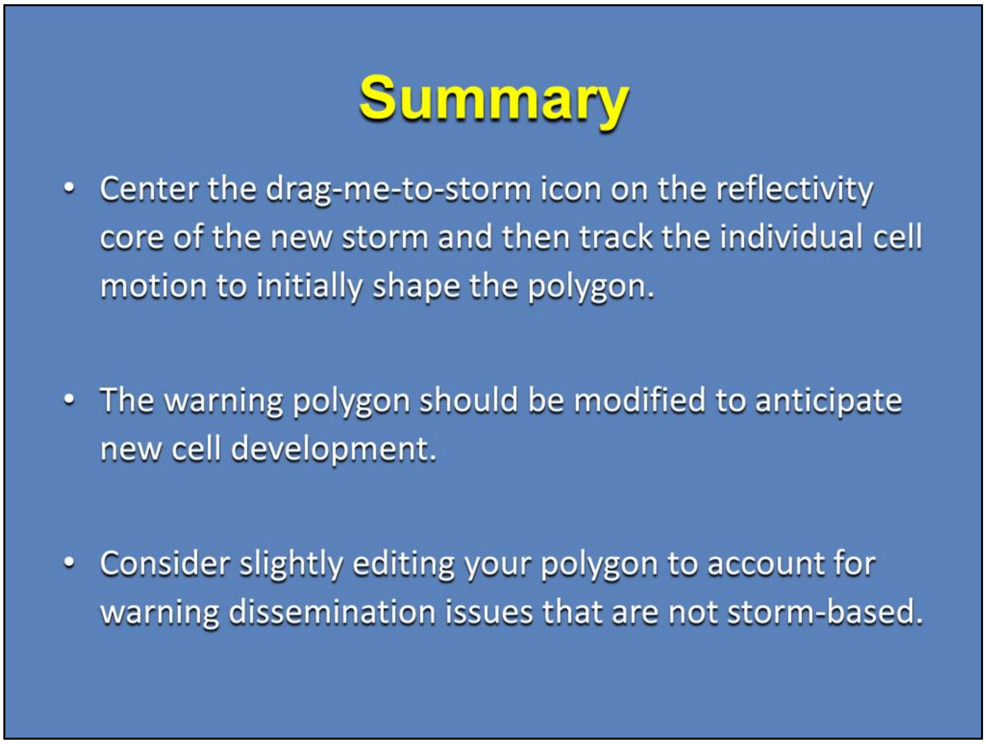
Accounting for Impacts of Dissemination



After considering a purely storm-based warning, there are still issues that need consideration with how your dissemination is impacted by the shape of your warning polygon. At times, you may have a purely storm-based warning that may slightly cross a political border. In this case, the southern tip of the warning crossed into another county border (labeled A). In order to prevent NOAA weather radios from tone alerting for every owner of one in county A, would you consider altering the warning polygon to remove the warning from there? If you believe that county A is not sufficiently threatened by the weather, then yes, edit the polygon.

For county B, you may believe the threat remains high enough to have a warning. You could create another polygon for county B but this strategy would diverge away from the spirit of storm-based warnings.

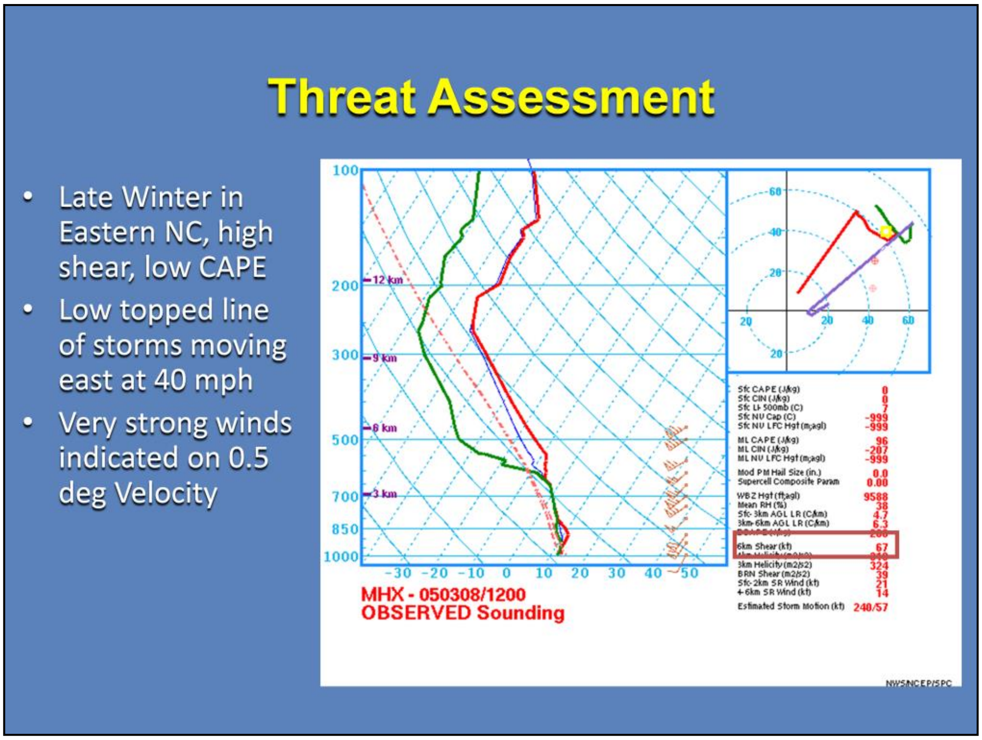
The final shape of this polygon adheres to the storm-based warning concept.



Center the drag-me-to-storm icon on the reflectivity core of the new storm and then track the individual cell motion to initially shape the polygon.

The warning polygon should be modified to anticipate new cell development. Consider slightly editing your polygon to account for warning dissemination issues that are not storm-based.

Welcome to the storm-based warning fundamentals lesson on How to Issue Severe thunderstorm Warnings for Squall Line Systems. This is another rather short lesson.



This is a late winter convective warning situation in eastern North Carolina. The environment was characterized by very strong 0-6 km shear (67kts) as seen in the 1200 UTC sounding from MHX. CAPE was very marginal but winds right above the surface were quite strong as indicated on the sounding and the 0.5 degree Velocity product, which you will see on the very next slide. The squall line was moving eastward at around 40 miles per hour.

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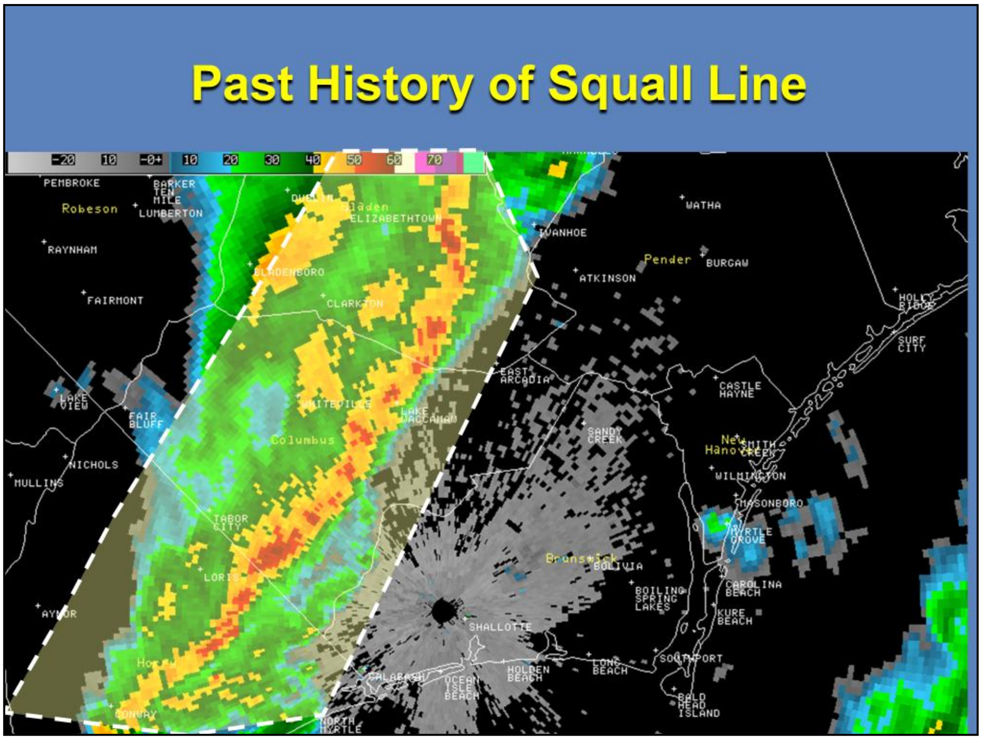
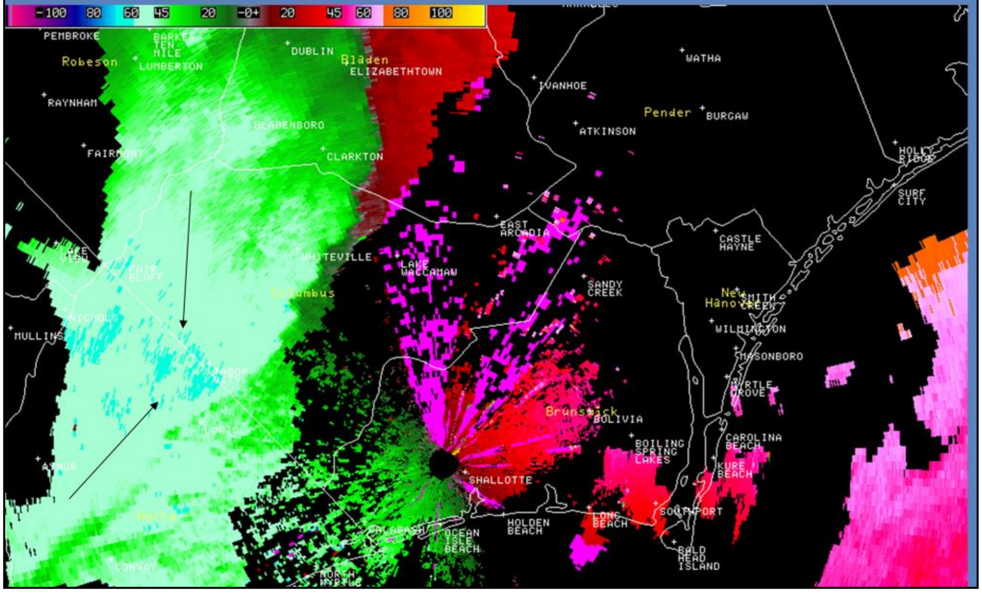


To get an idea of the movement of the squall line for this storm-based warning example, here (three clicks)is the 0.5 deg Reflectivity imagery for 3 volume scans from the WSR-88D at Wilmington, NC for 1505 UTC to 1514 UTC, March 8, 2005. (click) The current severe thunderstorm warning is shown in dashed white line. Many reports of severe damaging winds had already been reported up to now, but forecasters are concerned for an increase in wind potential as the line moved eastward and approached the coast.

Potential Extreme Winds Mixing Down



This is the 0.5 deg velocity product at 1505 UTC . (click) Note the large area of > 60 knot winds above the surface moving into western Columbus County.

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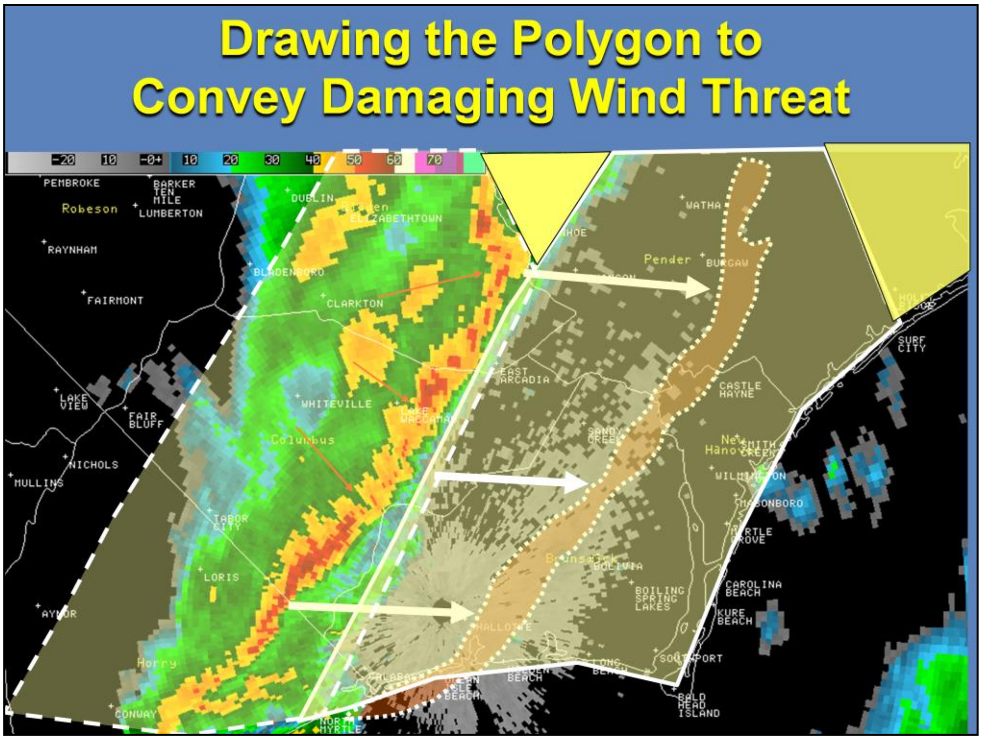

Figuring out where to place the warning polygon for this line of storms is a little tricky since the damaging winds at the surface (which are initially aloft) likely lag behind the leading edge of the strong reflectivity gradient. The gust front is aligned very close to this leading edge. Note the rear-inflow notches behind the leading edge reflectivity gradient indicative of a descending rear-inflow jet. Thus, since this is NOT your first warning (previous warning shown in dashed white), you will need to lay out the severe wind threat area ahead of the line AND a bit behind the leading edge to account for the lag. Since most portions of the line look capable of producing winds to severe limits, you will end up having to issue a pretty large warning to cover the threat. This is preferred in most line case unless you can break up the threat into adjacent polygons. Note: try to eliminate excess overlap with the new warning.

Thirty minute storm (line) motion vectors are shown with the large white arrows with projected leading line echo configuration in dashed brown. Note that based on this projection, the southern portion of the line will clear the coast, so a Special Marine Warning will also likely need to be issued now, if not previously, to enable boaters and other impacted offshore interests sufficient lead time.

In terms of duration of this storm-based warning, a 45 min. warning might be appropriate given the duration of gusty damaging winds in the wake of the leading line.

Use the WarnGen line tool to help you draw the big polygon by aligning the squall line threat area perpendicular to the line orientation, with the northern portion of the line slightly bowed out to account for accelerated line motion. Also, make sure you don't draw the WarnGen polygon into marine areas. Some important considerations: This squall line impacts counties in your adjacent CWAs, so make sure you coordinate with those offices on your storm-based warning. One big consideration when issuing storm-based warning for long squall lines: make sure you don’t have excessive number of locations impacted listed in the Warning Text.

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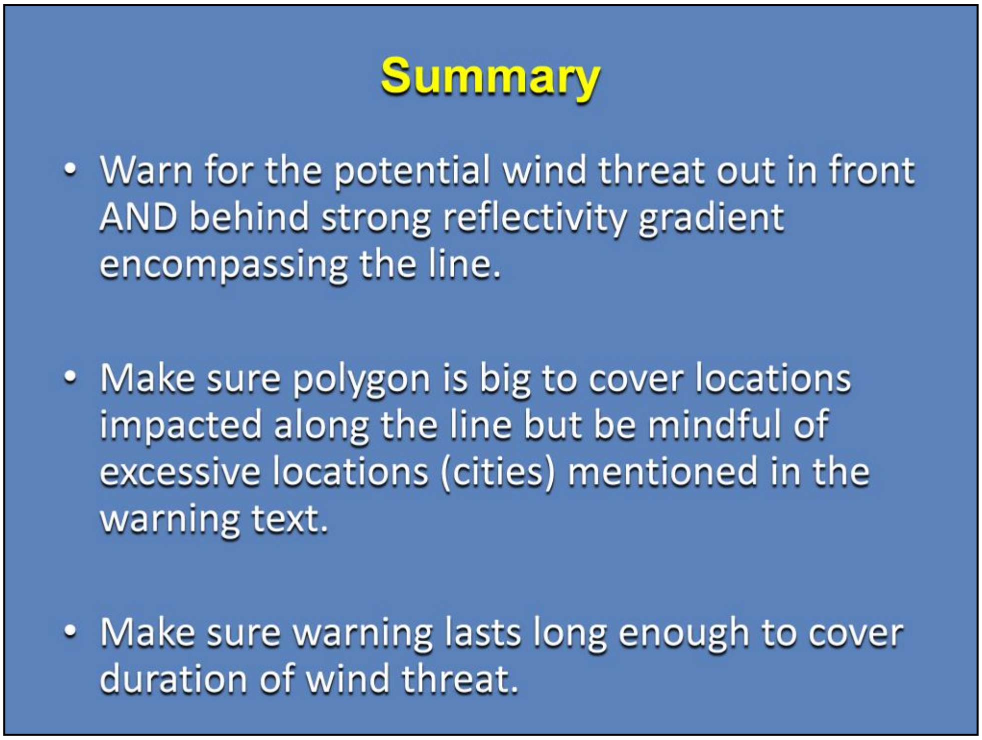
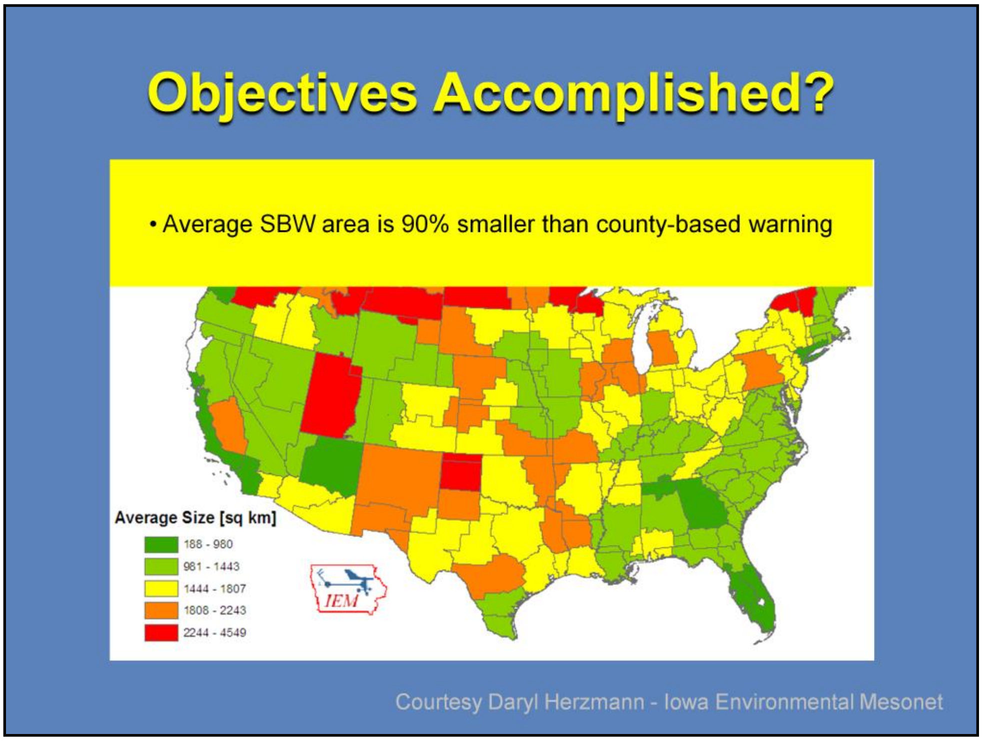


So, in summary, for this type of warning event, warn for the wind threat out ahead of the line AND a bit behind the strong reflectivity gradient. Make your polygon big to cover locations impacted along the line but be mindful of excessive locations (cities) mentioned in the Warning Text. Make sure your warning has a long enough fuse to account for longer duration winds. And in this particular case where the synoptic scale forcing will overcome any effects of a stabilizing effect of the marine layer, you would need to issue a special marine warning even before your final land warning.

Welcome to the Storm-Based Warning Fundamentals lesson entitled, "Special Considerations." This lesson addresses some of bigger challenges in storm-based warnings that have shown up on service assessments from 2009 to the present.

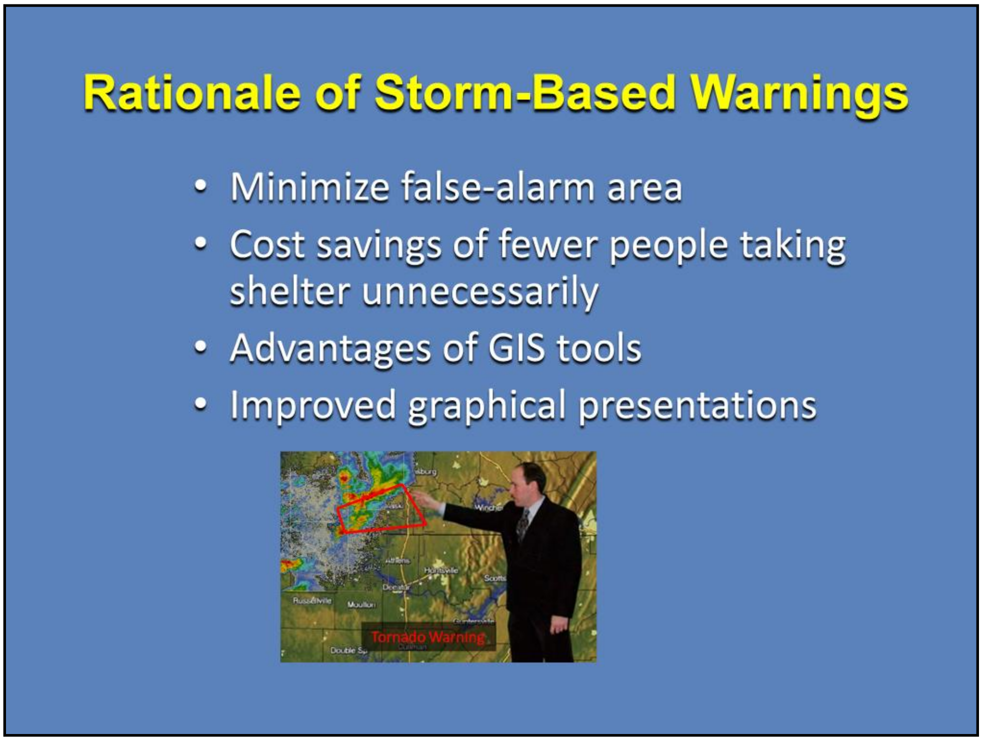


Storm-Based Warnings, or SBWs, became official NWS policy on October 1, 2007. From that point to the end of September 2008, over 31,000 SBWs have been issued. One of the primary purposes of SBWs is the reduction of Falsely Alarmed Area (FAA), which according to national statistics, has been at around 67% when compared to County-Based warnings. Other warning performance metrics such as Probability of Detection, Lead time, and False Alarm Ratio are all exceeding the SBW goals that have been set. (CLICK)

Here is a graphic from the Iowa Environment Mesonet (IEM), which is produced by Iowa State University Department of Agronomy. It shows average storm-based warning size from 1 Oct 2007 to 30 September 2008. Note that many warnings in the Western U.S. are naturally larger due to poor radar coverage and a lack of population and spotters. This graphic provides a context to the following statistics.

Reduction of false alarm areas have been most noticeable in the Western U.S., where the average SBW area is more than 90% smaller than the county-based warning area. Tracking improvement in reduction of the Falsely Alarmed Area (FAA) at the WFO level is more suited to a year-by-year analysis than by comparing WFO CWAs to each other. There are lots of issues when drawing polygons so the size varies from place to place and situation to situation.

Despite very effective performance measures for SBWs in 2007-08, some issues still exist. This module will address some of these issues.



The goal of SBWs remains the same as when it became operational in 2007: to provide geographically concise, timely, and meteorologically accurate, short-fuse warning information.

These four bullets encapsulate the primary goals and benefits of the storm-based warning system: Minimize false-alarm area, provide cost savings with fewer people taking shelter unnecessarily , take advantages of GIS tools, and improved graphical presentations of warning information.

While issues and limitations still exist in the storm-based warning system, especially in our dissemination methods, improvements such as impact-based warnings and eventually FACETs will evolve the warning messaging process into the future.

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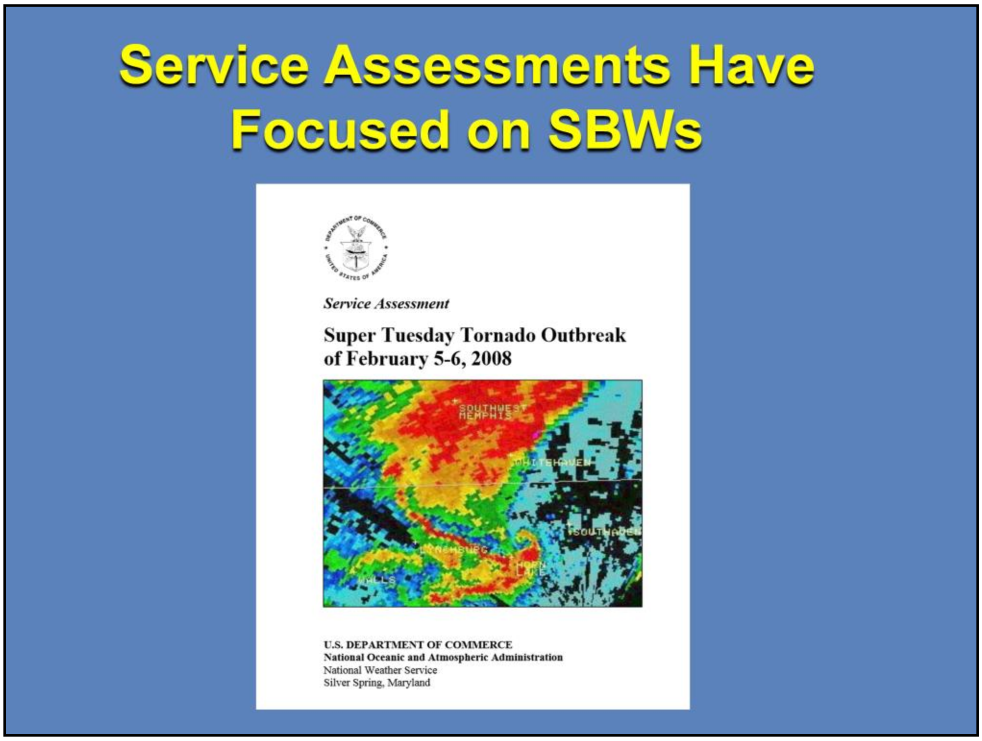
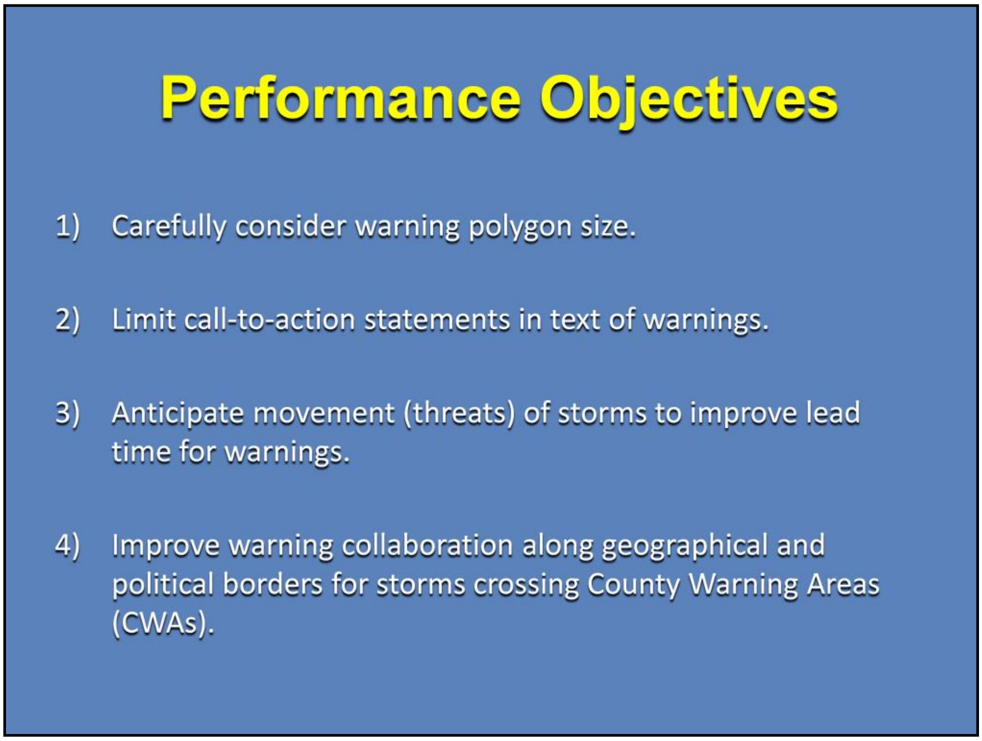


Training basis for storm-based warning has been on the operational assessment of performance from NWS service assessments such as the Super Tuesday Tornado Outbreak and the Service Assessment for the June 6-7, 2008 severe weather outbreak. More recent assessments have focused on communication and messaging issues which are a focus in the warning operations course.



These are the main points we want to emphasize in this storm-based warning fundamentals lesson.

1. Carefully consider warning polygon size. We want to minimize the use of extremely large SBW polygons in most, but not all situations. Some polygons contain so many counties/parishes that the associated warning text runs over the character limitations for some of our partners.

2. Reduce the amount of text in call-to-action statements.

The third objective listed here, anticipate movement of storms, was actually a recommendation from the Super Tuesday 2008 Service Assessment. In the Assessment, it was found that many guidelines presented in the first storm-based warning training were not followed.

For example, many polygons in the Super Tuesday Outbreak were truncated along county boundaries, with some shortened on the downstream end, reducing potential lead time. There was also a tendency to wait for a storm to be near the downstream edge of a polygon before the next warning polygon was issued. Thus, for the long track tornadoes, the lead time from one polygon to the next was often reduced.

Thus, for the case of fast-moving storms, we want to stress the importance of anticipating the need for new warnings well before a given storm moves out of a current polygon, and , we want to encourage forecasters to not remove counties from a polygon unless the forecaster has total confidence that the storm will not impact that area.

Finally, we want to address the need to clarify the coordination process for issuing SBWs at boundaries of Weather Forecast Office (WFO) responsibility, especially where complex boundaries were involved (such as rivers). There were several instances where confusing warning products were issued between adjoining WFOs County Warning Areas (CWAs) as a storm crossed from one CWA to the next.

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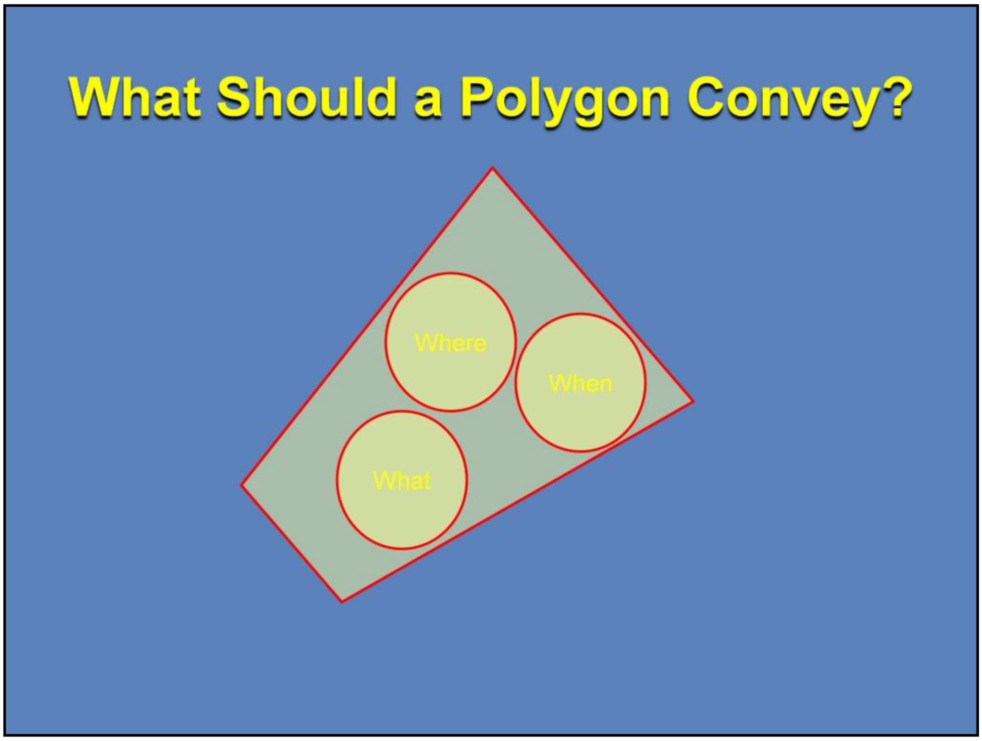

The storm-based warning polygon is a crucial piece of the warning conveyance mechanism. It helps describe graphically the what, where and when of the warning.

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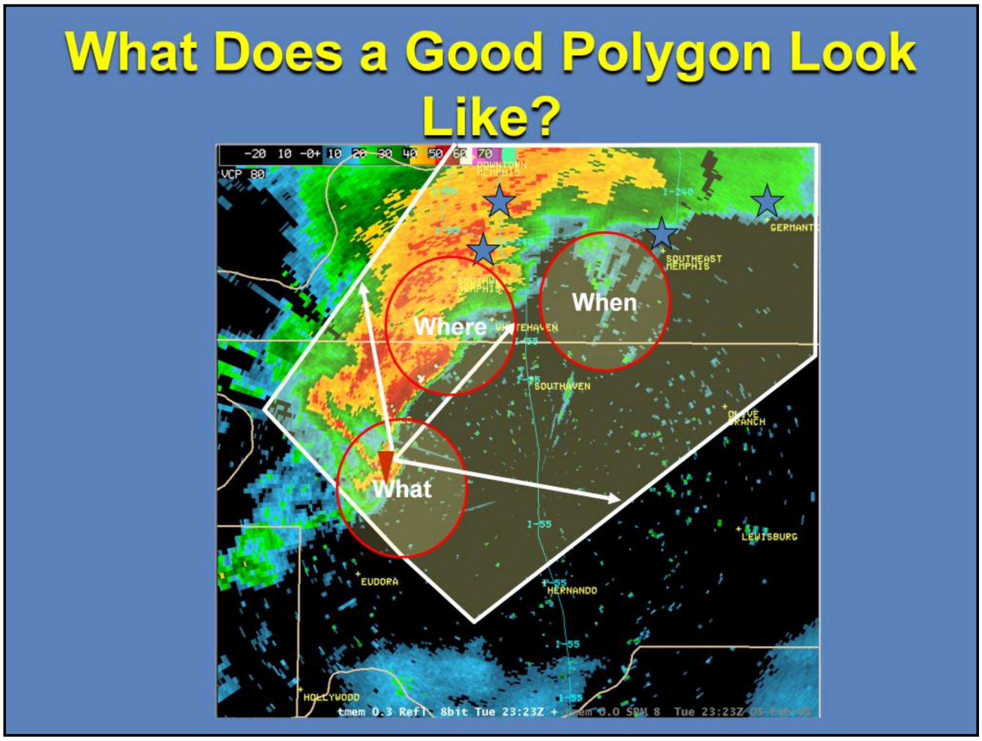


When you create a polygon, it tells the user that the entire area in the defined polygon is under risk of specific threat or threats. Try to treat the polygon as a threat event area, not a single point.

This is vitally important as you want people within the warned area to take precautions, not just along the pathcast. A good example of a well-designed polygon is this image from an event during the Super Tuesday outbreak in 2008.

The polygon uses several good practices of a storm-based warning:

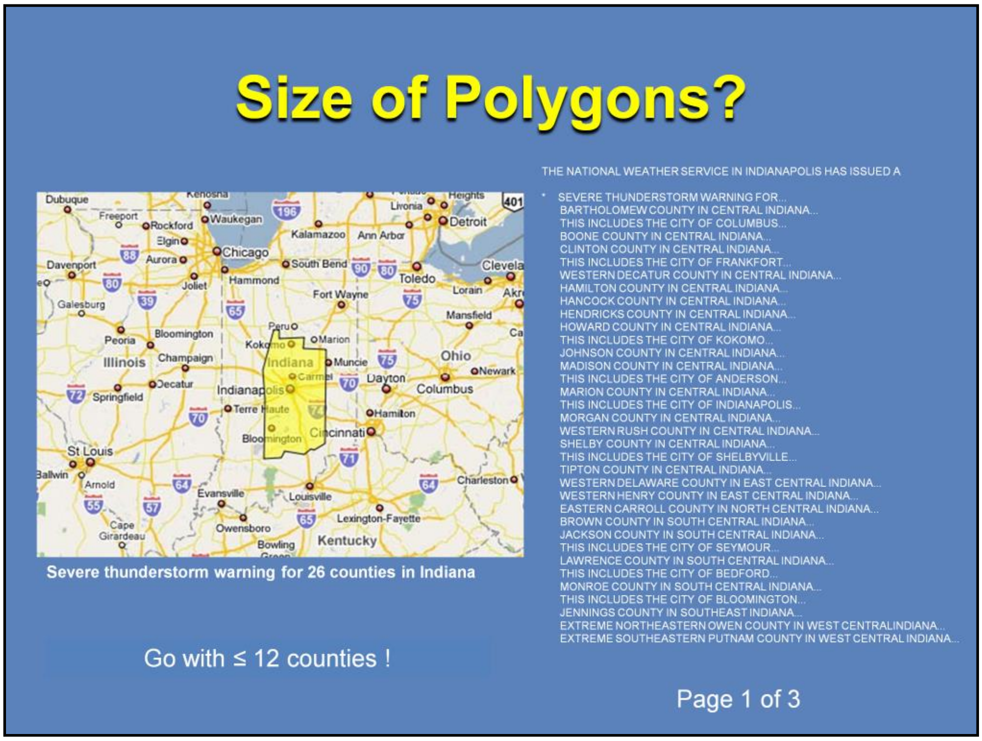
1) Depicts what the threat is – potential tornadic storm

2) Depicts where the threat is south of Walls.

3) Depicts where the threat can occur …allows for uncertainty in forecast movement of the threat and downstream propagation, thus a fairly large (3071 km2) polygon was used.

4) Depicts when the threat will occur, thus allows for a long enough lead time for decision makers.

5) All major populations areas expected to be impacted are included in area (such as Memphis and surrounding suburbs to the North and East)



Based on experiences during this first year of SBW use, a small percentage of severe thunderstorm warnings and flash flood warnings contained more than a dozen counties or parishes. For many partners, this causes problems in transmitting text warnings over mobile devices and television text crawls. There are so many locations listed that the basis of the warning is delayed or in some cases truncated altogether. This example from 2007 shows a severe thunderstorm warning in Indiana that was over 20,000 km2. Plans are to include new instruction in NWSI 10-511 and NWSI 10-922 that states tornado, severe thunderstorm and flash flood warnings should be limited to 12 counties/parishes.

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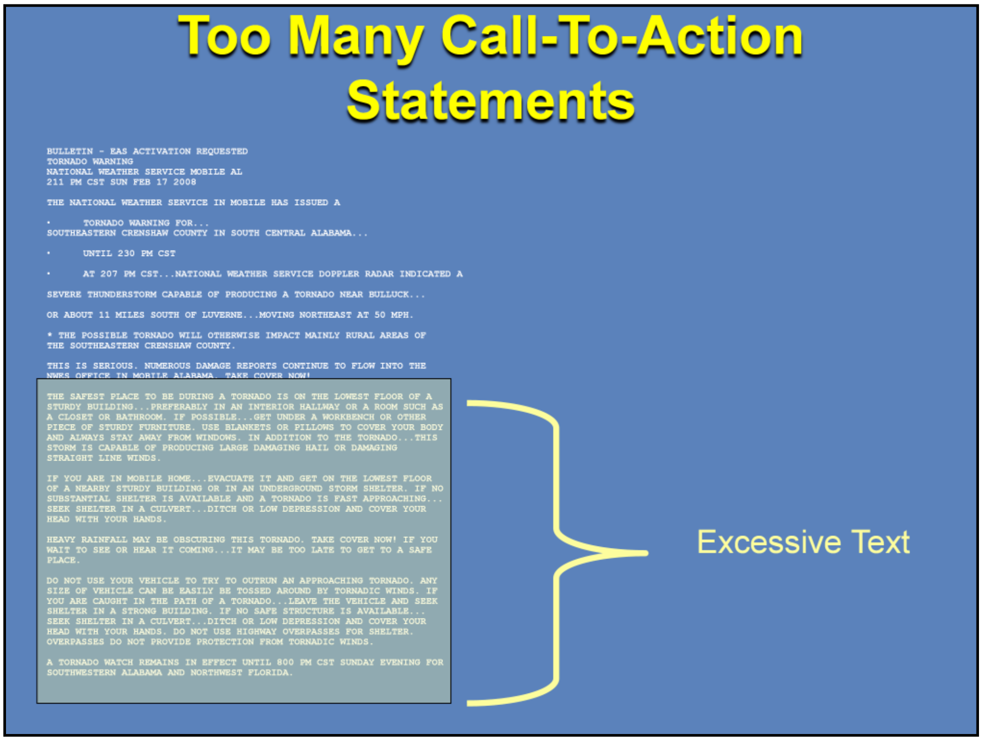
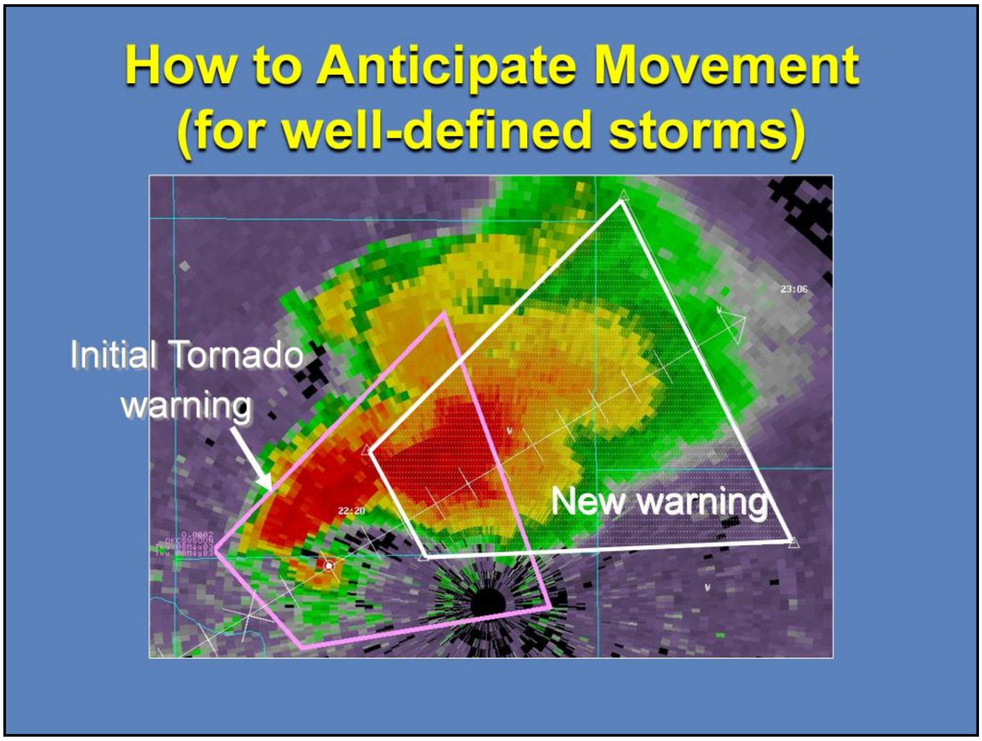


By the same token , having too many call-to-action statements can add to excessive text.

It is a best practice to include only one call-to-action statement per warning unless the situation dictates otherwise. AWIPS "Call-To-Action" tags before and after these statements now allow partners to more easily parse these statements, and if desired, remove them from cell phone text and television text crawls.



In favorable environment and high-confidence situations, it is important to issue downstream warnings well in advance. Don't wait until a storm is close to exiting an existing old warning. Go ahead and issue a new warning downstream.
Tornadic supercells are the one obvious situation.

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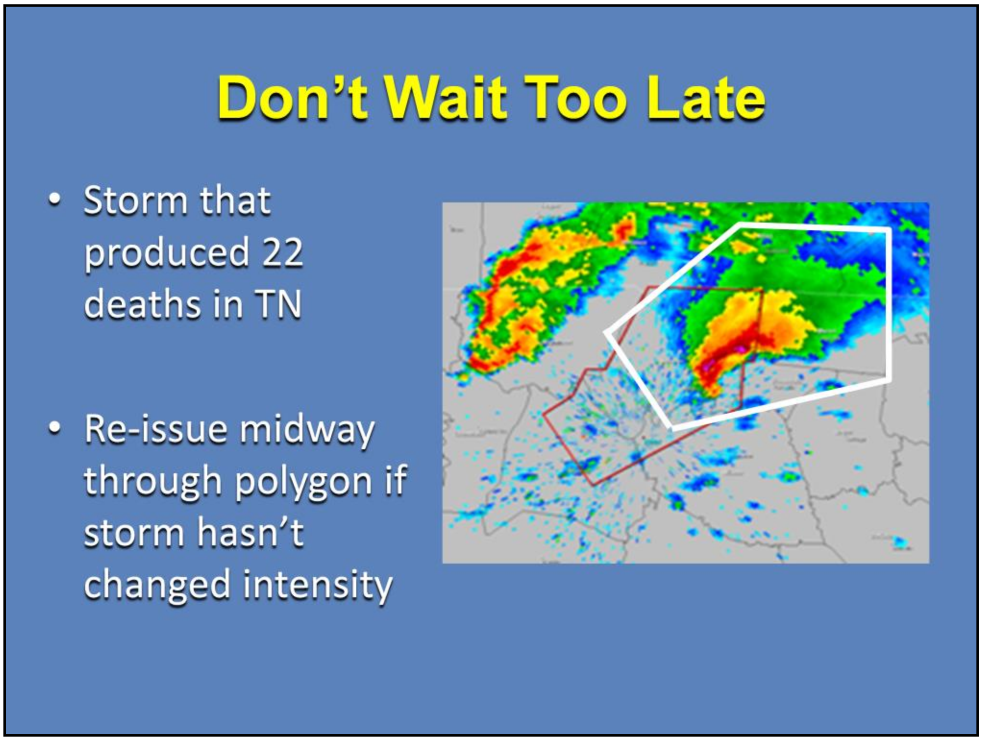

Here's another example from the Super Tuesday Tornado Outbreak where the existing warning was allowed to continue a little too long, especially with a potential killer tornadic storm nearing the edge of the warning.

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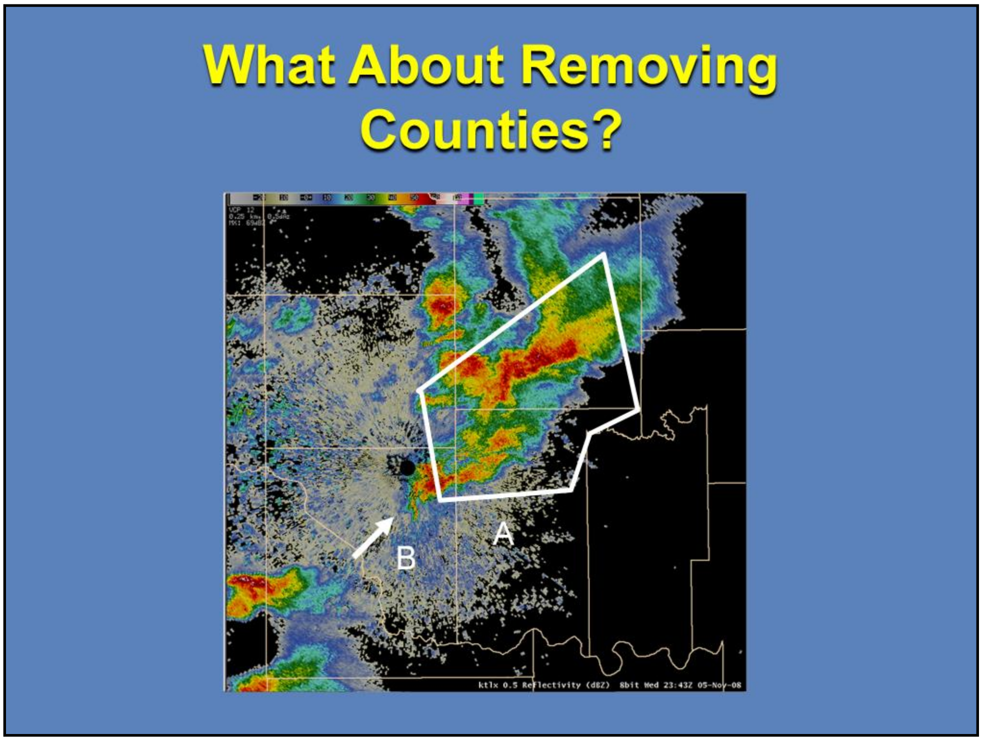

Based on the Super Tuesday Tornado Outbreak Service Assessment, some offices were too hasty in removing counties from warnings. This example illustrates a situation where despite the fact the principal hail threat is not in county A, it is advisable to include the portion of the county in the polygon (and not remove it) because of the potential, albeit slight, that the storm could still impact the area. Thus, for the reasons stated, and the fact that a weaker storm upstream in County B is moving into County A, how about this configuration for a polygon? (click). 20 minutes, it looks like the right decision as new development has occurred in northern portions of County A.

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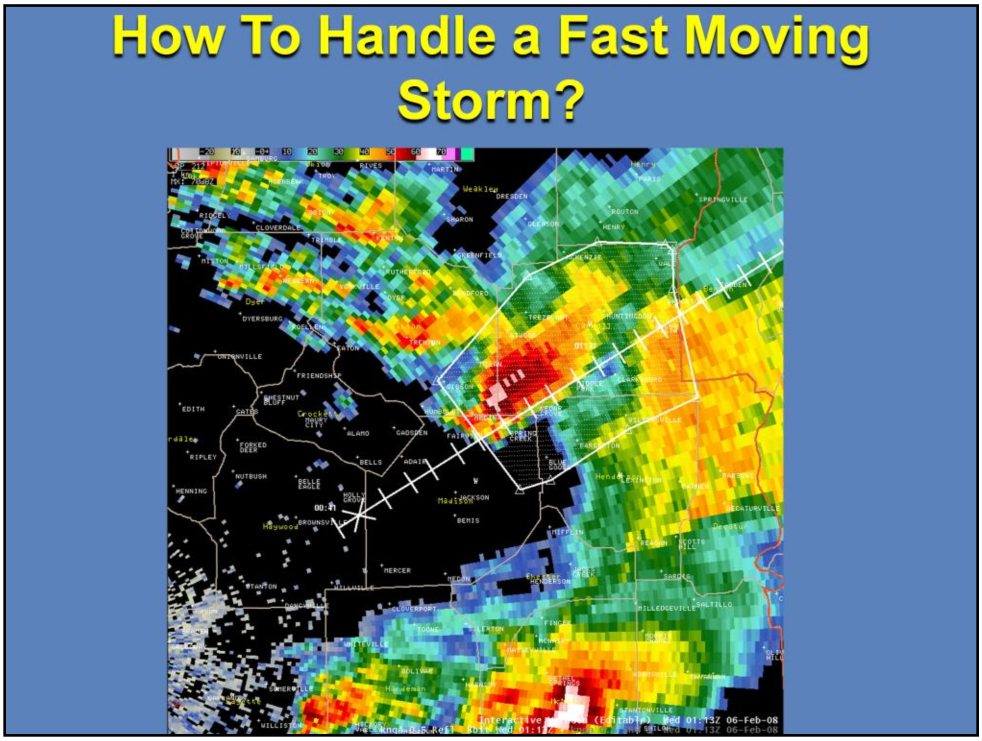

It’s important to anticipate movement in creating storm-based warnings for fast-moving storms such as this one which produced an EF4 tornado in Jackson, TN, on Feb. 5, 2008.

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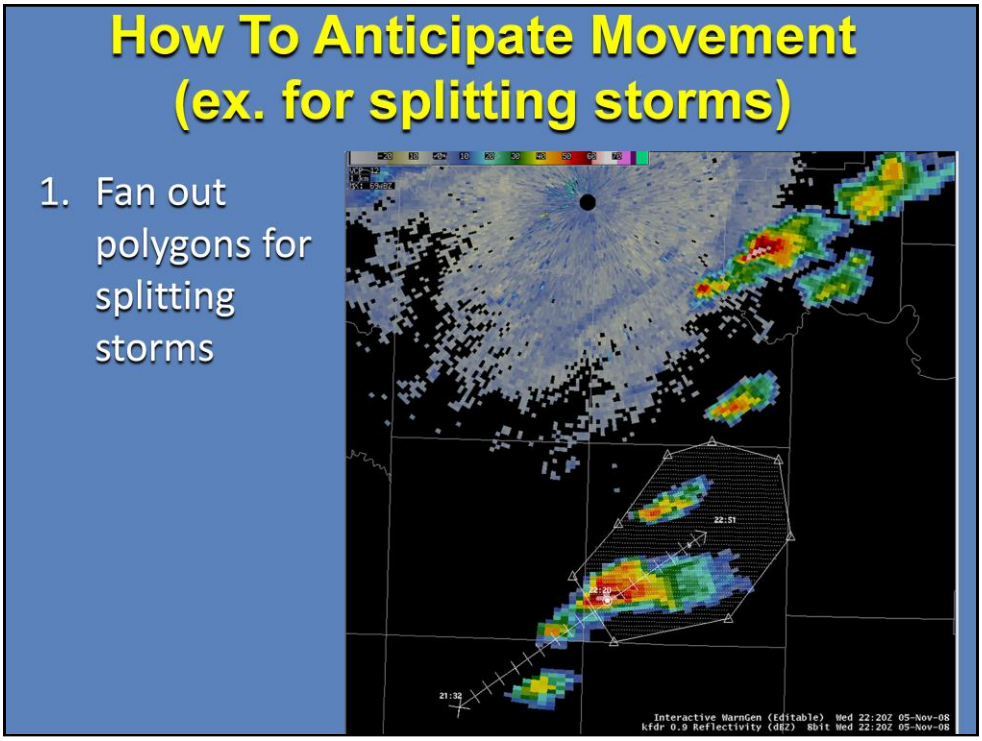

Storm-based warning polygons are most useful when forecasters incorporate the anticipated movement either due to propagation or advection. We have two examples to illustrate the method.

First example is to fan out the polygons when storm morphology is undergoing an evolution such as storms splitting, which can be anticipated by assessing the environment. Before the storm evolves and undergoes splitting, you can capture the threats by fanning the polygon out as depicted here. Keep in mind that , as with most storm splits the right mover will be stronger due internal dynamic of the supercell process.

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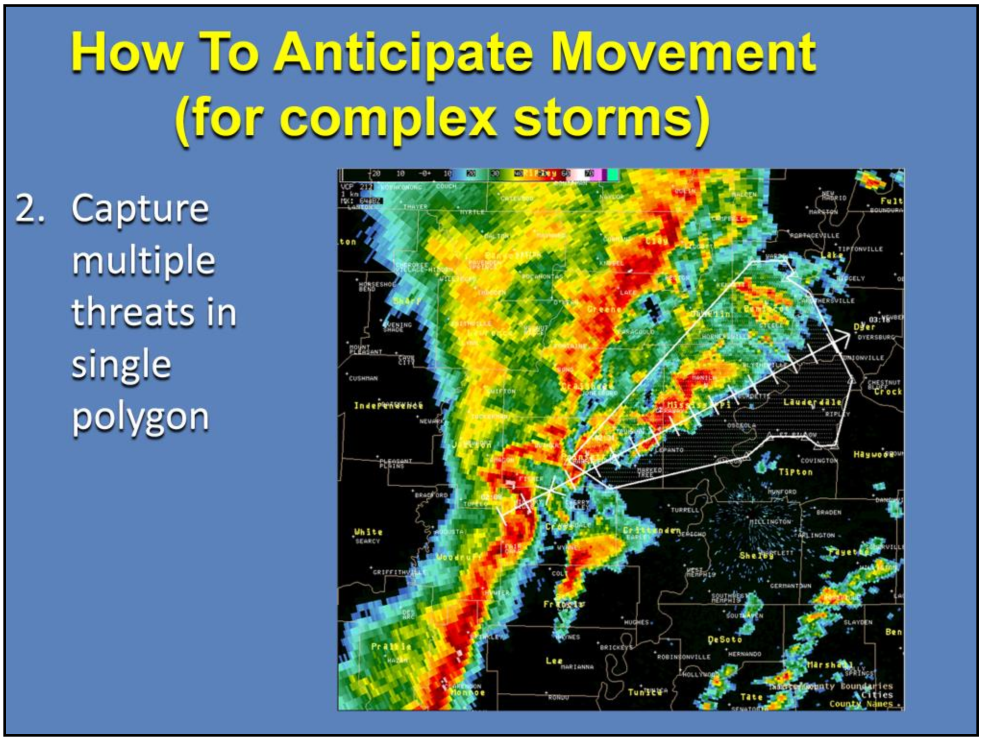

The second example shows an example which fans out the polygon when storm morphology, such as multiple threats in close proximity, is undergoing complex evolutions. As these storms start to develop cross the Mississippi River, notice how the two lead storms develop discrete updrafts . Thus, you can still capture the threats by putting them in one polygon. It might be a good idea to maintain a slightly longer warning duration, say 45 min, in this situation since you have propagation effects adding to the total duration time of the threats in these areas.

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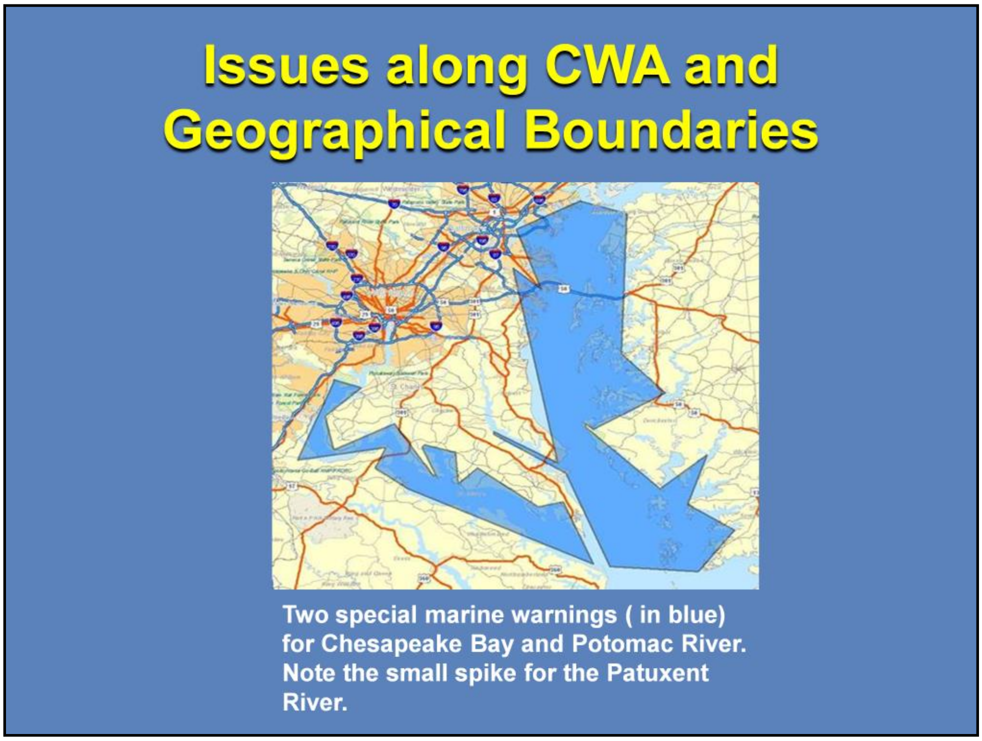

Most boundaries between WFOs county warning areas (CWA) are political boundaries that follow county lines. These are often rivers or other irregularly shaped boundaries. Since all warnings stop at the CWA boundary, this produces odd shaped polygons, and more importantly an inconsistent service for communities along these boundaries such as in this image of a severe thunderstorm polygon in yellow from the Ft. Worth WFO. The storm was moving east northeast along the Red River so the skinny connection was drawn in WarnGen due to the irregular borders along TX/OK.

Another example (click) is the marine warning shown in blue. When there are complex marine or land boundaries, due to the limit of 20 points to a polygon, when you graphically try to describe these complex boundaries with only a few points, it can produce very odd results.

As a frequent and reoccurring problem we recommend that to alleviate this , offices coordinate better to avoid odd shaped polygons.

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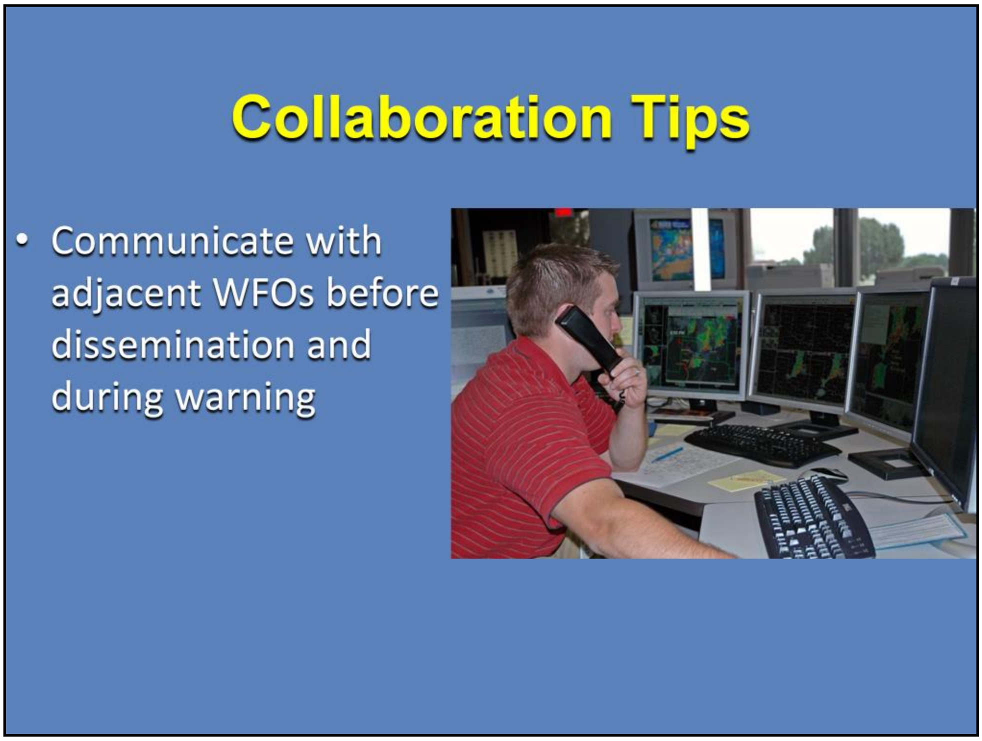

When a storm is about to cross over into an other CWA, or about to move into your CWA, it is recommended that you call the warning team and collaborate on the characteristics of the threat (especially movement) to coordinate polygon placement to maximize lead time. Don't wait for the storm to reach the CWA border, issue the warning well in advance. Use NWS Chat frequently to coordinate on aspects of storm movement.

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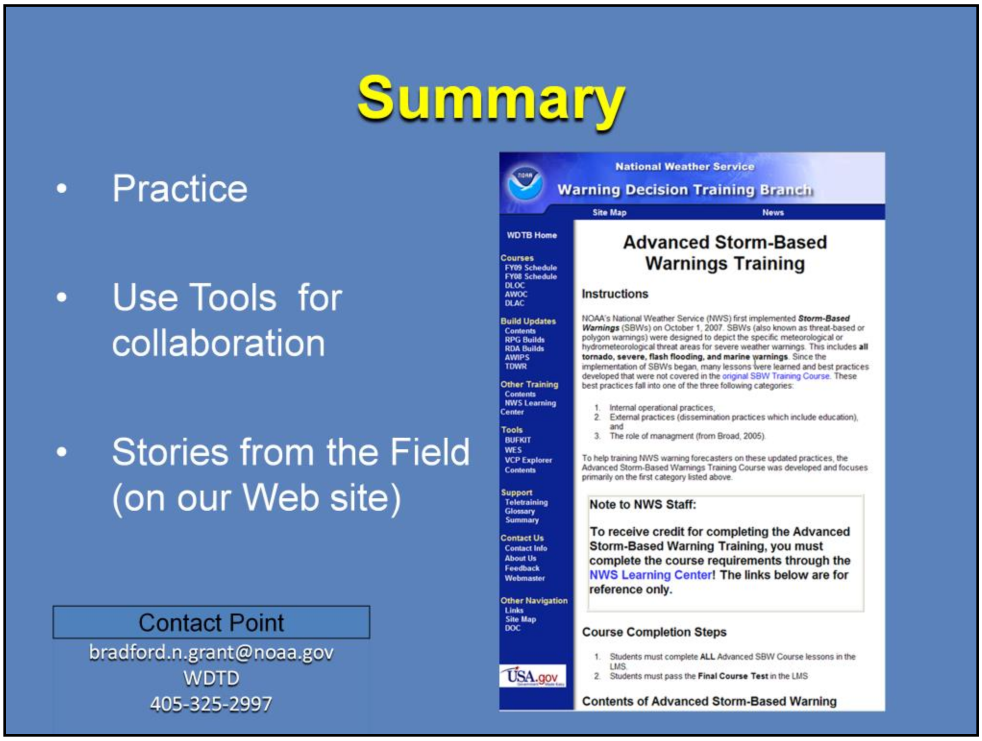

In summary, we have addressed some of the current issues NWS offices still struggle with in issuing storm-based warnings. Most of these will be overcome with more experience, practice, and good office to office collaboration. In addition to this Articulate, please see the stories from the field, which contain real-life warning cases, to help you learn more about issuing effective storm-based warnings. And finally, as with all WDTB training, please contact us at the information listed for rapid response to any questions.

Thank you.

This short lesson in the RAC topic on storm-based warning fundamentals is entitled “Two TORs in Close Proximity.” It is another instructional example showing you how to handle basic warning polygon situations. The material shown here is from Objective T2 of Lesson 2 of the original Storm-Based Warnings course, and it will be narrated by former instructor, Paul Schlatter. We would like to thank Al Pietrycha (SOO) and the rest of the Goodland office for the data and for reviewing this objective.

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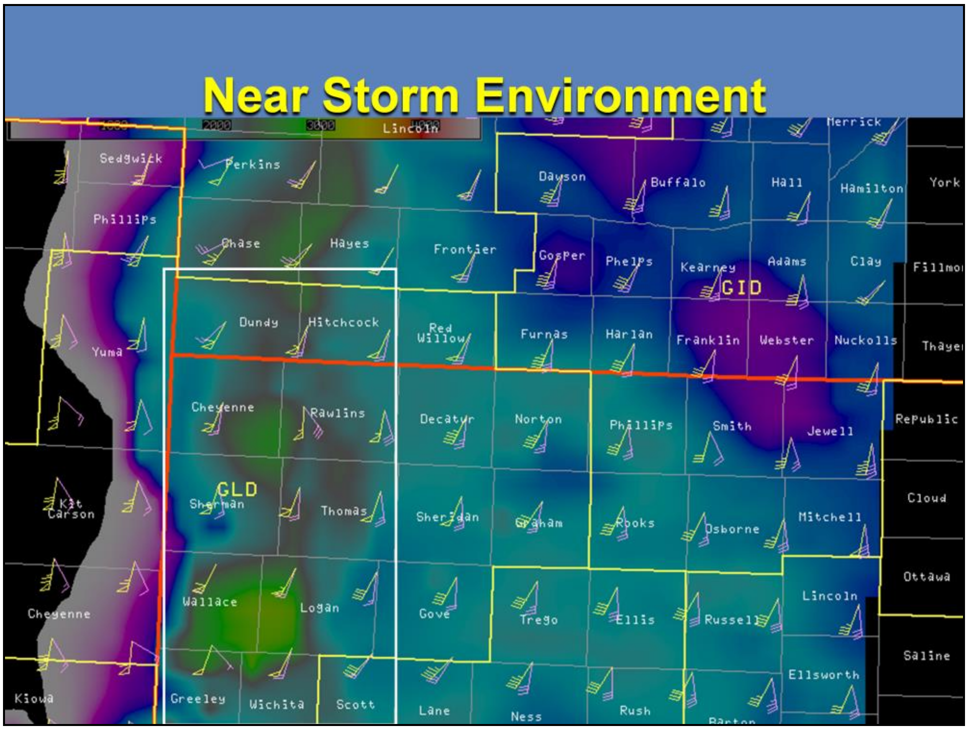
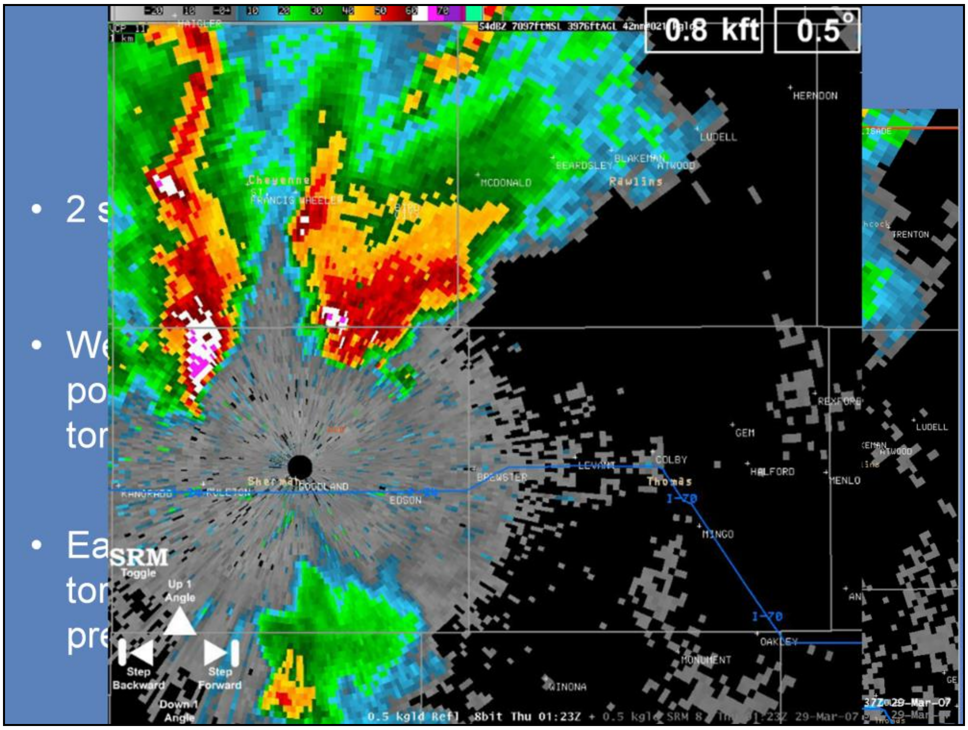


We are concerned with the Goodland, KS CWA, and in this D2D graphic is outlined in yellow, while state boundaries are in red. The environment was very supportive of supercells, firing along the dryline located along the Colorado/Kansas border. This is LAPS data for 0000 UTC on March 29th, 2007. Mixed layer CAPE is very high just east of the dryline across NW Kansas. Yellow wind barbs are 0-6 km wind shear, while pink wind barbs are 0-1 km wind shear. The western-most counties in Kansas and Southeast Nebraska outlined by this white box have very favorable shear for supercell tornadoes, and plenty of instability. SPC issued a Tornado Watch for this area, and a moderate risk. Storms have already fired along the dryline, and right moving supercells are moving just east of due north at 30-40 kts. Let's examine the radar situation.



Here is the current situation at 0137 Z, with 2 impressive looking supercells moving in essentially the same direction and speed, across southern Cheyenne County, Kansas. The western storm has only produced severe hail up to this point, but in the last few volume scans it has intensified in terms of reflectivity and structure, and the low level mesocyclone has intensified, such that a tornado warning would be warranted by this time and probably even 10 minutes prior to this time. Distance speed tool is included for the eastern storm, notice that the storm is moving 4 degrees east of due north. Radar signatures and spotter reports have indicated that a tornado was occurring at this time. A new TOR warning replacing the old one will be required for the eastern storm, and a new TOR, essentially an upgrade, will be required for the western storm. To give you an more thorough radar overview of both storms, a “poor person’s” all tilts flash graphic should now load in a separate window where you can toggle between Z/SRM, and step up and down in tilts for 4 volume scans. To cut down on analysis time and bandwidth, I’ve only included the 0.5, 2.4, 4.3, 7.5, and 12.0 degree tilts, which hit both storms at reasonable height increments AGL. As you step through in time and elevation angle, pay particular attention to: The debris associated with a tornado from the eastern supercell associated with a deep well-defined mesocyclone, the cyclic nature of the eastern supercell with 2 mesos evolving over time, the high reflectivities and strengthening mesocyclone in the western supercell, and WER/BWERS on both storms.

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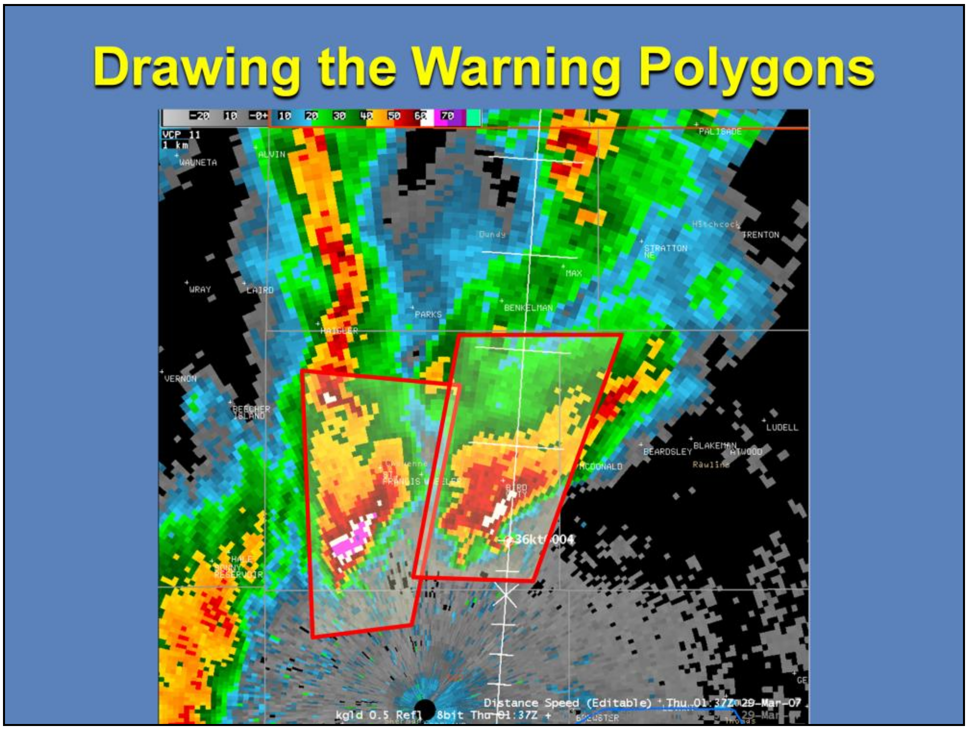

The environment ahead of these storms continues to be favorable for severe weather and tornadoes. With an expected storm motion of 36 knots, and in the interest of not making the polygons too big, it was decided to go with 30 minute tornado warnings for both of the supercells. In this event, it wasn't prudent to draw separate SVR and TOR boxes since the rotational signatures are moving along and just behind the areas expected to have the greatest hail threat. For the western storm , this was the tornado warning and it was issued at 125 UTC (12 minutes prior to this scan). St. Francis would be specifically mentioned in the text product, as would a mention of the threat of hail up to the size of tennis balls. Playing it safe, there is not a gap in between the 2 polygons . For the eastern storm, I couldn't rule out the possibility of the older mesocyclone containing a tornado at this volume scan, though clearly the newer mesocyclone located on the southeast flank of the storm, complete with a debris signature, is the stronger of the two. Thus, the tornado warning is further west to include the older mesocyclone. For this storm, Bird City would be mentioned as in the path of the tornado, and hail up to the size of golfballs would also be possible with this storm. These two warnings overlap across central Cheyenne County, thus a good deal of coordination would be required among warning forecasters and with their customers. The western polygon is more flared out because I am less sure about storm/mesocyclone motion than I am with the right polygon. An clear problem arises with NOAA weather radio with this type of situation: 2 warnings are in the same part of a county valid at the same time, potentially confusing our customers. This concludes objective T2, thanks for your attention.

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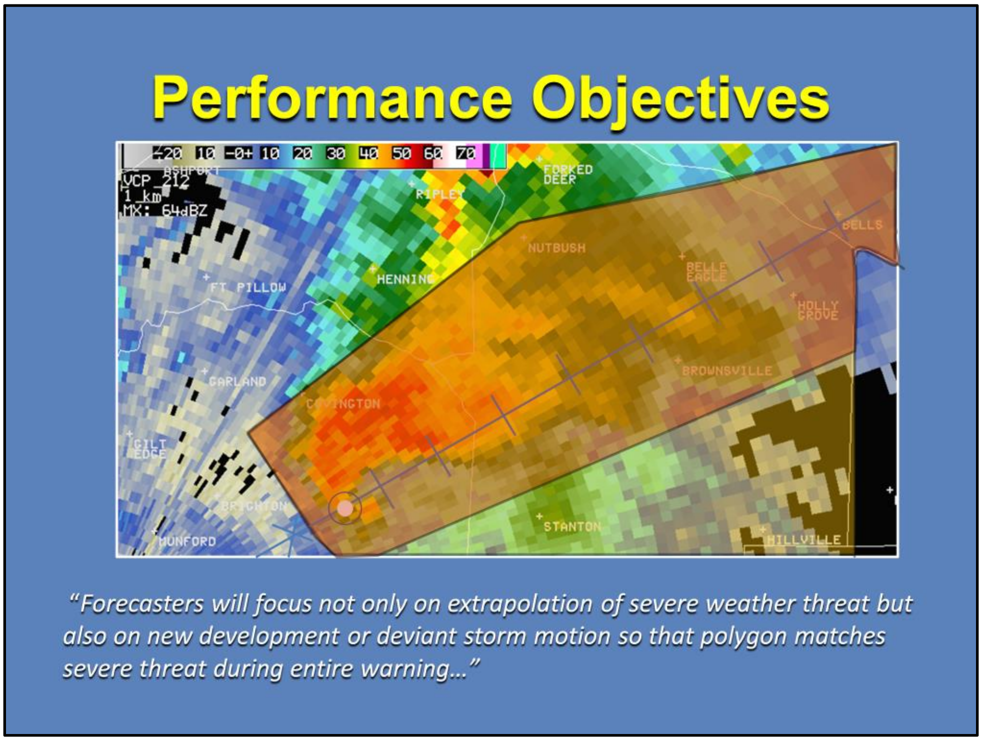
Welcome to RAC storm-based warning fundamentals lesson on non-linear motion. This instruction was designed to support the NWS training requirement to provide best practices for developing storm-based warnings. This lesson will deal with effective placement of warnings for storms with non-linear motion.



The performance objective for this particular lesson contains another Best Practice for issuing warnings:

Forecasters will focus not only on the extrapolation of the severe weather threat, but also on new development or deviant storm motion so that the polygon properly matches the severe threat during the entire warning time frame. So, to accomplish this, we are going to demonstrate ways to incorporate the use of AWIPS capabilities in conjunction with radar views and diagnostic fields as the polygon is being created. In addition, we are going to talk about ways you can issue polygons ahead of the threat when storms are moving in from an adjacent CWA.

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Learning Objectives

1. Identify factors that determine storm motion for ordinary cells, supercells, and multicells.
2. Identify products/parameters that can aid forecasters in determining threat motion.
3. Identify the feature which often influences to a large degree the propagation vector of supercells.
4. Identify types of multicell systems that exhibit accelerating downshear development.
5. Identify methods to develop polygons that match the threat area during the entire warning.

Here are the learning objectives. After you finish reading these, please advance to the next page.

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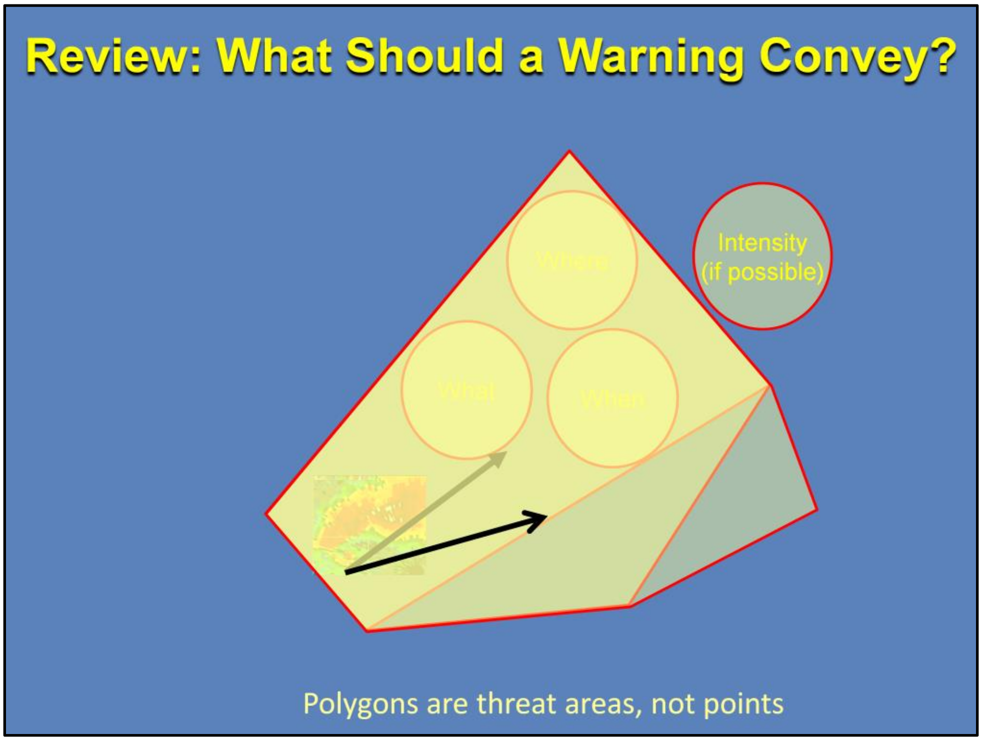

The warning conveyance mechanism should describe the what, where and when of the threat. The text should also help to convey the intensity of the threat (if possible) , and urgencies for taking precautionary measures. The where part is particularly difficult as determination of the forecast track dictates 2/3rds of the warning product. So, given this example supercell storm, if you start with a simple linear extrapolation, you'll typically get a track and associated polygon as shown with four vertices. Due to typical non-linear turning of the supercell, it is wise before you issue the first warning, to add a 5^{th} vertex on the southern side of the polygon. If acceleration is expected , or downstream development is anticipated, an even better approach is to add a 6^{th} vertex on the eastern side of the polygon as shown . Remember, you can't expand the original polygon, but as the threat evolves, you are encouraged to issue frequent updates. From a workload management perspective, if you start off with the best possible polygon configuration, it will help you over the duration of the entire warning. And finally, my advice is to use the storm-based warning polygon as an areal threat forecast, not a point threat update.

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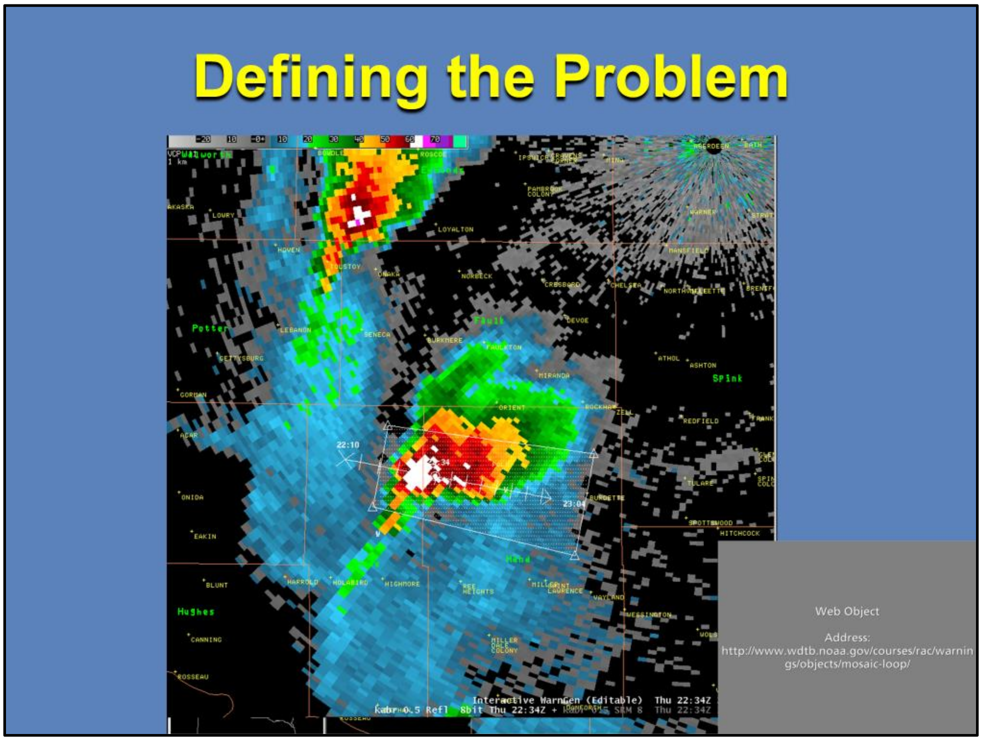

So again, the problem is how to determine storm motion so that the threat area in a storm-based polygon depicts the three basic elements of a warning: What, When, and Where. On paper, fairly simplistic, but in reality, quite complex. It is rarely as easy as moving the drag me to storm icon back a few frames and then letting WarnGen compute the polygon and track. Hey, if it were that easy, warning forecasters could get replaced by a computer application. Determining an accurate short term forecast area of the storm threat involves a 4-Dimensional analysis of observed conditions and a forecast of expected conditions. There are many mesoscale and storm scale factors that influence the forecast such that rarely will conditions allow a simple extrapolation of past radar motion to provide an effective warning threat area. This is especially true in cases where storms are exhibiting rapid, downwind propagation such as in this example from the May 8, 2009 multicell severe weather event which moved across several CWAs. This loop illustrates many of the complicating, non-linear factors associated with determining storm motion. It is extremely challenging to determine an accurate threat motion and then incorporate that into warning polygon and track creation. But, we are going to look at a few things that might help.

Defining the Problem

Spectrum of Threat Motions			
	Ordinary Cells	Supercells	Multicells
How to Determine Motion	Advection Effects	Advection + Propagation Effects (Shear)	Advection + Propagation + System Effects
>>>>>>>>>>	Mean Wind	Bunker's ID Method	Corfidi Vectors

Complicating Factors:
- Updraft forcing, shear profiles, dry air aloft, shear-cold pool interactions, instability gradients, boundary interactions

Determining the motion of threats is complicated and it obviously varies with storm type. In a simplistic sense, the spectrum of threat motions starts with ordinary cells, which are primarily influenced by advection of mass through the mean wind. With increasing amounts of shear, storm movement becomes a function of not only advection but propagation (due to the interaction of vertical wind shear on the updraft). This is where Bunker's ID Method (which is covered in DLOC Topic 7) of forecasting supercell motion is an important aid. Finally, with the most complex storm system, multicells , for determining motion, you also have to take into account system effects, such as cold pool strength and influences of Rear-Inflow Jet and the Coriolis Force, which influences system movement after several hours of evolution. For both backward propagating multicells and forward propagation, Corfidi Vectors are available to estimate system movement. Complication factors to determining motion include updraft forcing, depth of shear profiles, amount of dry air aloft, shear-cold pool interactions, instability gradients, and boundary interactions, which can override many of these factors by themselves. Topic 7 of DLOC contains several lessons on multicell motion, which would be a good review for warning forecasters.

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What Products Are Useful to Determine Warning Threat Motion?

- Environmental parameters (Kinematic/Shear related parameters)
  - Convective Steering-Layer Flow
    - Mean wind from top of the inflow layer to EL
  - Low-level Convergence
    - Effective inflow layer
  - Supercell Motion
    - Right and left moving forecast motion vectors
  - Corfidi Vectors
    - Backward and forward propagating

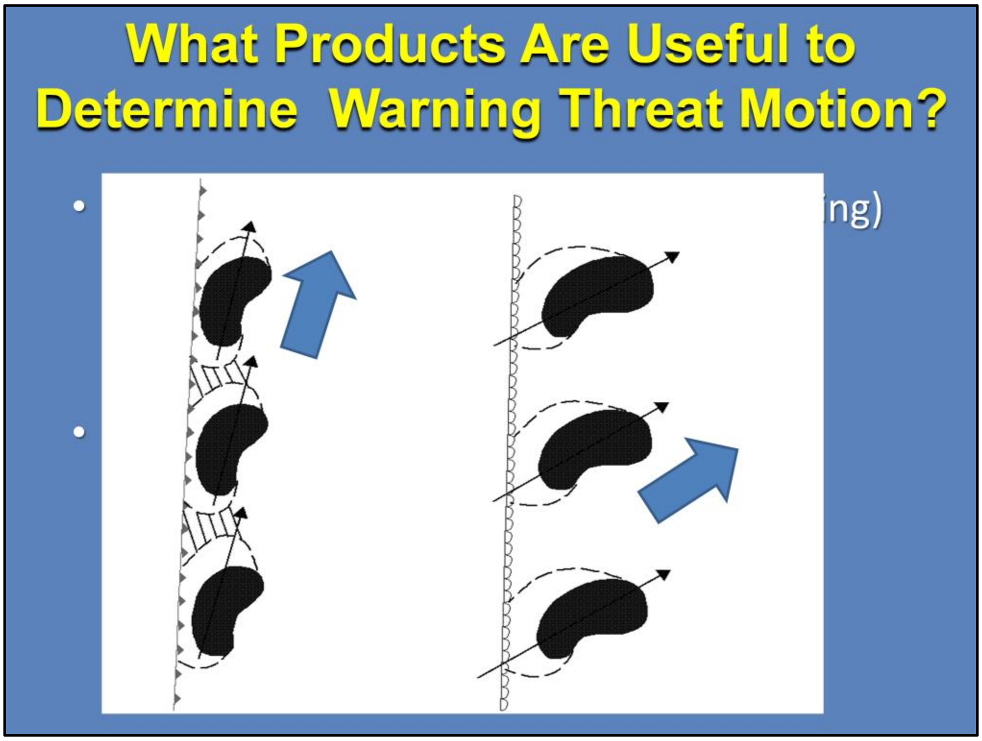
Here are some environmental kinematic parameters that can be useful for determining threat motion over the entire duration of the warning:

1) Convective Steering-Layer Flow, typically estimated by assessing the Mean Wind from top of the inflow layer to equilibrium level.
2) Low-level convergence, which influences updraft location and resulting storm/system propagation and maintenance, among other things. Typically, for storm motion, you will want to assess low-level convergence throughout the inflow layer of the storm threat area, usually in the lowest 1 to 2 kilometers. For storms whose updraft parcels are not rooted in the boundary layer, such as in situations of elevated convection, for determining motion, you may want to estimate effects from convergence at a higher depth above ground, say up to 3-5 km AGL.

3) Supercell Motion, use Bunker's Storm Motion estimate vectors for right and left moving supercells. Keep in mind storm-scale interactions such as collision of left and right movers, and instability gradients will likely alter the deviant motion estimate.

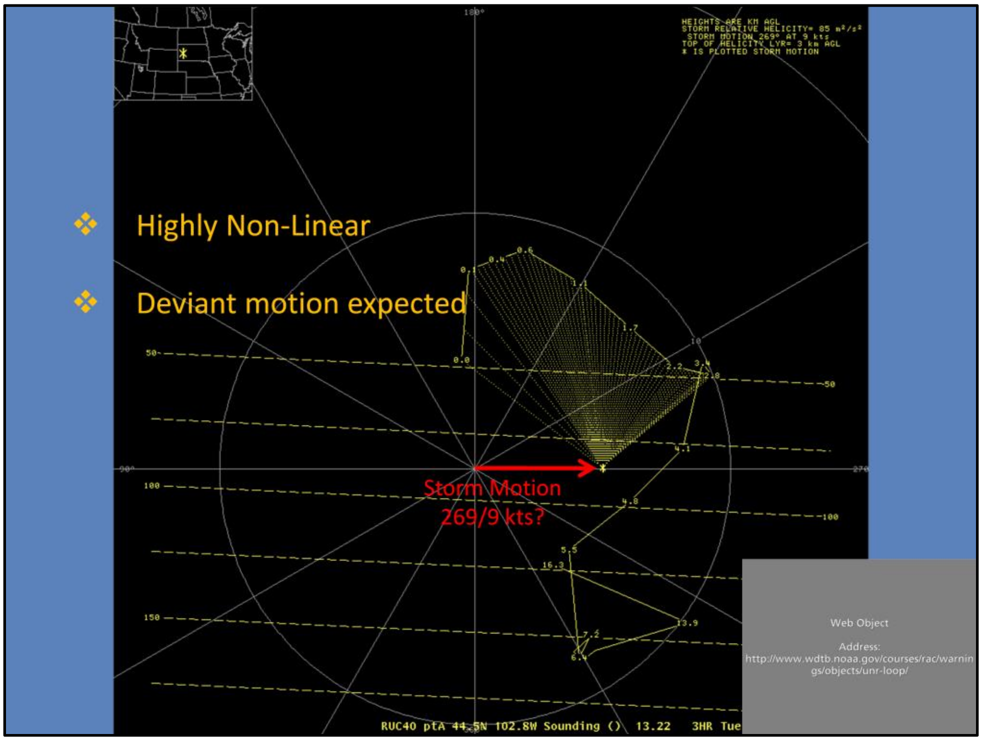
4) Corfidi Vectors, this is best for multicell motion, use both Backward and Forward Propagating vectors.

Note: there are lots of other complicating factors that influence multicell motion, and in fact, both backward and forward propagation can be occurring simultaneously.



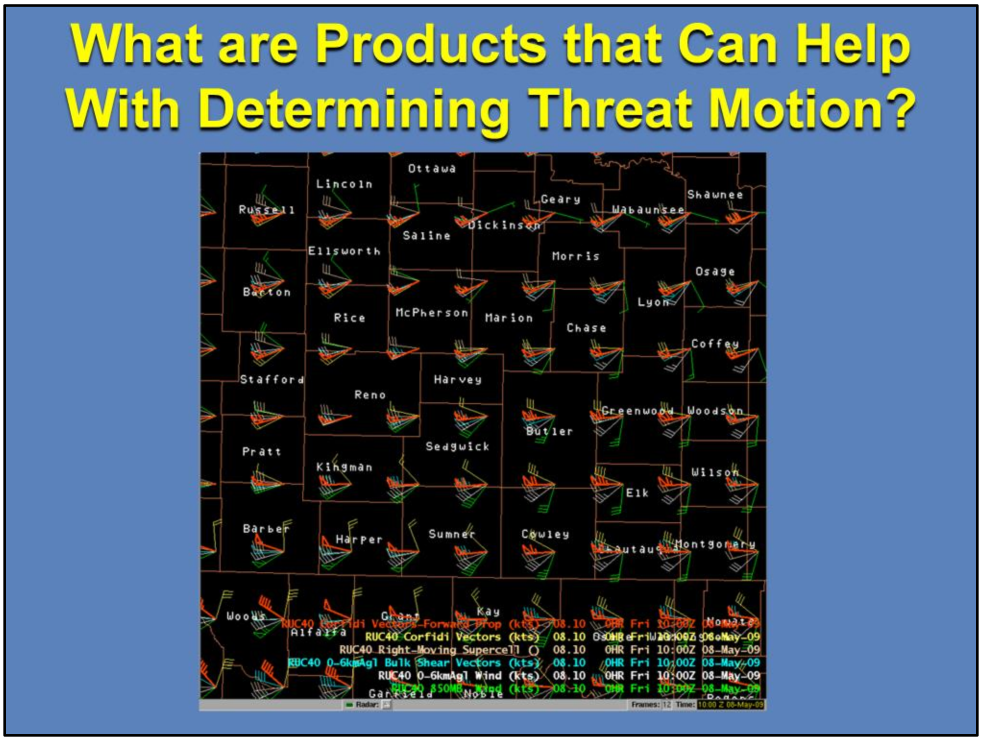
Many environmental parameters modulate updraft forcing and depending on the particular situation can significantly influence a storm or storm system motion, especially after storm initiation. Influences of CAPE and CIN and these other updraft related parameters are pretty well documented and have been covered in DLOC and AWOC. The role of boundary interactions is probably not as well known and can over-modulate all other factors even with multicells.

One of the big influences on resulting storm type is the orientation of the shear vector on the boundary itself. For example, in general, boundary parallel shear usually leads to multicells whereas boundary normal shear often leads to discrete supercells. This configuration is normally valid only in the initial phase of convective development before a storm system becomes mature.



As a start, we'll look at some factors associated with supercell motion. Observations and numerical modeling simulations suggest that supercells frequently do not exhibit purely linear motion and steady-state evolution throughout its entire lifetime. In fact, most supercells exhibit characteristics that are highly non-linear owing to effects of shear on the updraft. This deviant motion is typically estimated by evaluating a proximity storm hodograph like the one shown. For example, in a sheared environment characterized by a cyclonically curved hodograph (as shown here by a series of RUC forecast hodographs), supercells would be expected to deviate to the right of the shear vector. As an example to illustrate the effects of Supercell propagation on motion, note how this supercell propagated southeastward across western South Dakota on 13 July 2009. In determining an accurate polygon threat motion for this event, I overlaid the Right-Moving Supercell vector from the AWIPS volume browser, plotted on the radar loop by the blue vector, derived from the NAM. Even though the ID method provides a physically viable supercell motion estimates for both Right and Left-moving vectors (which are available in AWIPS volume browser) and are superior to the motion plotted on the AWIPS Skew-T hodographs, there are still some uncertainties on what the actual deviant motion is because of other mechanisms, like boundary influences.

In this example, the location of the rear flank downdraft and associated gust front acts as a focal point for the storm updraft to ingest vertical vorticity and propagate along the boundary. The storm itself appears to decelerate and turn to the right toward the end of the loop, so that the actual path of the potential tornado vortex moves to near Cottonwood, whereas a purely linear track follows a track further north. From a service standpoint, examples like these lend themselves to issuing frequent follow-up statements which adjust the storm's track.



Now, as we transition to multicells and determining threat motion, again, estimating threat motion gets more complicated. You'll typically assess a number of potential factors that provide guidance. You can use the Volume Browser to create Procedures which display storm motion estimates such as Bunker's Right-Moving Supercell and Left-Moving Supercell vectors, Corfidi Vectors for multicell motion, both for backward (just called Corfidi Vectors) and forward propagation. In this example, I am showing plan-view plots of various Motion Vectors as forecast from the RUC. These vectors are useful in helping forecasters determine a reasonable estimate for threat motion for ALL storm types. The case shown (08 May '09) will be used to illustrate how difficult it is to determine storm motion in a complex storm evolution when linear extrapolation falls short.

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Web Object

Address:
http://www.wdtb.noaa.gov/courses/rac/warnings/objects/kict-motion/

When the multicell system first evolved and congealed into a linear structure in south central Kansas, it appeared that it would move SEWD into OK. However, owing to a development of the system cold pool, low-level convergence along the leading edge of the system, and a strong Rear-Inflow Jet, the system began to turn east and accelerate into SE Kansas and eventually into SW Missouri. Along the way, you can observe non-linear motion as transverse bands of convection formed by the strong isentropic lift and convergence of large mass of moisture due to the low-level jet. In addition, a bow echo developed just northeast of the radar site and helped to absorb a couple of supercells which at the time were moving ENE.

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Web Object

Address:
http://www.wdtb.noaa.gov/courses/rac/warnings/objects/kict-motion-aided/

This next loop shows how the storms are moving relative to the 0-6 km mean wind (the yellow vectors). When a multicell system begins to exhibit rapid downshear movement due to increasing low-level moisture flux convergence, and strong mid to upper level shear, it is usually necessary to estimate motion using the Corfidi Forward Propagation Vectors, shown here in red from the LAPS. Again, simple extrapolation will underestimate the complex motion of individual updrafts and resulting cold pool motion of the system.

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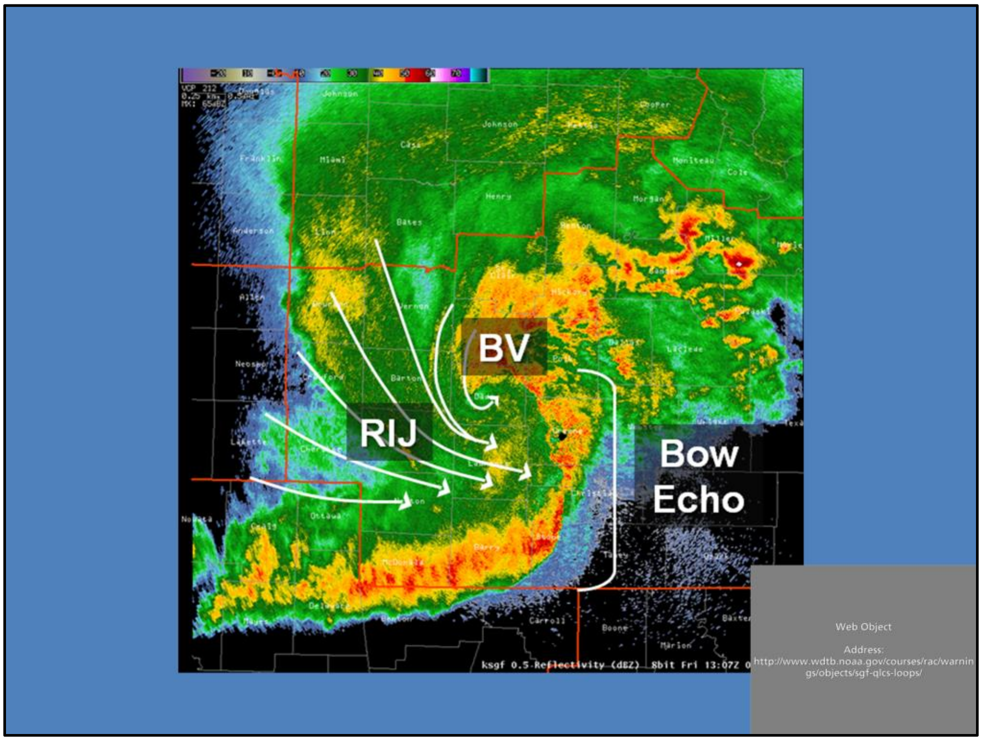

For this case, over the next several hours, there were many factors influencing the motion of the system and subsequent threats. If you were trying to track the motion linearly like the WarnGen track and box shown, you might mis-represent the highest impact areas. There are many external factors which are influencing the asymmetric shape of the multicell complex and variable threat motion including: for example, the development of at least two accelerating bow echo segments, a tremendously powerful RIJ (Rear-Inflow Jet) as evidenced in Velocity data and several rear-inflow notches in Reflectivity data, and a big, bookend vortex (BV) on the northern end of the system which is causing the entire line to turn to a more easterly direction and take the major wind damage directly toward Springfield in Green County. Please take note of mesovortices along the line which move considerably different than the line itself.

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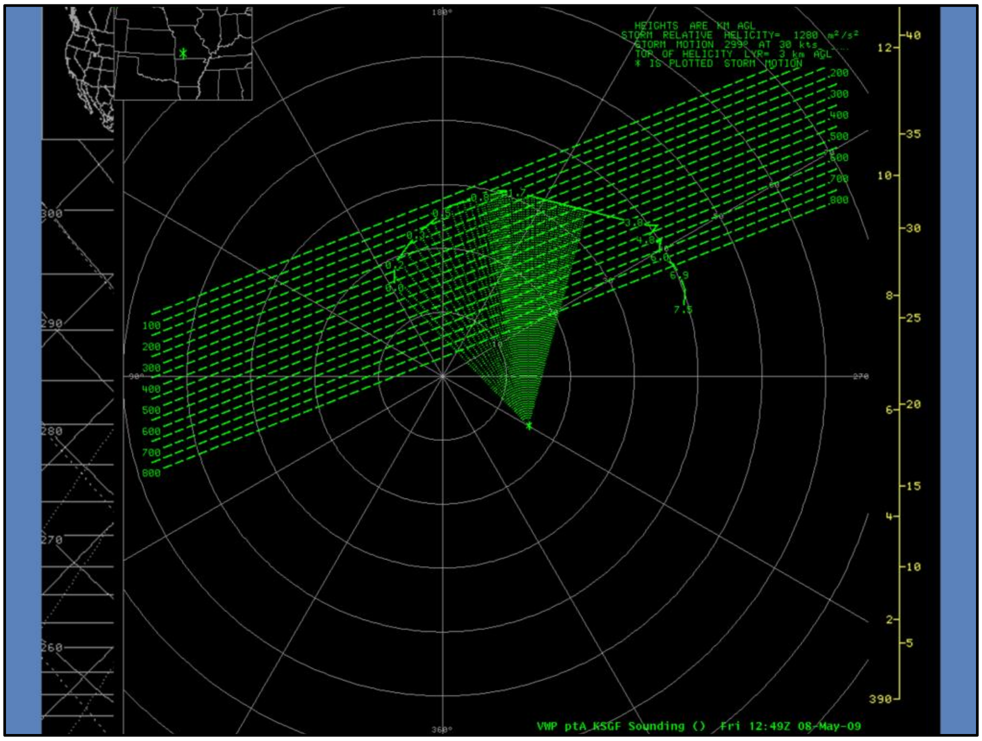
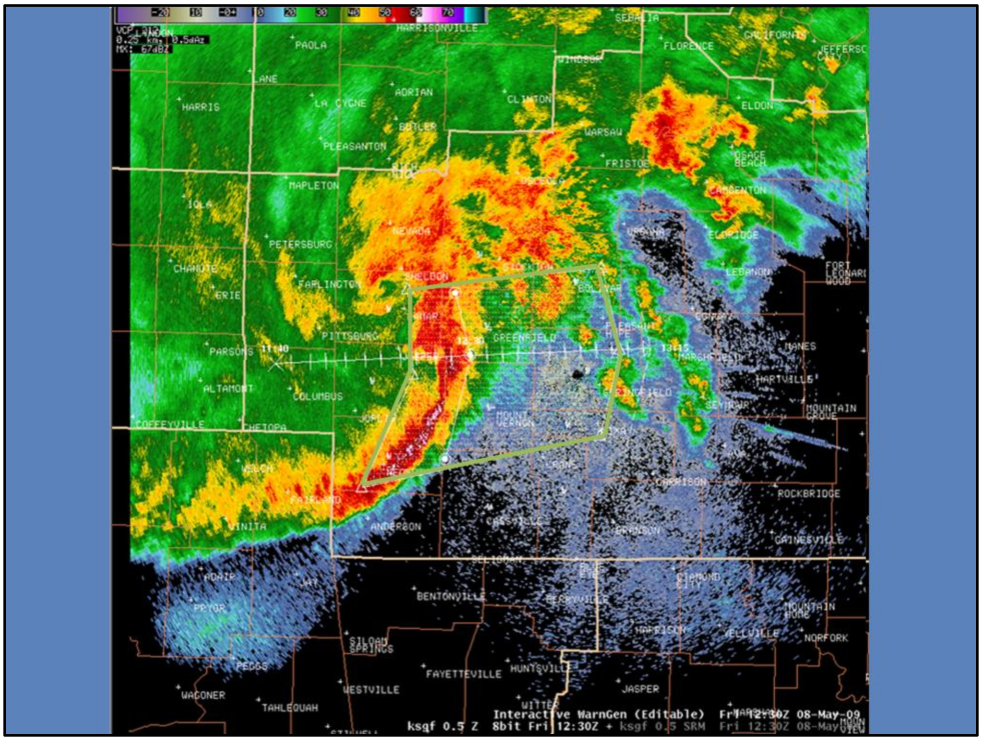


So, as in this particular case, if you take into account some of the environmental data, such as the 12z sounding and accompanying VWP hodograph from the KSGF radar, you can start to recognize some of the factors that are affecting your storm motion, that again, in this case, is causing the entire system to move more easterly and develop potential tornadic mesovortices along the way.



Now, let’s incorporate some of the environmental factors into the warning motion of the leading line, specifically, the Corfidi Vectors for Forward Propagation, we can see what a non-linear threat area might look like, at the ending time of the previous loop.

If we use the Forward propagation vectors as a reasonable first estimate, we can draw a slightly different threat area and track.

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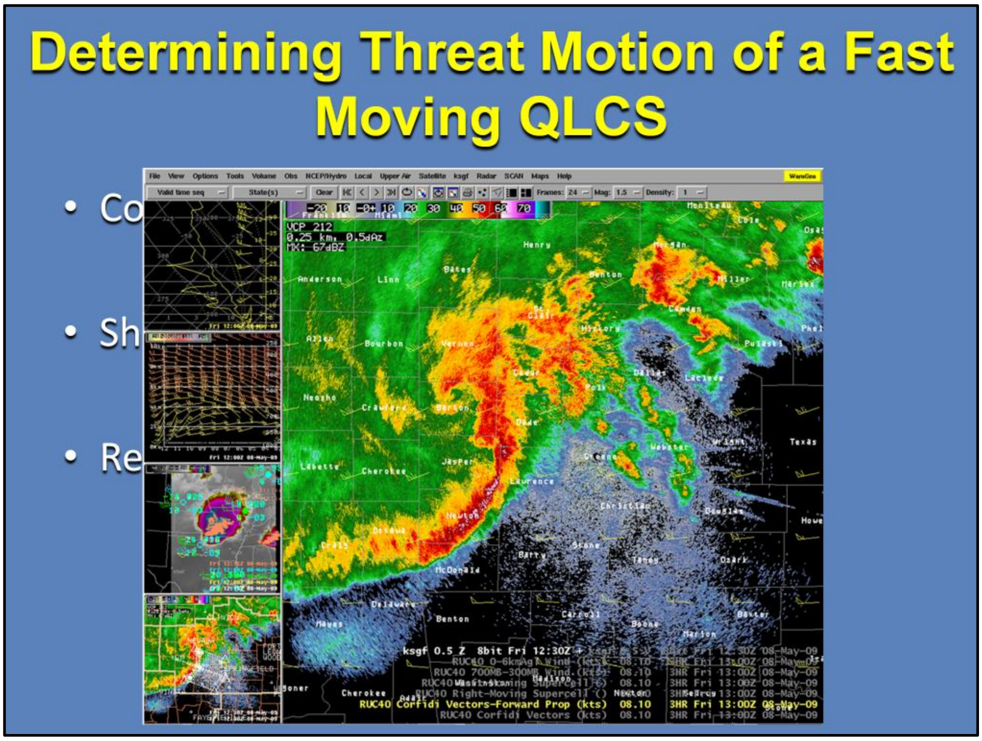
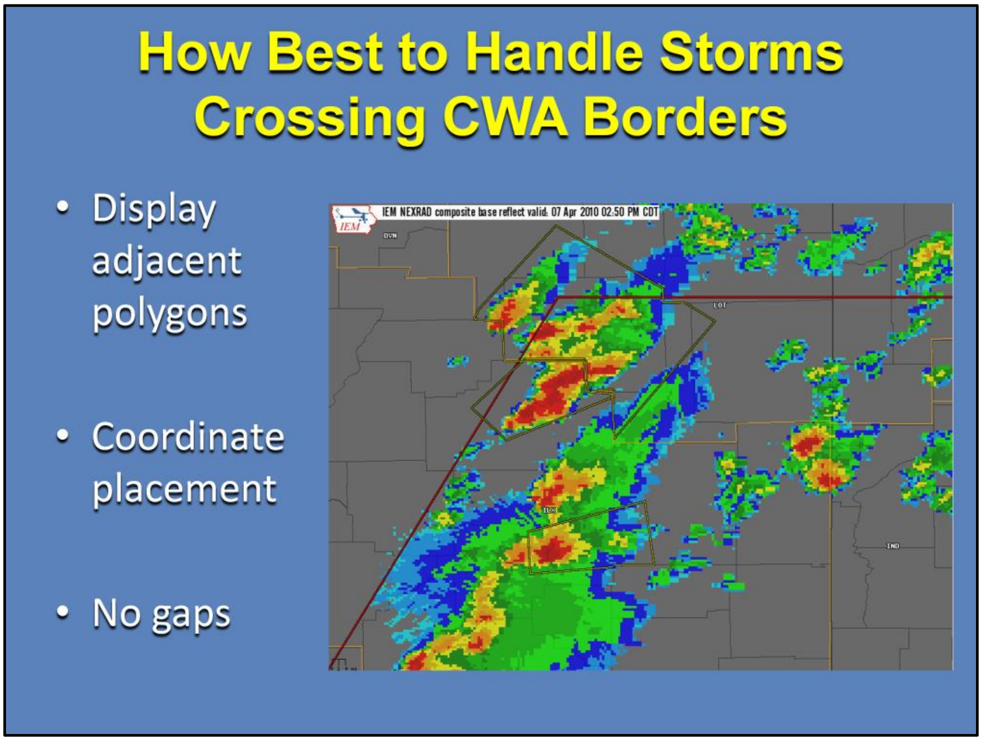
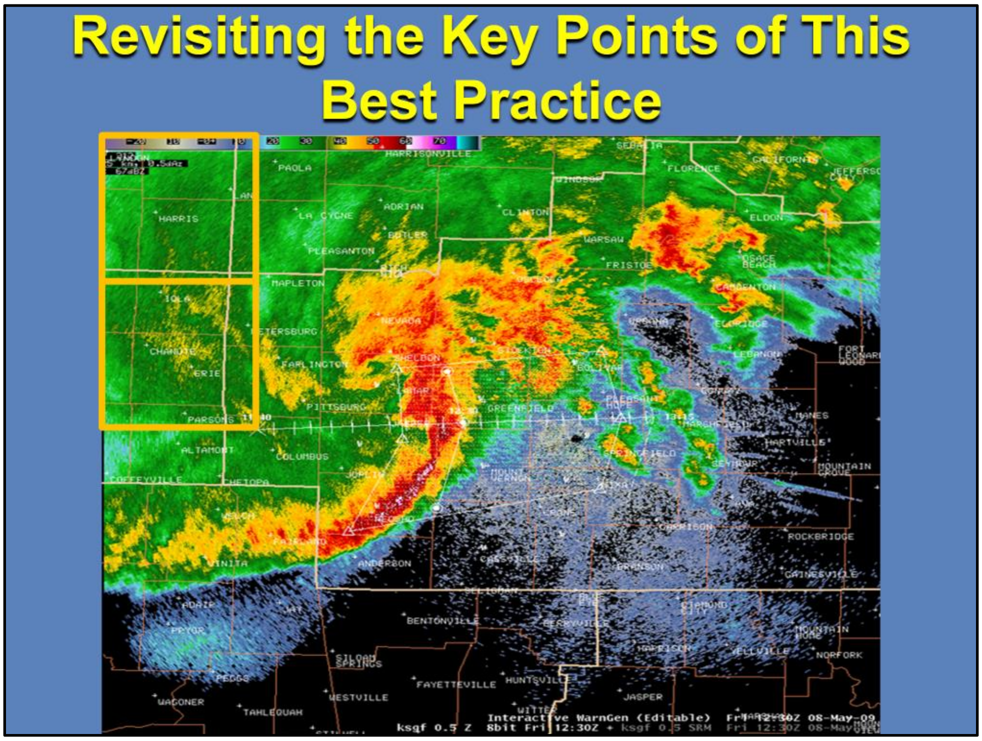


In summary, when the Cold Pool is large and effecting a mature multicell system, the deep layer shear very strong, and a RIJ is persistent , use the Corfidi Vectors for Forward Propagation to help determine non-linear system threat motions.



One last thing that I want to mention is about situations when storms are crossing CWA borders. As a best practice, it is important to include warning polygons from local and adjacent CWAs on your warning generation display monitors. In this example, note how Chicago (LOT) issued an unusual multi-sided polygon that matched up well and allowed for downstream movement from ILX's severe thunderstorm warning. In many situations, current displays like these in the warning preparation phase will help minimize unintended gaps between warnings and provide a seamless warning service for our users.



Many factors influence storm motion: updraft forcing, shear, boundary location and orientation, among others.

Know the relationship of these physical factors on storm motion and use those relationships to help guide the effective placement of storm-based polygons so that they incorporate non-linear and/or downstream development.

This brief lesson will illustrate some of the issues involved with drawing storm-based warning polygons for merging storms. The lesson will consist of an example of two storms whose individual motions will bring them to roughly the same location at the same time. There will also be a summary slide with the key points to walk away with from this example.

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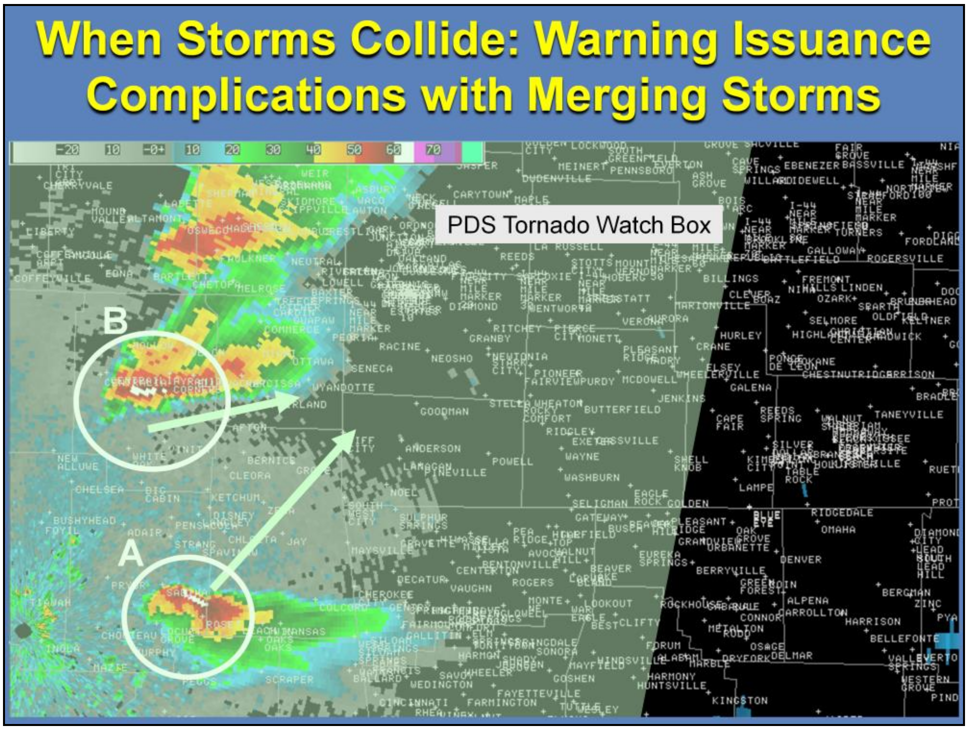

For this example, we will present a case where two storms will likely interact, or merge, near the end of the current warning time period. [A & B labels appear] The discussion will focus on storms A and B. [watch box becomes visible] Both storms are in an area covered by a PDS Tornado Watch with MLCAPE around 3000 J/kg and strong deep (0-6 km shear ~ 40-50 kts) and low-level (0-3 km SRH ~ 300 m2s-2) shear. [watch box disappears] …brief pause...

[storm A circle and arrow appear] Storm A is a strong left-moving supercell that formed during a storm split further to the south (green arrows represent storm motion vectors). [storm B circle and arrow appear] Storm B is an even stronger right-moving supercell. Your office has received several severe hail reports from Storm A. With little observed change in storm structure, the warning forecaster has decided to reissue a SVR for this storm. Storm B has had persistent, deep rotation for several volume scans but no reported tornadoes. Nonetheless, the warning forecaster thinks that reissuing a TOR for this storm is the best course of action. [circles move along arrow to show future storm location] By putting the circles in motion, we can see the approximate area where the storms should be in the next 30 minutes or so.

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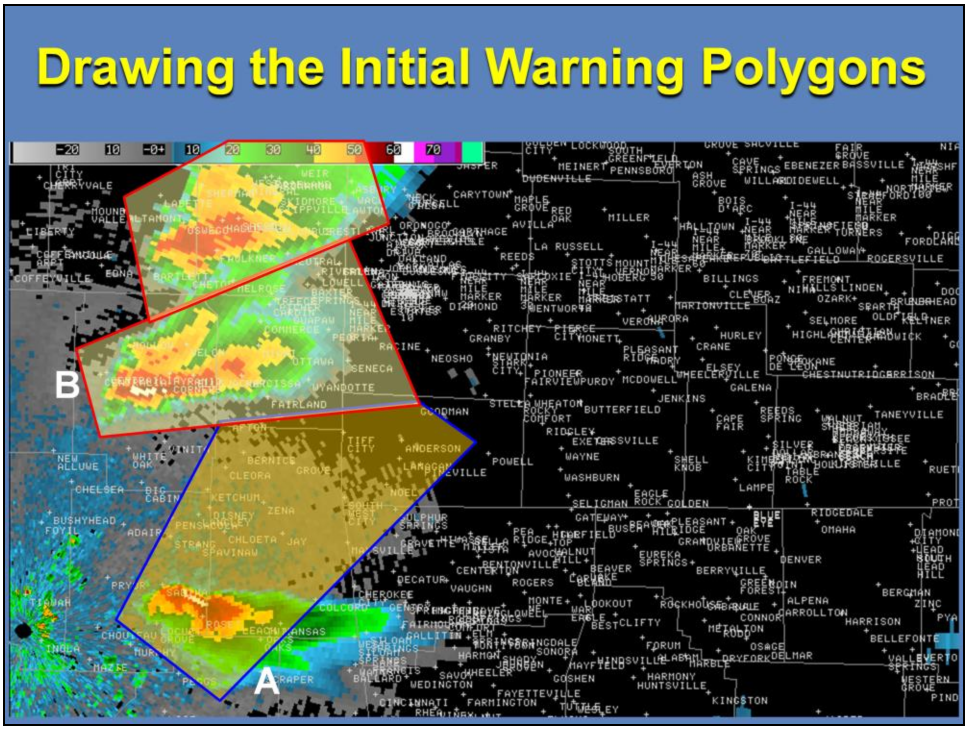

The primary issue here is how to draw the polygons so that all threatened areas are covered with a minimal overlap to limit potential confusion. [warning polygons appear] This case is a little more clear cut than most. The TOR (with Storm B) is the more significant threat, so the SVR (with Storm A) was drawn to cut off at the TOR boundary. To make this solution work best, you would want to either have (a) two separate warning forecasters coordinating their warning polygons or (b) the TOR for Storm B is issued prior to the SVR for Storm A.

Let’s move ahead 30 minutes or so and see what to do with the next warning decision.

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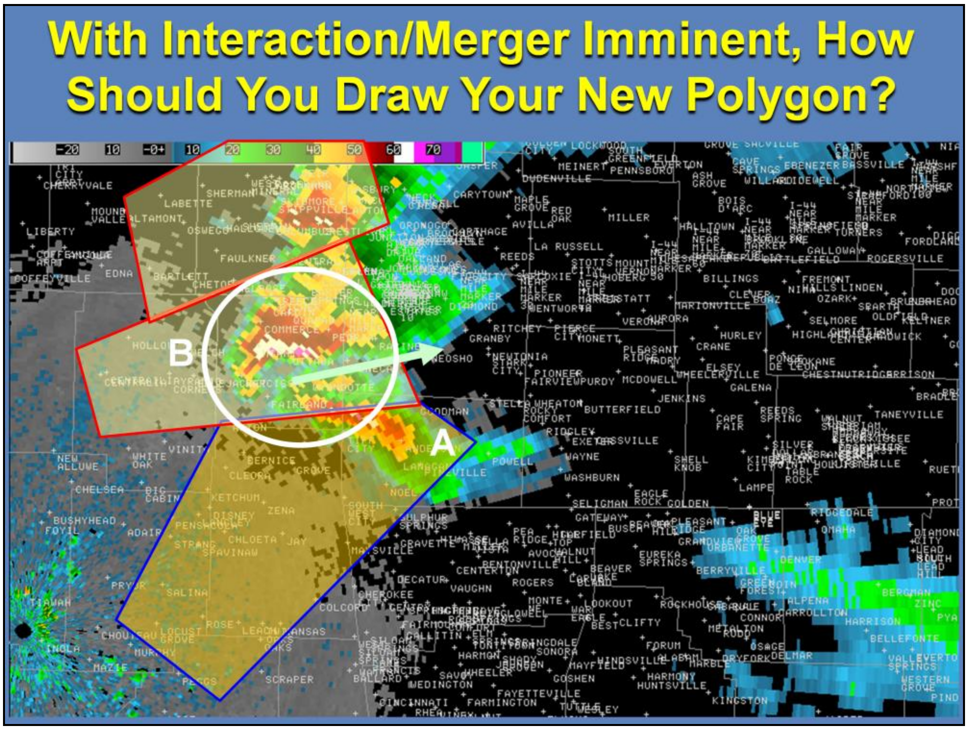

With the warnings due to expire, you can see that the storm interaction/merger is imminent. [warning polygons fade] During the last half-hour or so, Storm A has weakened slightly while Storm B appears to have intensified. Your office staff has had some good, vigorous discussion and are not sure if these storms will actually merge. The consensus opinion is that Storm A will likely continue to weaken or dissipate as the storms interact. [storm B circle and arrow appear] Taking this into account, the warning forecaster has decided to issue a single TOR following the general path of Storm B. [storm B circle moves forward in time] Once again, we will move the circle forward in time to see where our storm should be, approximately, in the next half-hour or so.

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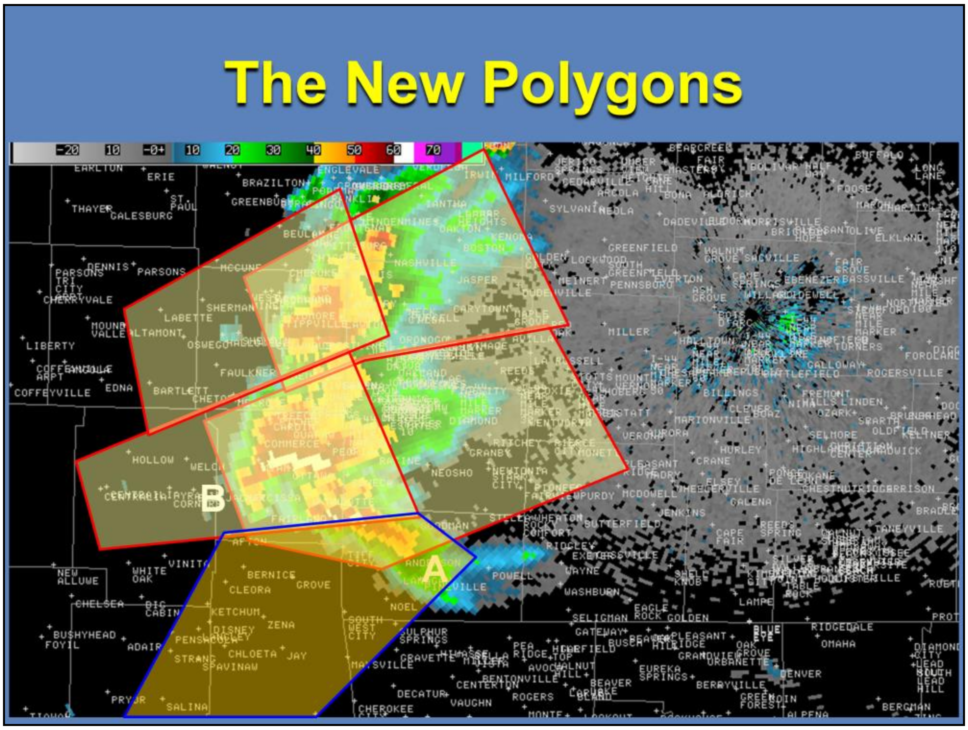

To display the next polygons downstream, we need to shift the image a little. [old polygons fade to dashed lines] We will leave an outline of the old warnings up to provide a frame of reference. In addition to moving the image, the storms are a little closer to the next radar downstream, so we have switched views to that radar.

[new polygons appear] Here is the subsequent warning for Storm's A and B. The polygon has been drawn a little larger due to the uncertainty issue of the merger/interaction. At the same time the polygon was drawn such that the warning for the storm to the north could be drawn with as little overlap as possible (but no unintentionally unwarned areas).

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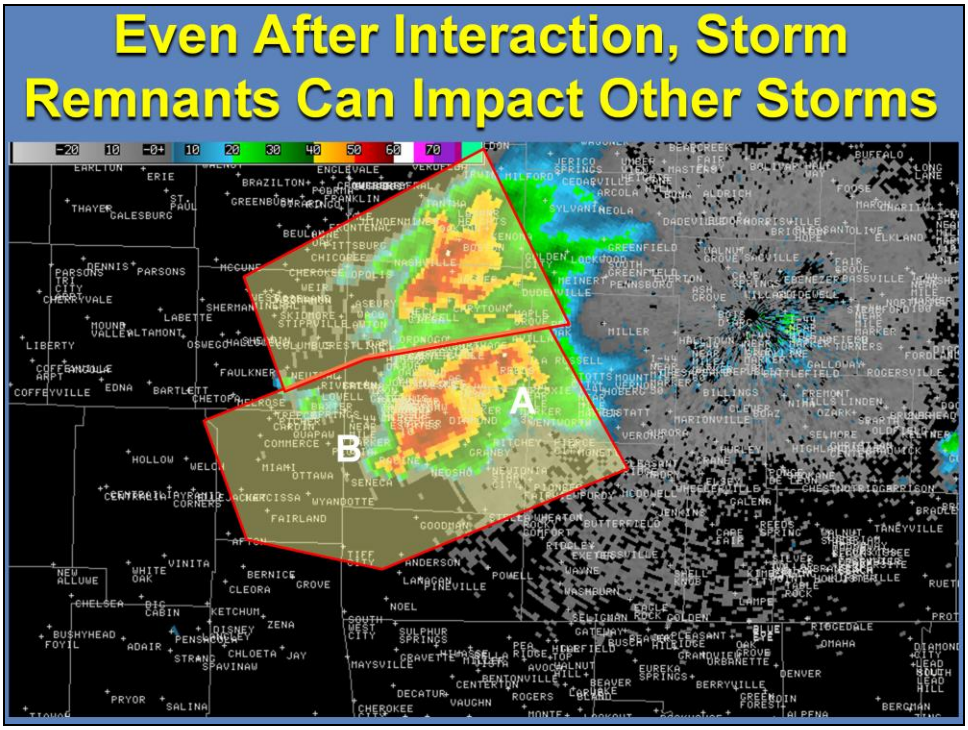
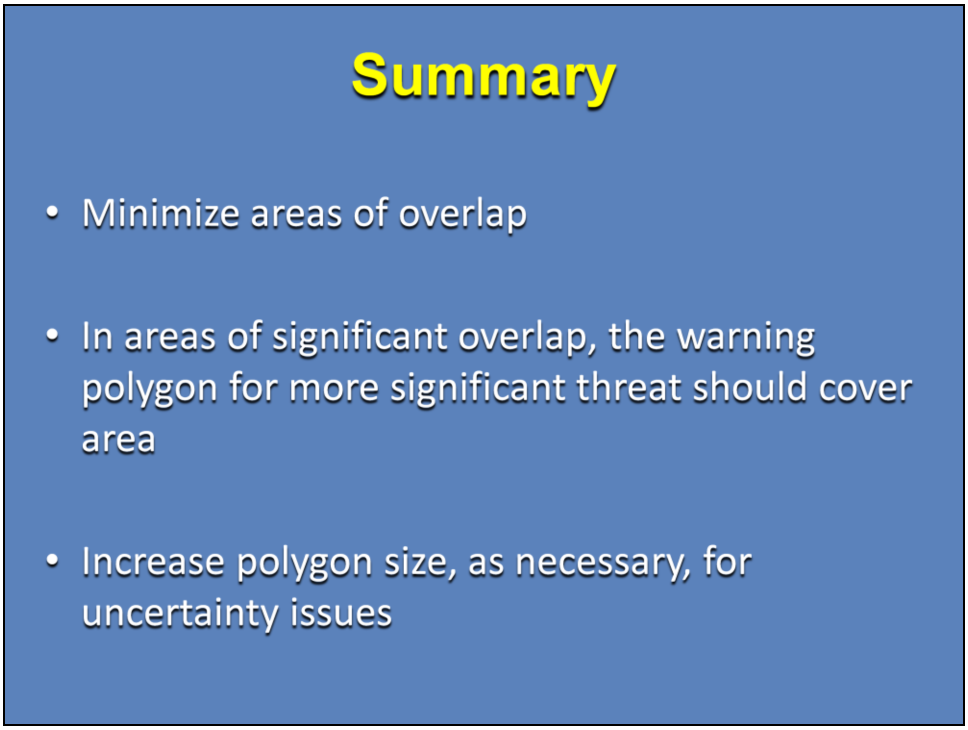


Here is an image of Storm’s A and B about another 30 minutes later. Storm A has continued to weaken, but appears to remain an independent storm from Storm B. In fact, it appears that Storm A may merge/interact with the storm to the north. Although we could continue, I think you have seen enough to get the point of this example. Let’s move on to the summary.



In summary, here are the key points from this example. [first bullet appears] Just like other situations where you have multiple storms, you want to minimize any areas of overlap between different warning polygons. [second bullet appears] In areas where there would be significant overlap between the polygons due to interaction or merger of the storms, you will need to cut back one or more of the polygons to minimize the overlap. In these cases, the polygon for the more significant threat should cover the overlap area. [third bullet appears] Lastly, remember to take into account uncertainty issues with these situations by increasing the polygon size as needed, especially for warnings that cover post storm merger, or interaction, evolution.

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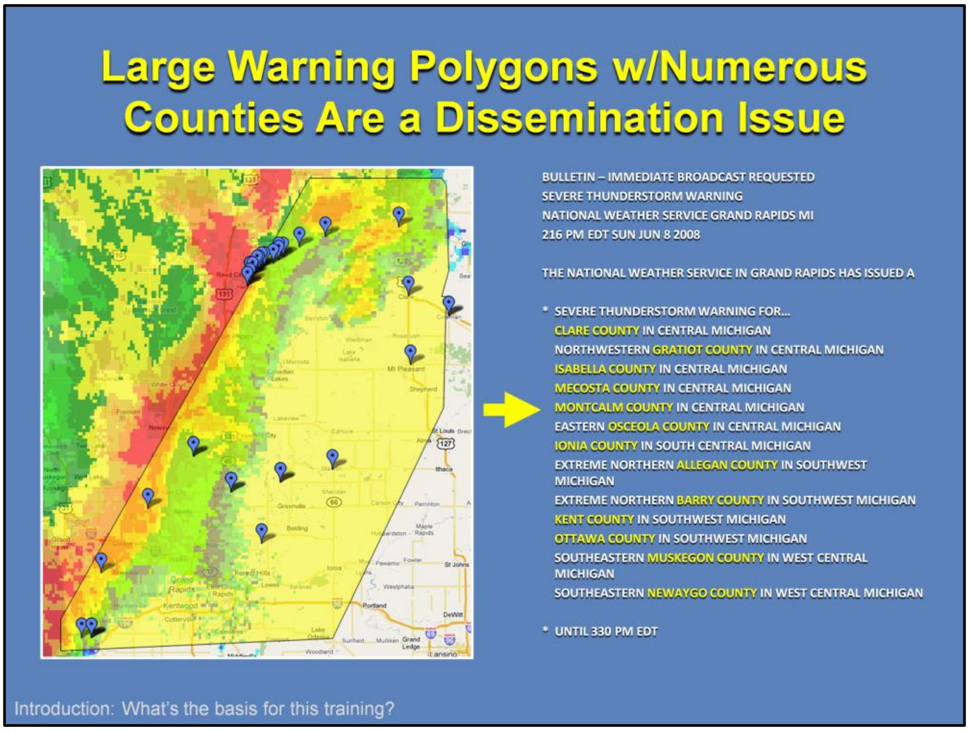
Welcome to the RAC Storm-Based Warning Fundamentals lesson on limiting the number of counties in warnings. This lesson addresses the NWS policy on the size of warning polygons. Lesson addresses when a convective threat area is too large for a single warning polygon. Then there will be a discussion on guidelines for dividing a phenomenon into multiple threat areas for warning polygons. This lesson should take approximately 30 minutes to complete.



So why are large warning polygons a problem? Large polygons often include lots of counties and result in longer text products. That can lead to dissemination issues. *[show text & arrow]* In the example shown, the warning polygon included parts of 13 counties. The warning text would take any reading technology (e.g., CRS, human readers, and TV text scrolls) a long time to communicate.

From the graphic, you can see the office received reports throughout the warned area. So, the locations included in the warning indicated the potential threat area well. However, multiple warning polygons would have better communicated the threat.

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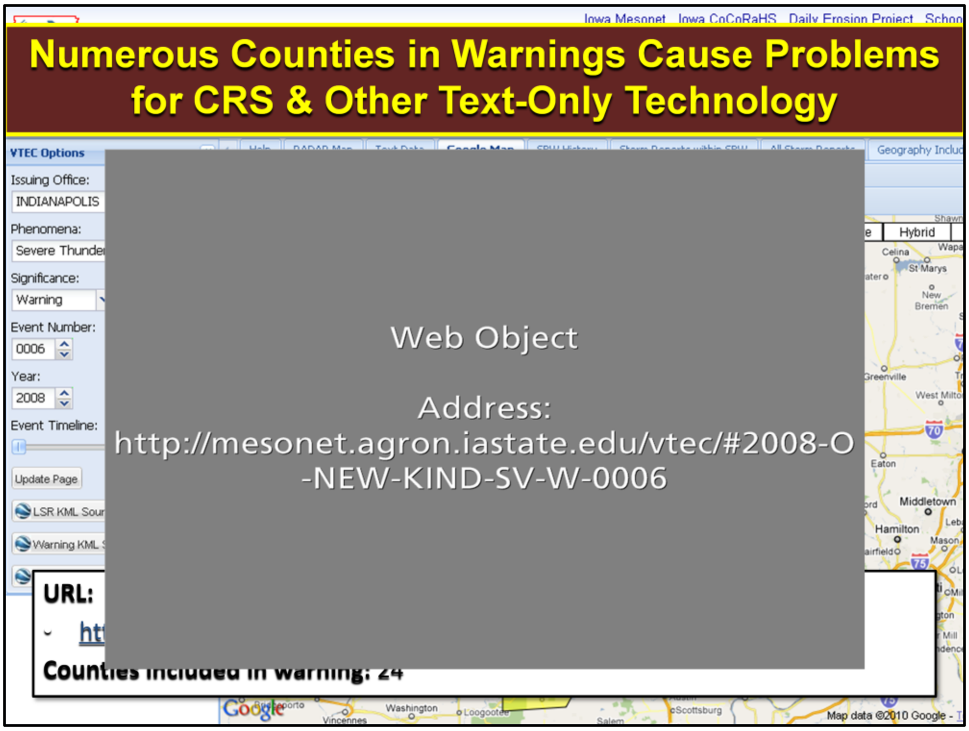
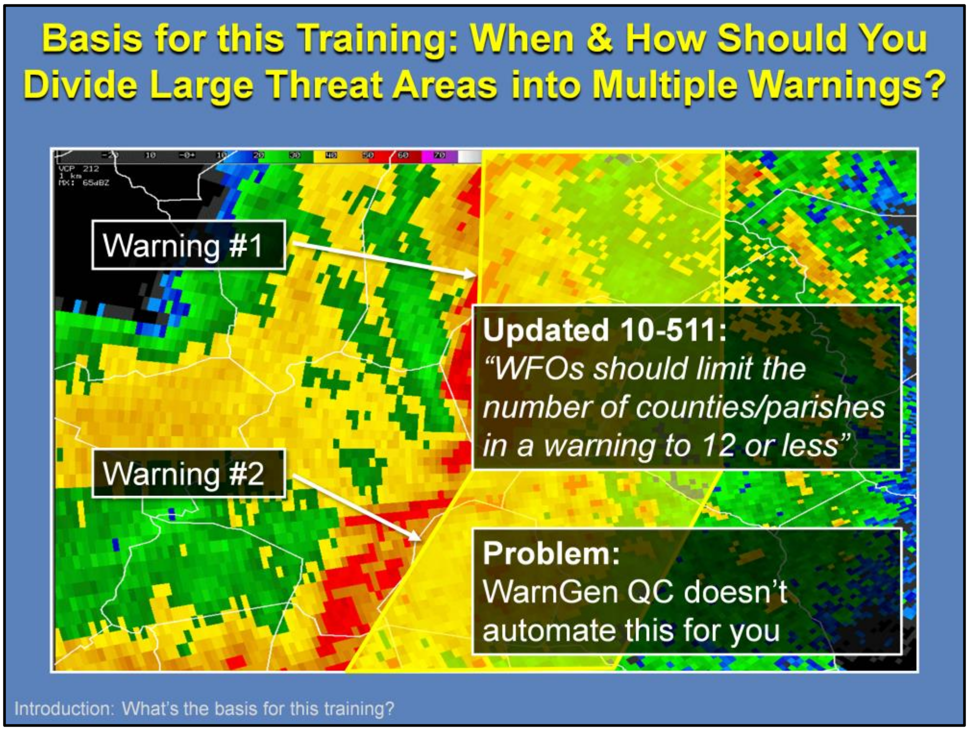


In the external browser window, you'll see another example of a large warning polygon. The display uses the Iowa Environmental Mesonet VTEC web page to better see all of the warning details. If you are not familiar with this web page, I highly recommend it for reviewing warnings as part of any post-mortem process. *[show arrow]* Besides showing the warning polygon, this site also gives you the opportunity to view the warning text, *[move arrow]* overlay storm reports, and review other data associated with the warning.



Hopefully, it's clear to you how large warnings can lead to dissemination problems? To prevent future issues, NWS Instruction 10-511 was updated in April 2010 to limit the size of Severe Thunderstorm or Tornado Warning polygons. *[show 1st text box]* Specifically, these warning polygons should contain 12 counties or less. *[show 2nd text box]* Unfortunately, WarnGen doesn't quality control warning text for the number of counties. Forecasters need to be diligent when creating warning products to ensure they meet this guideline.

So now that you know when you should break up larger threat areas, the next question is how? That's what the rest of this lesson will discuss.

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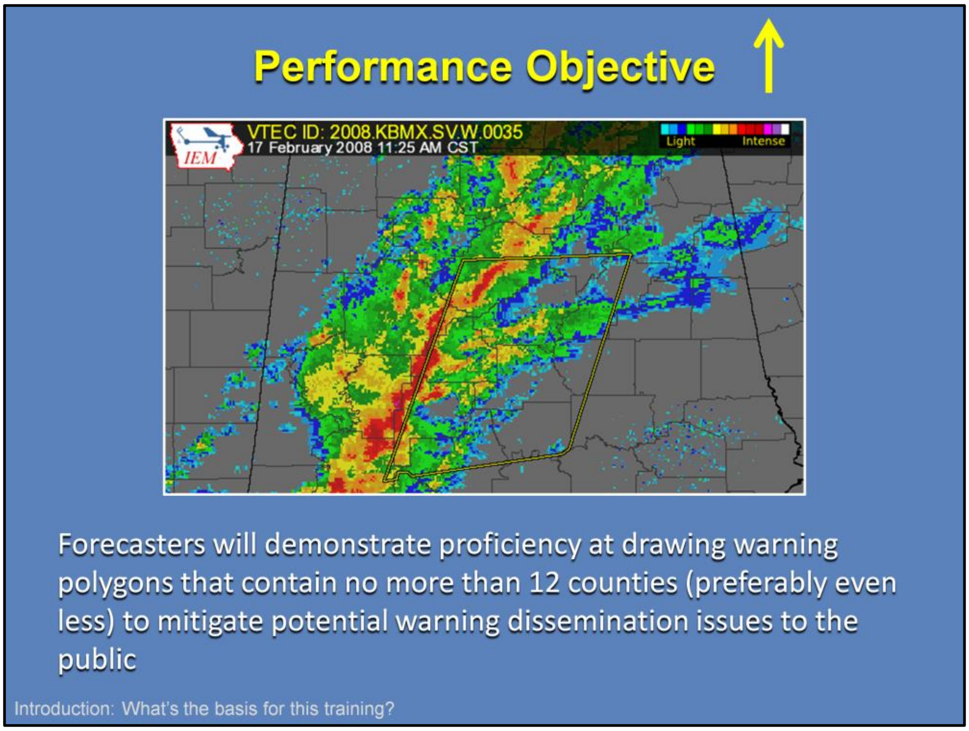
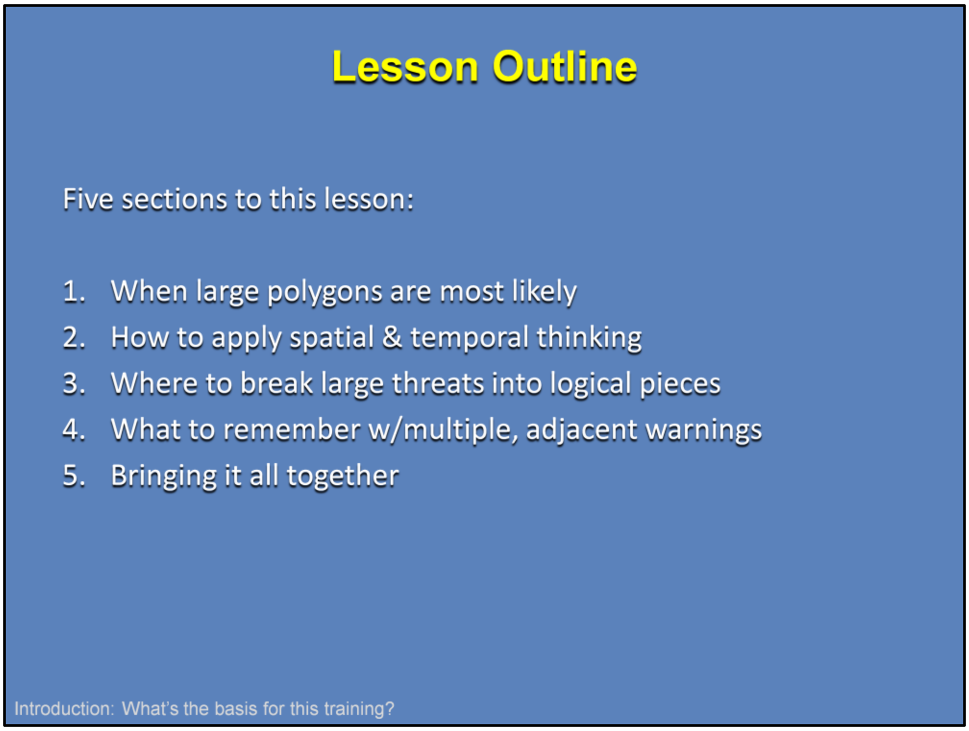


Take a moment to read the performance objective shown on the slide. *[show arrow]* You can also review the learning objectives for this lesson by clicking the tab in the upper-right corner of the window. These objectives, which are accessible throughout the presentation, will be covered by the quiz questions in the LMS upon completion of this course. *[hide arrow]* Once you have reviewed the objective, click the “Next Slide” button to proceed with this lesson.



The remainder of this lesson consists of five sections. *[show 1st bullet]* First, we'll cover when large warning polygons are most likely. *[show 2nd bullet]* Next, we'll discuss how spatial & temporal factors influence the size of a warning polygon. *[show 3rd bullet]* Then, we'll talk about breaking up large threats into logical pieces. *[show 4th bullet]* The fourth section will cover some important fundamentals about drawing adjacent warnings. *[show 5th bullet]* Lastly, I'll you some quiz questions to help bring all of these topics together.

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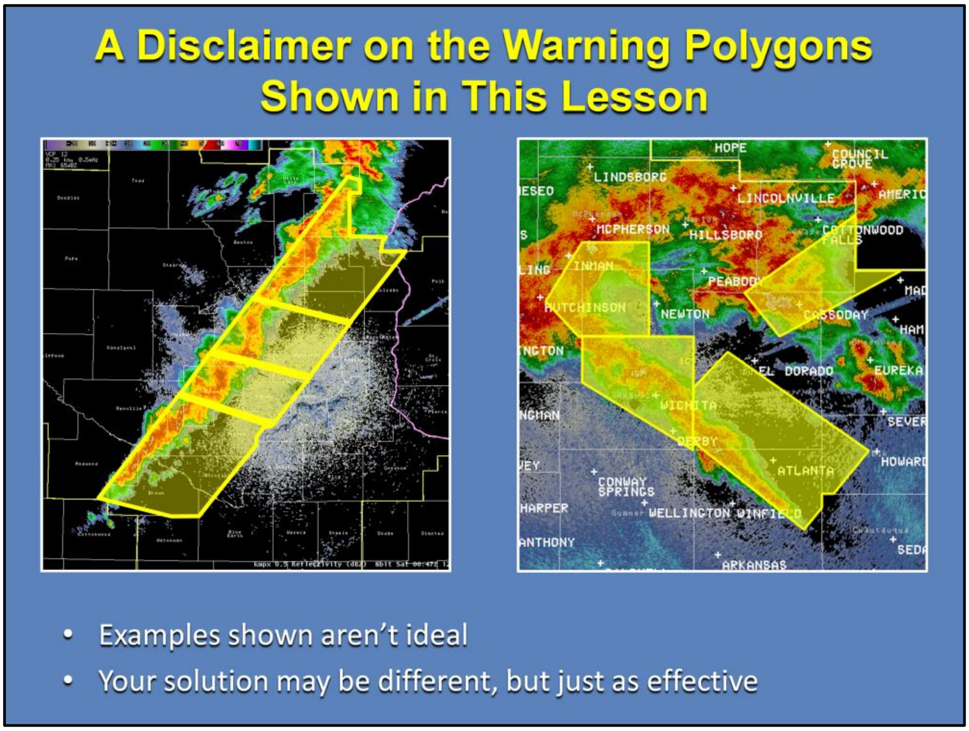
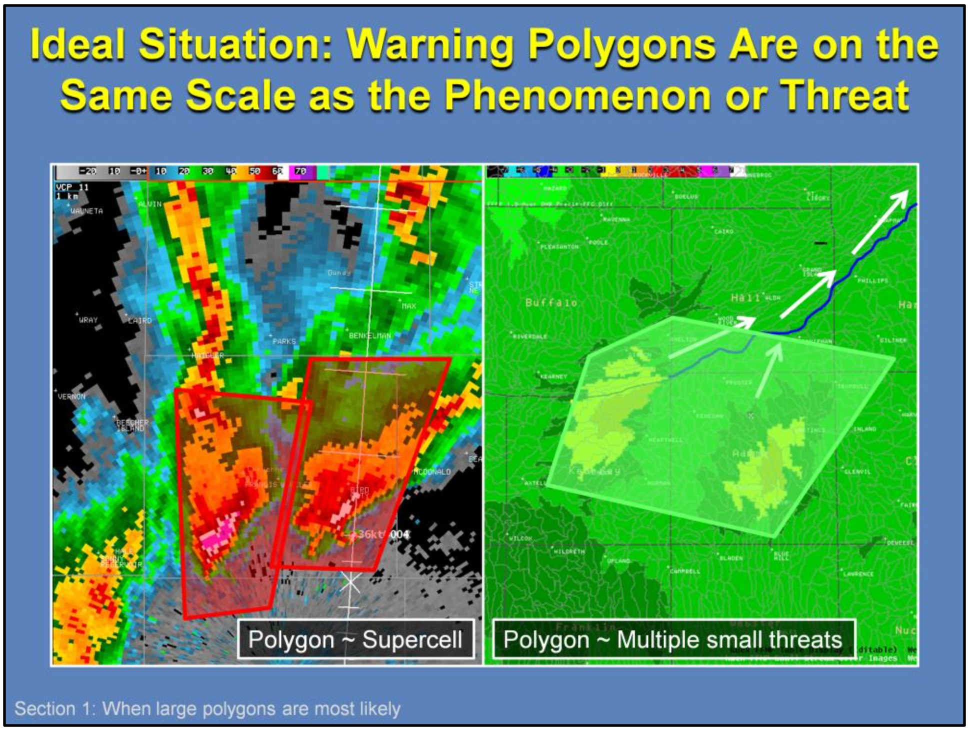


As you go through this lesson, you will see many warning polygon examples. Some of these examples involve actual warning polygons while other polygons were drawn by the instructor to support the goal of this lesson. *[show 1st bullet]* Regardless of the source, the warnings shown here shouldn't be interpreted as the ideal solution. They show just one way to break up a large threat area into multiple polygons. *[show 2nd bullet]* You might draw polygons that are different, but just as effective, as the ones shown here.



Ideally, warning polygons will be roughly the same size as the threat they cover. Actually, they should be a little larger than that to account for various forms of data uncertainty. But, they would be on the same relative scale.

In reality, this process is easier said than done. *[show TOR polygons]* For instance, Tornado Warnings are generally drawn on the same scale as the tornadic supercell. If I ask 10 forecasters to draw a warning polygon for a tornadic supercell, the results will likely vary somewhat. However, the polygons' areas should be fairly similar.

[show FFW polygon] Flash Flood Warnings, on the other hand, are basin-based phenomenon. Due to forecaster and data uncertainties, these warning polygons are often larger in scale than the actual threat area. As in the example here, a single FFW polygon may cover several, separate threat areas that flow into the same drainage basin. When threat areas are small, that's OK.

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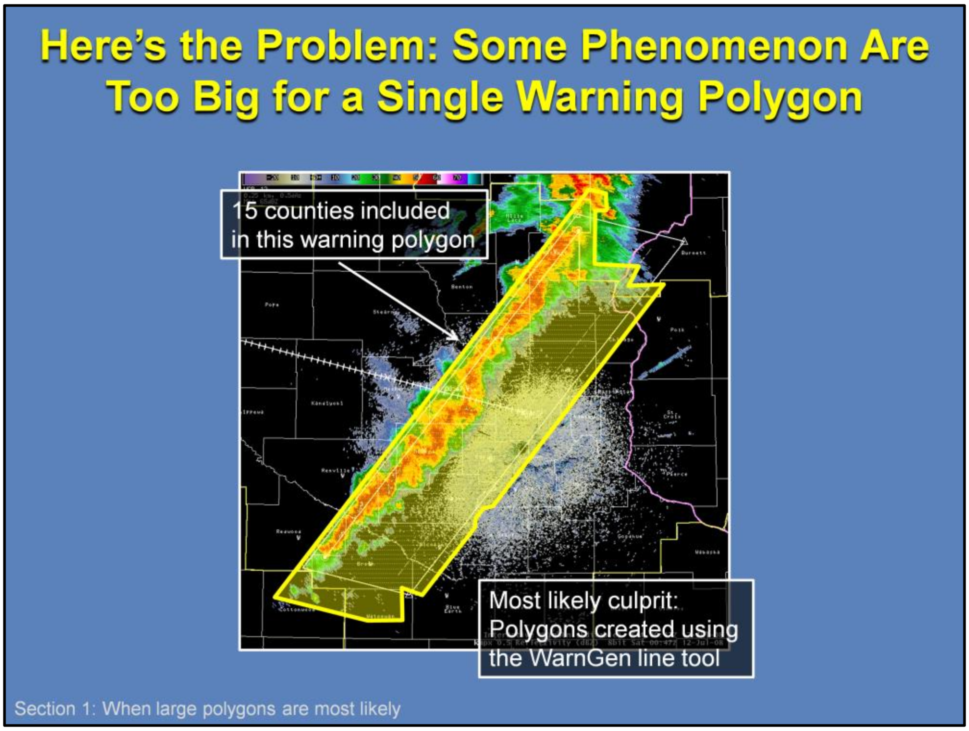

However, when the threat area is big due to a large meteorological phenomena, then warning size is a problem. Take this squall line, for example. *[show SVR polygon]* If you draw the polygon on the same scale as the phenomenon, it might look something like this. Since the squall line extends from one side of the CWA to the other, so does the warning. *[show 1st textbox]* The polygon shown here includes 15 counties.

[show 2nd textbox] From the examples I've shown, you may already realize the following: Having too many counties in a polygon is strongly linked to use of the "Line of Storms" tool in WarnGen. As a result, this lesson will focus primarily on its use in warning generation.

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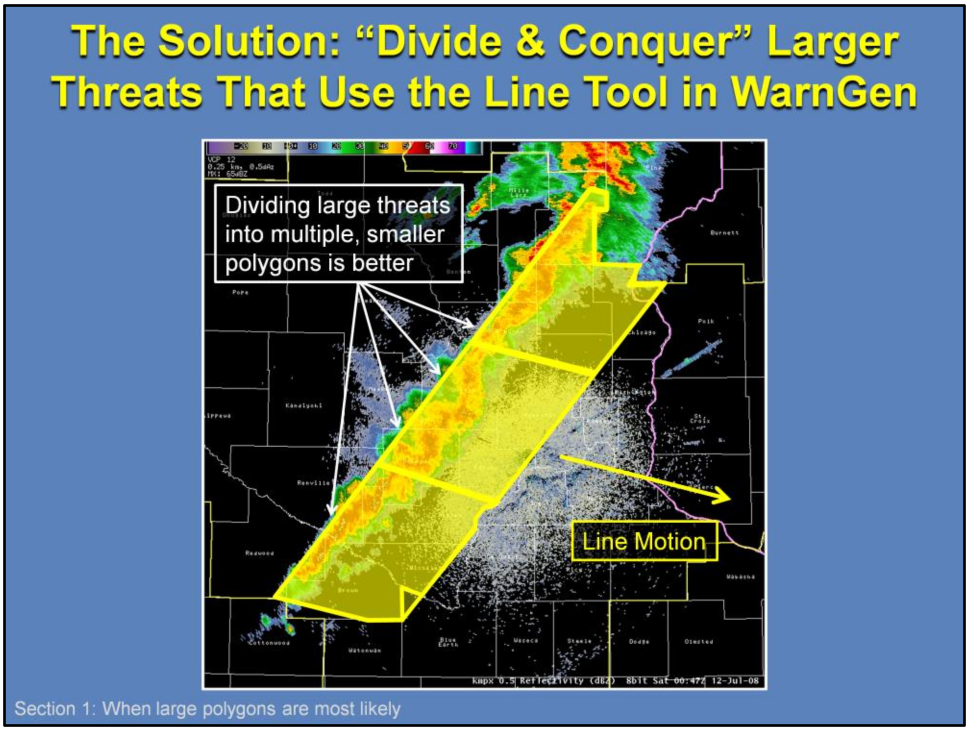

With that problem in mind, let's talk about the solution: Breaking up the phenomenon into multiple, smaller threat areas. What I'm advocating here is the old adage of divide and conquer. *[show smaller polygons]* For this example, the original SVR polygon might look something like this. The same general area is covered by these smaller polygons. *[show textbox]* The benefit of the smaller warning is that the dissemination issues seen with the larger warnings are less likely.

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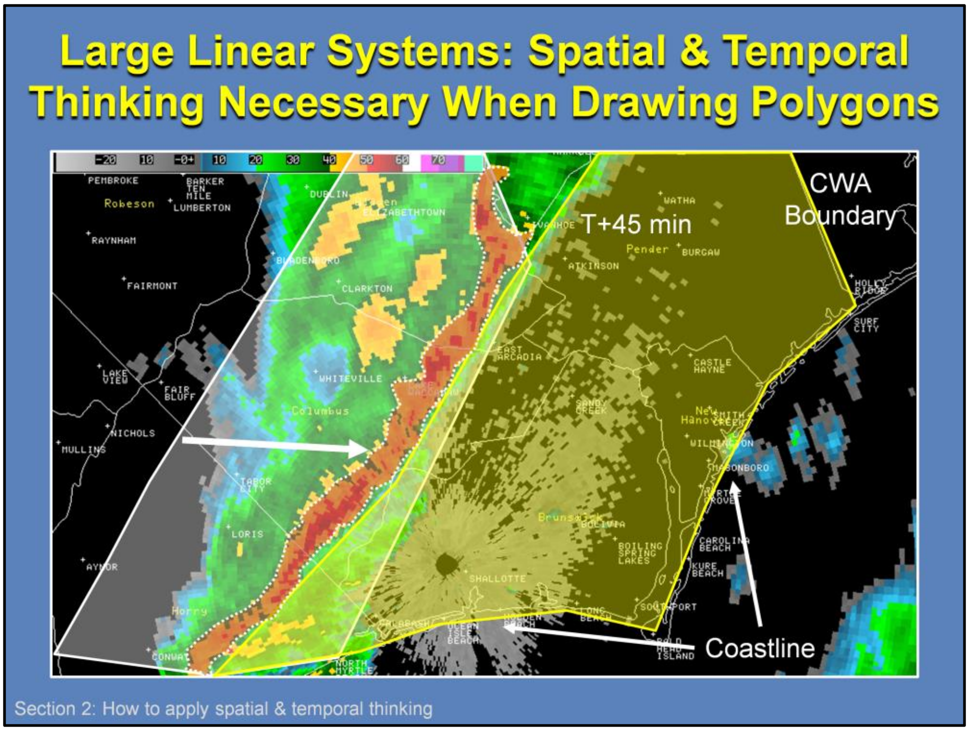

[show textbox] There are four primary factors impacting warning polygon size. Some have primarily spatial importance, while others are more temporal in importance. These factors are:

- The spatial area of the threat itself,
- The velocity of that threat,
- The time until expiration of the warning, and
- Any uncertainty the forecaster has about the threat over time.

[Hide text & show old warning] We'll use this example to illustrate. The polygon shown will expire in approximately 10 minutes. We'll reissue the SVR for this storm. *[show arrow & storm outline]* The line is moving in this general direction and, *[move storm outline]* in 45 minutes, the line should be about here. Most of the LSRs have resulted from the area along the leading edge of the storm. Storm motion and evolution has been pretty steady, so uncertainty is fairly low. *[show new warning]* We'll draw our new SVR polygon like so. *[show text & arrows]* In this case, the warning extends to the coastline & boundary with another CWA. So, those boundaries will limit the extent of the warning as well.

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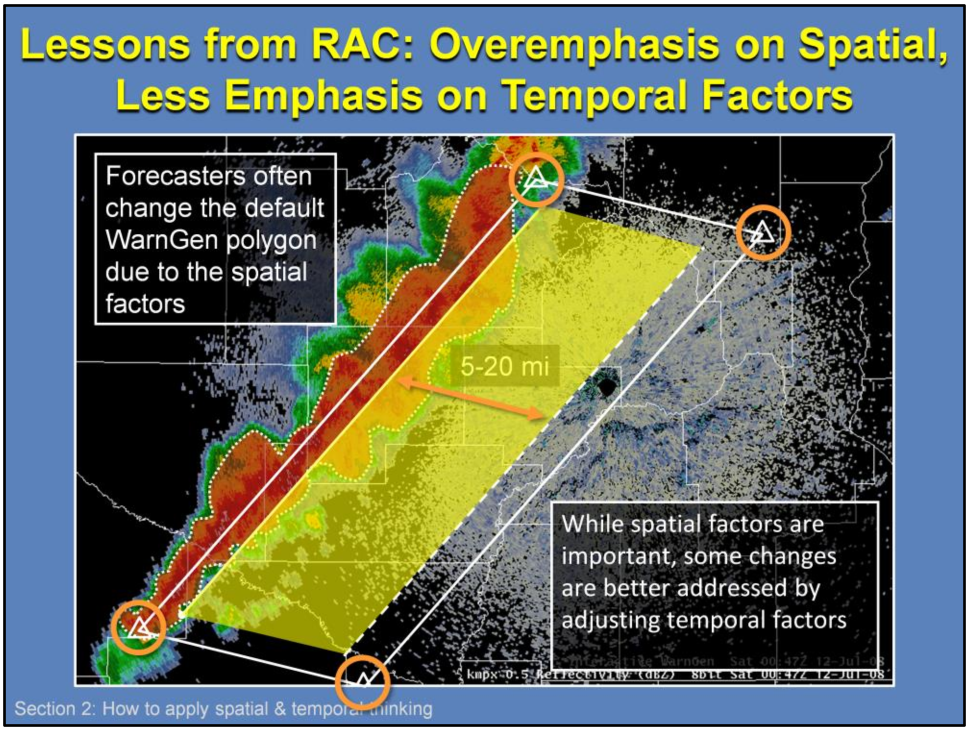
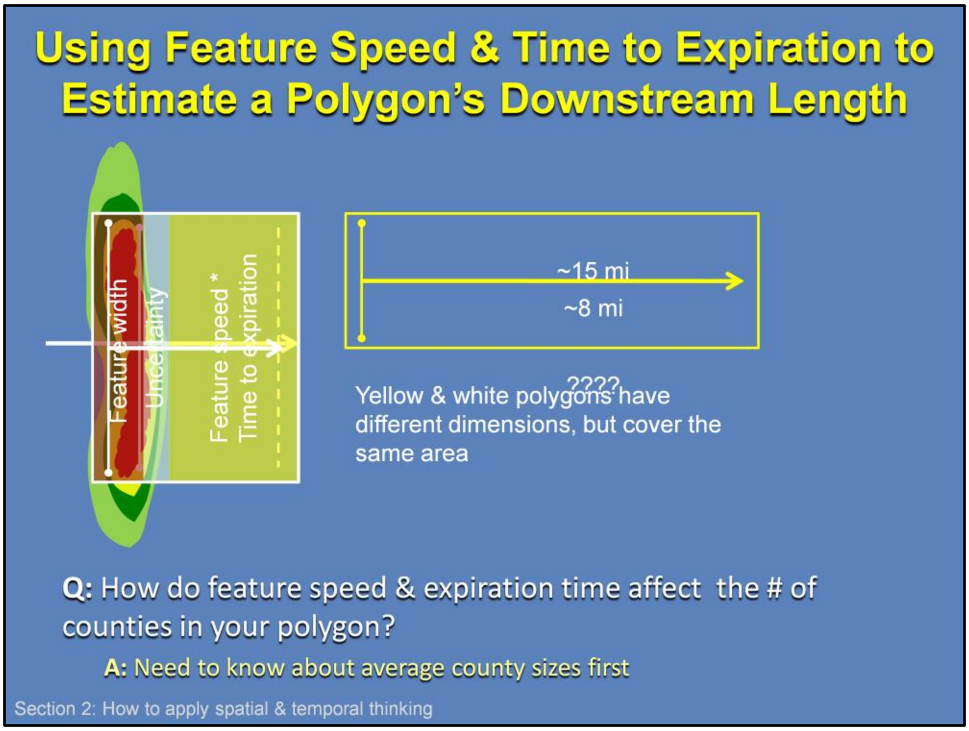


So how do these different factors impact warning size? Well, it depends on the situation. *[show textbox]* What I can tell you is an observation I've noticed over the years. Novice forecasters focus their warning efforts on manually adjusting for spatial factors much more than on temporal factors. *[show circles]* They often change the polygon's vertices to customize its shape when *[show arrow]* changing the storm motion vector or the expiration time would be better.

For example, if we use the WarnGen line tool for the outlined convection, then the polygon and lines shown are the default. *[show outline of squall line]* Now this squall line – depending on where you measure - is roughly 5-20 miles across. Using the larger value, that's about 40% of the polygon's downstream length. *[move outline]* Compare that to where WarnGen predicts the line will be when the warning expires based on storm motion. This distance is almost 40 miles.

Now, not all large threats will have those same proportions. *[show textbox & yellow area in polygon]* But often a large portion of the area covered by a warning is due to storm motion and time to expiration. Don't forget this info when customizing your warning polygon!



You've probably wondering where I'm going with all of this spatial and temporal factors stuff. *[show polygons & text]* Well, if you're polygon has a maximum size, then the cross-stream and downstream dimensions of your warnings are inversely linked. *[show arrows & lines]* The longer the downstream propagation vector, the shorter your line tool needs to be to meet the policy requirement. So, we've come up with some guidance in this area, but first let me show you how we came up with it.

[show polygon] Say this polygon is a warning generated for this storm. *[fade in & drag polygon fills]* Breaking up the downstream distance into separate terms, it illustrates the role that the temporal components play. *[rotate fills & fade in text]* If we assign some "average" values to feature width and uncertainty, then it allows us to solve a problem: *[show Q & A text]* How do the feature speed & expiration time affect the number of counties in your warning polygon? Before we can solve this problem, first we need to know what the average county size is.

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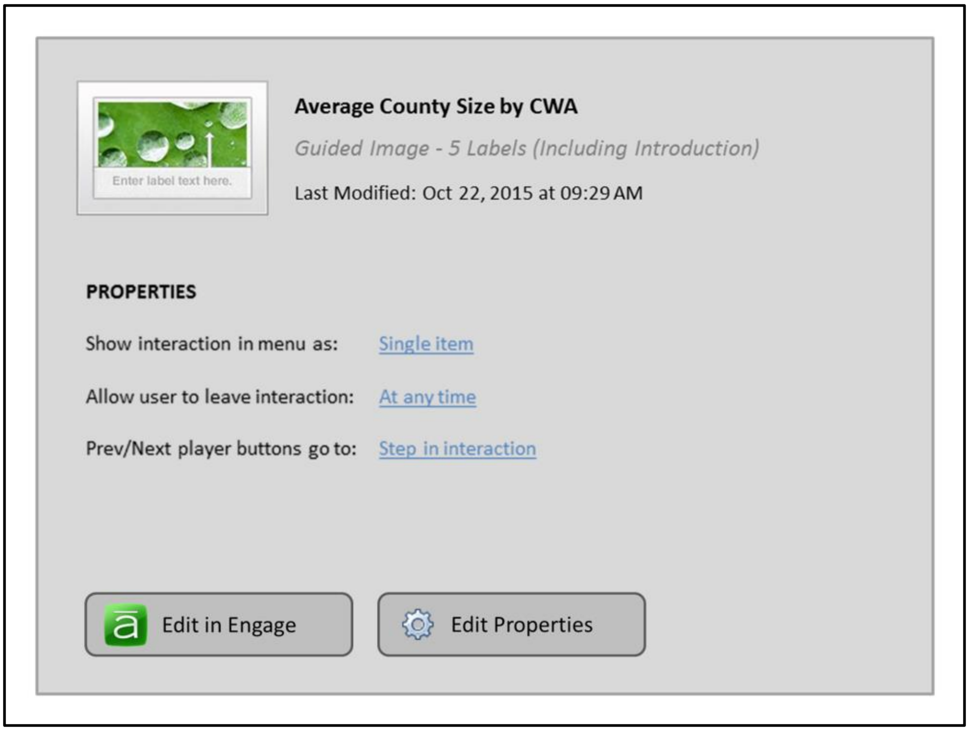

Do you know how big the counties are in your CWA? We used ArcGIS to figure that out for each CWA in the Contiguous 48 States and group them into four categories.

Use this interaction to learn more about each of the categories. Each category has an average for the county dimensions in that area. We'll use those dimensions for some back of the envelope calculations on the next slide.

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Back of the Envelope Calculation: How Far Does a Storm Travel During a Warning?

Distance covered:

	15 mph	20 mph	25 mph	30 mph	35 mph	40 mph	45 mph	50 mph
30 min	7.5	10	12.5	15	17.5	20	22.5	25
45 min	11.3	15	19.8	22.5	26.3	30	33.8	37.5
60 min	15	20	25	30	35	40	45	50

Next, we need to determine how far a storm travels during the warning period. The table on this slide shows these distances for a handful of speeds and expiration times. To simplify things, I grouped the values into three categories and color coded them. We'll discuss the relevance of the color-coded categories on the next slide.

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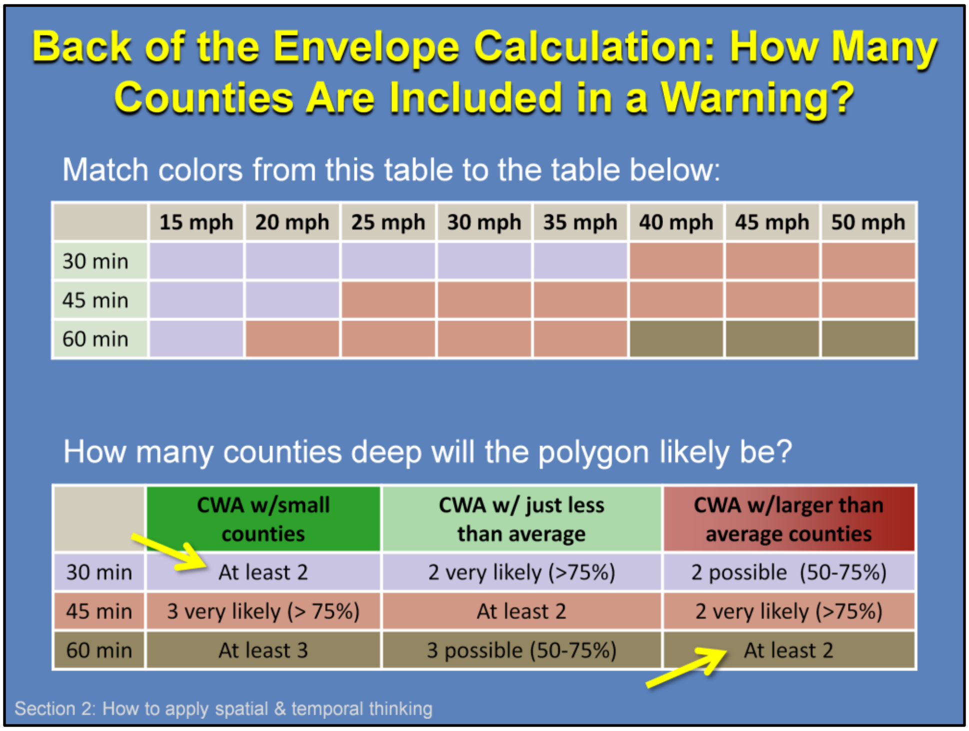
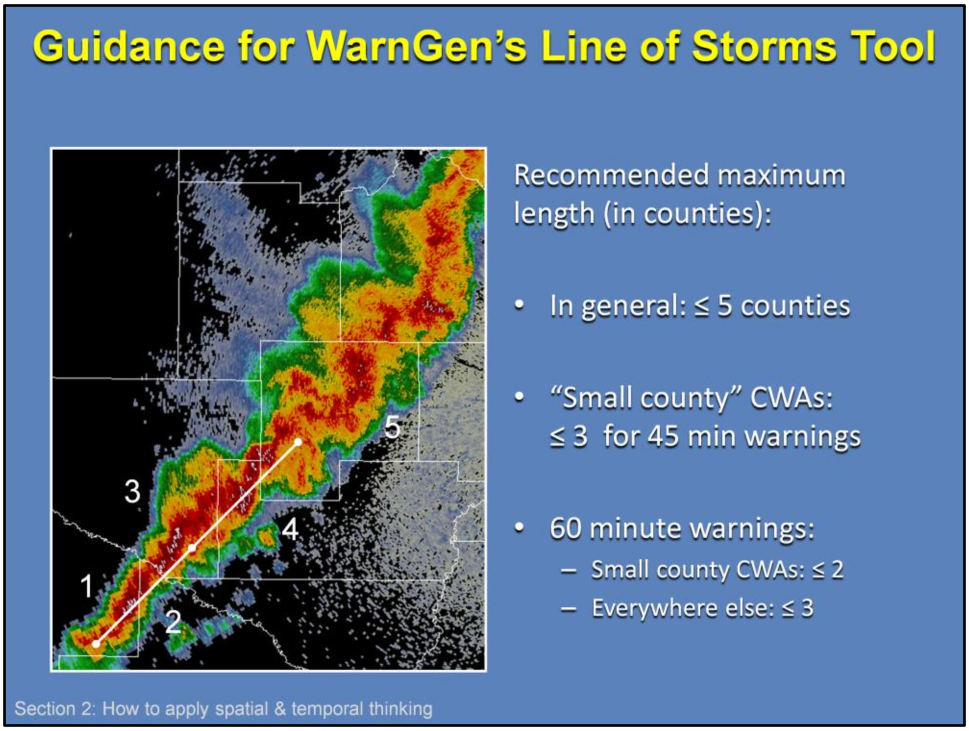


The colors in the table near the top of the screen help indicate the downstream length of your warning polygon in counties. This number varies depending on the average size of counties in your CWA. *[show 1st arrow]* For instance, even at slow speeds & short durations, WFOs with small average county sizes often issue warnings that are at least two counties deep. Just to be clear, that's the county the storm is currently in and the next one downstream. *[show 2nd arrow]* On the other hand, if you have larger than average county sizes in your area, then it usually takes faster storms with longer warnings to include a comparable number of counties.

Based on these values, we'll discuss some basic guidance on the next slide.



So, now that I've gone through this exercise, what does it all mean? *[show 1st bullet]* When using the Line of Storms tool in WarnGen, add up the counties that the tool touches. To ensure that your warning polygon contains less than the maximum in the directive, you generally want it to touch five counties or less. *[show 2nd bullet]* If you are issuing warnings for an area with "small counties", limit the number of counties the tool touches to three. At least for warnings of 45 minutes. *[show 3rd bullet]* If you are issuing a 60 minute warning, then:

- The tool should only cover two counties in a "small county" CWA, otherwise
- Limit the number of counties the tool touches to three or less.

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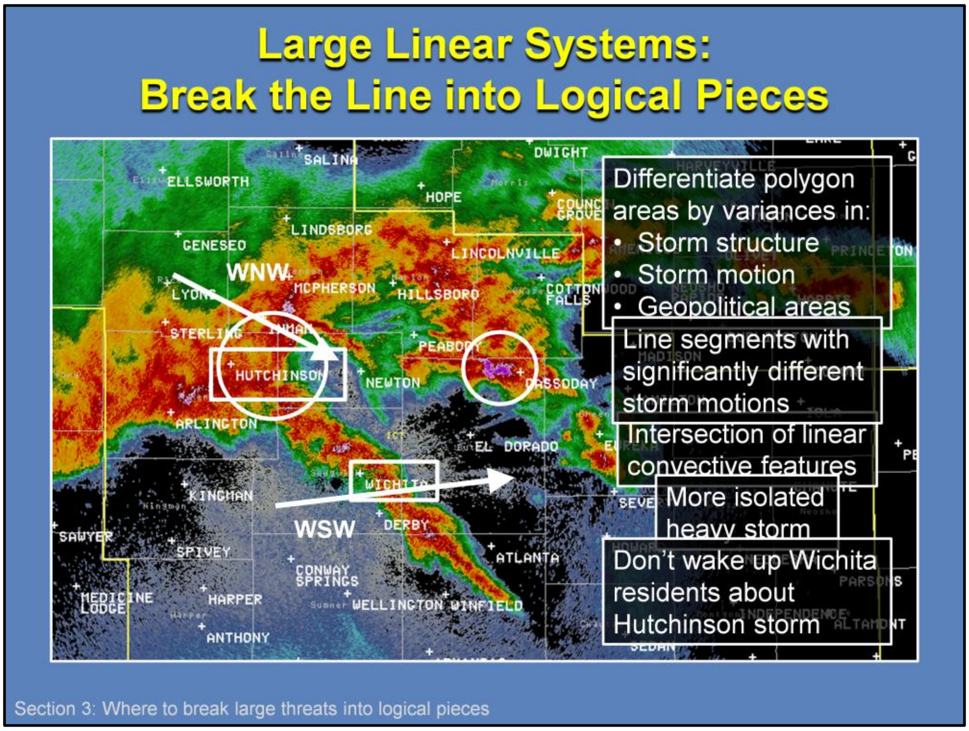
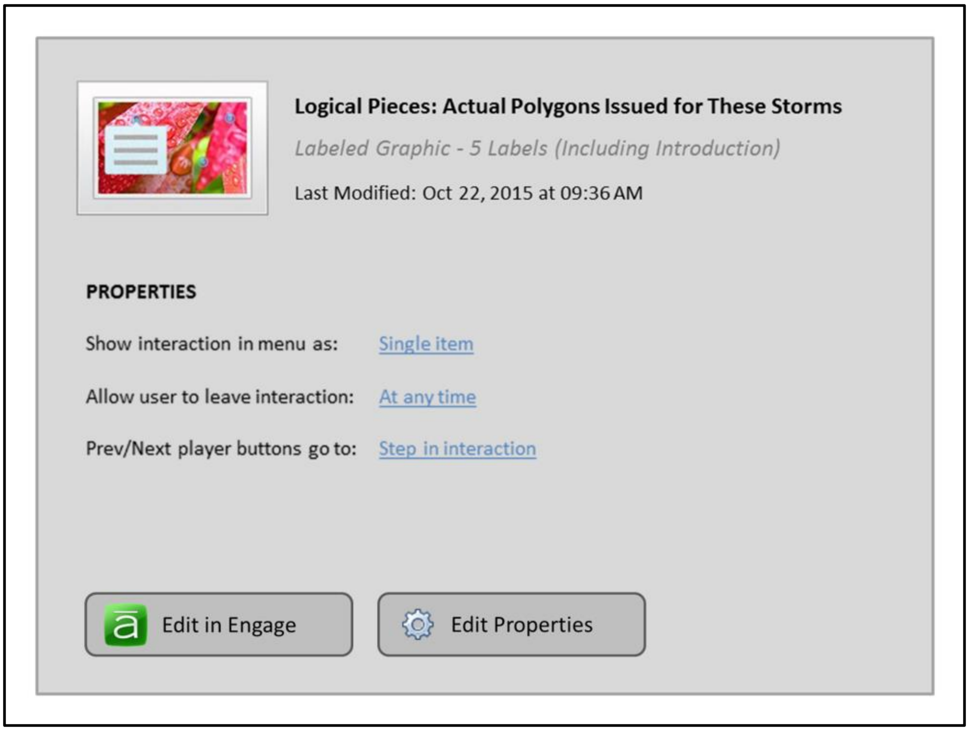


So, if you need to break up a large threat into separate threat areas, how do you do it? *[show 1st text box]* When identifying these threat areas, it's best to look for variations in storm structure, storm motion, and significant geopolitical features. Let's look at an example to show you what I mean.

In the case shown, there are two lines of convection that intersect near Hutchinson. *[show 2nd text box]* The SW-NE line is moving from the WNW while the NW-SE line is moving almost WSW. So, that's one logical break. *[show 3rd text box]* The intersection point between the two features will likely be a focal point of severe weather, so it should have a separate warning. *[show 4th text box]* While not a part of either of these lines, this isolated heavy storm near Cassoday will likely require a warning as well. *[show arrow]* Since the NW-SE line is moving in that general direction, you will likely want to draw your polygons for each threat appropriately.

[show 5th text box] Lastly, we look at the area around Hutchinson and Wichita. These cities – about 25 miles apart - are the two largest in south-central KS. If you were to receive reports from one area, but not the other, you risk over stating the threat to the second city if you include them in one polygon.



This interactive graphic shows how the Wichita WFO broke up their warnings for a 15 minute period for the example shown on the previous slide. This case was very complex. The polygons illustrate some issues that can come up when breaking up large threats into multiple warnings. Click on the arrows in the upper right-hand corner of the slide to step through details of each warning. You can also view a specific polygon's info by clicking on its red icon. Click on the next slide button to proceed with the lesson.

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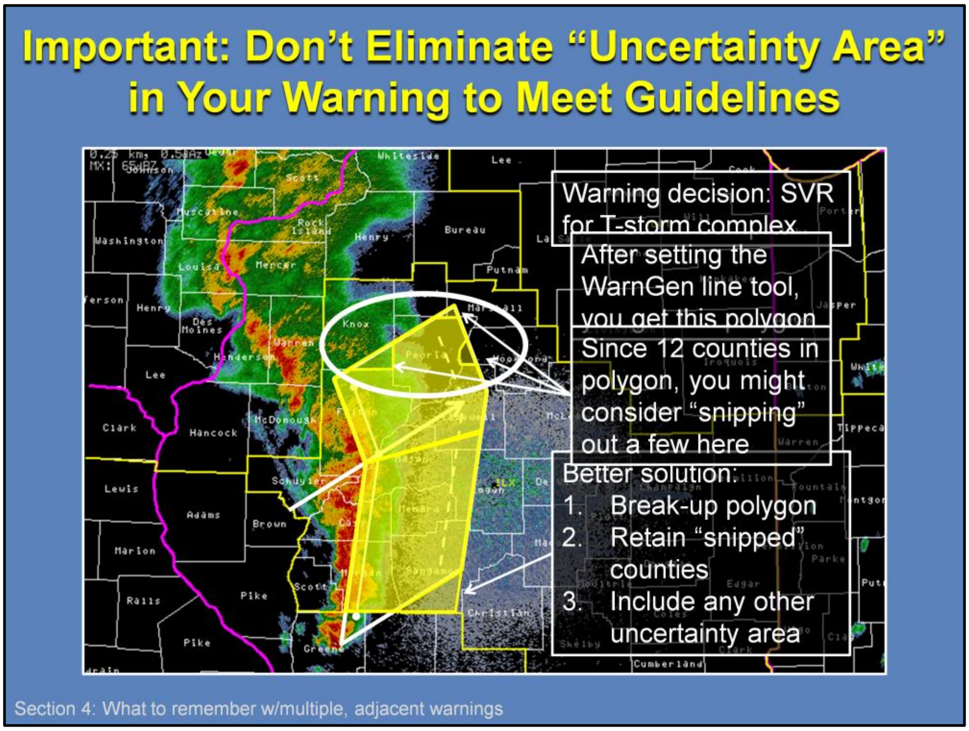
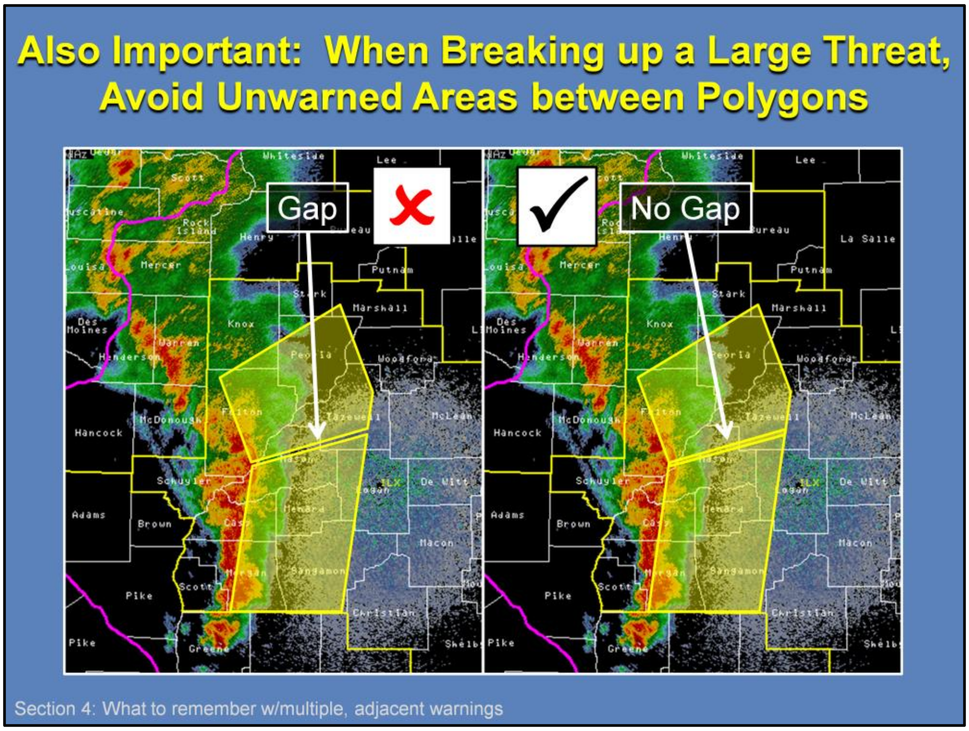


Let's say you are confronted with the following situation. *[show 1st text box]* You decide to issue a SVR for the thunderstorm complex shown on the slide. *[show 2nd text box]* After setting up the WarnGen Line of Storms tool, you get the polygon shown on the screen. *[show 3rd text box]* This polygon contains parts of 12 counties, so you might be tempted to manually remove some of the counties. *[show 4th text box]* If you find yourself in this situation, consider breaking up the polygon instead. In this case two separate polygons will do. *[show 2nd bullet]* Then, you can easily retain these areas in the warning that provide some room for uncertainty. *[show 3rd bullet]* Doing so covers any additional development that occurs along the southern edge of the line prior to the warning's expiration time.



When drawing adjacent warning polygons, it's important to avoid unwarned areas between the polygons. *[show 1st set of polygons]* The best way to avoid this problem is to have a small area of overlap between the two warning polygons. *[show 2nd set of polygons]* This small overlap area will ensure that no area is let out of the warning and minimizes any confusion that may occur in the overlap area.

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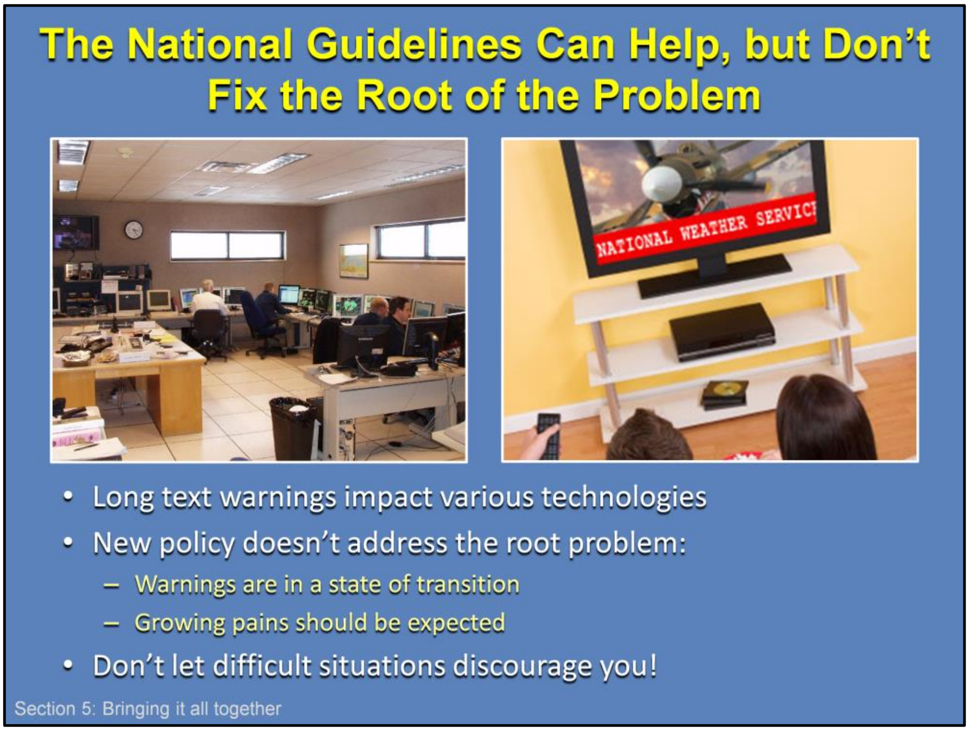
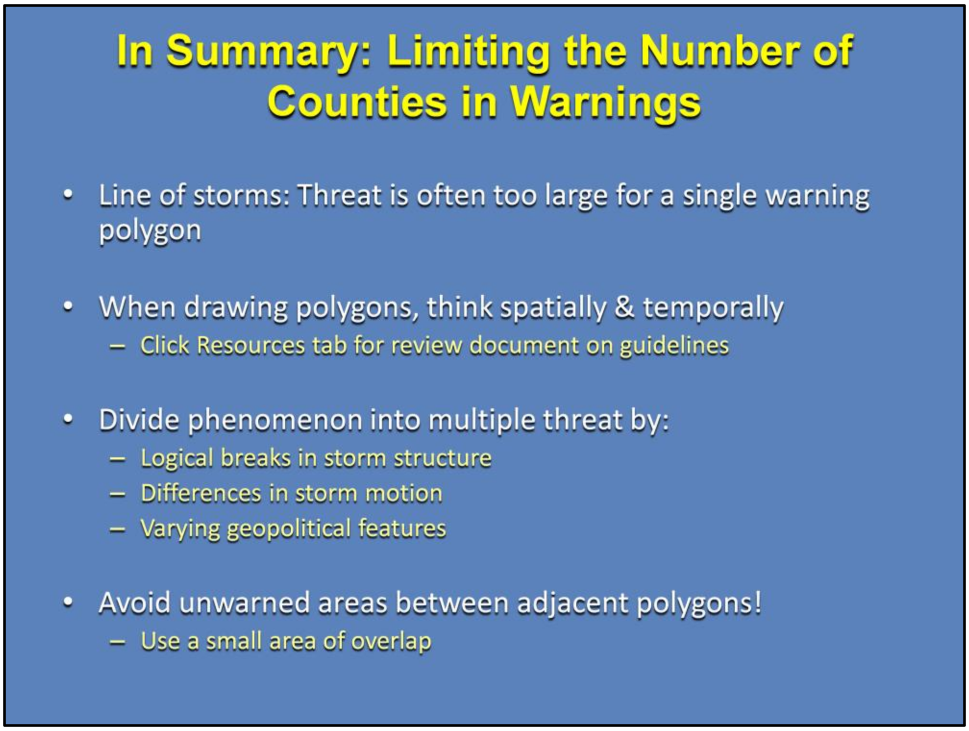


The 12 county maximum policy was written to help NWS forecasters provide good customer service. *[show 1st bullet]* Large polygons hamper technologies such as Specific Area Message Encoding, text crawls, and cell phones apps where users can customize NWS products to their local area. These same products can cause issues for older technologies like NOAA weather radio.

[show 2nd bullet] Even with this new policy, we haven't fully addressed the root problem. NWS warnings are in a state of transition. We need to support older tools such as NOAA weather radio while moving forward with newer technologies. Growing pains should be expected. Even the best warning solution may still seem awkward. *[show 3rd bullet]* Don't let these situations discourage you from providing the best service possible. Weather happens.



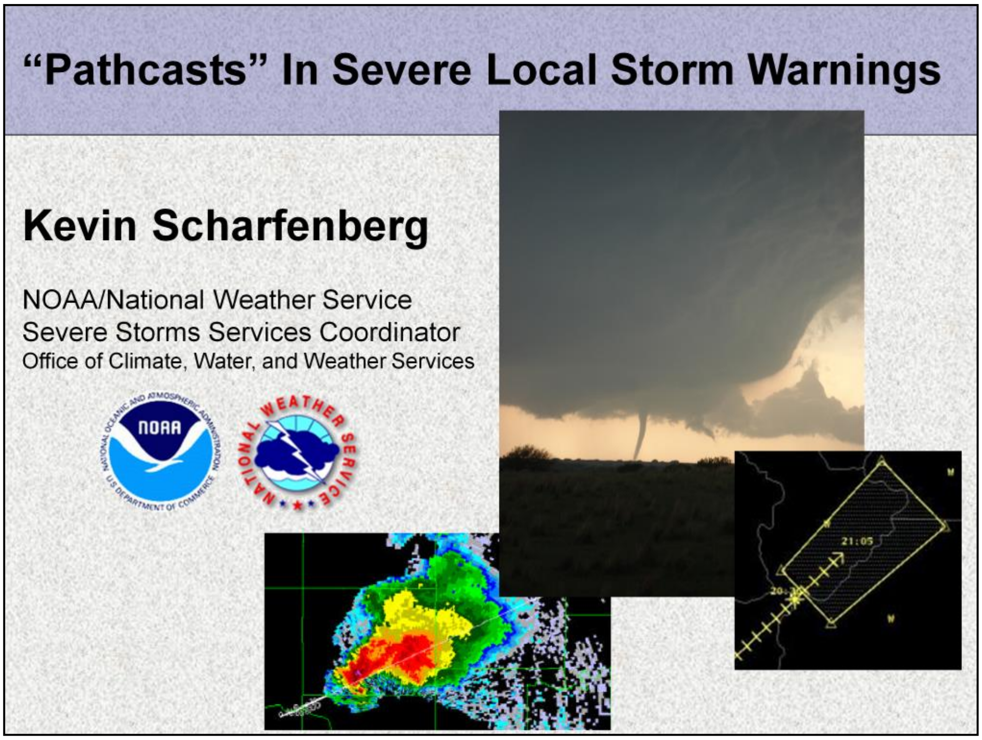
In summary, using the Line of Storms tool in WarnGen can result in warning polygons that exceed NWS national guidelines. *[show 1st bullet]* In these cases, the threat is simply too large for a single warning polygon.

[show 2nd bullet] When using the Line of Storms tool, it's important to think spatially and temporally. Novice forecasters often spend less time on the temporal factors on warning size even though they often result in the largest portion of the polygon's area. *[show sub-bullet]* Several guidelines were provided for using the Line of Storms tool depending on the average county sizes in your local area.

[show 3rd bullet] When dividing large phenomena into multiple threat areas, many times forecasters will intuitively know what to do. *[show sub-bullets]* When intuition fails, look for variations in storm structure, storm motion, and significant geopolitical features to identify logical breaks.

[show 4th bullet] Regardless of warning type, or how the warning is generated, adjacent warning polygons can result in some unwarned areas if forecasters aren't careful. *[show sub-bullet]* Avoid these unwarned areas by having a small area of overlap between the adjacent polygons.

Following these simple steps can help you know when multiple polygons are better than one for a specific threat.



Welcome to this informational seminar about the use of "Pathcasts" in severe local storm warnings. My name is Kevin Scharfenberg, and I'm working with the Office of Climate, Water, and Weather Services as NWS severe storms services coordinator. This presentation should last about 25 minutes.

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Outline

Objective:

➢ Be able to describe the error sources inherent to the creation of “pathcasts” in severe local storm warnings

- Verification/validation studies of “Pathcasts”
- Operational “best practice” recommendations

The objective of this course is to be able to describe the error sources a forecaster can expect to face when attempting to create a “pathcast” in a severe thunderstorm warning, tornado warning, or follow-up severe weather statement. First we will take a look at results from recent and ongoing research, and use those results to make some “best practice” recommendations for operations.

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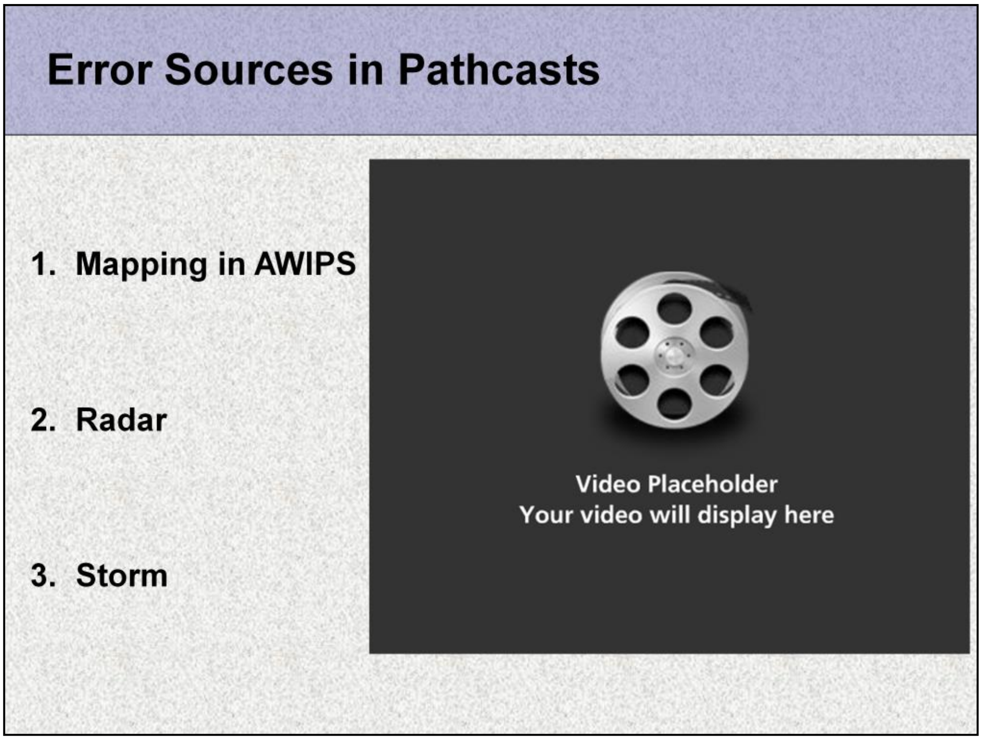
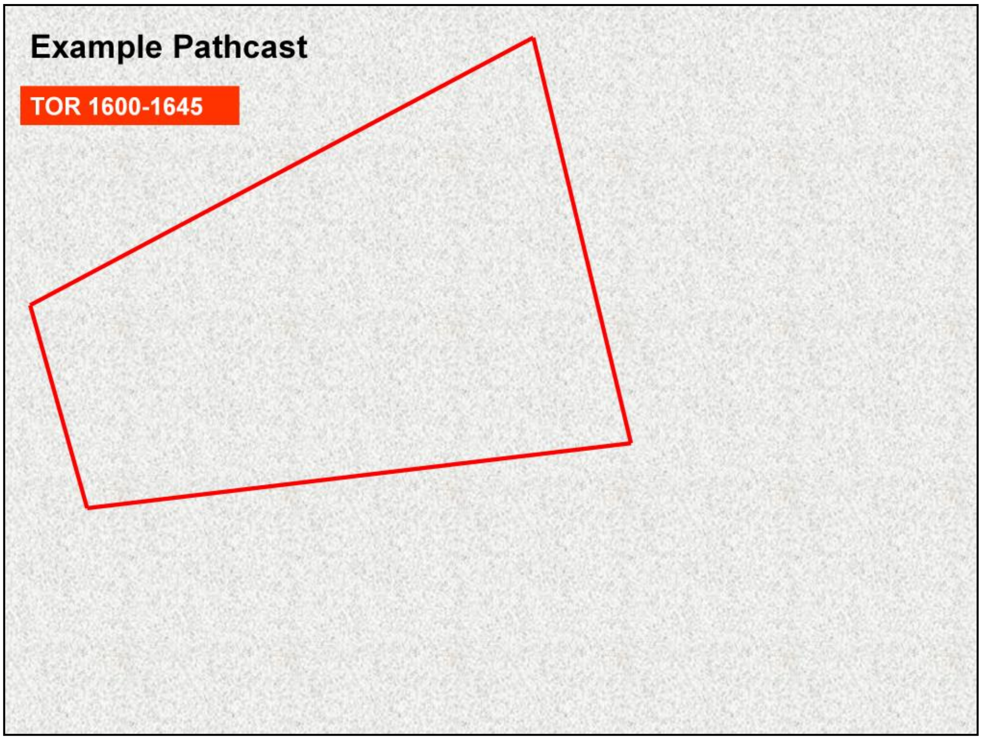


Studies have found there are three main error sources inherent to pathcasts. The first error source is in the way AWIPS handles maps. We have found that many cities, towns, and landmarks in AWIPS are simply in the wrong location. Some forecast offices have spent a great deal of time quality-controlling their location databases, and have had to make dozens of corrections. Even so, many locations are treated as a single point instead of areas, even some relatively large communities are treated as single points. We'll talk more about that in a minute. Finally, there are some implicit uncertainties in describing locations because AWIPS uses an 8-point compass, as well as 1-mile precision and 2-decimal place geocoordinate precision. The next major source of error is due to radar sampling. We know storms have some tilt with height, and in areas of poor low-level sampling that can turn out to be pretty significant. The strongest radar signature can be somewhat displaced from the area of greatest severe weather at the surface. Sometimes the radar data are not mapped absolutely perfectly, particularly far from the radar, and that can lead to small errors. The radar signatures may be mapped correctly, but beam-filling issues or messy and ambiguous signatures can lead to a lot of trouble figuring out where to put the “drag me to storm” dot. For example, a tornado is generally much smaller than the mesocyclone being sampled by radar, and it's not always in the center of the signature. Finally, storm processes can lead to significant errors when creating pathcasts. Warngen treats a pathcast as a linear extrapolation, but we know storms don't often work that way. Instead complex processes are often at work, including curving paths, occlusion of circulations, propagation, and so on. When these processes dominate, the skill of a pathcast can go out the window pretty quickly. Finally, we have to remember that warngen uses a single point to represent the storm, when really the severe weather threat we are trying to track can have a relatively large area associated with it.



Before we go any further, let's stop and take a look at how a pathcast is created by the warngen software. Suppose we have a tornado warning polygon that looks like this, and let's say it's in effect from 1600 to 1645.

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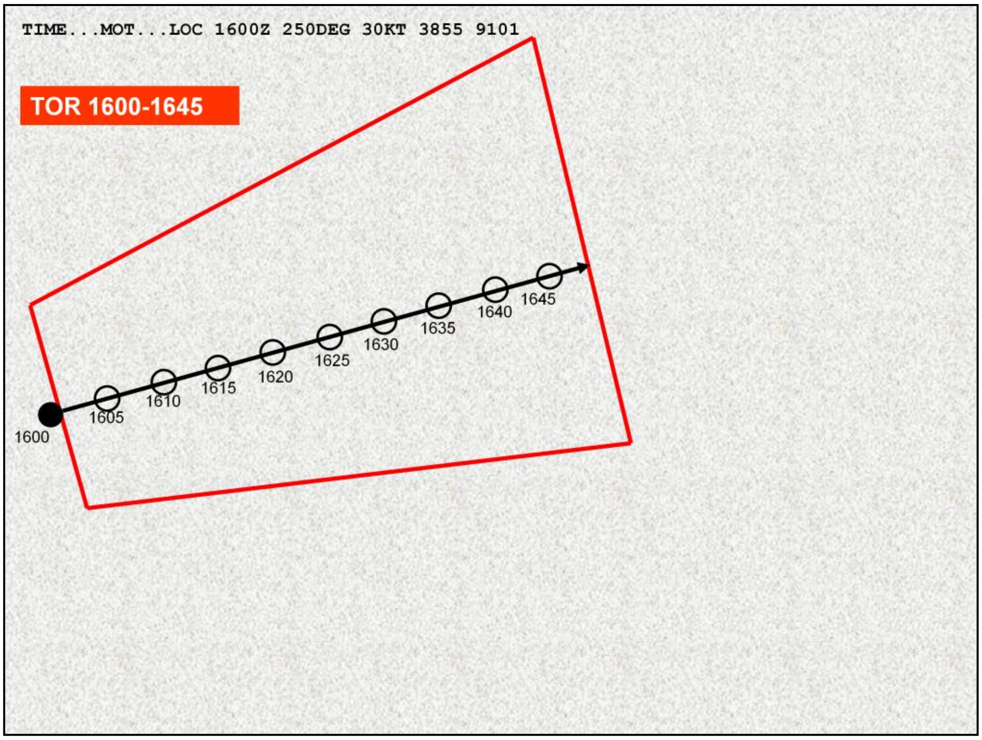
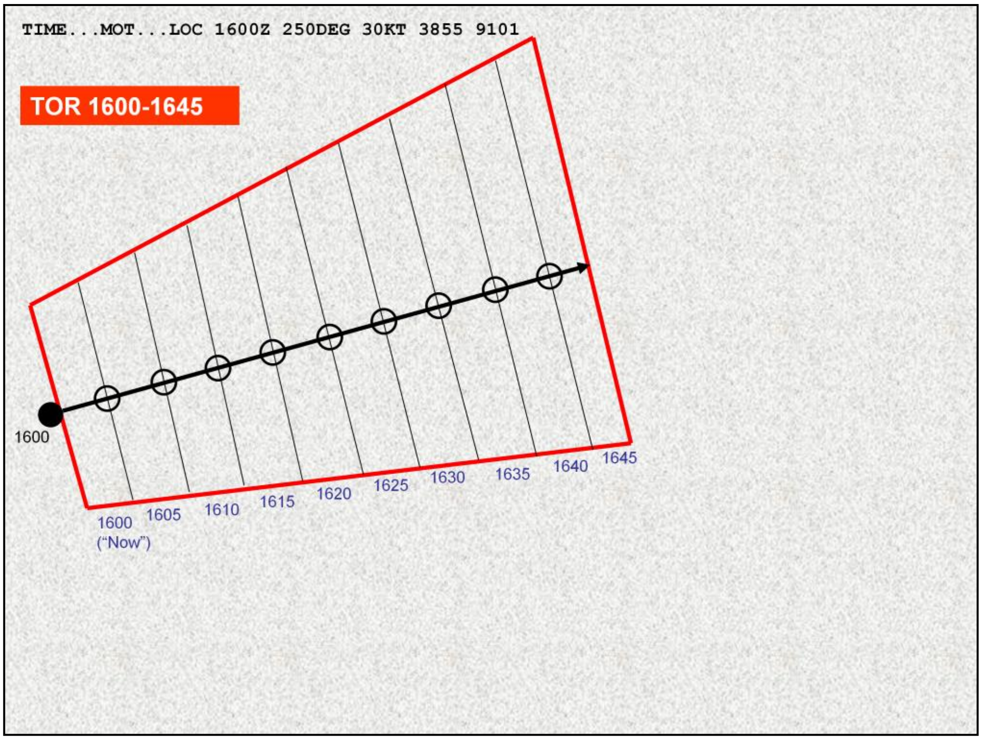
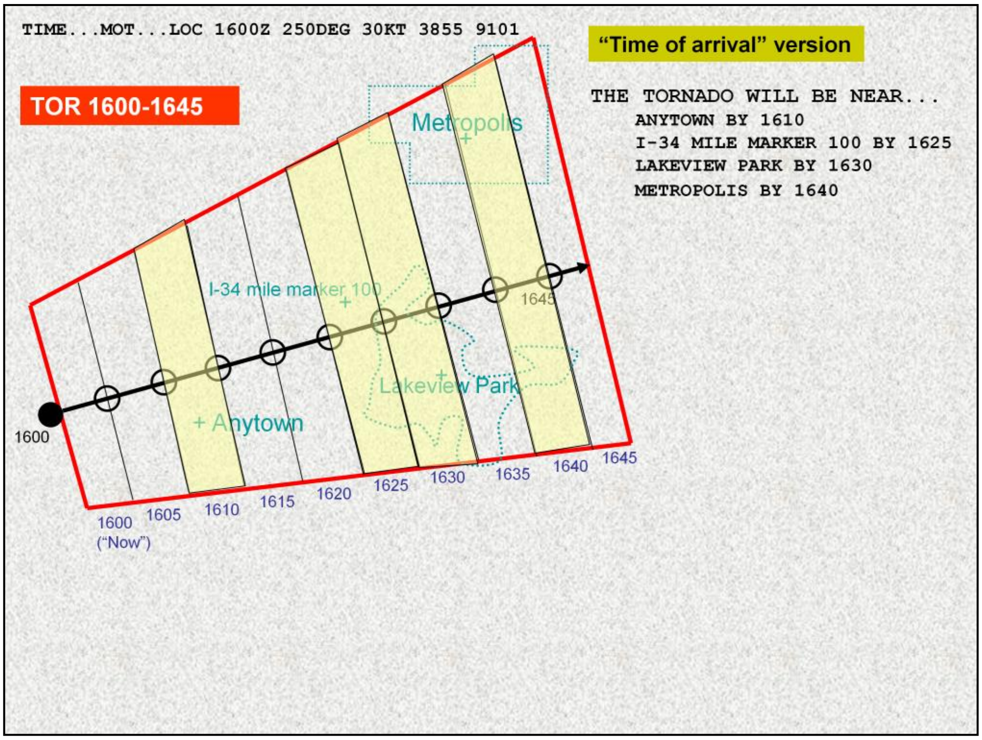


To create the warning, the forecaster drags the dot to a current storm location at 1600, then goes back a few volume scans and drags the dot back to an old location. This creates a linear extrapolated path, which goes out to the end of the warning time, in this case 45 minutes.



Next, the polygon is divided up into a bunch of skinny polygons normal to the path of the storm, corresponding to five minutes of storm motion. This is how the "time of arrival" is calculated. In the first upstream skinny polygon, the time of arrival is the current time, 1600. In the next skinny polygon downstream, it's 1605, and so on, to the most downstream polygon which in this case is 1645.



Now let's see how locations are determined. For locations that are treated as single points, which is the majority of locations, the time of arrival is simply the time of the skinny polygon that location is inside. In this example, the time of arrival for "Anytown" will be listed as 1610. The same goes for any point location, which might include any sort of landmark programmed into the map database, such as an interstate mile marker. Notice that we're treating metropolis and Lakeview Park as single points that get a single arrival time, even though those locations might have a large surface area. Warngen can be made to show a list of locations and times of arrival, and for the purposes of this presentation we will call this the "time of arrival" version of the pathcast.

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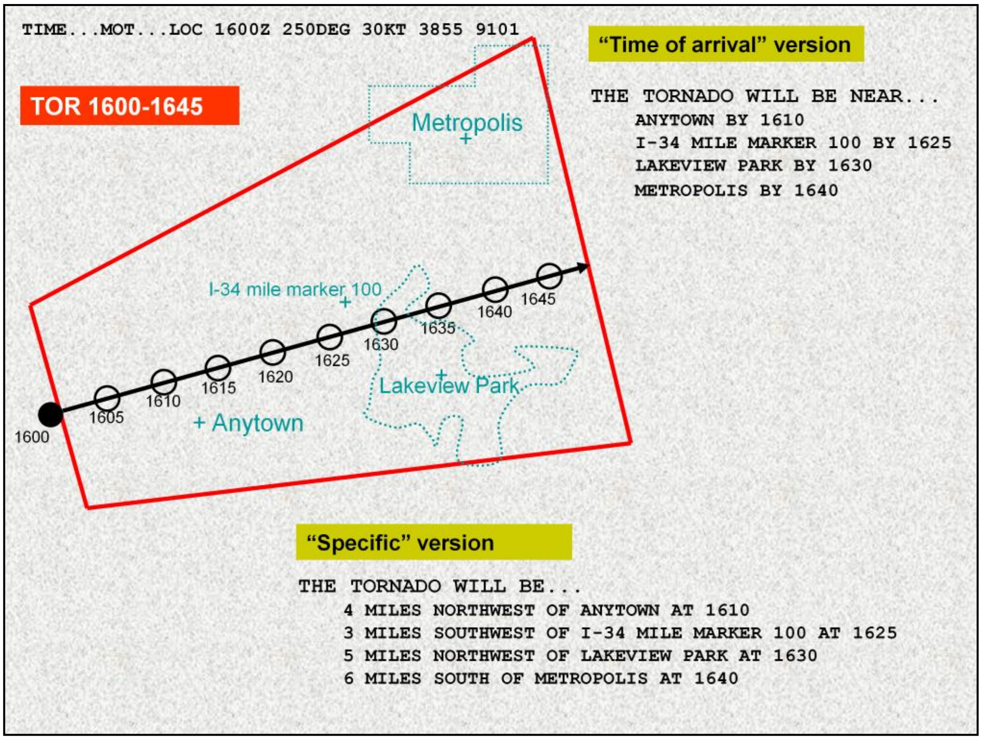

Depending on how warngen is configured, a "specific" version of the pathcast can be used instead. This version gives specific locations of the forecast storm centroid along with the times of arrival. In this example, warngen might output that the storm or tornado will be 4 miles northwest of Anytown at 1610, 3 miles southwest of the interstate mile marker at 1625, and so on. Next, we will discuss reasons why this version of the pathcast should not be used operationally.

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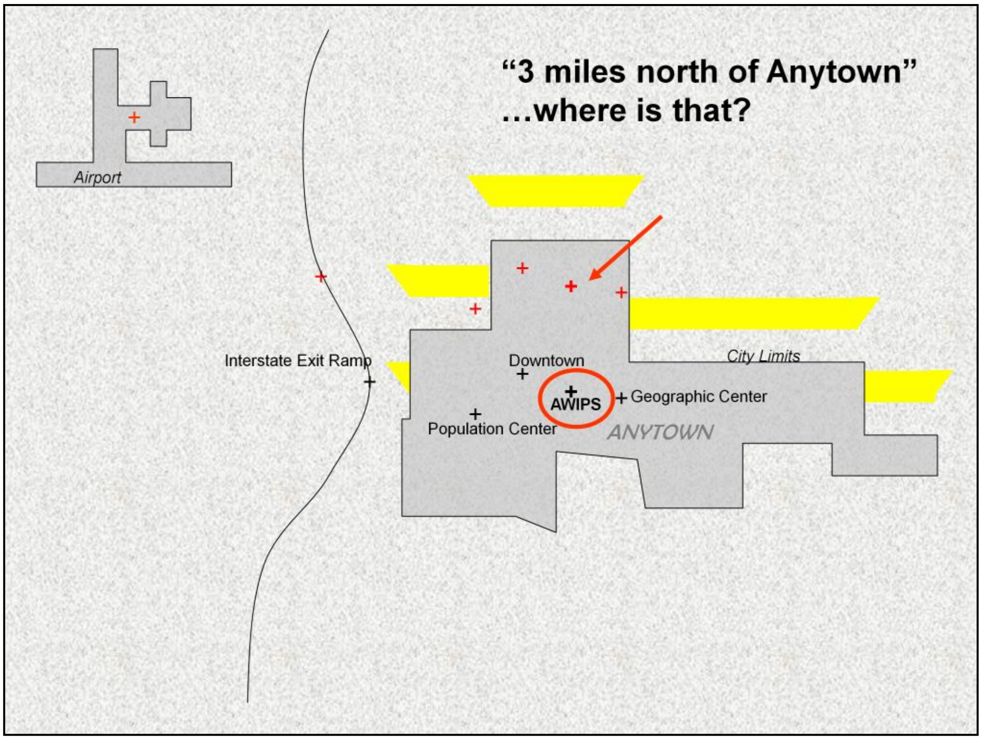
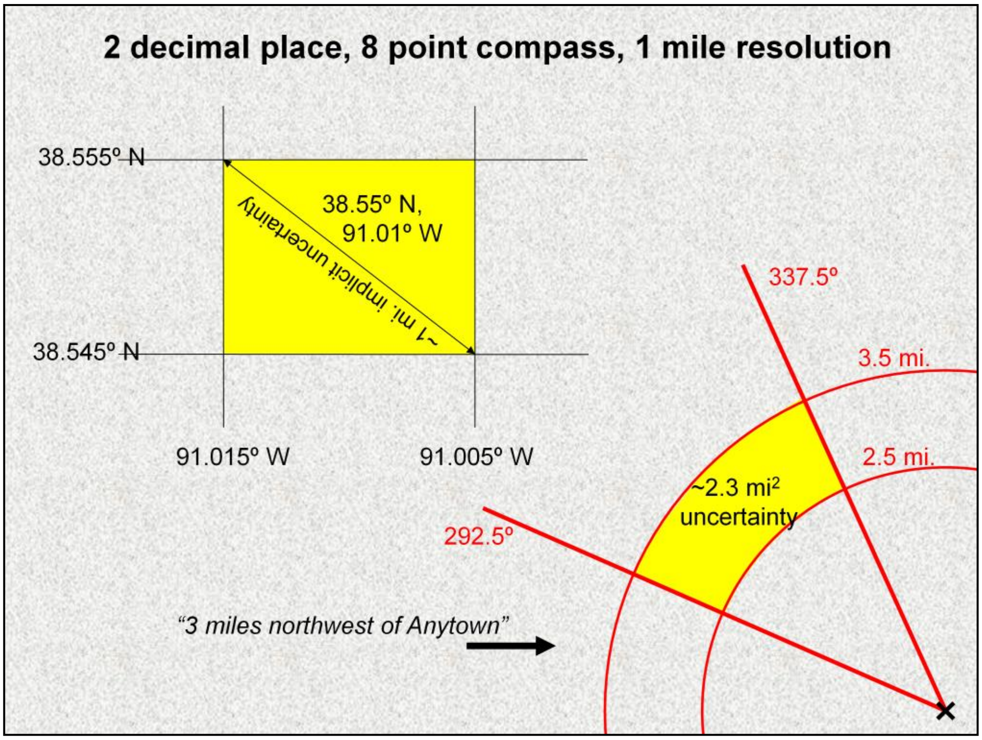


When reading a "specific" pathcast, one question that might come to mind right away is: what exactly does "3 miles north of Anytown" mean, anyway? Now those of us with an AWIPS workstation can see where the point for "anytown" is located and measure out the location 3 miles to the north, but our end-users don't have access to the AWIPS location. They may think it refers to the population center, the geographic center, or the downtown. Some end-users might even think it refers to the location 3 miles north of the town's highway exit ramp, or 3 miles north of the airport because that's where the weather station is often located. Many others can perceive it to mean 3 miles north of the city limits, which could be any of the yellow area on this example map.



Another source of mapping error is due to the uncertainty associated with AWIPS precision in describing geocoordinates. Since AWIPS only uses 2 decimal places for latitude and longitude in warngen, we know we are not actually describing a point on earth's surface, but a two-dimensional area with four sides. In most of North America, that automatically implies about 1 mile of location uncertainty in the diagonal direction. Another source of mapping uncertainty is due to the 8-point compass and 1 mile precision used in warngen calculations. Because of this, the description "3 miles northwest of anytown" actually describes a possible area on earth's surface about 2.3 square miles in size. Obviously if we were to say "7 miles northwest of anytown" that describes a possible surface area that is even larger.

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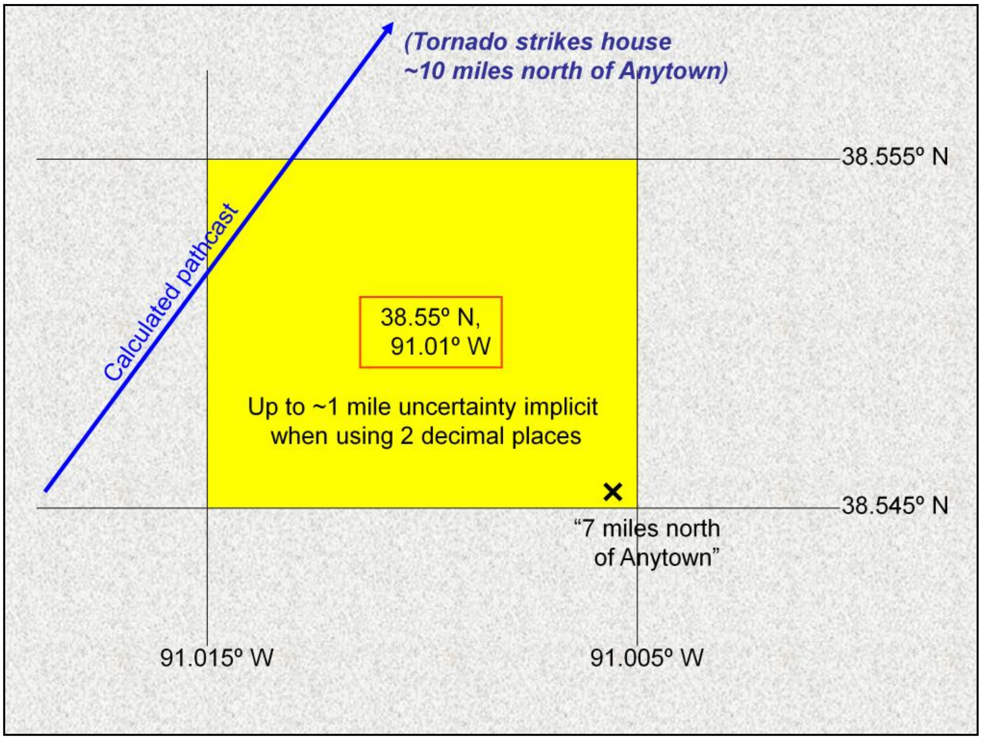

Here is an example of how these mapping errors can cause problems, even with a perfectly accurate pathcast. Let's suppose warngen calculates a tornado pathcast along the blue line and the forecaster chooses to include a "specific" pathcast in the warning. Warngen takes the projected tornado path to the coordinates 38.55 north, 91.01 west, and let's suppose that AWIPS interprets that location to be 7 miles north of Anytown. In reality, the pathcast clipped the northwest corner of that latitude-longitude box, and the actual AWIPS location of 7 miles north of Anytown is more toward the southeast corner of the same latitude-longitude box, about a mile away. Even if the tornado ended up moving right down the blue line, it could end up striking a house located more like ten miles north of town. You can see how the wording "7 miles north of anytown" can cause a lot of confusion in this case, even for a perfect pathcast, because of the way we handle maps.

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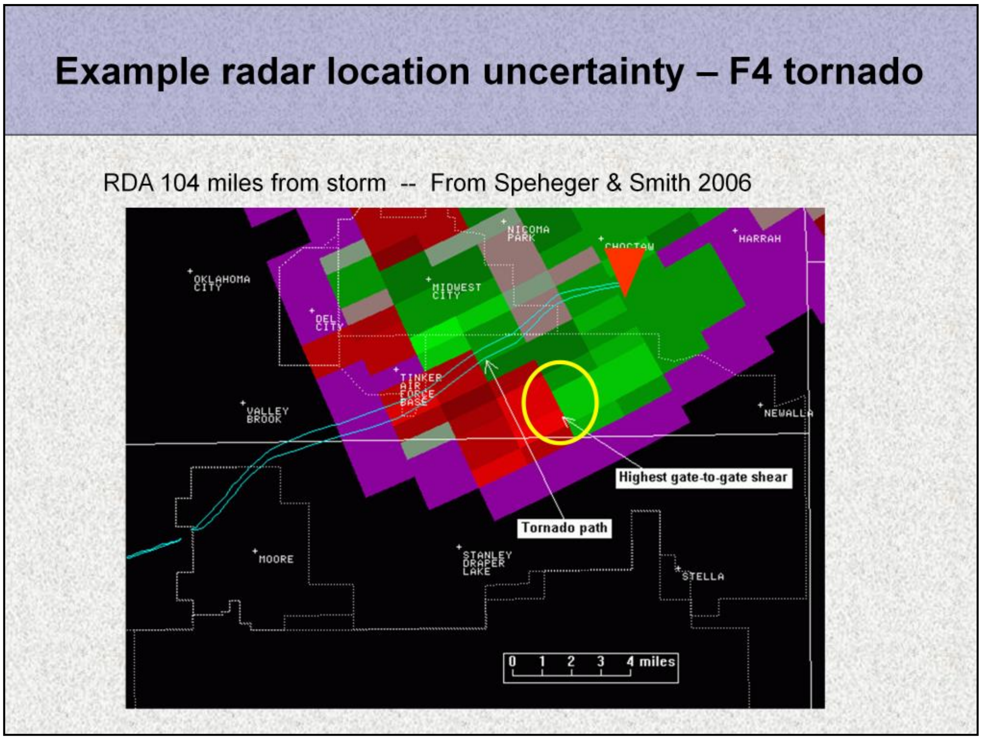
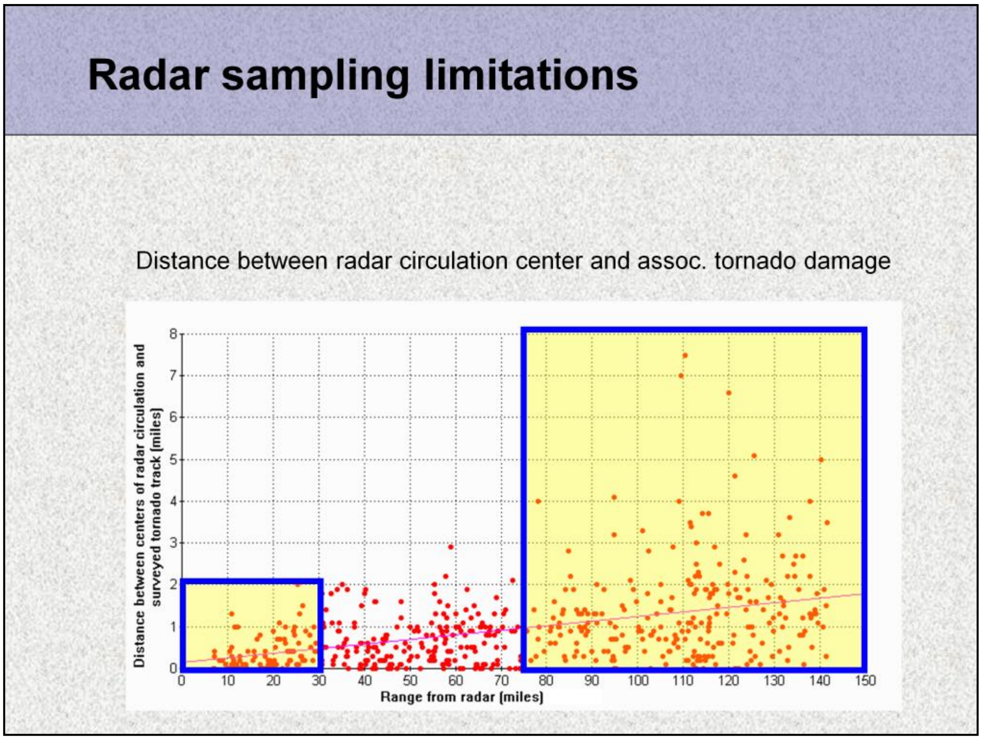


Next we'll move on to the second major error source associated with pathcasts, and that involves radar sampling. This image from a paper by Doug Speheger and Rick Smith is a good example of a case where the severe weather at the surface was displaced from the best radar signature. This storm was producing an F4 tornado at the time of the image, at a range of approximately 104 miles from the RDA. The tornado damage path is within the blue contours, and the tornado at this time was located near the tip of the error marked "tornado path". From the radar's perspective, however, the highest gate-to-gate shear was displaced several miles to the southeast of the tornado. In this case the mesocyclone was fairly large, there was storm tilt with height, and the tornado was occluded back in the northwest part of the circulation. You can see how creating a warning with a "specific" pathcast at this moment might create warning text that says the tornado will pass well south of the town of Harrah, when in reality the ongoing violent tornado is aimed right for Harrah.



Speheger and Smith (2006) repeated this process for a lot of tornadoes, measuring the distance between the location of the tornado and the location of the strongest gate-to-gate shear. They found that even with tornadoes happening within 30 miles of the radar, the best shear signature is often displaced one to two miles away from the actual surface tornado damage location. For events farther from the radar, beyond 75 miles, the error can range from 3 miles to 6 miles or even more.

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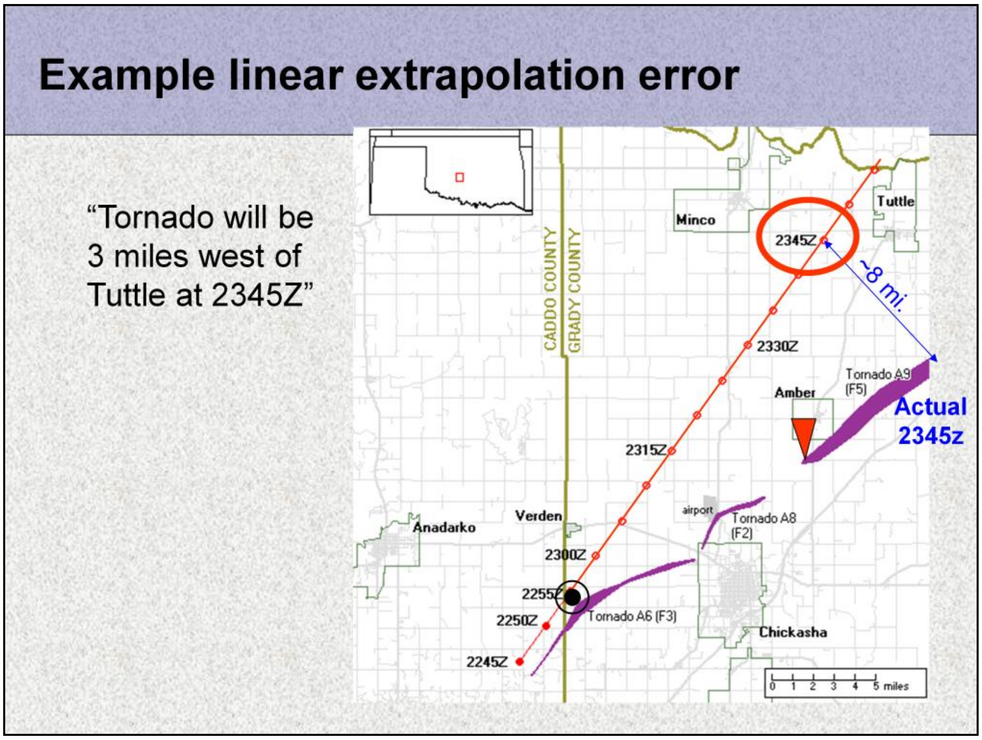

Our third and final major source of pathcast error is due to non-linear storm processes. In this example, the storm is about 50 miles from the nearest radar and showing very strong and clear signatures. Suppose we're issuing a tornado warning for a storm at 2255 UTC located near the southwest part of this map. In Warngen we would drag the dot to the 2255 UTC location of strongest shear, then go back a couple of volume scans and drag the dot back to the 2245 UTC location. This would create a linear path represented by the solid red line, and extrapolated locations shown by open red circles at 5 minute intervals downstream. Note in this case that the signature was offset by about one mile to the northwest of the damage path, which is shown in purple. Let's suppose we ran our tornado warning out to 2345 UTC, and we used the "specific" version of the pathcast. This would probably cause warngen to create text that said "the tornado will be 3 miles west of Tuttle at 2345". In reality, just after we created the warning, the storm took a subtle turn to the right, at about an angle of 10 to 15 degrees. The resulting F5 tornado at 2345 UTC was actually located well south-southeast of Tuttle, about 8 miles from the original extrapolated path. These sorts of errors were observed many times in the verification of pathcasts issued by the NWS.

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Error Sources in Pathcasts

Mapping in AWIPS - **observed to be 3+ miles in some cases**
- City/town/landmark location error
- Treating most locations as single points instead of areas
- 8-point compass, 1 mile, 2 decimal place lat/lon uncertainty

Radar - **observed to be 3+ miles in some cases**
- Storm tilt / poor low-level sampling
- Radar data mapping errors
- Radar beam-filling issues (large mesocyclone, small tornado)
- Messy/ambiguous signatures

Storm - **observed to be 3+ miles in some cases**
- Cyclic occlusion processes, curving paths, acceleration (deceleration)
- Discrete propagation, boundary collisions, etc.
- The storm is not a single "point"

→Preliminary study results: errors of 5-10 miles/minutes are <u>frequently</u> observed in Pathcasts!

Looking at our detailed list of error sources in pathcasts, we have seen in ongoing verification and validation studies that each error source can be independently responsible for errors of 3 or more miles. In a worst case scenario, they may add up to 9 or 10 miles. As a matter of fact, we've found that errors of 5 miles or so are quite frequent in "specific" pathcasts, and 10 miles are not unheard of. For a storm moving at 60 miles per hour, that can correspond to errors of 5 to 10 minutes when forecasting the time of arrival.

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Problems with Interpreting Pathcasts

The "skinny black line" issue:

- *Which is the warning: the pathcast or the polygon?*
- Invites users to focus on an exact storm path forecast?
- Minimizes the threat elsewhere in the warning polygon?

Communication barriers:

- Where is "6 miles south of Metropolis?"
- "Lakeview Park" is a big place!
- Am I safe until the time in the Pathcast? Safe afterwards?
- I'm south of Anytown and NWS says the tornado will be north of Anytown, so I must be safe

Can imply forecast precision we do not have!

In addition to the quantitative errors that can be associated with pathcasts, there is some concern about the end-user interpretations of pathcasts. First, in hurricane forecasts, there is something we call the "skinny black line" issue. The famous hurricane track forecast maps show both a thin black line that represents the forecaster's best track forecast of the eye of the storm, and also a "cone of uncertainty" representing the area the hurricane might track. We want all the people in the cone of uncertainty and warning to be taking action, regardless of the exact path forecast of the hurricane's eye. The same issue comes into play when pathcasts are issued in severe local storm warnings. There is a similar concern that including the path forecast invites users to focus on the skinny black line of the pathcast when really we want everyone in the warning polygon to be taking action. There is also a concern that communications barriers exist when trying to convey pathcast information in text and in audio broadcasts. For example, saying a tornado will be 3 miles north of Anytown might convey that people in the town itself and south of town are safe, even if they are in the polygon. Also, we don't have good information about how people use exact timing information included with some warnings. The important thing to remember is that by including exact times and locations we run the risk of implying forecast precision we do not have.

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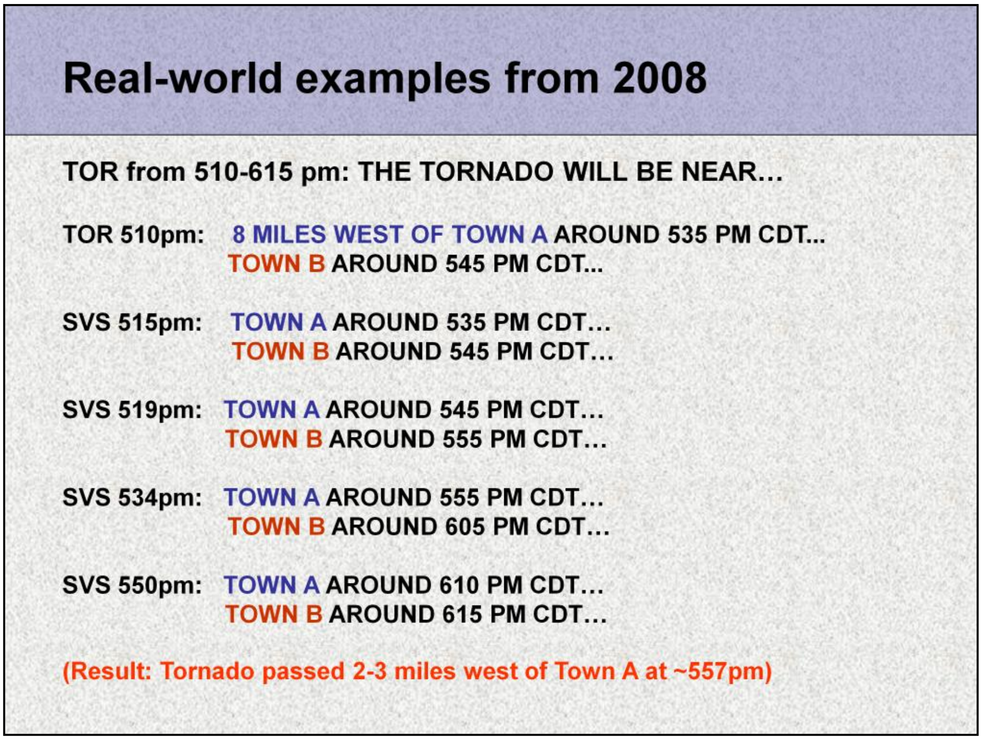

The following slides show a few examples of pathcasts issued operationally in 2008. In this example a tornado warning was issued at 5:10 pm effective until 6:15 pm. Note that's 65 minutes is considered too long for most tornado warnings, we recommend limiting the valid time of tornado warnings to 30 to 45 minutes. Now this supercell thunderstorm was about 60 to 70 miles from the radar with relatively strong signatures. The initial tornado warning state the tornado would pass 8 miles west of town A, but the follow-up severe weather statement 5 minutes later just said "Town A". Then the next SVS a few minutes later changed the times of arrival by 10 minutes. The next SVS 15 minutes later changed the times again, and finally the last SVS issued at 5:50 pm extended the times of arrival even more, so that over 40 minutes of warnings, four different times of arrival were stated for each town and they changed by a total of 30-35 minutes. It turns out a tornado passed a few miles west of town A at about 5:57 pm, so you can see that the last SVS issued was actually less skillful than the one issued at 5:34 pm. This example shows that even time of arrival information can be very unstable when going through the pathcast creation process several times in quick succession.

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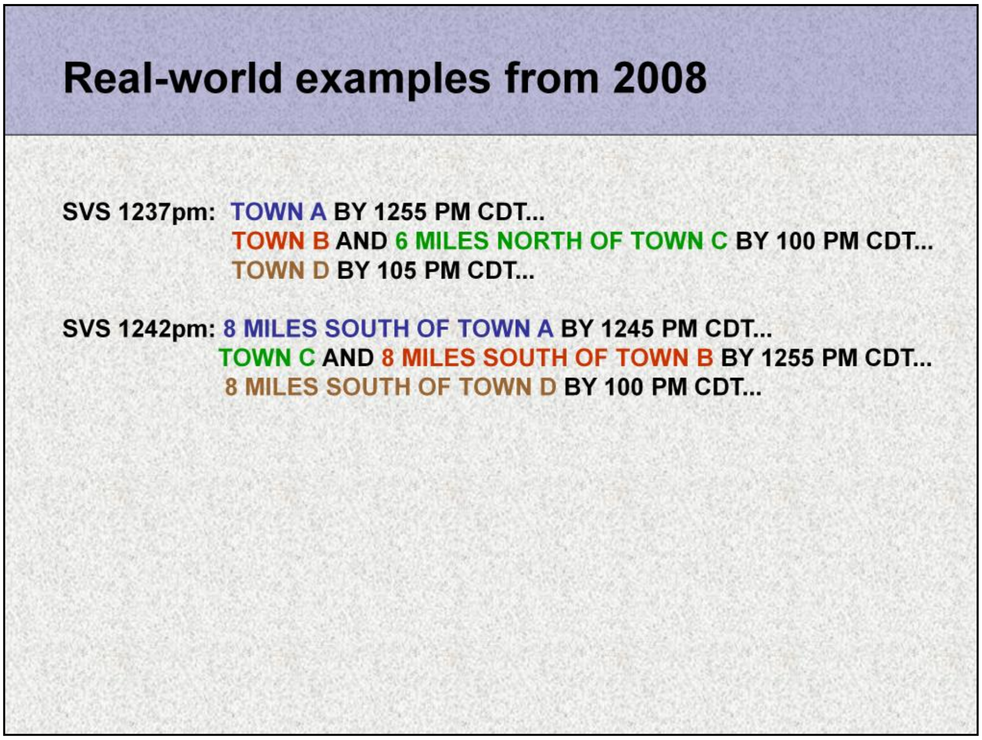


Here’s another example from 2008, of a couple of severe weather statements issued 5 minutes apart as follow-up to a tornado warning. In this case, in just one volume scan all 4 locations and all 3 times changed radically. This again shows how unstable the results can be when repeating the pathcast process.

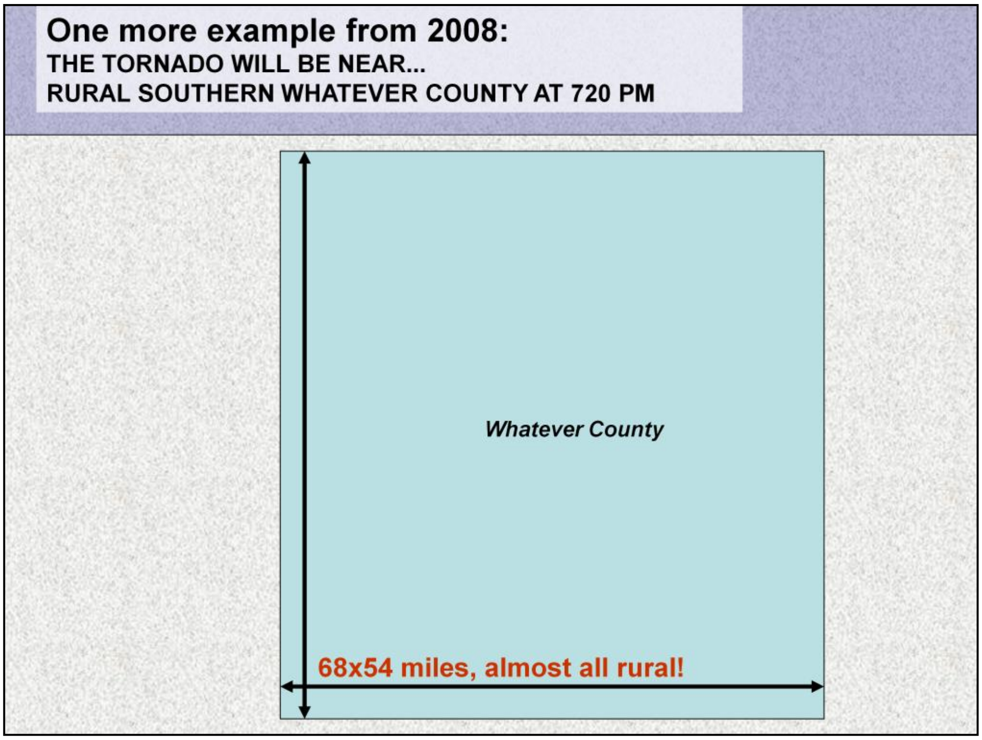
Real-world examples from 2008

SVS 553pm:

Radar-indicated tornado located "NEAR TOWN A"
will be "8 MILES NORTHWEST OF TOWN B BY 615 PM."

Tornado was actually located ~6 miles southeast of Town A at the time and passed ~2 miles south of Town B at ~618 pm.

Here is another example severe weather statement in 2008 associated with a violent tornado event. The initial location in the basis statement of the warning said the tornado was near Town A, and would be 8 miles northwest of town B in 22 minutes. The forecaster didn't know it at the time but the tornado was ongoing at the time this statement was issued, but was actually 6 miles southeast of Town A. It passed just south of town B 25 minutes later. As it turns out the forecaster was using the "specific" version of the pathcast despite the fact the radar signatures were quite messy and the storm was far from the radar. This shows how errors can be large even at the initial time step, and can grow very quickly during the forecast period.



One final example from 2008. In this case the warngen-created wording in the pathcast was “the tornado will be near rural southern whatever county at 7:20 pm” but that makes little sense when you consider the county is 68 miles tall by 54 miles across, and almost entirely rural. In this case the software was asked to create pathcast wording but the polygon did not intercept any landmarks, so some rather ridiculous wording ended up being created and transmitted.

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Recommendations

- **Do not use** “specific” pathcasts (“the storm/tornado will be 5 miles south of Anytown at 345 pm”) – science and software do not yet validate this method, plus communication barriers
- **Avoid using** “time of arrival” version of pathcasts unless there is unusually high confidence in location and movement vector of the threat
- **Educate** users & stakeholders – ALL locations in the warning are under threat and should be taking precautions

The Next Generation Warning Tool team is working with software developers toward improved tools for communicating “time of arrival” and “greatest threat” information.

Based on this research, here are a few “best practice” recommendations for operations. First, do not use the specific version of pathcasts, such as stating in warnings the tornado will end up 5 miles south of Anytown at 345 pm. The science does not validate this approach is yet possible, and the software does not yet take into account the necessary uncertainty. In addition, there is great concern that end-users are not interpreting this sort of information properly. Second, it’s generally a good idea to avoid using “time of arrival” pathcast functionality, except in unusual situations where you are very confident about the location and movement vector of the threat, and nonlinear processes seem to be minor. But again, generally it’s best just to leave it out. Finally, and most importantly, we need to reinforce to users and stakeholders that ALL locations in the warning are considered to be threatened and everyone inside the polygon should be taking immediate precautionary action, regardless of any times and specific locations listed. It should be noted that the next generation warning tool team is working with software developers and social scientists to improve the software in AWIPS II so that we can perhaps have some better tools to convey time of arrival and greatest threat area information.

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Thanks for listening!

Questions and discussion?

Contact: Kevin.Scharfenberg@noaa.gov

References:

Speheger, D. A., and R. D. Smith, 2006: On the Imprecision of Radar Signature Locations and Storm Path Forecasts. *Natl. Wea. Dig.*, **30**, 3-10. Available at http://www.spegweb.com/papers/radar/

Scharfenberg, K. A., D. Speheger, A. R. Dean, K. L. Ortega, and K. L. Manross, 2009: Operational forecasting of tornado locations: a verification study of “pathcasts”. *Preprints, 23rd Conf. on Wea. Analysis and Forecasting,* Amer. Meteor. Soc., Omaha, NE.

This concludes the informational seminar on pathcasts in severe local storm warnings. Thanks for taking a look. If you have any comments or questions please be in touch, again my name is Kevin Scharfenberg and my e-mail address is there on the screen.

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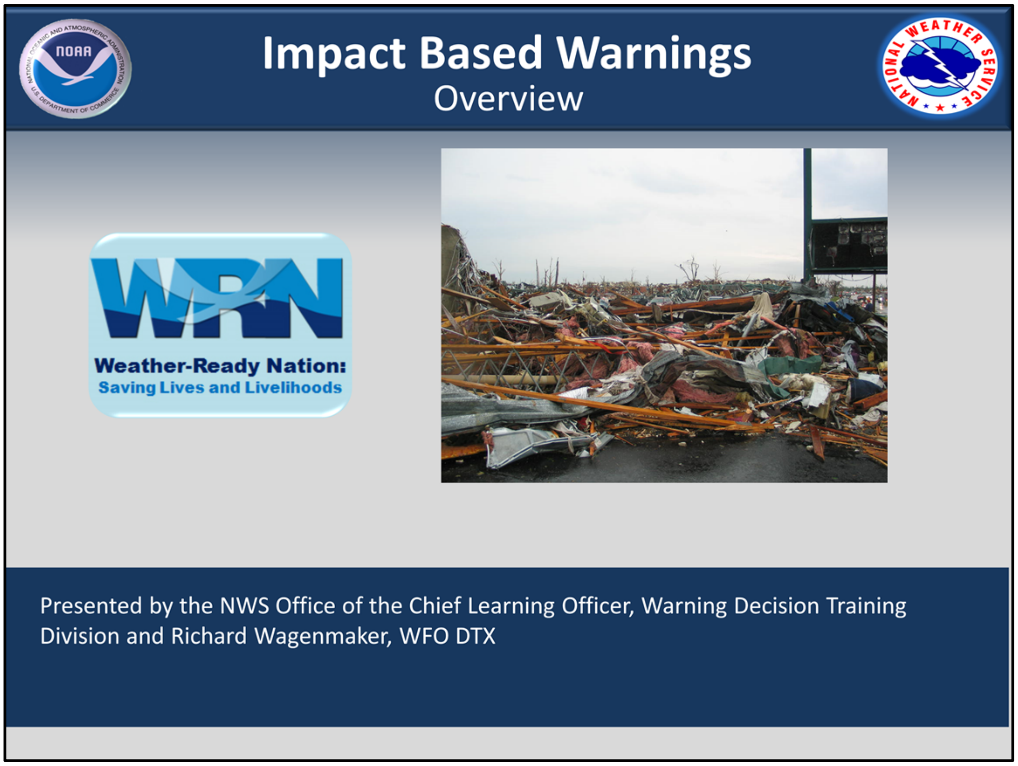

Hello. This is Brad Grant of the Warning Decision Training Division of the Office of the Chief Learning Officer. This is a 2-part course on Impact Based Warnings, or IBW. The first part of the course is intended to be an overview of IBW to help NWS warning forecasters become more familiar with the updated warning practices brought about by the implementation of IBW. You will be hearing from Dick Wagenmaker, MIC of NWS DTX who has been one of the leaders for the IBW demonstration project, first started in Central Region.

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IBW
Learning Objectives

1. Be able to explain to NWS customers and partners the 3 key rationale driving the move toward IBW .
2. Be able to identify and effectively select in warning situations the correct IBW impact damage statements that can be selected for various warning situations .
3. Be able to correctly use the issuance criteria for damage threat tags for tornado warnings especially considerable and catastrophic.
4. Be able to analyze the four principal inputs in IBW warning decision methodology to better anticipate the most intense and damaging tornadic events.
5. Be able to effectively use the latest research showing the conditional relationships of STP and Vrot with tornado intensity.

These are the learning objectives for the IBW Course: Be able to explain to NWS customers and partners the 3 key rationale driving the move toward IBW.

Be able to identify and effectively select in warning situations the correct IBW impact damage statements that can be selected for various warning situations.

Be able to correctly use the issuance criteria for damage threat tags for tornado warnings especially considerable and catastrophic.

Be able to analyze the four principal inputs in IBW warning decision methodology to better anticipate the most intense and damaging tornadic events.

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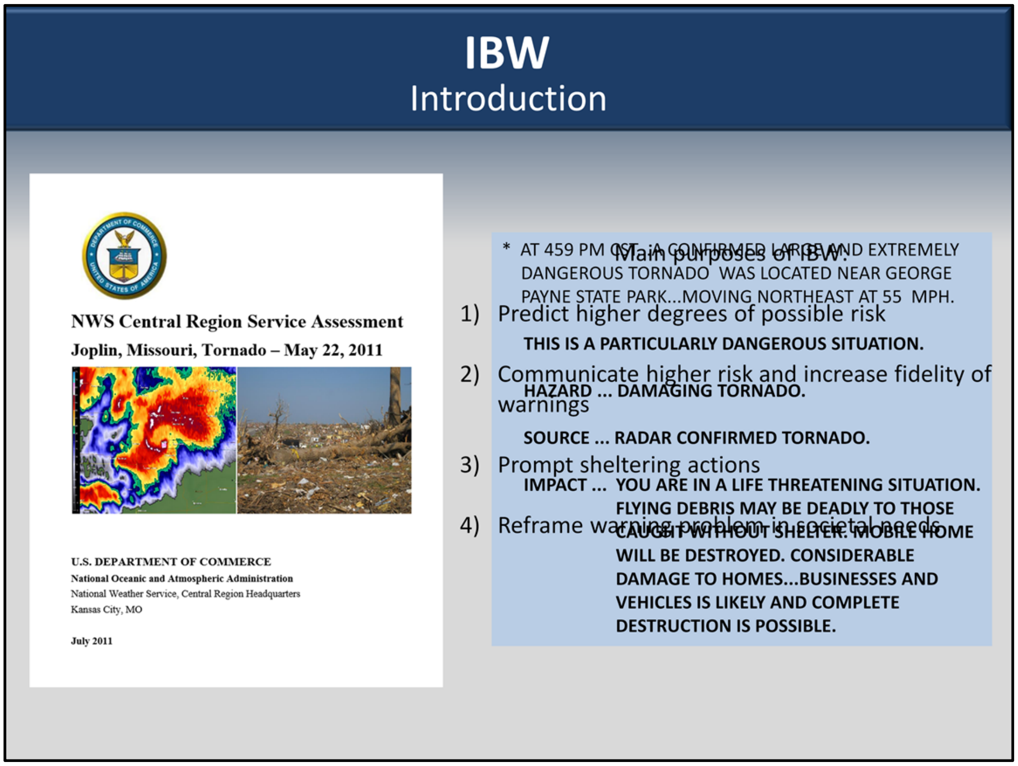

Hi. This is Dick Wagenmaker of NWS WFO DTX. Welcome to this introduction and overview of the Impact Based Warning training course. As most of you know, the content and construct of our severe weather warnings have changed little in 50 years. Following the tornado disasters in the spring of 2011, the Joplin, MO Tornado Service Assessment used its findings to propose exploring an evolution of the existing NWS warning system to facilitate improved public response and decision making in the most life-threatening weather events. IBW is intended to be a simple incremental first step in the evolution of these warnings to provide a better service. This is not an evolutionary leap. Since the initial proposals, noteworthy progress in both research and operational aspects of NWS tornado warnings have led to spirited debate in order to improve the utility of our warnings.

Essentially, IBW is a “risk-based” approach designed to 1) predict higher degrees of risk when possible (like any other type of warning); 2) communicate higher risk and increase the fidelity of warnings by telling people what we know; 3) prompt sheltering actions by adding emphasis for the most life-threatening weather events; and 4) reframe the warning problem in terms of societal needs.

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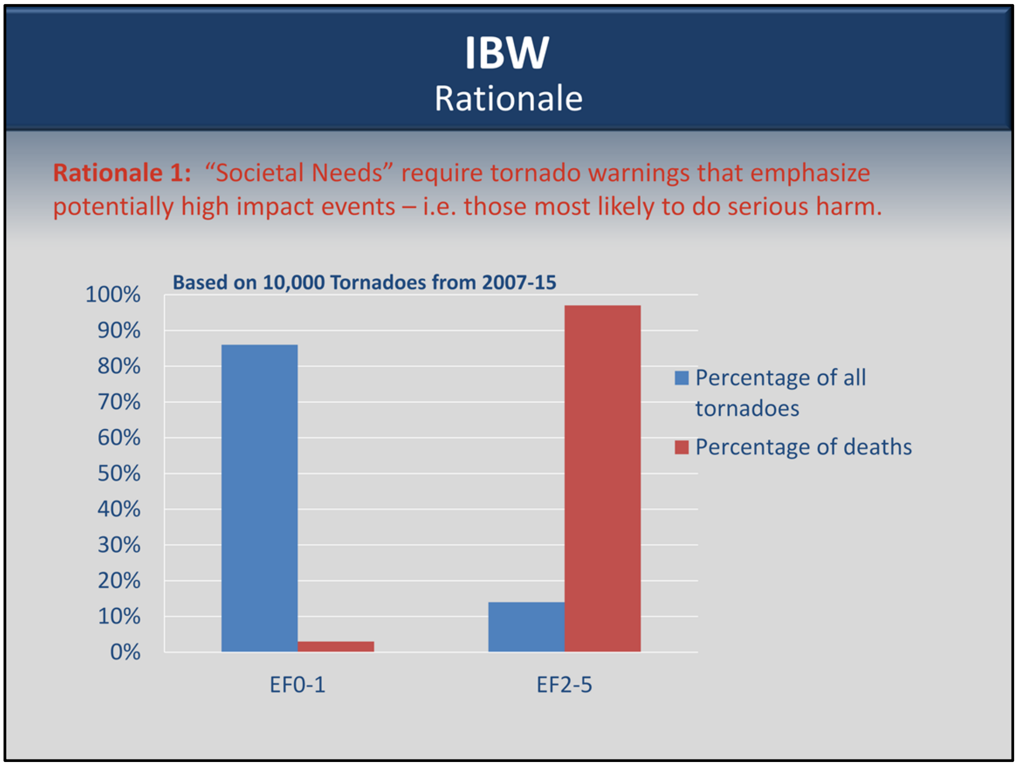

What is meant by reframing the warning problem in terms of societal needs is rationale number 1: That the public as a whole require tornado warnings that highlight events that have the most potential to do serious harm. It is important to note here that, yes, all tornadoes are dangerous - as are all severe thunderstorms - and the IBW project does not imply otherwise. However, the numbers supporting risk-based warning concepts are compelling. Nationally, over the most recent 8 year period, which included over 10,000 tornadoes, just 14% were rated EF2-5… but these result in 97% of the fatalities. Contrast that with EF0-1 tornadoes which constitute 86% of all tornadoes, but only 3% of the fatalities. Only 2 fatalities resulted from a very large number of EF0’s, suggesting a mortality rate for weak tornadoes is roughly equivalent to the mortality rate from severe thunderstorm winds. Clearly, while all tornadoes are dangerous to degrees, all tornadoes are not the same. And based on mortality, there is a clear societal need for tornado warnings that emphasize potential high impact events. Over the past two decades much of the research in this field has focused largely on the tornadogenesis problem and distinguishing tornadic storms from non-tornadic storms. IBW simply tries to reframe the warning problem into better distinguishing strong tornadoes from weak tornadoes; thereby correcting what many view as a flaw in the legacy tornado warning paradigm , and one that leaves the public exposed to the dangers of high end tornadoes.

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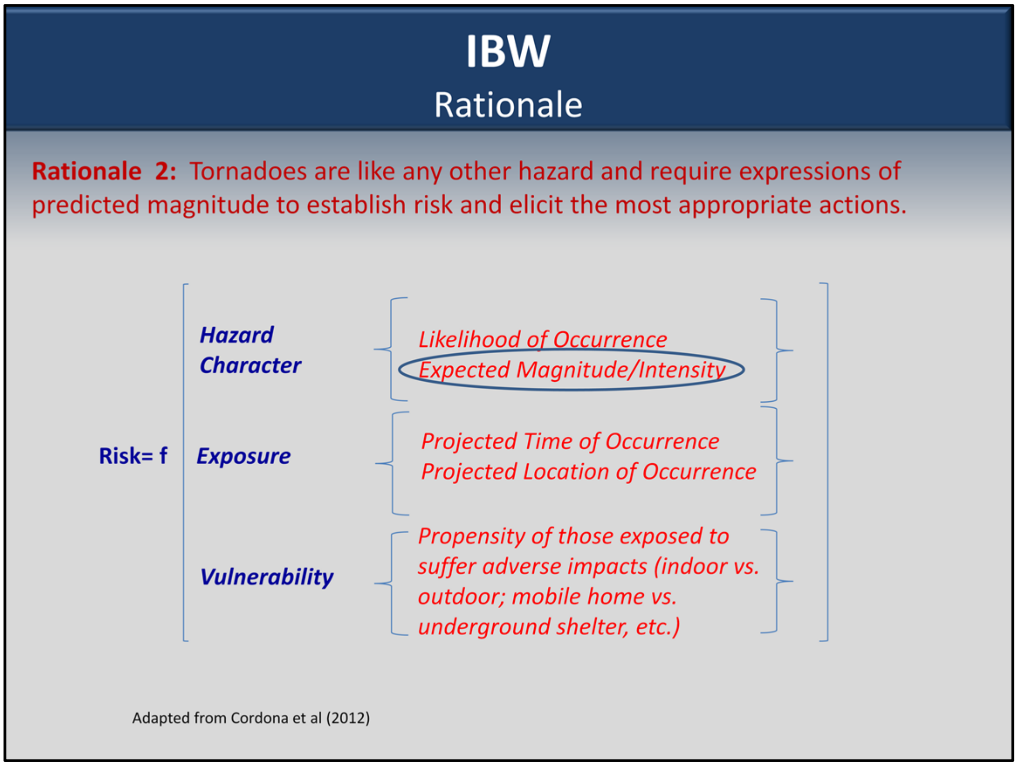

Following on these ideas, the second rationale for conducting the IBW project is to help provide clarity on risk assessment for users of our warnings. At the beginning of IBW, project social scientists surveyed Emergency Management personnel in Kansas and Missouri concerning risk communication. Their response was that knowing the potential intensity or magnitude of the tornado was an important factor in helping them determine a course of action. This makes obvious sense. What if we issued a flood warning for the Red River in Fargo, but refused to say how high above flood stage the river would get? Or, if we predicted hurricane landfall without offering max wind speeds or storm surge; or if we forecasted fog at a major airport without providing an expected visibility. We could on and on with examples. (Click) On this slide the simple risk paradigm adapted from Cordona et al. (2012) provides a summary of the basic information people need to assess their personal risk from any weather hazard. In this model, risk is expressed as a function of hazard character, exposure to the hazard, and vulnerability to the hazard. From the point of view of those issuing warnings, this includes identifying the likelihood of the hazard, the magnitude of the hazard, the expected time of occurrence, and the expected location of the hazard. The missing piece of the risk paradigm in tornado warnings is information on hazard magnitude. Rationale #2 is that tornadoes are like any other hazard and require expressions of magnitude to establish a level of risk and elicit the most appropriate actions. This should especially resonate given the huge differences in mortality between strong tornadoes and weak tornadoes.

IBW

Rationale

Rationale 3: Clear and credible risk communication is necessary for people to take immediate protective action.

Key findings from 2013 National Institute Standards and Technology (NIST) Report on the Joplin tornado and recent NWS Service Assessments:

- High-intensity cues (risk signals) prompt people to take action; outside of IBW, there are few mechanisms to elevate threats within NWS tornado warnings.
- Most seek confirmation from additional sources before seeking shelter. Thus, consistency of message is important. Conflicting or incomplete information delays sheltering actions.
- Existing dissemination systems not fully compatible with storm-based warning polygons can cause confusion over threat location when there are multiple polygons.
- Perceptions of false alarms may negatively impact warning credibility.

Finally, clear and credible risk communication is necessary for people to take timely protective action. Social scientists tell us that improving communication of risk is the prime public warning challenge for events like tornadoes. A key is converting people's natural perception of safety (which is called optimism bias) to a perception of risk… and thus speed-up risk assessment and sheltering actions. To do this people need clarity on impacts, as in does this affect me ? And how severe is it going to be? The intent is not to scare people (as many incorrectly suggest IBW intends), but to create fidelity in the warning message. What is meant by this is simply that we should inform people of what we know, and by doing so help people make quick and proper sheltering decisions.

Going back almost a half century, the Lubbock Tornado Service Assessment from 1970 was the first to recommend a different siren tone for tornadoes as a way of elevating the threat. More recently, a 2½ year study by NIST of the Joplin tornado echoed NWS Service Assessment findings that showed high intensity cues are what prompted people to take sheltering actions…and that people will seek confirmation from additional sources before sheltering. These studies also stressed the importance of consistent messaging across the weather enterprise. Inconsistent or incomplete messaging can result in delayed or incomplete sheltering.

Existing dissemination systems are also not fully compatible with storm-based warning polygons and these can cause confusion over threat location when there are multiple polygons, especially overlapping ones. (click) Lastly, a recent study from Ripberger et al. showed that the credibility of the warning is important and that perceptions of false alarms and missed events can play a role in public response. We'll talk a little later in this presentation about IBW warnings and confidence markers.

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IBW
Overview

What are Impact Statements?

- Provide end-users high intensity cues for particularly dangerous situations
- Describe what may happen **IF** hazard impacts people or structures

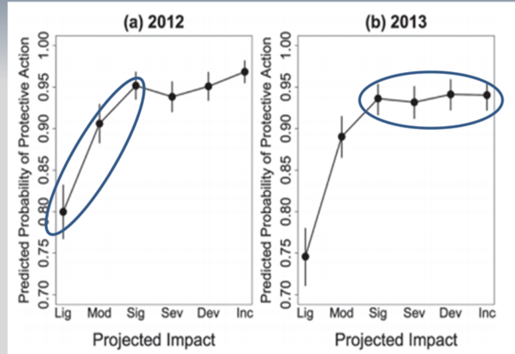
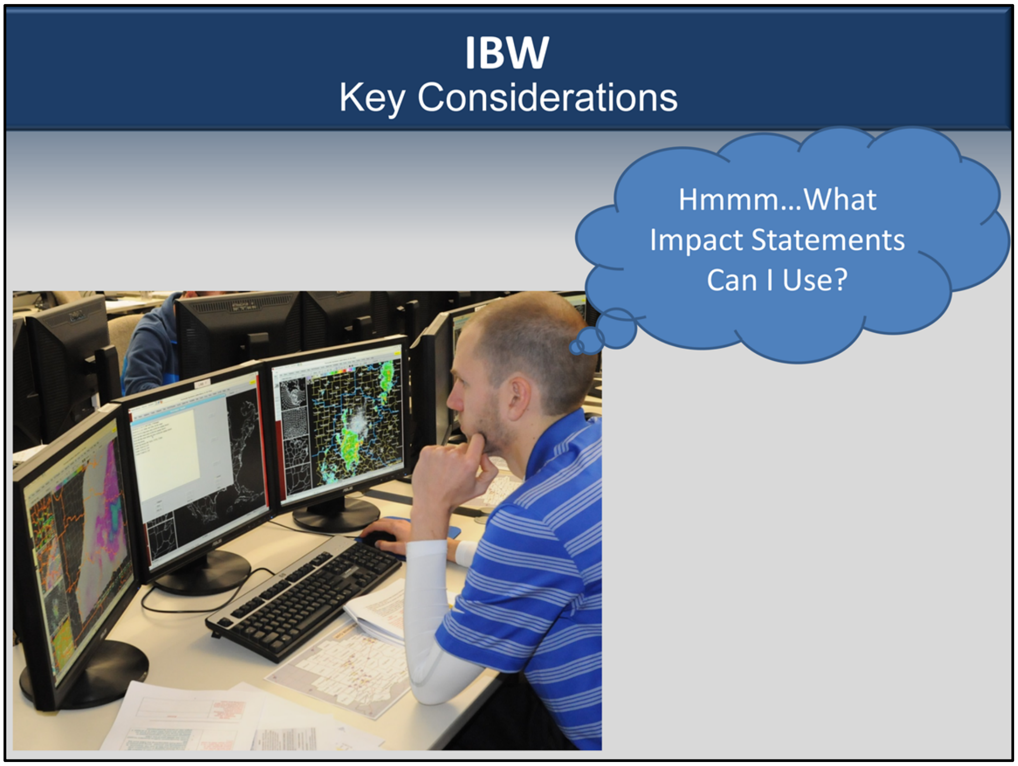


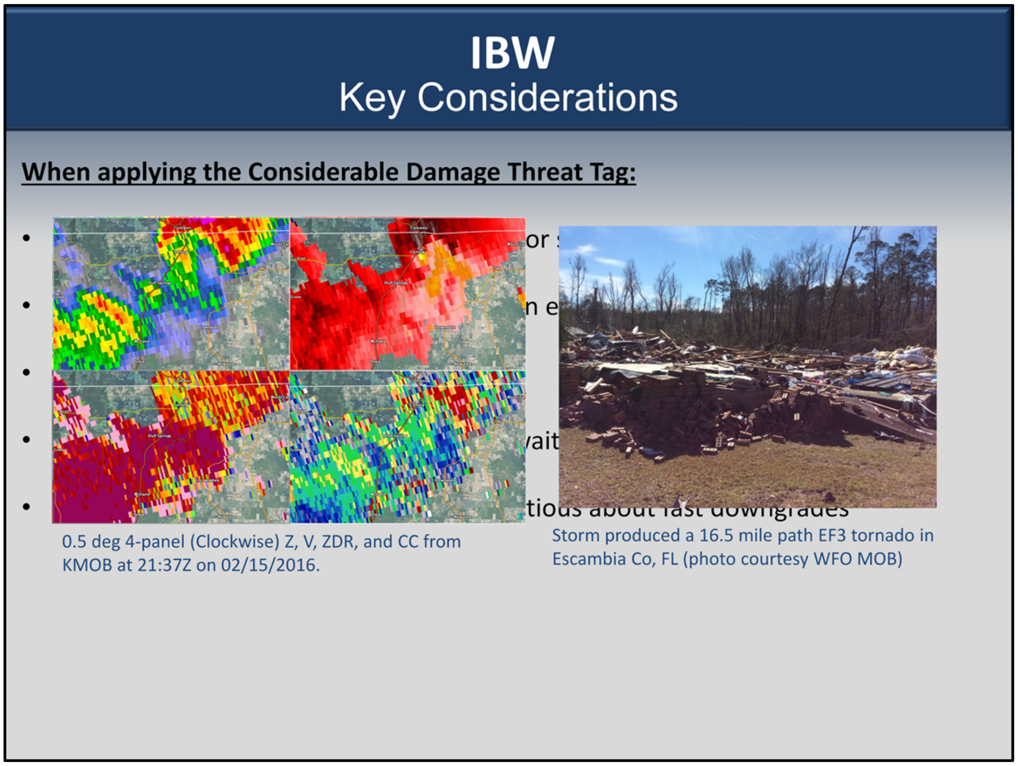
Fig. 3. Predicted influence of projected impact on binary protective action behavior; the predictions were derived from the (a) 2012 and (b) 2013 test models summarized in Table 1.

Ripberger et al (2014)

As previously mentioned, a goal of the IBW demonstration is to provide high intensity cues to emergency managers when we know it for particularly dangerous situations. To do this tags have been expanded from severe thunderstorm warnings to tornado warnings so that national users can code software to read details about the warning without having to do extensive word searching of the warning text. Impact statements commensurate with the damage threat indicators are sometimes referred to as consequence-based messages and are intended to serve as the high-intensity cues as referred to in the NIST report. A 2014 study by Ripberger et al. presented empirical evidence that consequence-based language can have an important and desirable effect on people's propensity to take sheltering actions - up to a point. Their findings specifically showed that vulnerable residents told to expect a high-consequence event were more likely to take sheltering actions than residents who were told to expect a low-consequence event. This is shown in the figure on the right showing the probability of protective action rises sharply with higher-consequence messaging but thereafter levels off with more dire consequence messaging. To correct for that, starting in 2014, extreme wording in the impact statements in the tornado emergency was scaled back to match that for the considerable tag. The severe and tornado impact statements are meant to be conditional (that is, what may occur should the expected tornado strike infrastructure, trees, etc.). They fall directly out of your choice of tag and are commensurate with damage threats associated with the EF spectrum. These were formulated through a Regional Labor Council effort with input from social scientists and meteorologists. During the decision-making process you should be less concerned with the impact statements (which again are designed as cues for end-product users)… and focus on the meteorology associated with distinguishing strong tornadoes vs weak tornadoes vs. no tornado.



Next we are going to provide a series Engage interactions that describe the new IBW SVR and TOR tags and impact statements for the various types of tornado, wind, and hail hazards.



When applying the considerable damage tag, remember, the intent of IBW is to warn for high-impact events rather than try to predict actual storm impacts. So, the primary IBW tool to alert for high-impact tornadoes is the "Considerable" damage threat tag. As warning forecasters, your target range for the "Considerable" tag are EF2-5 tornadoes. This is also where enhanced, conditional, impact statements kick in to provide needed high-intensity cues for end-users and partners. By the way, for those wondering, the phrase "considerable" for this damage threat indicator was selected by emergency managers as a more descriptive proxy for "significant" as defined by SPC). The considerable tag should be selected only rarely and for those tornado warnings where the storm information (from near storm environment and radar signatures, or even spotter reports) suggest the possibility of a strong tornado. Don't try to pinpoint EF scale. Its perfectly acceptable if an EF1 occurs on a Considerable tag or an EF2 occurs on a Base tier warning. Radar signatures are the primary method for distinguishing between significant tornadoes and small tornadoes. But you do not need to wait for a report of a tornado.

You can upgrade a tornado warning using the SVS option, but be cautious about downgrading too soon. Here's an example of a tornadic storm that occurred with an outbreak severe weather in the southeastern U.S. on President's Day 2016. This storm moved across western portions of the Florida Panhandle and Southern Alabama with a swath of damage.

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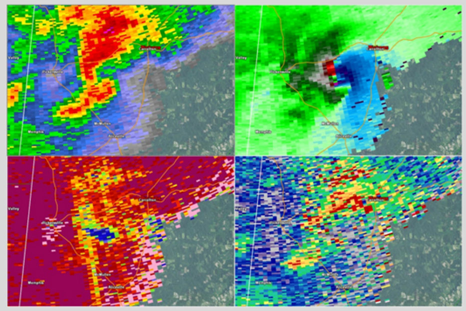
IBW
Key Considerations

<u>When applying the Catastrophic Damage Threat Tag:</u>

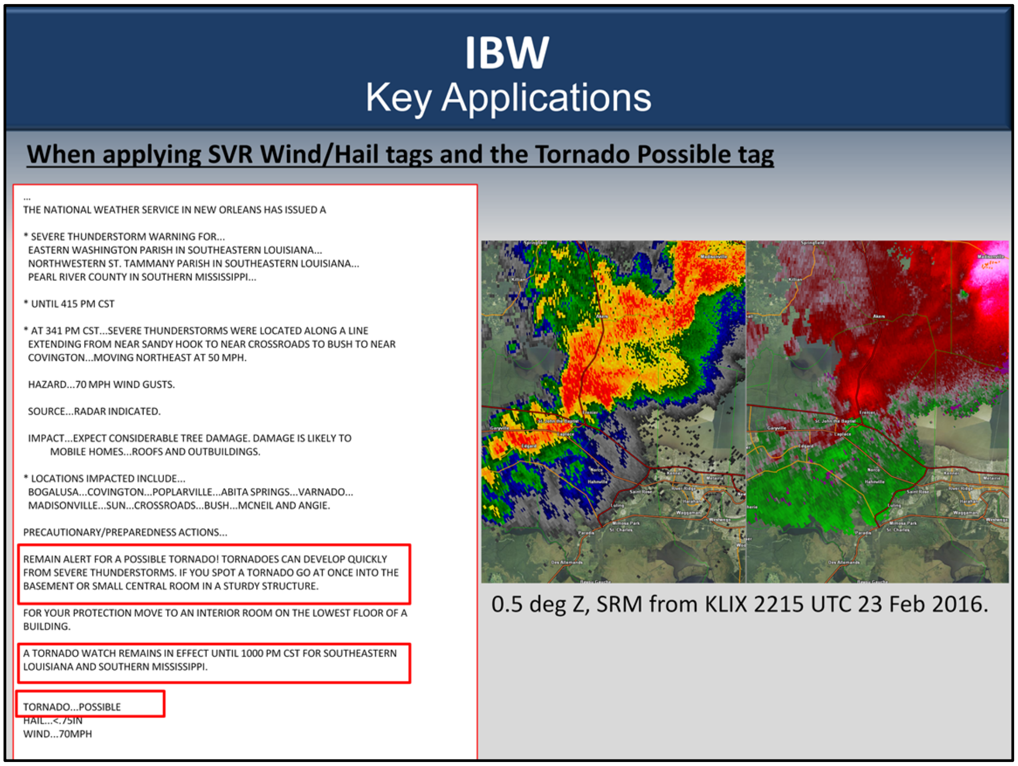
- Very similar to “Tornado Emergency”
- Issue when a severe threat to human life is imminent or ongoing.
- Catastrophic damage is imminent or ongoing (i.e., expected to impact pop. footprint)
- Tornado source confirmed via:
  1. Visual
  2. Radar indicates strong existence of a damaging tornado (TDS).



0.5 degree 4-panel Z, V, ZDR, and CC from KGWX at 2251 UTC showing tornadic storm with debris signature near McMullen, AL on 2 Feb. 2016.

When applying the catastrophic damage threat tag, here are the important considerations:
First, recall the term “tornado emergency” has been in the forecaster toolbox for 15 years and so in the IBW framework, we've adopted the “catastrophic” damage threat tag to be very similar to the use of Tornado Emergency criteria. In other words, the catastrophic damage tag is appropriate for the warning situation if <u>all</u> of the following criteria are met:

a. A severe threat to human life is imminent or ongoing,
b. Catastrophic damage is imminent or ongoing , AND you expect the tornado to impact a population footprint.
c. Reliable sources confirm the tornado , either by a visual or via radar imagery, which strongly suggests the existence of the damaging tornado (e.g. debris ball signatures).
Since the interpretation of the first part of the catastrophic criteria is somewhat subjective, especially the determination of the size of population footprint impacted, it is requested that you work within your CWA partners and Regional Severe Weather Program Focal points to determine the best use of these rare situations.



Severe thunderstorm warnings and SVSs continue to have wind and hail tags. The value next to the tag is an indication of how strong the winds may be. Although most warnings will have a 60 or 70 mph value in the tag, the tag allows forecasters to express much stronger winds. This is useful for describing impacts from high winds associated with a derecho, for example. Hail tags are optional in tornado warnings - but wind tags are not used in tornado warnings to avoid confusion with regard to tornadic winds. Impact statements are commensurate with the expected hazard are also included in severe thunderstorm warnings.

The “tornado possible” tag is used in severe thunderstorm warnings for situations where a severe thunderstorm has some potential for producing a brief, small tornado, but forecaster confidence is not high enough to issue a Tornado Warning. This tag has also been in the forecaster toolbox for years according to NWS directives, and is typically used in QLCS severe thunderstorm events, or in severe thunderstorm warnings within tornado watches.

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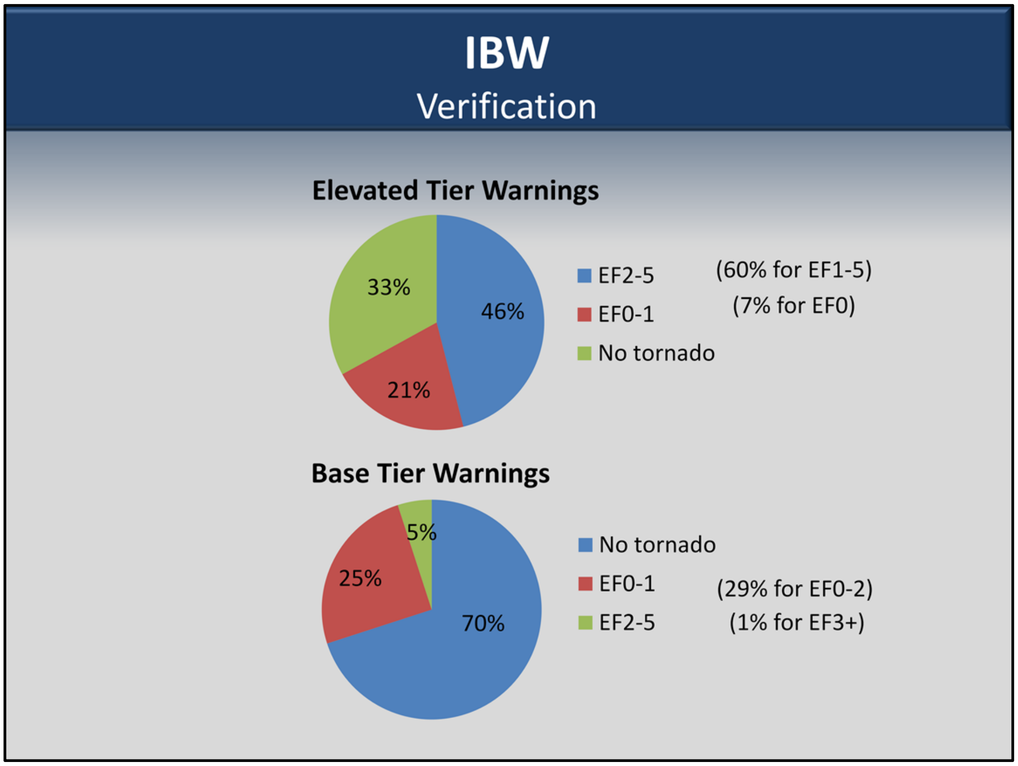

The IBW demonstration project included a verification project from 2012 to 2014 to verify both warning perspective metrics such as success ratios and false alarm ratios as well as event perspective metrics. The comparisons summarized on the next two slides here show value was added using warnings with damage threat tags (so-called "elevated tier" tornado warnings) over legacy warnings, or the so-called "base tier" warnings. In particular, the project showed that since the NWS warns for nearly all EF3-5's and can use elevated tier tags for half of them, the FAR is less than half than that for the base tier warnings. For example, the most likely outcome when an Elevated Tier Tornado Warning was issued for EF2-5 tornado occurrence was 46% (60% for EF1-5 occurrence), 21% for EF0-1 (7% for EF0 occurrence), and 33% for no tornado (i.e., a False Alarm). Contrast those statistics showing the most likely outcome when a Base Tier Warning is issued: 70% no tornado outcome, 25% of an EF0-1, and only 5% of an EF2 or greater.

What does this data all mean? Well, for most base tier warnings issued, the most likely outcome is a false alarm, by a 70% majority. This is compared to the 33% false alarm ratio for elevated tier warnings. In short, you can see that false alarms in NWS warnings are largely the result of trying to warn for weak tornadoes.

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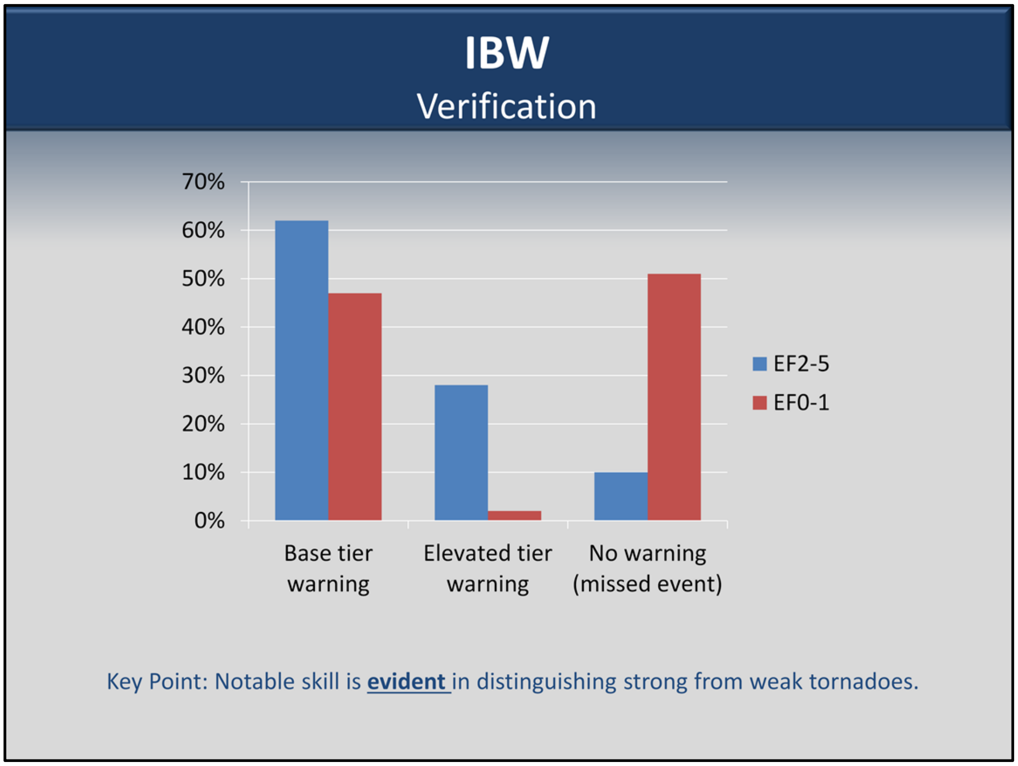
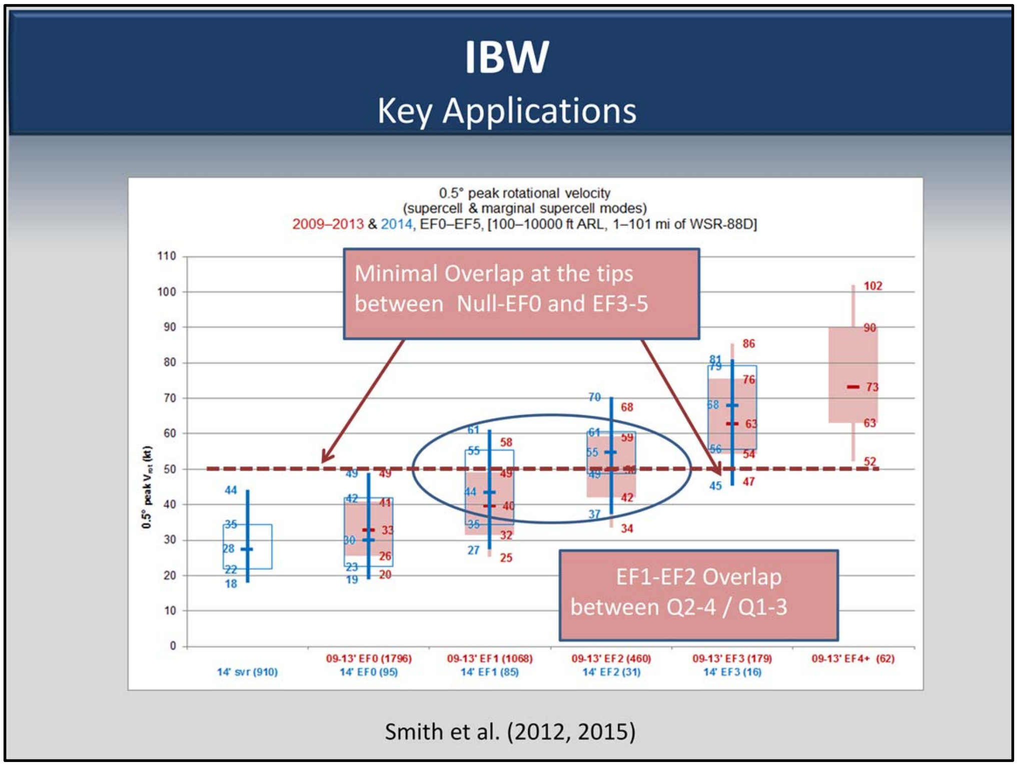


From an event perspective, looking at tornado detection ratios and missed event ratios, when a EF2-5 tornado occurs (the blue series in the histogram) it is associated with a base tornado warning – 62% of time (51% when EF3+ event occurs), an elevated tier warning – 28% of the time (47% when EF3+ event occurs), and no warning (Missed Event), 10% of the time (2% when EF3+ event occurs). On the other hand, when a EF0-1 tornado occurs (red bar graphs) , it is associated with no warnings 51% of the time (54% when EF0 event occurs), 47% of the time with a base tornado warning (45% when EF0 event occurs), and only 2% with an elevated tier warning (1% when EF0 event occurs).

What does this all mean? Approximately 90% of EF2-5 tornadoes are warned with a warning of any tier. This is also true for 98% of EF3-5 tornadoes. Roughly half of EF0-1 tornadoes are warned and most of those are warned with base tier warnings. The verification also found that forecasters underutilize enhanced tags and/or issue them late. While the vast majority of strong tornadoes are warned, they are mostly covered with base tier warnings and only 28% by elevated tier warnings. This increases to 47% of EF3-5 tornadoes. While 13% of all tornadoes are of the strong variety, elevated tags are included in just 5% of all warnings.

Finally, skill in specifically predicting EF2-5 and EF0-1s independently about the same as distinguishing a tornado from no tornado. However, when using near misses (that is, partial credit for EF1s in elevated tier warnings and for EF2s in base tier warnings) notable skill is evident in broadly distinguishing strong from weak tornadoes.



This SPC relational climatology by Smith et al from 2012, 2015 shows a significant relationship between increasing maximum 0.5 degree rotational velocity and increasing maximum EF scale of occurring tornadoes. The box and whiskers chart shown is for max low level rotational velocity signatures below 10000 feet and for supercell and marginal supercell convective modes. The light red is data from 2009-2013, while the blue is data from 2014 and includes rotational velocities from non-tornadic severe supercells.

The box and whiskers have standard configurations with the box bounded by the bottom of the 2nd quartile and top of the 3rd quartile - and the tips of the whiskers represent the 10th and 90th percentiles. The dash in the middle of each box is the median or top of the 2nd quartile. It is important to note that for each event the study recorded rotational velocities immediately prior to tornado touchdown until just prior to tornado dissipation.

Again, we are not trying to pinpoint tornado intensity by EF scale – just “ring the bell” a little louder for more significant tornado events. This chart shows why. You’ll note there is plenty of overlap in max low level rotational velocity associated with high end EF1 and low end EF2 – but you can also see there is little overlap between null events/EF0’s and EF3-5’s. Again, it won’t be unusual for an EF1 to occur on Elevated Tier Warnings, nor unusual for EF2’s to occur on Base Tier Warnings. We should avoid as much as possible having EF3’s or greater occur on Base Warnings or No Warning, and avoid EF0’s and Null events occur on Elevated Tier warnings. The graphic here certainly hints at some capacity for distinguishing between weak and strong tornadoes in that respect… and also hints at the viability of probabilistic approaches to the IBW warning process.

There is no perfect answer to the question of when to use a “considerable” tag, but that is rarely the case for anything in operational meteorology. Keep in mind that the value of your role in the warning decision process comes into play by staying situationally aware and considering a wide variety of factors to stay one step ahead of the tornado threat.

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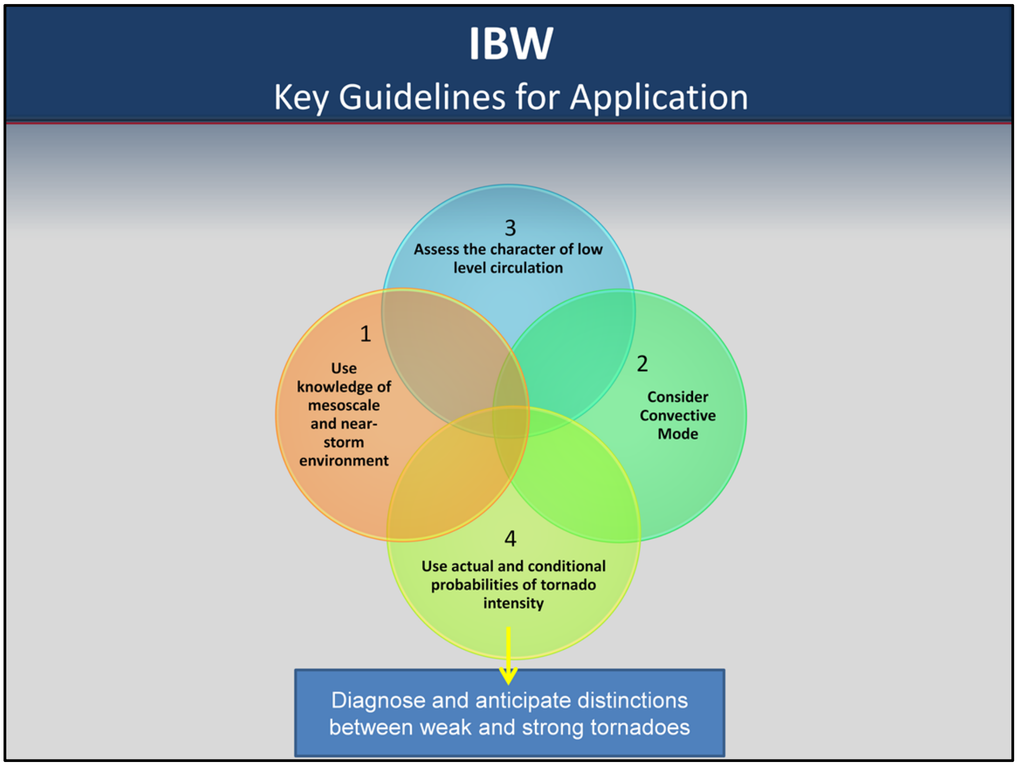
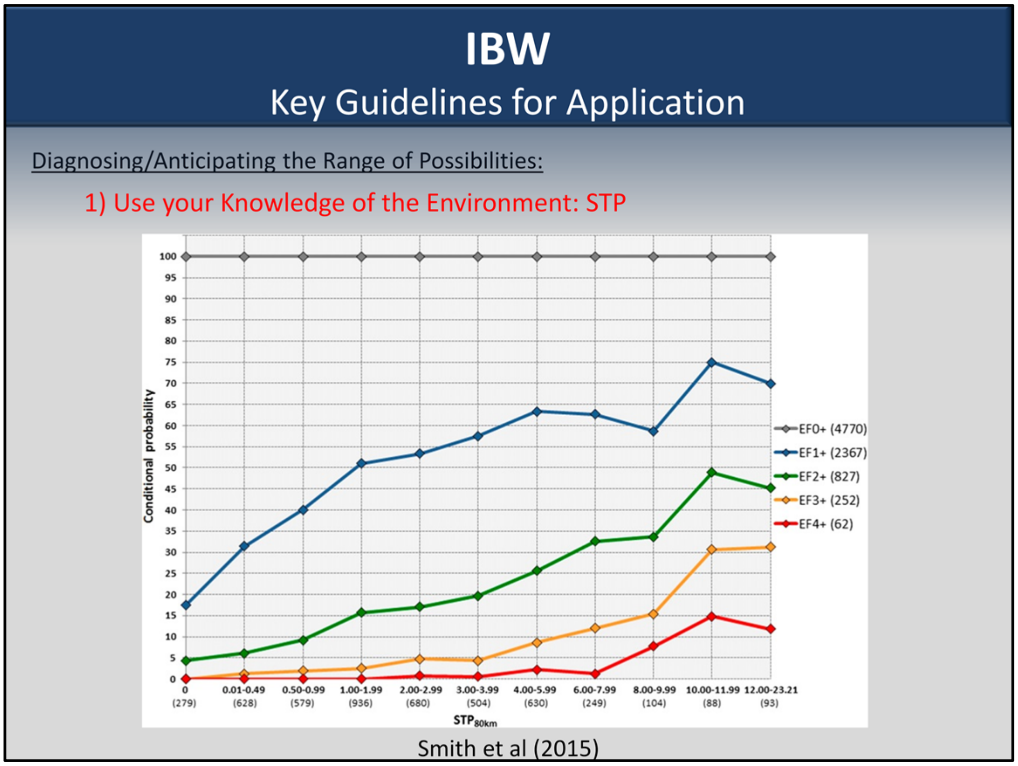


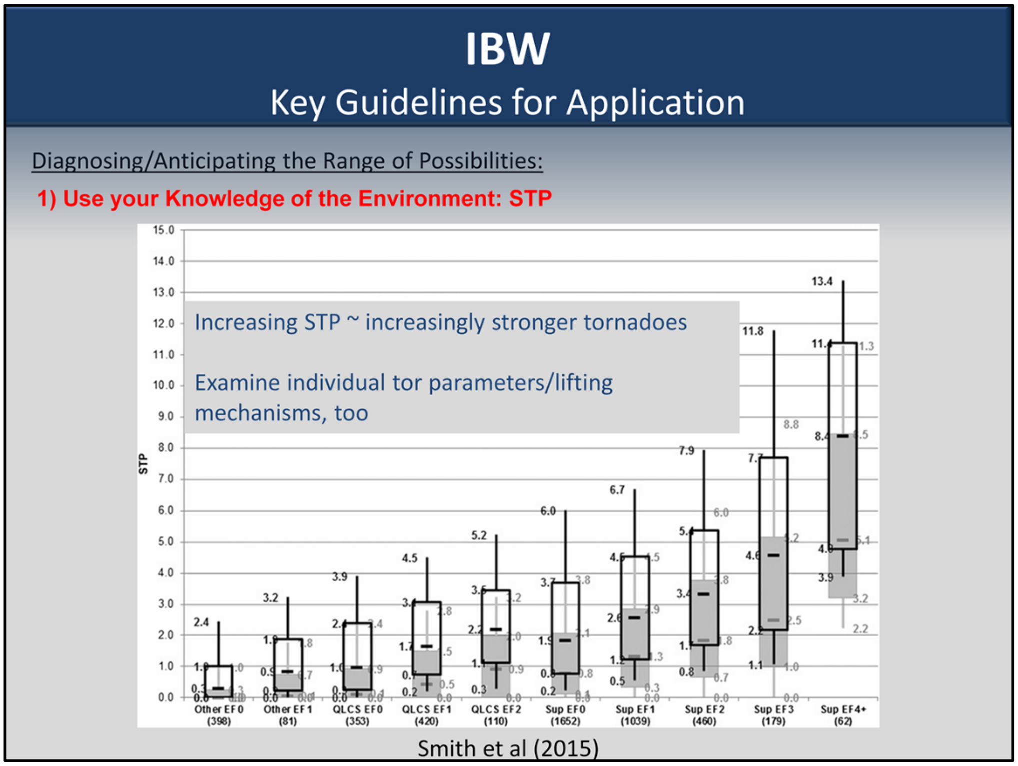
At this point we'll lay out some basic guidelines for distinguishing weak tornadoes from strong tornadoes. Essentially, there are 4 steps in the process which is diagnosing and anticipating the range of possibilities. First, use your situational awareness to assess the mesoscale and near-storm environments. Second, use your knowledge and understanding of convective modes and storm evolution as they relate to the environment. Third, use your understanding of the 4-dimensional character of radar-depicted mesocyclone circulations, especially the strength of low level rotational velocity, and 4thly, use your understanding of actual and conditional probabilities of tornado intensity (null vs. weak vs. strong) as related to low-level rotational velocity.



We’ll first look at environmental parameters that serve as a baseline for determining the likelihood that strong tornadoes may occur in a given situation. The Significant Tornado Parameter (STP) 80 km is a multiple component parameter meant to highlight co-existence of low-level CAPE and shear which are crucial ingredients for right moving supercells. Based on past studies, STP exhibits greater skill in discriminating between nontornadic and significantly tornadic supercell environments compared to any of its individual components or any other parameters among the 38-variable database at the SPC

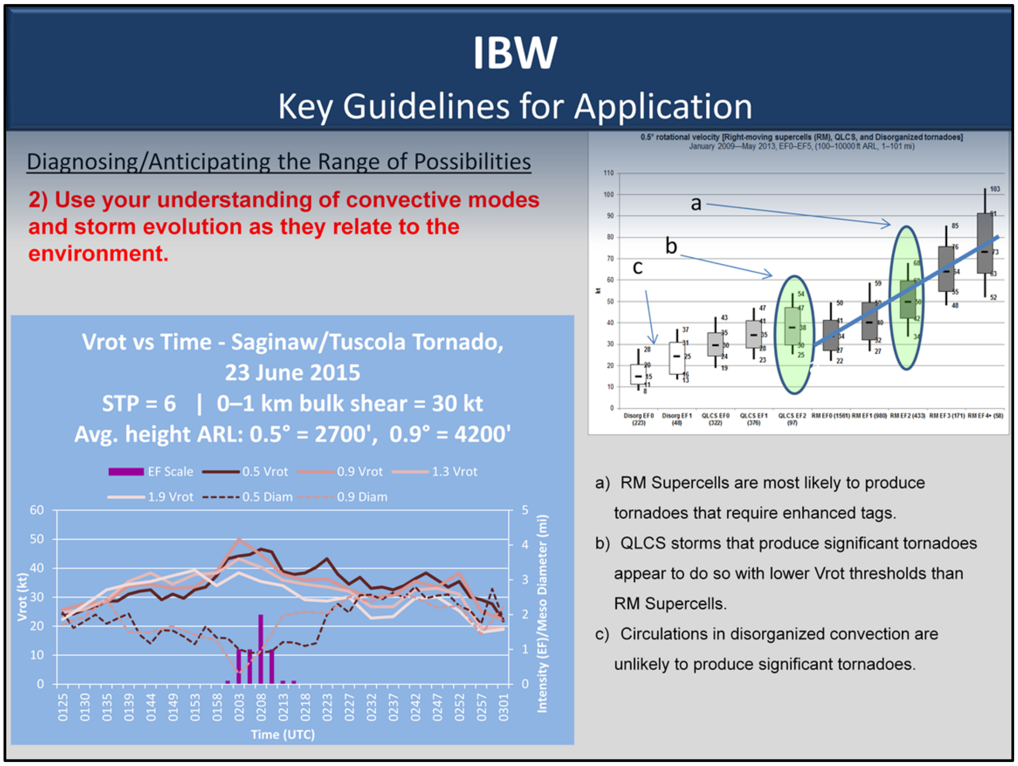
There is a relational climatology between increasing **conditional tornado intensity** and increasing values of STP 80km as measured on hourly SPC mesoscale objective analysis. Results from examining environmental and radar attributes, Smith et al (2015) found that increasing conditional probability for greater EF-scale damage, both STP and 0.5° peak Vrot increase, especially with supercells. This figure shows conditional probability of meeting or exceeding a given EF-scale rating (for the 5 series shown in the legend) for STP 80km for all convective mode tornado events from 2009–13.

The conditional probabilities may give you an idea ahead of time on how aggressive you can be on potential considerable tornado tags during the warning process.



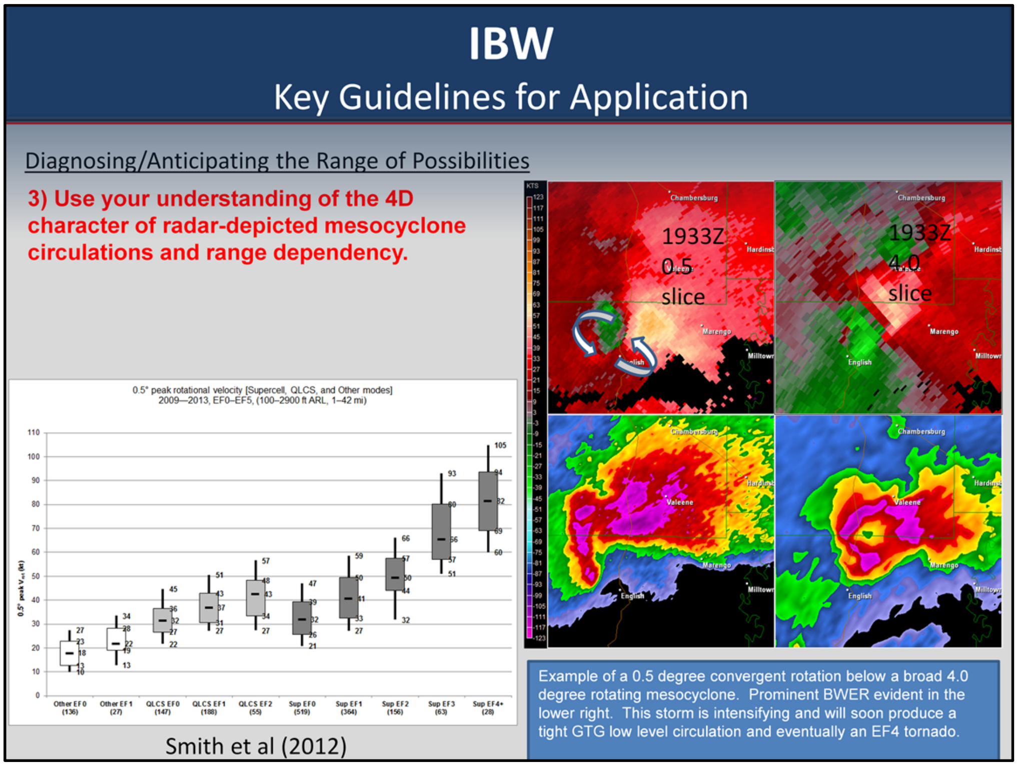
Next to further illustrate the relationship, here is a box and whiskers chart showing effective-layer STP (a dimensionless number) for all supercell, QLCS EF0–EF2 tornadoes, and other modes EF0 and EF1 tornadoes by EF-scale damage rating classes. The 40-km grid data are shaded gray, labels on right. The black overlays (with labels on left) denote STP 80 km grid point values, at the analysis time immediately preceding the event time. Using either the nearest STP grid point value or the neighborhood maximum value (which is the STP 80km) STP increases as tornado damage classifications increase. Supercell events tended to exhibit higher STP values than QLCS and other modes for the same EF-Scale damage rating. The STP for supercell, QLCS, and other modes tended to increase monotonically with increasing damage class ratings (aside from the 10th percentile). Substantial overlap exists in the distributions between adjacent EF-scale ratings, though the higher values of STP 80km (i.e., > 6) are more common for a greater proportion of supercell events at higher EF-scale rating classes (i.e., EF3+).

It must be stressed that composite parameters such as the STP 80 km should not be examined alone, but rather in concert with the individual components in the STP that identify important supercell tornado ingredients. Despite STP utility as a composite tornado predictor, there is no replacement for a thorough diagnosis of the mesoscale environment. You have to be aware of rapid storm interactions due to low-level boundary interactions which produce rapid tilting and/or stretching of local vorticity maxima. Also, closely monitor 0-1 km effective bulk shear, subsequent updraft helicity, and LCL heights < 1500 m AGL which are all important ingredients in the tornado development process.



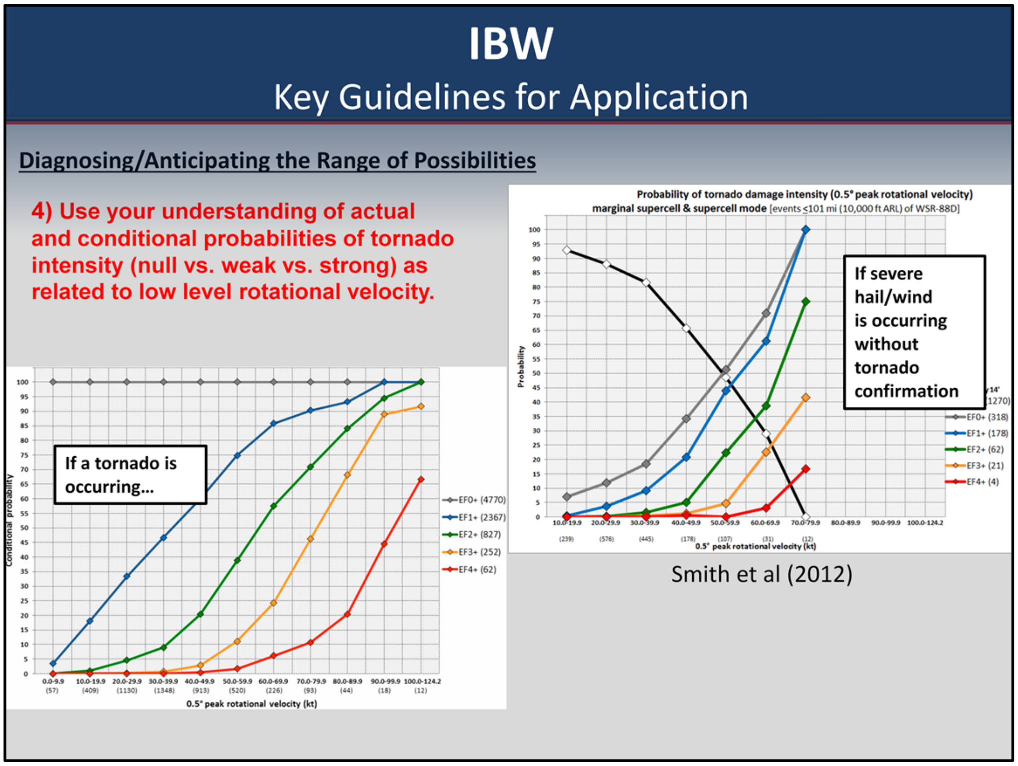
Here we'll discuss convective modes and rotational velocity evolution, or Vrot evolution. The graphic on the left is a marginal supercell tornado example from a study by Frey and Thompson in 2015. It shows the time evolution of Vr at various elevation slices through a storm. It also shows the time evolution of mesocyclone diameter through the storm cycle. On this graphic you can see a broad peak in 0.5 degree Vr around 45 knots starting near the time of tornadogenesis and a 0.9 degree peak near 50 knots right before a brief EF2 occurrence. Also note the max Vr starts at higher elevation slices 1.3 and 1.9 degrees but shifts to the lower elevation slices just prior to tornadogenesis. Additionally note how the meso diameter tightens as we approach tornadogenesis. This is a nice presentation of how you can view the full time evolution of a circulation to help make a determination of tornado development and potential max intensity.

On the right side of the slide is the Smith et al. study breaking down max Vrot distributions vs. Max EF-Scale for each convective mode. Obviously, supercell modes have the strongest relationship and most strong tornadoes occur with these modes. On the opposite end of the spectrum, it is highly unlikely to have a strong tornado occur with weak disorganized convection. Last, it is interesting to note that strong tornadoes can occur with QLCS modes – but QLCS storms that do produce significant tornadoes appear to do so with lower Vrot values than RM Supercells. This possibly due to enhanced forward motion vector contributions on right flanks of low level circulations.



Thirdly, you must use your understanding of the 4-dimensional character of the radar-depicted mesocyclone and range dependency. On the right hand side of the screen is an example of how you should anticipate how convergent low level circulations will behave given the near-storm environment. The Smith et al study uses both broad Vrot maxima and Gate-to-Gate Vrot maxima, depending on which is strongest for a given case. It goes without saying that a Gate-to-Gate Vrot maxima should operationally command more weight and a lower Vrot probability threshold for EF2+ events. This example shows a 0.5 degree convergent rotation below a broad 4.0 degree rotating mesocyclone. Note the prominent BWER signature evident in the lower right. This storm is intensifying and will soon produce a tight GTG low level circulation and eventually an EF4 tornado.

On the left is the range dependency of the dataset. The relationship between Vr and EF scale is not as pronounced at longer ranges from the radar, and very pronounced at shorter ranges. Probabilities of tornado intensity increase as range from the radar decreases.



Lastly, here are two figures representing the raw probability space from the box and whiskers graphic that was previously shown. First, since there are several caveats that apply to the dataset, these probabilities should be considered ESTIMATES of tornado damage intensity as related to max 0.5 degree rotational velocity. Second, these data are only for supercells and marginal supercells. Data from most QLCS and non-mesocyclone tornadoes are not factored into the probability calculations. There is range dependency not accounted for in these graphs, which we'll explore more in the next slides. There is no filtering of the data to account for likely underestimation of EF scale that might be associated with tornadoes in areas sparsely populated with damage indicators, such as in the high plains. Time evolution of rotational velocity is not accounted for. Instead, the climatology relates max EF-Scale to max Rotational Velocity only. Circulation diameter is loosely accounted for, but specific distinctions between broader signatures and gate-to-gate signatures are not fully accounted for. And last, the null sample only includes events corresponding to significant severe events for large hail and winds – and this data was collected only from 2014.

Despite these caveats, the probability estimates contained here can be very useful if applied generally and in conjunction with other tools. In the upper right are the actual probabilities of EF-Scale supercell tornado intensity while on the lower left are conditional probabilities of tornado intensity (provided a tornado is occurring). As mentioned you can use each of these to help diagnose the need to issue a "considerable" tag while also considering range dependency, the character of the low level circulation, the favorability of the ambient environment, and time evolution of the supercell. These continue to be refined as more data is collected.

An interesting observation between the box and whiskers chart previously shown and the probability chart here on the right is that distinguishing between null severe events and EF0 tornado events using rotational velocity is nearly impossible. The probability distribution for null events vs EF0's is almost completely driven by the comparatively high volume of null events. In fact, once the probability of a tornado reaches 50%, the most likely intensity outcome quickly approaches EF2 or greater.

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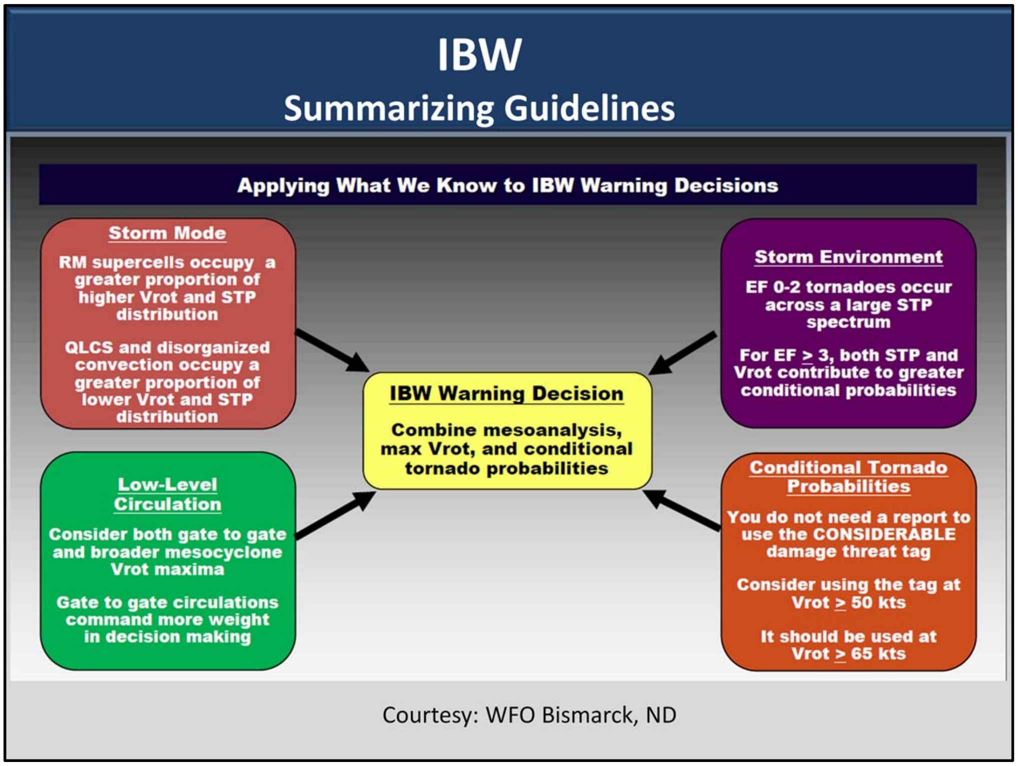

Here is a one-pager summarizing the various applications to IBW warning decisions, looking at environment, mode, circulation strength, and conditional probabilities. This summary come from WFO BIS.

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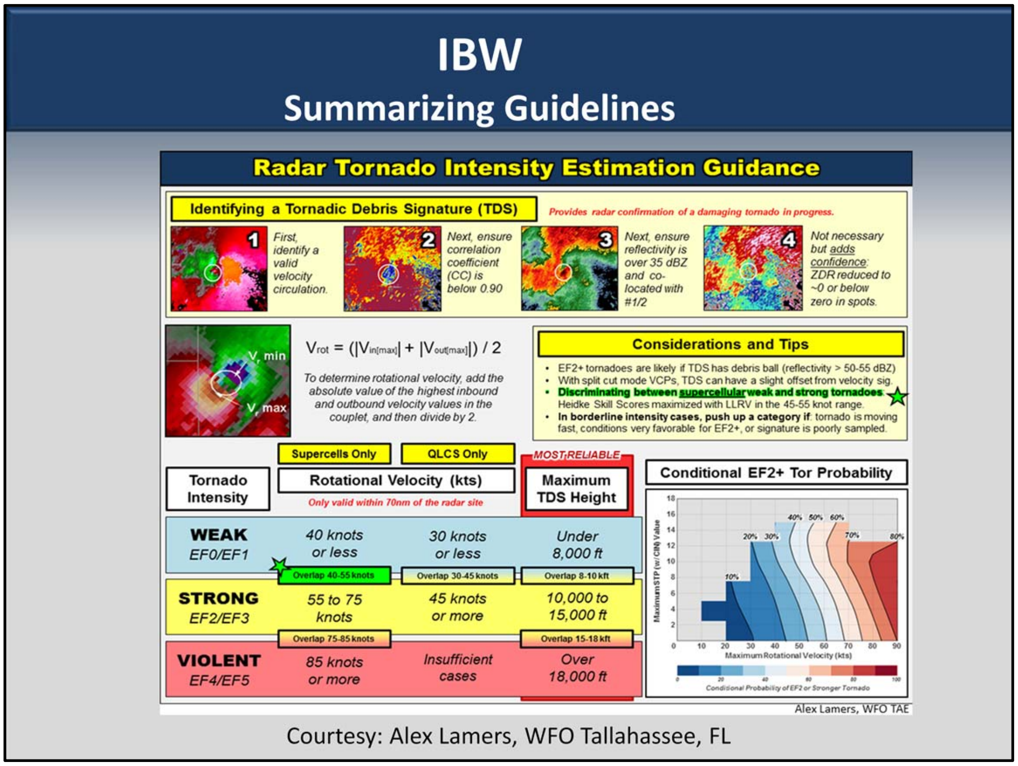

Here's another one-page summary from SR that's provides the most recent methodology of evaluating Tornado intensity using radar only signatures including TDS height. All of the considerations and tips are based on peer-reviewed papers. Notice the categories of Weak, Strong, and Violent Tornadoes somewhat coincide with the selection of no damage tag, considerable, and catastrophic.

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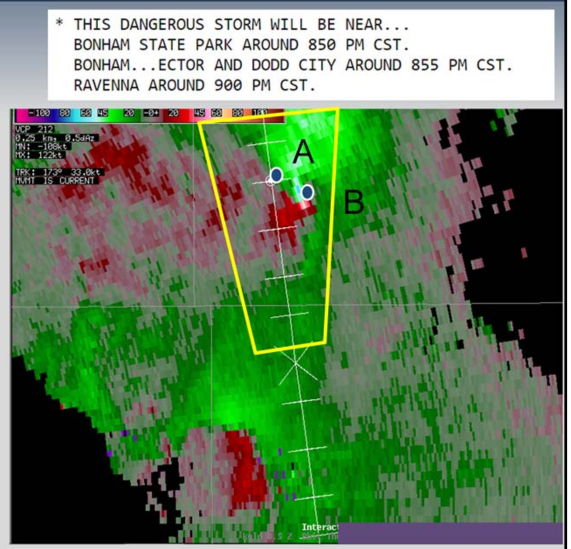
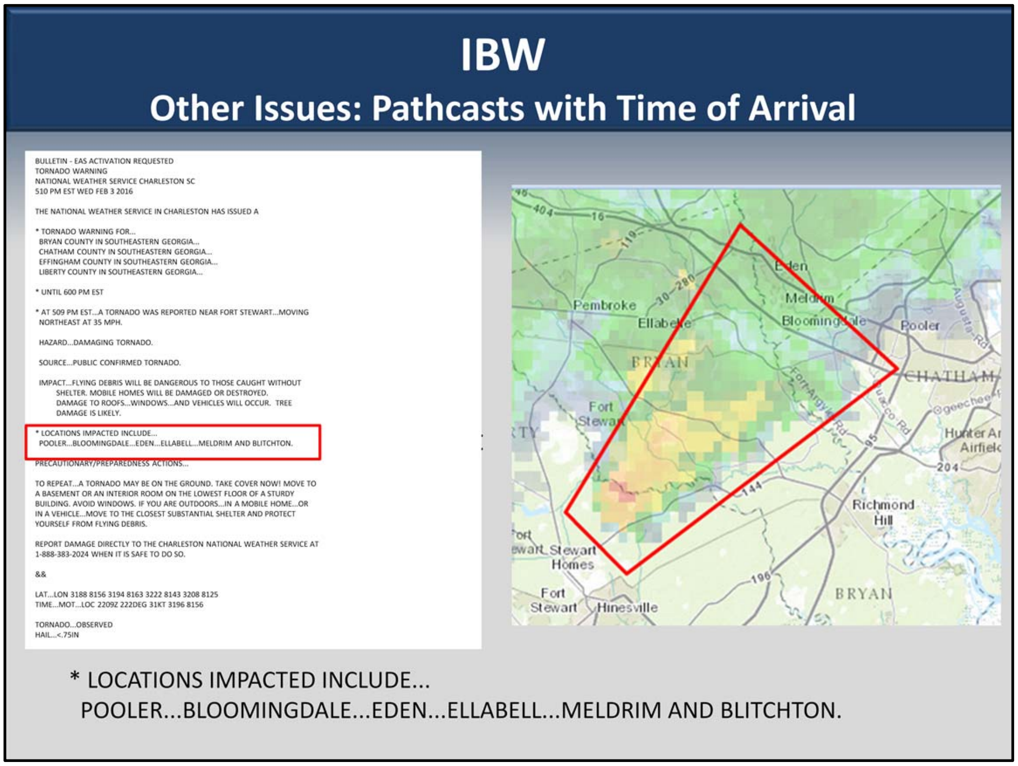
IBW
Other Issues: Pathcasts

- Recall technical limitations:
  - Radar resolution and range
  - Placing the "Drag Me To Storm" dot correctly
  - Large/Irregularly shaped cities
- Meteorological Limitations
  - Non-Linear Storm Motion
  - Multiple Threats from a Single Storm



Town "A" is in the pathcast; Town "B" is not.

Since pathcasts are turned on with the default setting in WarnGen IBW templates, you will need to be very careful with using the time of arrival option version. Recall the technological limitations due to radar resolution and range, issues when you don't place the "Drag Me To Storm" dot correctly, and of course, all the problems caused in the shapefiles due to large and/or irregularly shaped cities. In addition, there are known meteorological limitations with using specific time of arrival locations in warnings such as non-linear storm motion, and conveying multiple threats from a single storm. Please review some of the specific practices regarding the misuse of pathcasts at wdtd.noaa.gov.



Some best practices of using pathcasts, as reiterated from previous storm-based warning training from WDTD are:

- Always keep your storm track vector accurate (this keeps your threat motion attributes in the best possible location)
- Issue frequent SVS updates (keep trimming back unnecessary areas)
- Configure your WarnGen customization files for the best local configuration of cities and towns to be included along a track.
- And finally, when in doubt about time of arrival, leave it out.

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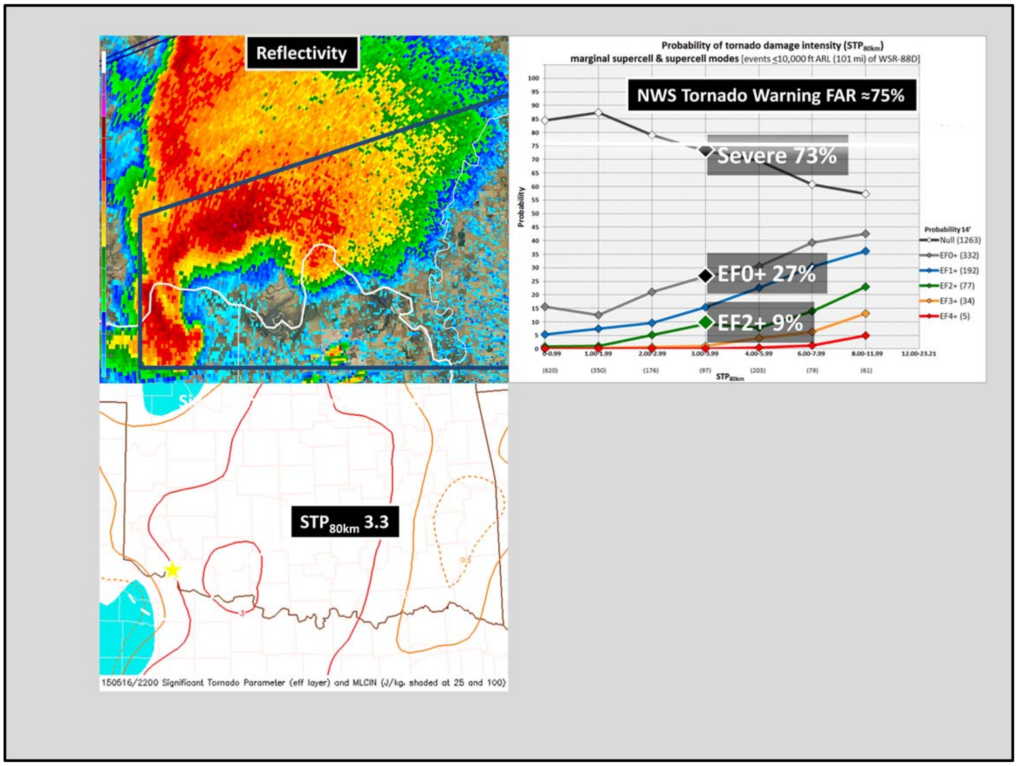

Finally, we're going to demonstrate a way in which the probability information can be applied. Only a few snapshots in the evolution of a tornadic storm are going to be shown for training purposes. Obviously more information would be available in a real-time setting and we recognize that the warning meteorologist is considering more than 0.5° reflectivity/velocity/CC data. Focus on the application of the probabilities and the resulting decision-making process. Keep in mind this is a basic example to illustrate how to apply the underlying concepts.

In this case, the STP is rather low and the probability of an EF2 or greater occurring in the region is quite low. There is an isolated supercell in southwest Oklahoma that will be the focus of the IBW decision. Distance to the radar is less than 40 miles, so 0.5 Vr relationships to EF-Scale potential are pretty reliable. Note there is already a SVR issued for this storm based on a detection of a severe updraft.

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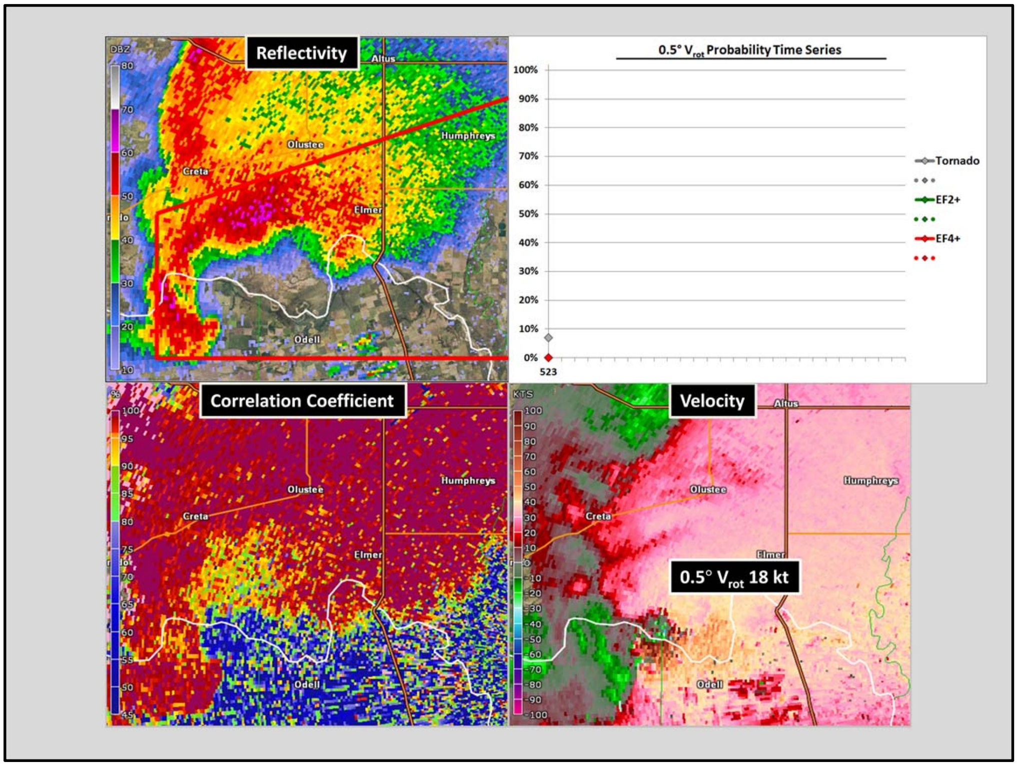
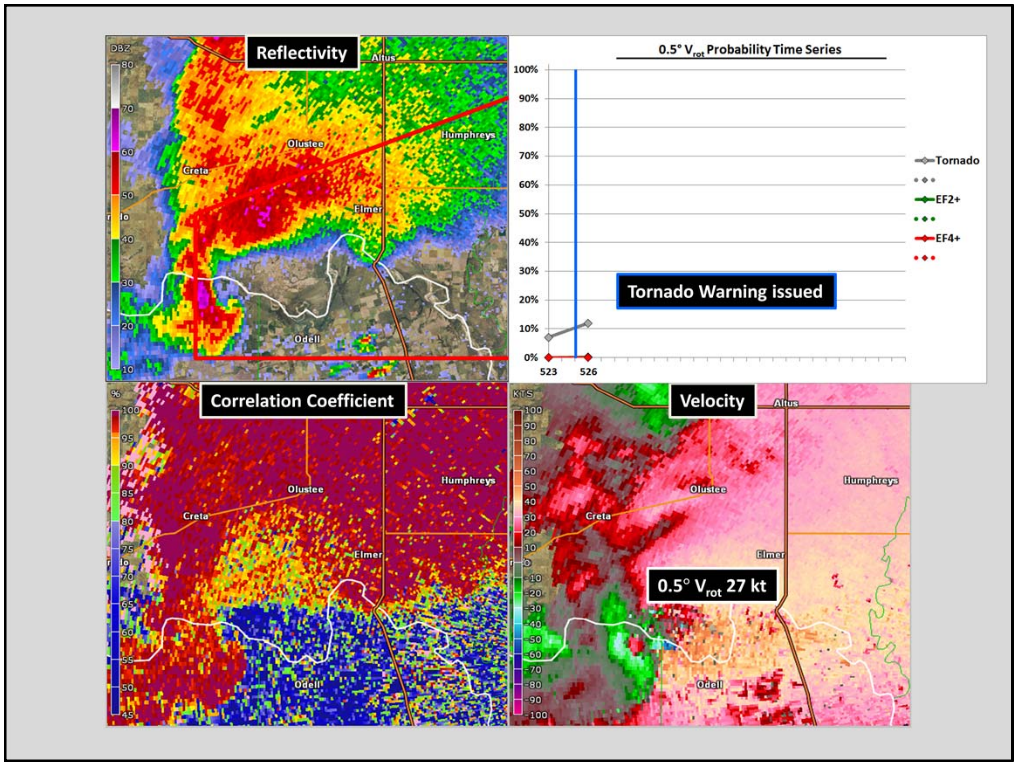
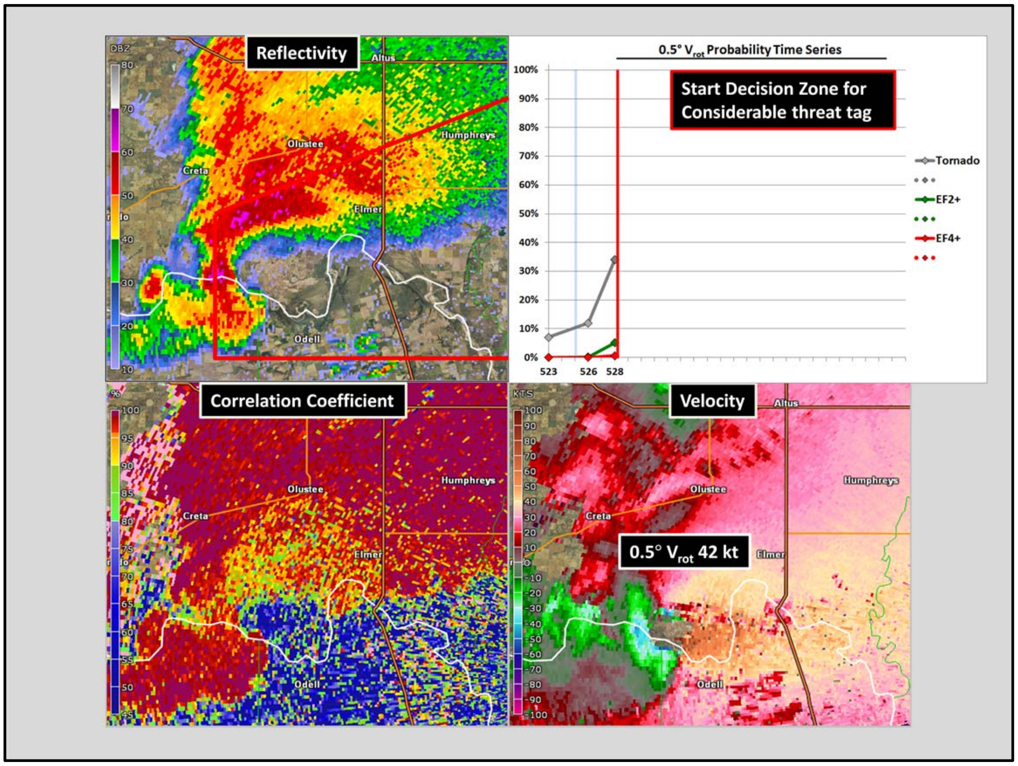


At 523 PM probabilities are very low and low level Vrot is pretty paltry. Nonetheless, strengthening was anticipated and a tornado warning was issued at 525.



At 525 PM the tornado warning is issued and by 526 pm Vrot was 27 knots and probabilities have risen slightly but are still pretty low.



At this point, full attention should be paid toward the potential need for a considerable tag. Vrot is 42 knots and probability of a tornado is 35% and probability of a stronger tornado is 5%. Things are trending upward though and you should be anticipating very closely.

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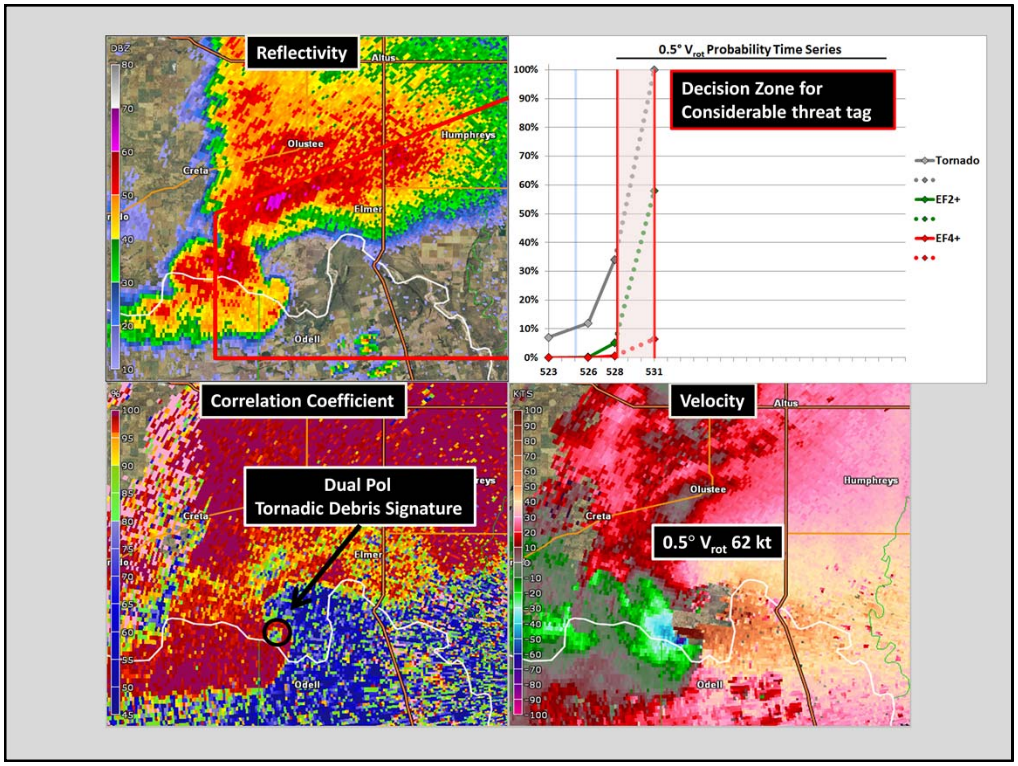
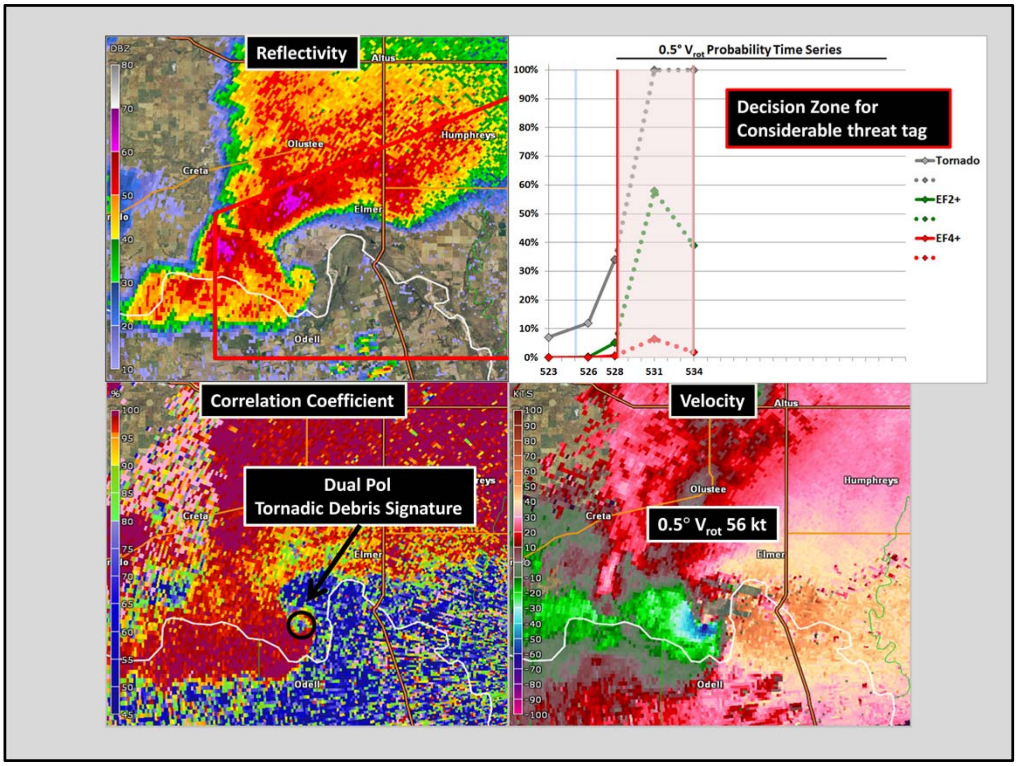


At the 531 PM CDT volume scan, the first sign of a CC minima is evident, at which point probability source should switch to the conditional probability graph. Vrot has risen substantially and quickly to 62 knots and the probability of a strong tornado has climbed to 60%. At this point the most likely outcome is an EF2 or stronger tornado. If you haven't already done so, a considerable tag upgrade is a likely choice.



At the 534 PM CDT volume scan, TDS signature continues with Vrot at 56 kt. If you haven't already done so, once again, the considerable tag upgrade is a likely choice.

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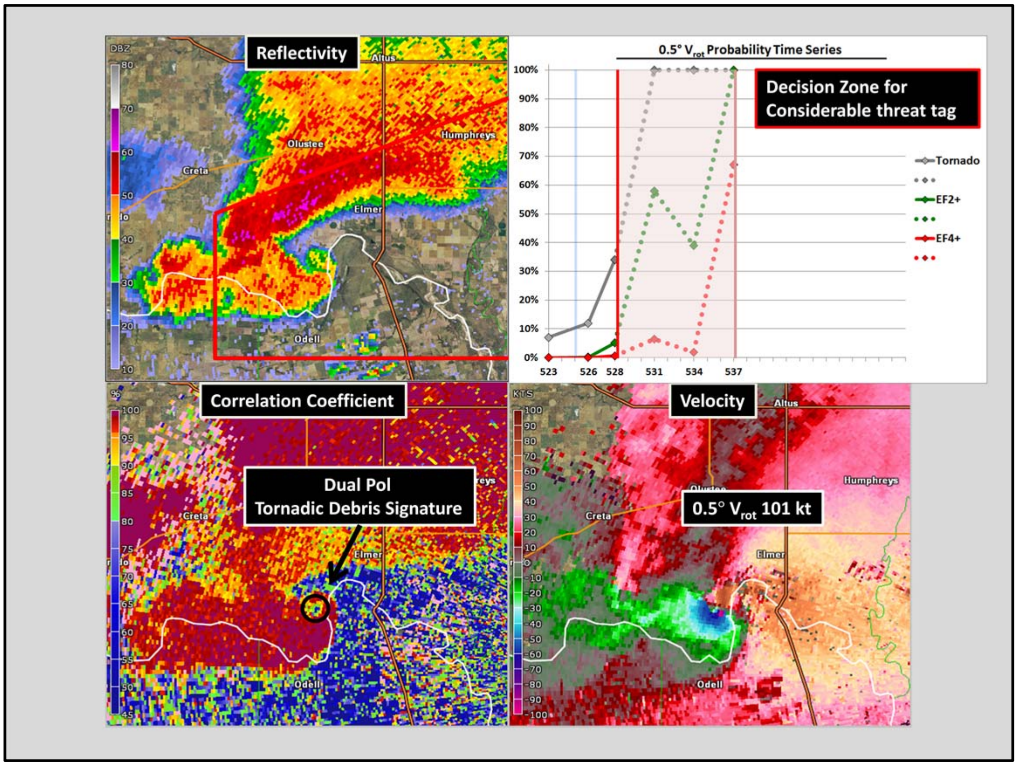

At the 537 PM CDT volume scan, TDS signature continues with Vrot now up to 101 kts. If you haven’t already done so, once again, the considerable tag upgrade is a likely choice.

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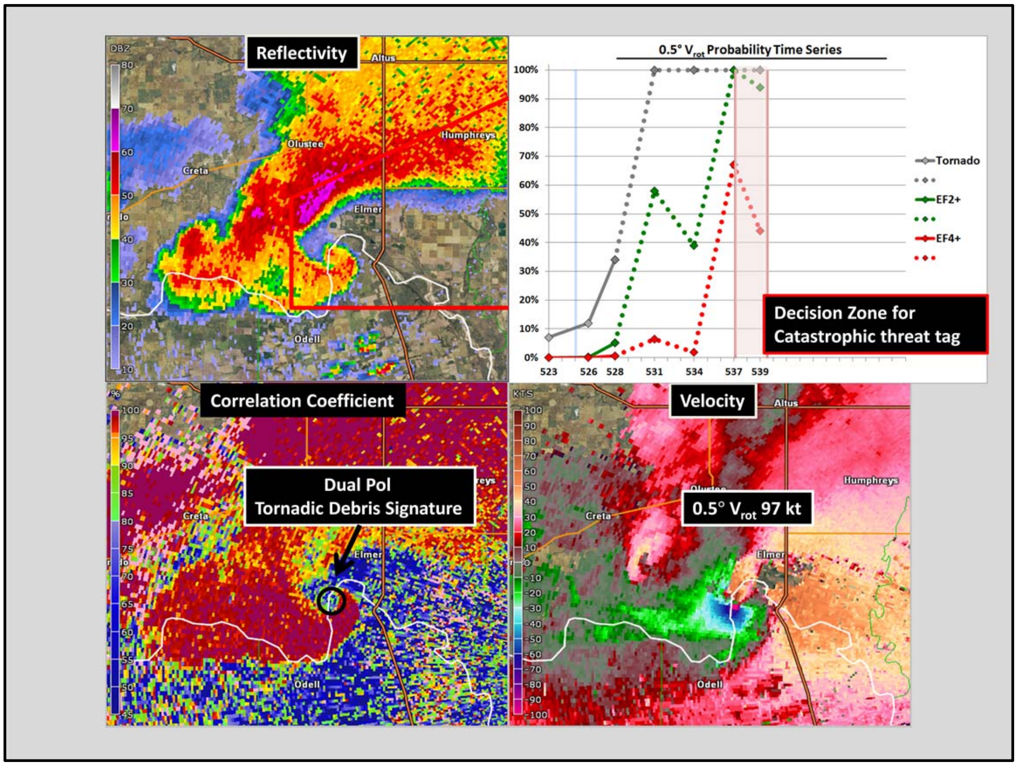

At the 539 PM CDT volume scan, TDS signature continues with Vrot now at 97 kts. As the tornado is approaching Elmer, you should start considering upgrading to a catastrophic threat tag.

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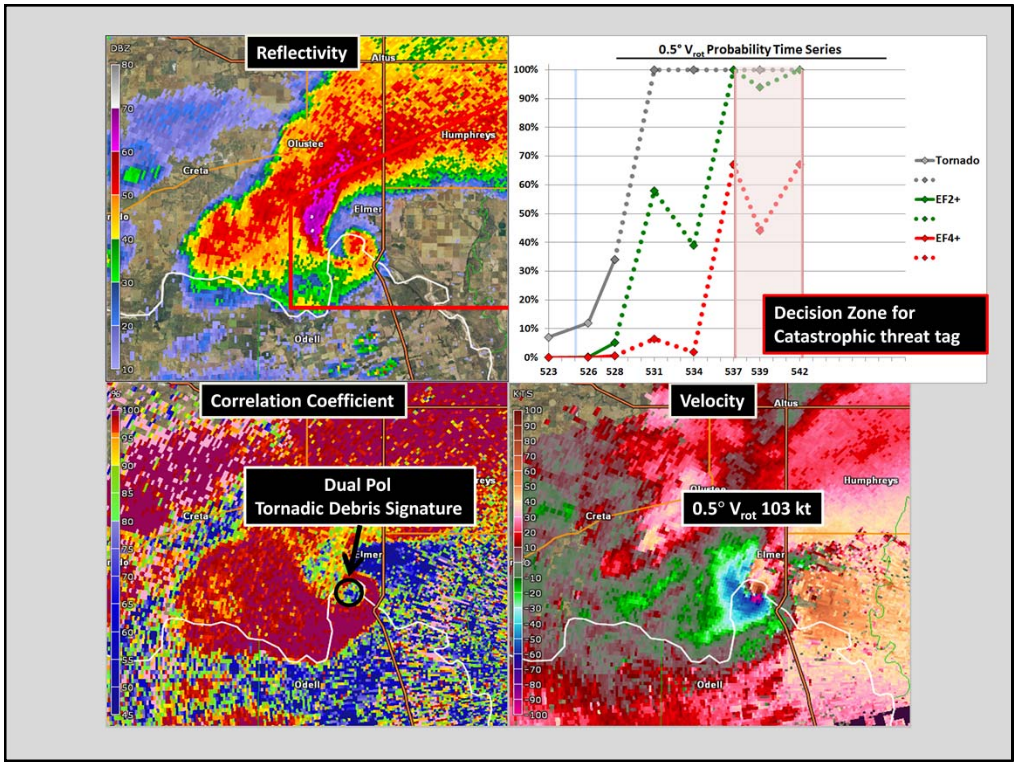

At the 542 PM CDT volume scan, TDS signature continues with Vrot now at 103 kts. As the tornado is approaching Elmer, you should start considering upgrading to a catastrophic threat tag

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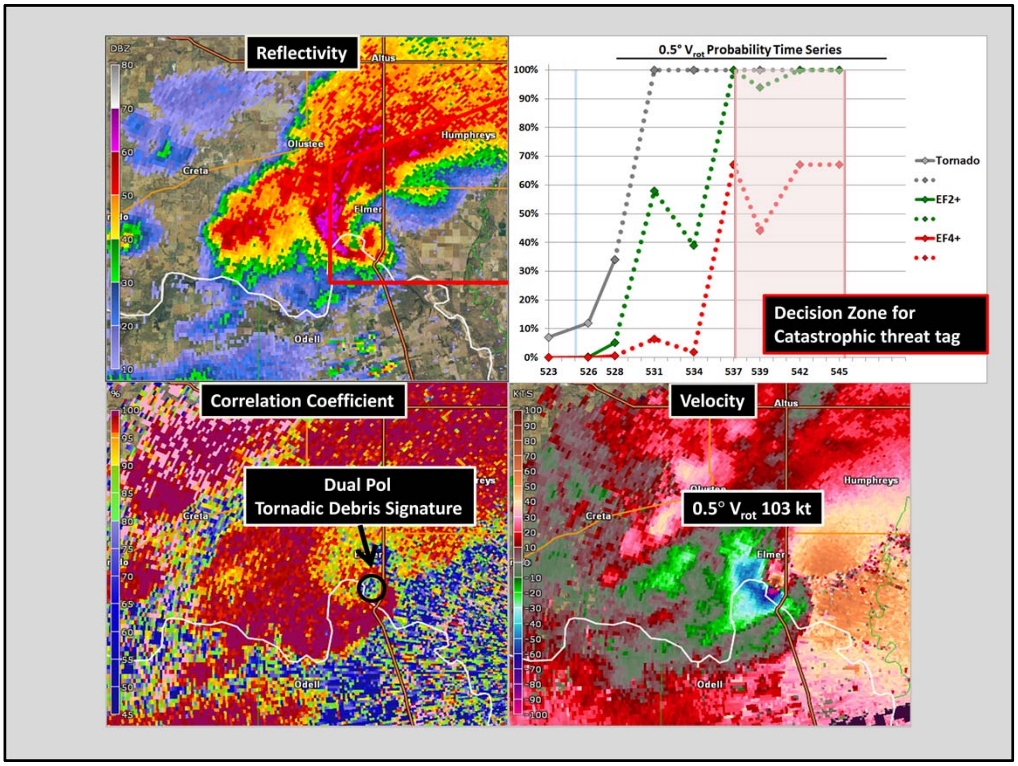

At the 545 PM CDT volume scan, TDS signature continues with Vrot still at 103 kts. As the tornado is entering Elmer, you should start considering upgrading to a catastrophic threat tag.

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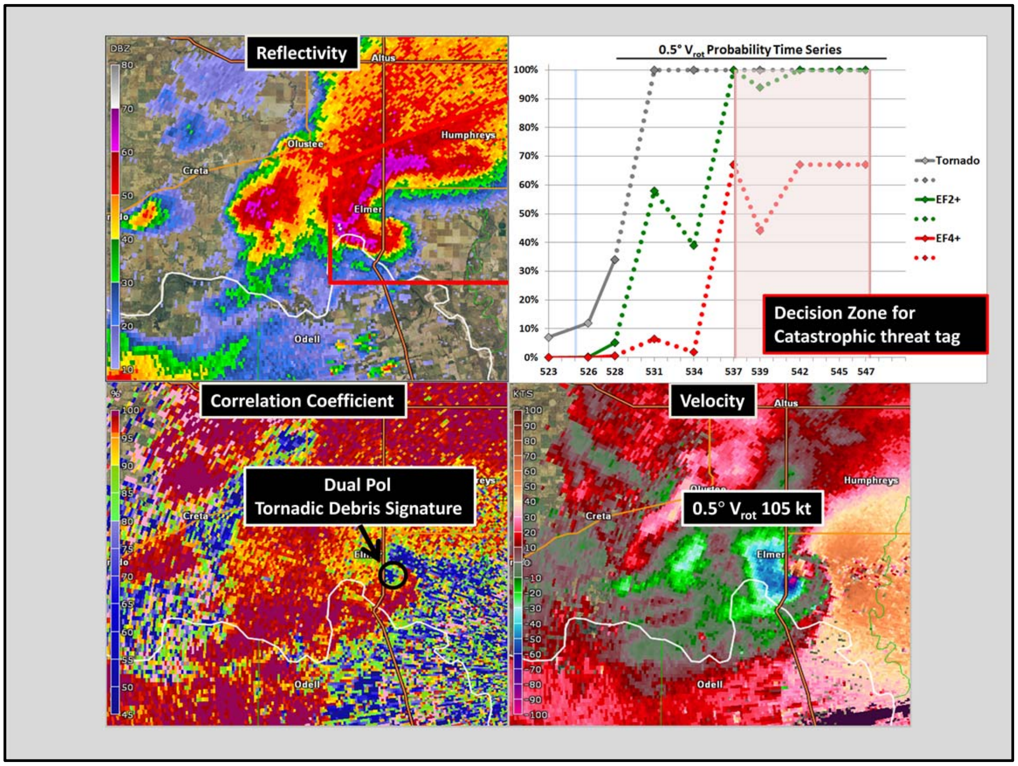

At the 547 PM CDT volume scan, TDS signature continues with Vrot up to 105 kts. As the tornado is entering Elmer, you are in the decision zone for considering a catastrophic threat tag.

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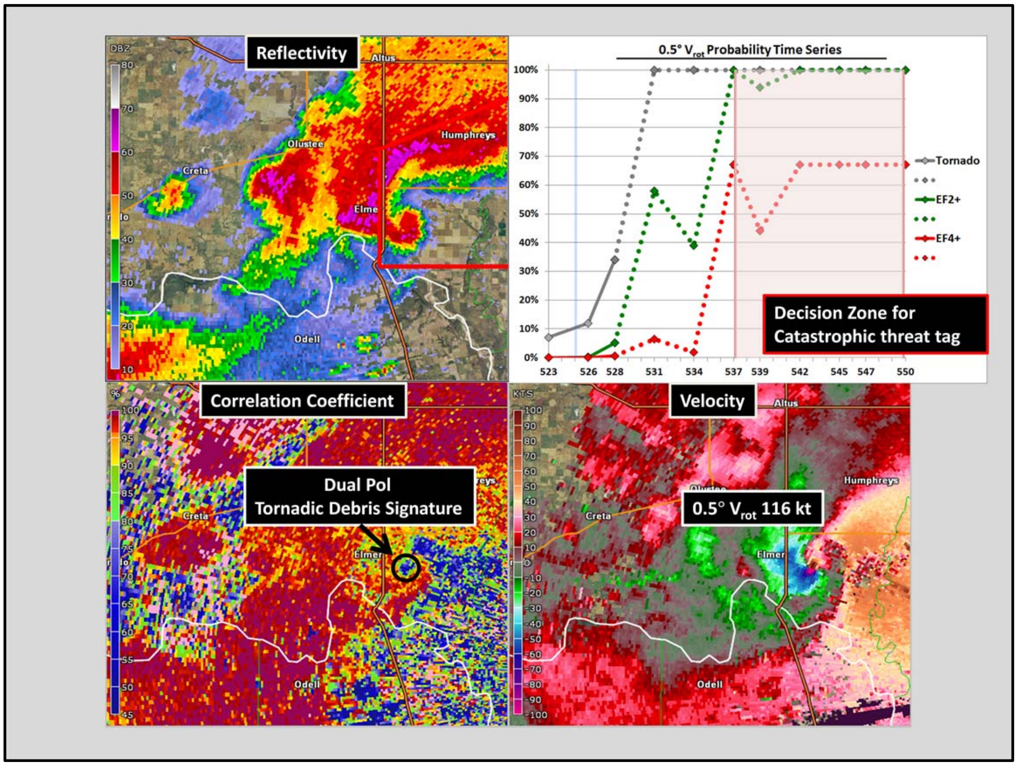

The 116 kt 0.5° V_{rot} is the 3rd highest of the super-resolution radar era (mid 2008–present). The Elmer, OK tornado was 1 mile wide and the sparse density of damage indicators yielded EF3 damage. The Norman Forecast Office in their damage assessment mentioned the tornado was likely violent (EF4+) based on video and radar presentation.

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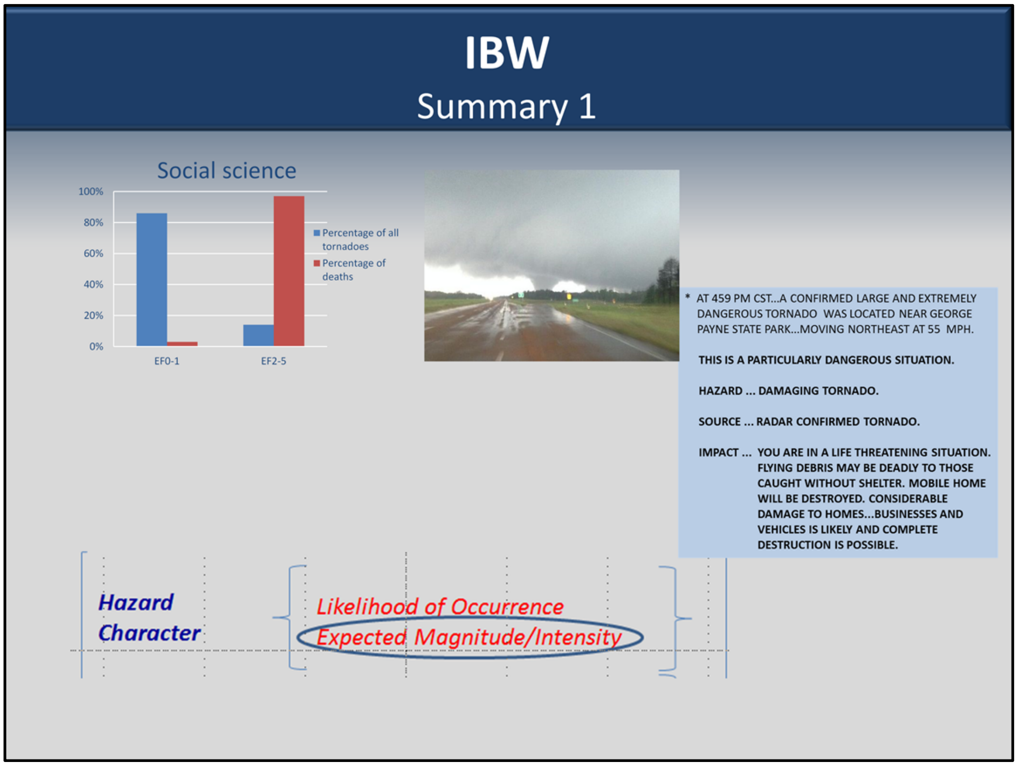
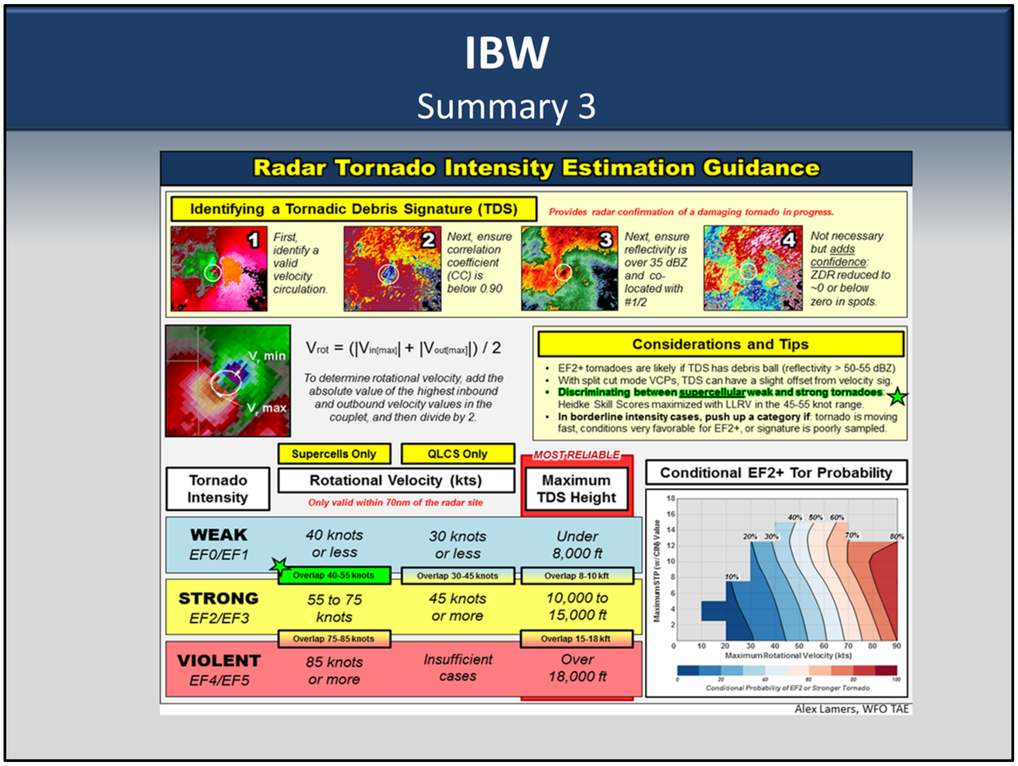


In summary, IBW provides an updated framework for providing high intensity cues for warnings that is based on social science and risk communication principals which require tornado warnings to highlight events that have the most potential to do serious harm. As part of that risk communication process, the character of a weather hazard like a tornado must have expressions of magnitude to establish a level of risk to elicit the most appropriate actions. High-intensity cues are the risk signals that prompt people to take action. These cues form the basis of the impact statements that seek to elevate threats within NWS warnings.

To highlight specific risks and impacts, IBW provides some options based on expected severe hazard risks and impacts. These are the impact statements and associated tags. Make the selections for the appropriate impact statement in your warnings to highlight the potential risk of damage expected.



Finally, IBW is not just some half-baked policy update. The warning paradigm shift brought about by IBW is based on sound observational research which show a degree of skill in discriminating between tornado intensity. The use of STP along with other near storm environment considerations, rotational velocity, and tornado debris signatures in a probabilistic sense should be used to develop your warning methodology to better anticipate and warn for situations where the most intense and destructive tornado events can occur.

A complete list of references used in this presentation are available at http://www.wdtd.noaa.gov/courses/ibw/references.php.

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Welcome to part II of the NWS course on Overview and Introduction to Impact Based Warnings. In the first part, we talked about the rationale and motivation for moving to IBW and showed you the specific impact damage statements and tags options. In this second part of the course, Dick Wagenmaker will look at the validation of IBW including some verification studies showing the relationship of occurrence of tornadoes via EF scale and tiered warnings, and the scientific research behind key environmental and radar guidelines for successfully diagnosing and anticipating the range of possibilities for tornado intensity. Finally, there will a short example illustrating how you might apply the enhanced tags in a warning situation.

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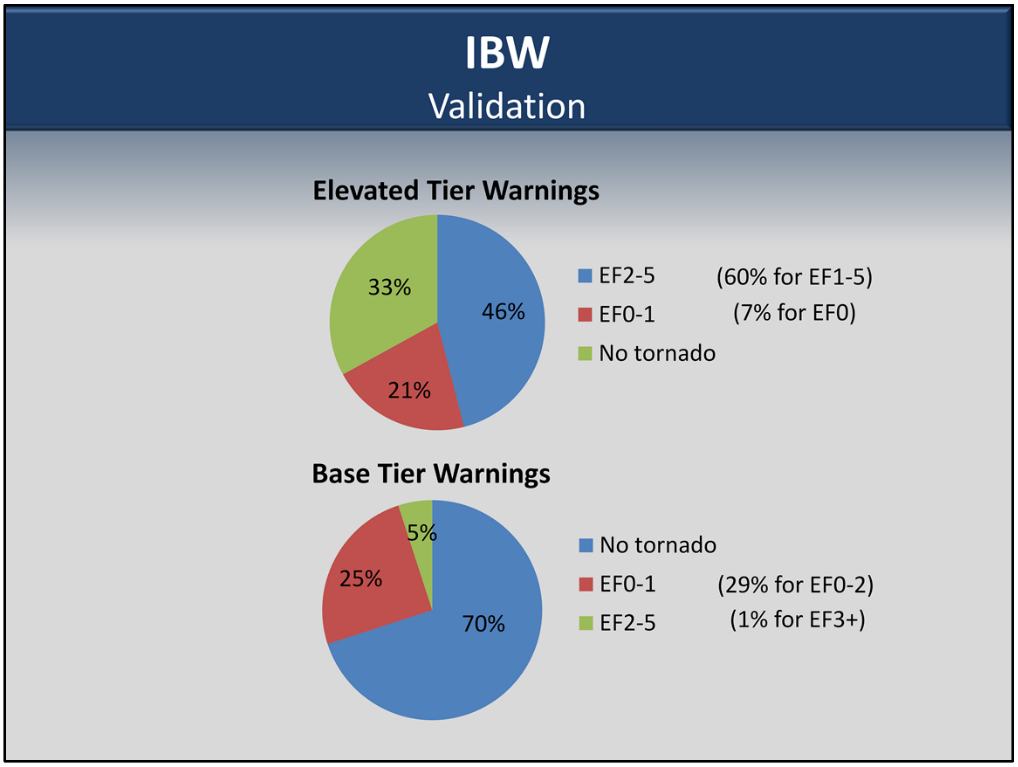

The IBW demonstration project included a verification period from 2012 to 2014 to verify both warning perspective metrics such as success ratios and false alarm ratios as well as event perspective metrics. The comparisons summarized on the next two slides here show value was added using warnings with damage threat tags (so-called "elevated tier" tornado warnings) over legacy warnings, or the so-called "base tier" warnings. In particular, the project showed that since the NWS warns for nearly all EF3-5's and can use elevated tier tags for half of them, the FAR is less than half than that for the base tier warnings. For example, the most likely outcome when an Elevated Tier Tornado Warning was issued for EF2-5 tornado occurrence was 46% (60% for EF1-5 occurrence), 21% for EF0-1 (7% for EF0 occurrence), and 33% for no tornado (i.e., a False Alarm). Contrast those statistics showing the most likely outcome when a Base Tier Warning is issued: 70% no tornado outcome, 25% of an EF0-1, and only 5% of an EF2 or greater. What does this data all mean? Well, for most base tier warnings issued, the most likely outcome is a false alarm, by a 70% majority. This is compared to the 33% false alarm ratio for elevated tier warnings. In short, you can see that false alarms in NWS warnings are largely the result of trying to warn for weak tornadoes.

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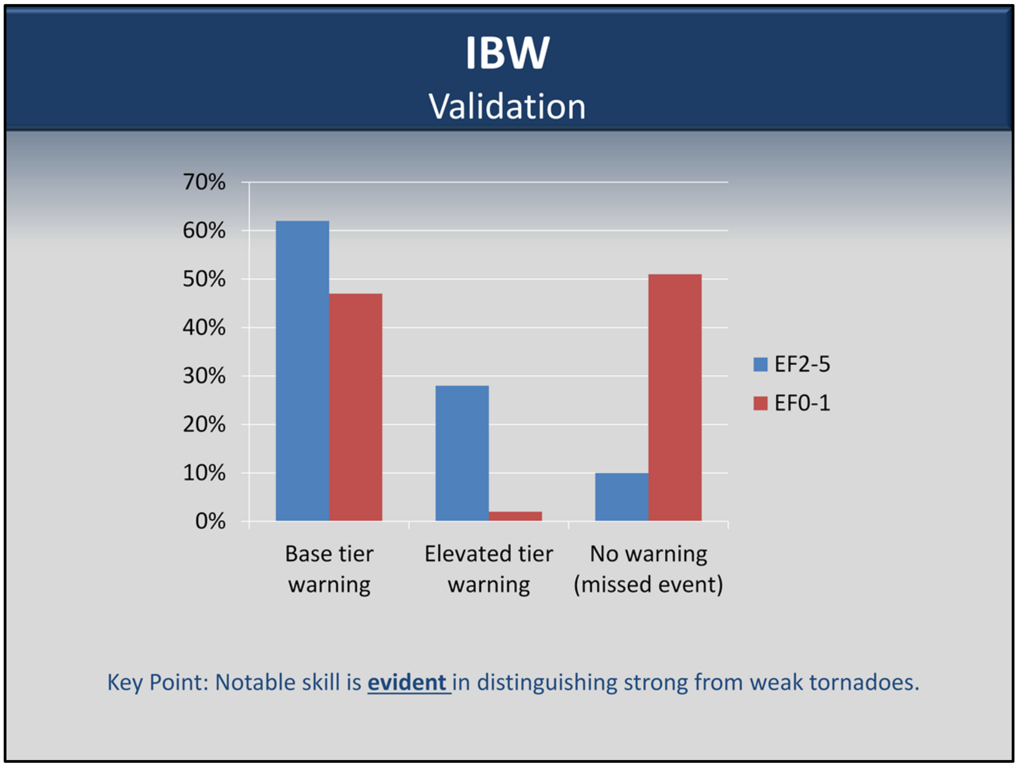
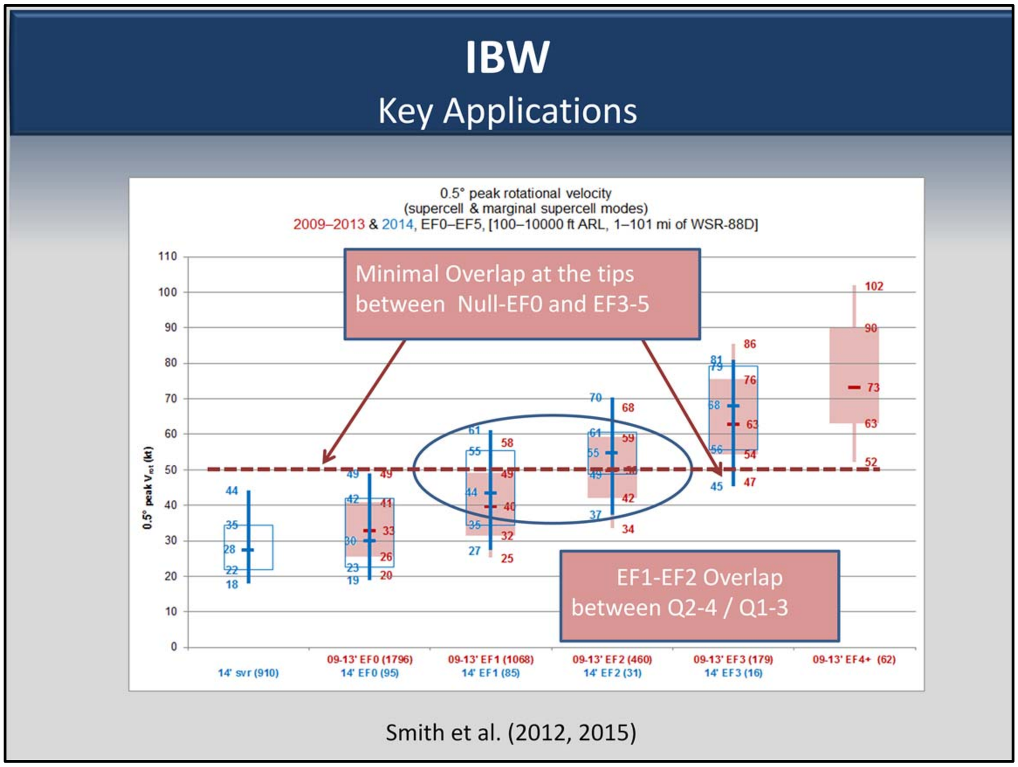


From an event perspective, looking at tornado detection ratios and missed event ratios, when a EF2-5 tornado occurs (the blue series in the histogram) it is associated with a base tornado warning – 62% of time (51% when EF3+ event occurs), an elevated tier warning – 28% of the time (47% when EF3+ event occurs), and no warning (Missed Event), 10% of the time (2% when EF3+ event occurs). On the other hand, when a EF0-1 tornado occurs (red bar graphs) , it is associated with no warnings 51% of the time (54% when EF0 event occurs), 47% of the time with a base tornado warning (45% when EF0 event occurs), and only 2% with an elevated tier warning (1% when EF0 event occurs).

What does this all mean? Approximately 90% of EF2-5 tornadoes are warned with a warning of any tier. This is also true for 98% of EF3-5 tornadoes. Roughly half of EF0-1 tornadoes are warned and most of those are warned with base tier warnings. The verification also found that forecasters underutilize enhanced tags and/or issue them late. While the vast majority of strong tornadoes are warned, they are mostly covered with base tier warnings and only 28% by elevated tier warnings. This increases to 47% of EF3-5 tornadoes. While 13% of all tornadoes are of the strong variety, elevated tags are included in just 5% of all warnings.

Finally, skill in specifically predicting EF2-5 and EF0-1s independently about the same as distinguishing a tornado from no tornado. However, when using near misses (that is, partial credit for EF1s in elevated tier warnings and for EF2s in base tier warnings) notable skill is evident in broadly distinguishing strong from weak tornadoes.

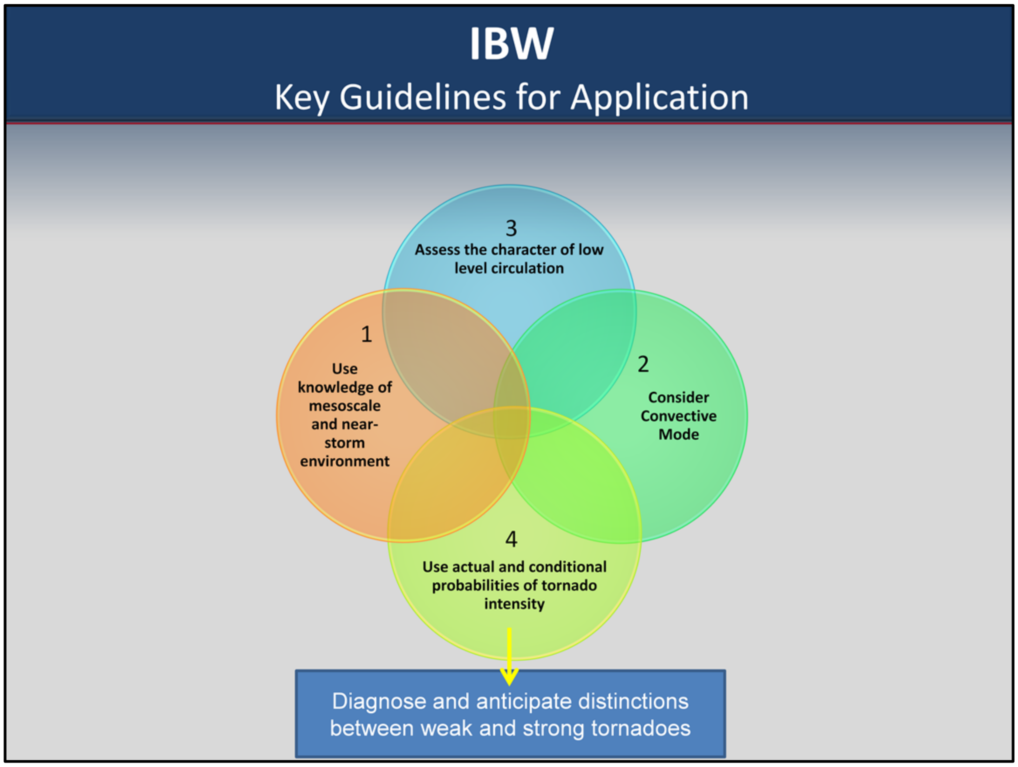


This SPC relational climatology by Smith et al from 2012, 2015 shows a significant relationship between increasing maximum 0.5 degree rotational velocity and increasing maximum EF scale of occurring tornadoes. The box and whiskers chart shown is for max low level rotational velocity signatures below 10000 feet and for supercell and marginal supercell convective modes. The light red is data from 2009-2013, while the blue is data from 2014 and includes rotational velocities from non-tornadic severe supercells.

The box and whiskers have standard configurations with the box bounded by the bottom of the 2nd quartile and top of the 3rd quartile - and the tips of the whiskers represent the 10th and 90th percentiles. The dash in the middle of each box is the median or top of the 2nd quartile. It is important to note that for each event the study recorded rotational velocities immediately prior to tornado touchdown until just prior to tornado dissipation.

Again, we are not trying to pinpoint tornado intensity by EF scale – just “ring the bell” a little louder for more significant tornado events. This chart shows why. You’ll note there is plenty of overlap in max low level rotational velocity associated with high end EF1 and low end EF2 – but you can also see there is little overlap between null events/EF0’s and EF3-5’s. Again, it won’t be unusual for an EF1 to occur on Elevated Tier Warnings, nor unusual for EF2’s to occur on Base Tier Warnings. We should avoid as much as possible having EF3’s or greater occur on Base Warnings or No Warning, and avoid EF0’s and Null events occur on Elevated Tier warnings. The graphic here certainly hints at some capacity for distinguishing between weak and strong tornadoes in that respect… and also hints at the viability of probabilistic approaches to the IBW warning process.

There is no perfect answer to the question of when to use a “considerable” tag, but that is rarely the case for anything in operational meteorology. Keep in mind that the value of your role in the warning decision process comes into play by staying situationally aware and considering a wide variety of factors to stay one step ahead of the tornado threat.



At this point we'll lay out some basic guidelines for distinguishing weak tornadoes from strong tornadoes. Essentially, there are 4 steps in the process which is diagnosing and anticipating the range of possibilities. First, use your situational awareness to assess the mesoscale and near-storm environments. Second, use your knowledge and understanding of convective modes and storm evolution as they relate to the environment. Third, use your understanding of the 4-dimensional character of radar-depicted mesocyclone circulations, especially the strength of low level rotational velocity, and 4thly, use your understanding of actual and conditional probabilities of tornado intensity (null vs. weak vs. strong) as related to low-level rotational velocity.

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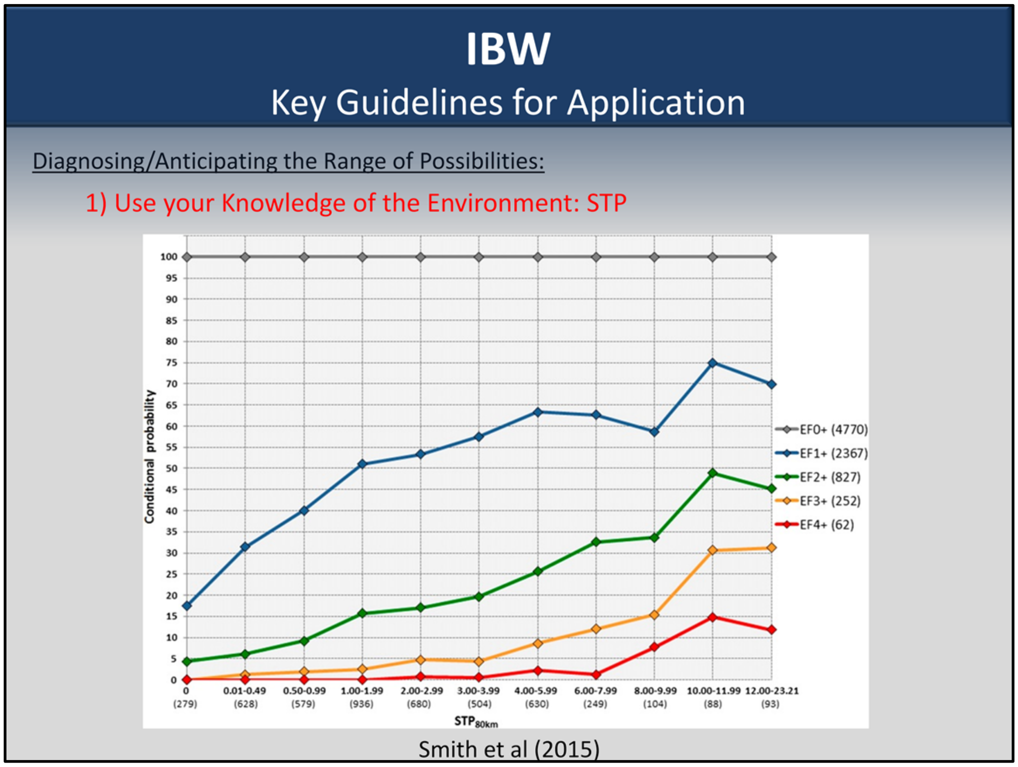

We'll first look at environmental parameters that serve as a baseline for determining the likelihood that strong tornadoes may occur in a given situation. The Significant Tornado Parameter (STP) 80 km is a multiple component parameter meant to highlight co-existence of low-level CAPE and shear which are crucial ingredients for right moving supercells. Based on past studies, STP exhibits greater skill in discriminating between nontornadic and significantly tornadic supercell environments compared to any of its individual components or any other parameters among the 38-variable database at the SPC.

There is a relational climatology between increasing **conditional tornado intensity** and increasing values of STP 80km as measured on hourly SPC mesoscale objective analysis. Results from examining environmental and radar attributes, Smith et al (2015) found that increasing conditional probability for greater EF-scale damage, both STP and 0.5° peak Vrot increase, especially with supercells. This figure shows conditional probability of meeting or exceeding a given EF-scale rating (for the 5 series shown in the legend) for STP 80km for all convective mode tornado events from 2009–13.

The conditional probabilities may give you an idea ahead of time on how aggressive you can be on potential considerable tornado tags during the warning process.

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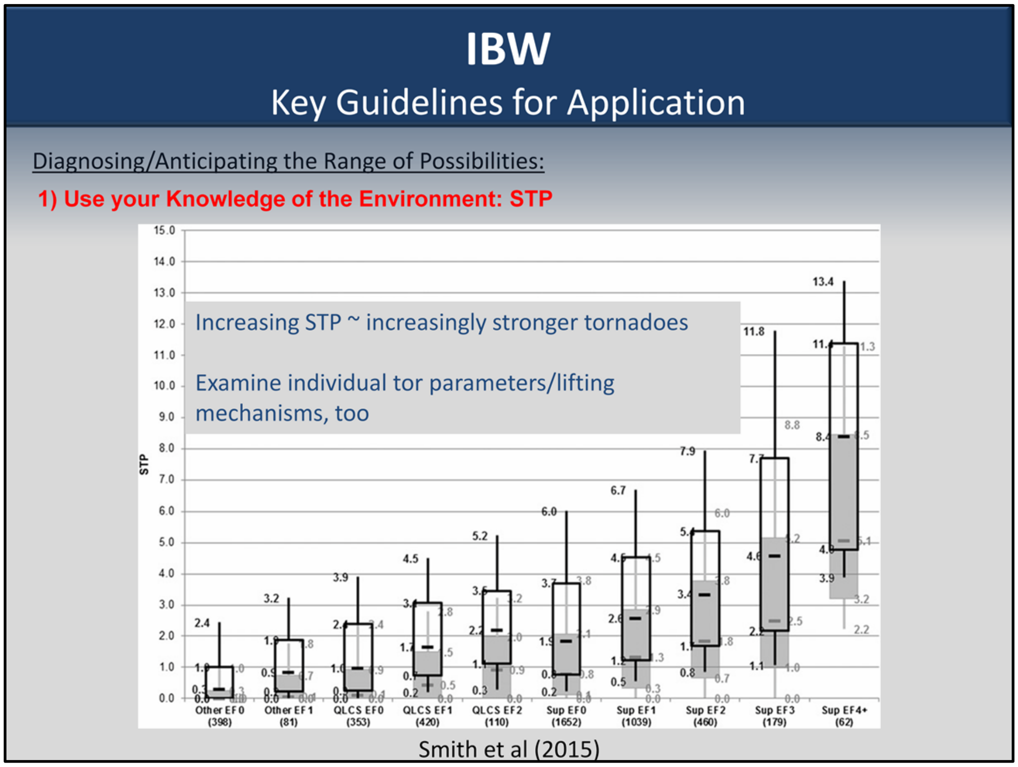
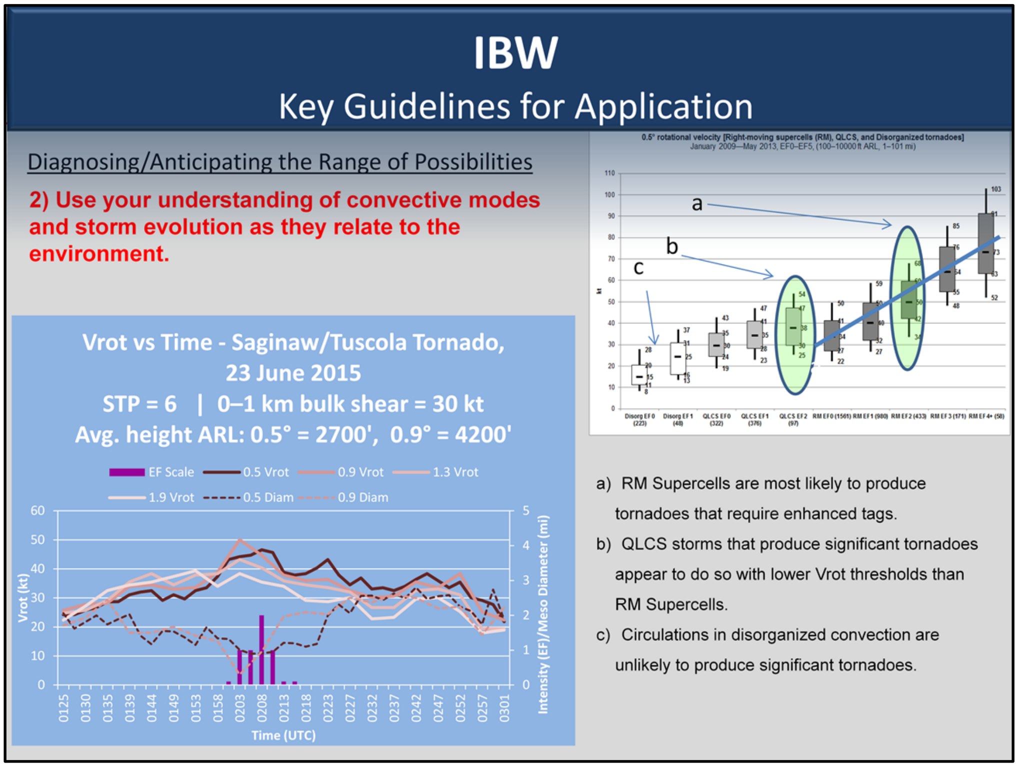


Next to further illustrate the relationship, here is a box and whiskers chart showing effective-layer STP (a dimensionless number) for all supercell, QLCS EF0–EF2 tornadoes, and other modes EF0 and EF1 tornadoes by EF-scale damage rating classes. The 40-km grid data are shaded gray, labels on right. The black overlays (with labels on left) denote STP 80 km grid point values, at the analysis time immediately preceding the event time. Using either the nearest STP grid point value or the neighborhood maximum value (which is the STP 80km) STP increases as tornado damage classifications increase. Supercell events tended to exhibit higher STP values than QLCS and other modes for the same EF-Scale damage rating. The STP for supercell, QLCS, and other modes tended to increase monotonically with increasing damage class ratings (aside from the 10th percentile). Substantial overlap exists in the distributions between adjacent EF-scale ratings, though the higher values of STP 80km (i.e., > 6) are more common for a greater proportion of supercell events at higher EF-scale rating classes (i.e., EF3+).

It must be stressed that composite parameters such as the STP 80 km should not be examined alone, but rather in concert with the individual components in the STP that identify important supercell tornado ingredients. Despite STP utility as a composite tornado predictor, there is no replacement for a thorough diagnosis of the mesoscale environment. You have to be aware of rapid storm interactions due to low-level boundary interactions which produce rapid tilting and/or stretching of local vorticity maxima. Also, closely monitor 0-1 km effective bulk shear, subsequent updraft helicity, and LCL heights < 1500 m AGL which are all important ingredients in the tornado development process.



Here we'll discuss convective modes and rotational velocity evolution, or Vrot evolution. The graphic on the left is a marginal supercell tornado example from a study by Frey and Thompson in 2015. It shows the time evolution of Vr at various elevation slices through a storm. It also shows the time evolution of mesocyclone diameter through the storm cycle. On this graphic you can see a broad peak in 0.5 degree Vr around 45 knots starting near the time of tornadogenesis and a 0.9 degree peak near 50 knots right before a brief EF2 occurrence. Also note the max Vr starts at higher elevation slices 1.3 and 1.9 degrees but shifts to the lower elevation slices just prior to tornadogenesis. Additionally note how the meso diameter tightens as we approach tornadogenesis. This is a nice presentation of how you can view the full time evolution of a circulation to help make a determination of tornado development and potential max intensity.

On the right side of the slide is the Smith et al. study breaking down max Vrot distributions vs. Max EF-Scale for each convective mode. Obviously, supercell modes have the strongest relationship and most strong tornadoes occur with these modes. On the opposite end of the spectrum, it is highly unlikely to have a strong tornado occur with weak disorganized convection. Last, it is interesting to note that strong tornadoes can occur with QLCS modes – but QLCS storms that do produce significant tornadoes appear to do so with lower Vrot values than RM Supercells. This possibly due to enhanced forward motion vector contributions on right flanks of low level circulations.

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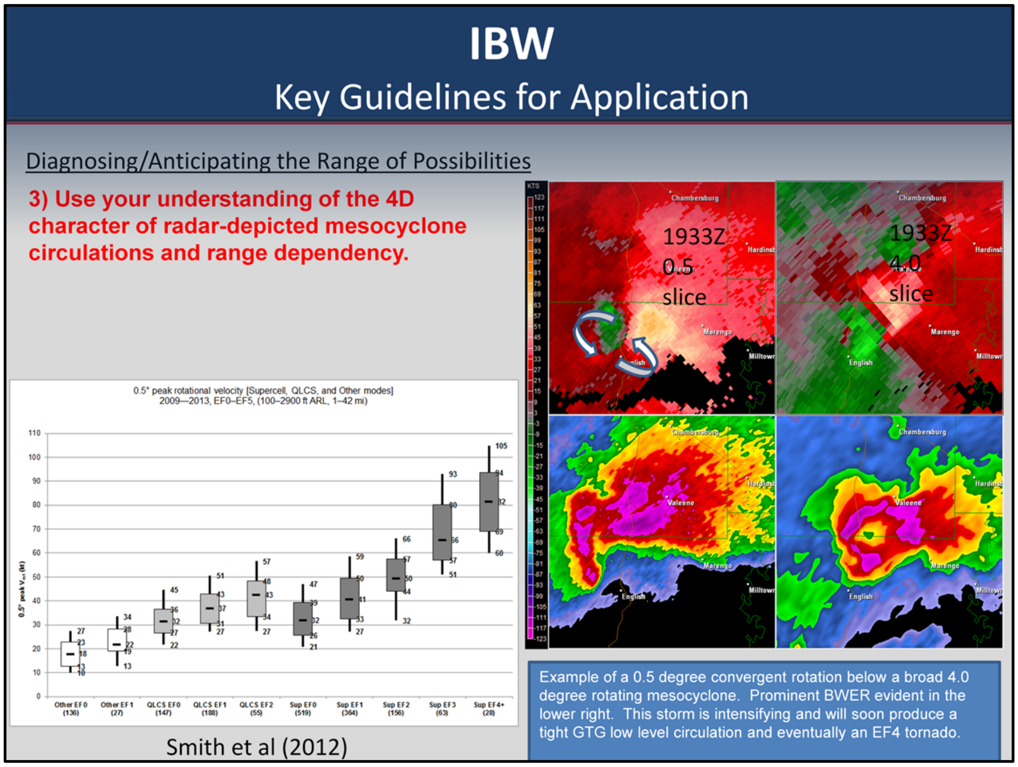

Thirdly, you must use your understanding of the 4-dimensional character of the radar-depicted mesocyclone and range dependency. On the right hand side of the screen is an example of how you should anticipate how convergent low level circulations will behave given the near-storm environment. The Smith et al study uses both broad Vrot maxima and Gate-to-Gate Vrot maxima, depending on which is strongest for a given case. It goes without saying that a Gate-to-Gate Vrot maxima should operationally command more weight and a lower Vrot probability threshold for EF2+ events. This example shows a 0.5 degree convergent rotation below a broad 4.0 degree rotating mesocyclone. Note the prominent BWER signature evident in the lower right. This storm is intensifying and will soon produce a tight GTG low level circulation and eventually an EF4 tornado.

On the left is the range dependency of the dataset. The relationship between Vr and EF scale is not as pronounced at longer ranges from the radar, and very pronounced at shorter ranges. Probabilities of tornado intensity increase as range from the radar decreases.

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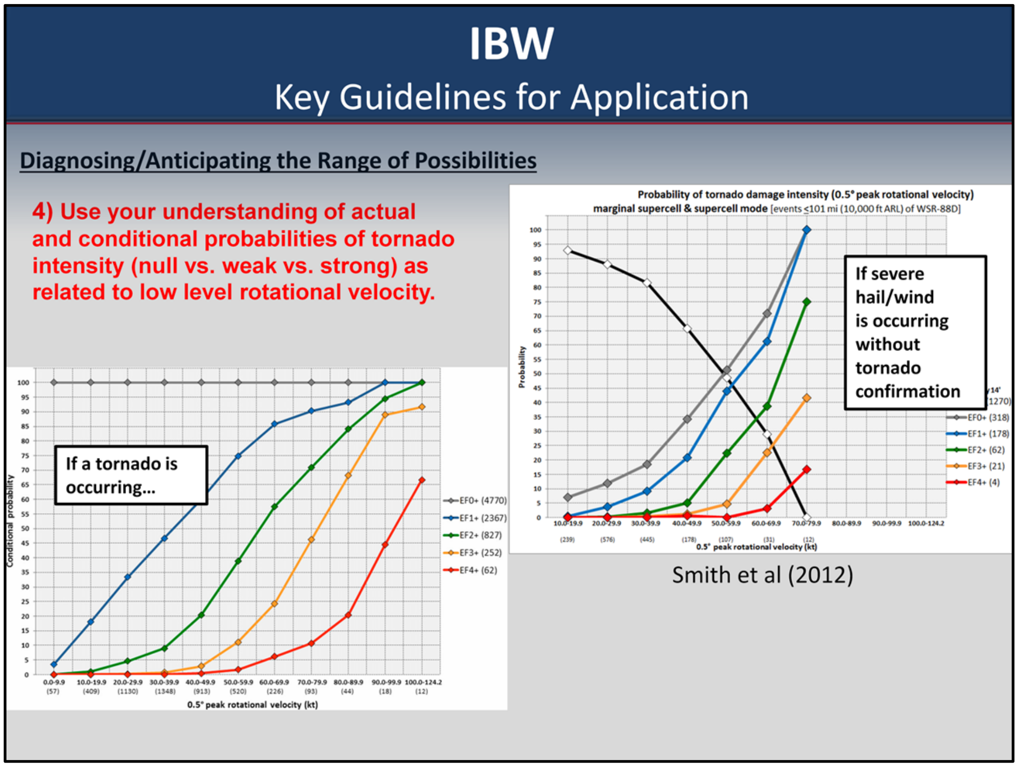

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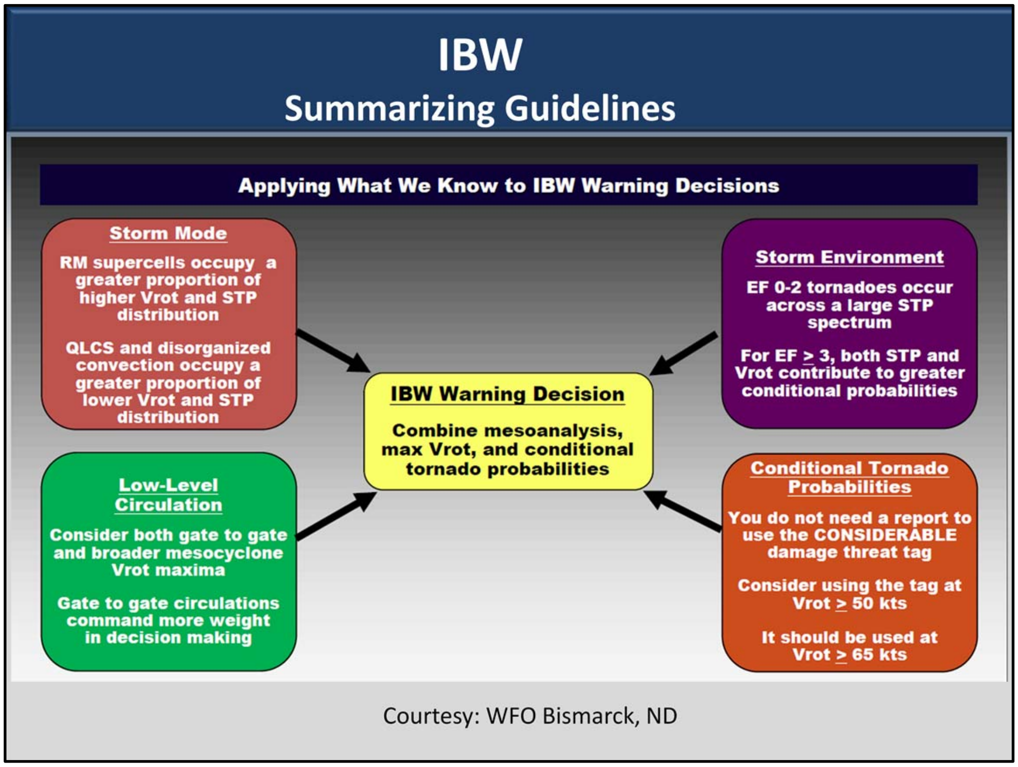

Here is a one-pager summarizing the various applications to IBW warning decisions, looking at environment, mode, circulation strength, and conditional probabilities. This summary comes from WFO BIS.

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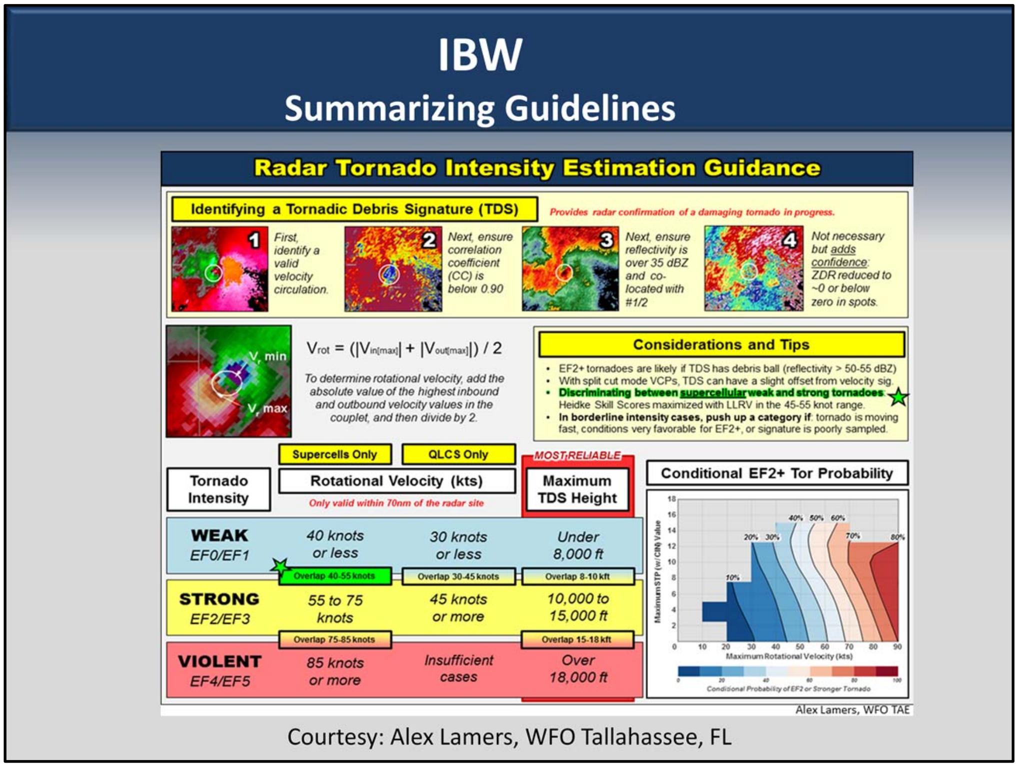

Here's another one-page summary from SR that's provides the most recent methodology of evaluating Tornado intensity using radar only signatures including TDS height. All of the considerations and tips are based on peer-reviewed papers. Notice the categories of Weak, Strong, and Violent Tornadoes somewhat coincide with the selection of no damage tag, considerable, and catastrophic.

IBW
Other Issues: Pathcasts

- Recall technical limitations:
  - Radar resolution and range
  - Placing the “Drag Me To Storm” dot correctly
  - Large/Irregularly shaped cities
- Meteorological Limitations
  - Non-Linear Storm Motion
  - Multiple Threats from a Single Storm

```
* THIS DANGEROUS STORM WILL BE NEAR...
  BONHAM STATE PARK AROUND 850 PM CST.
  BONHAM...ECTOR AND DODD CITY AROUND 855 PM CST.
  RAVENNA AROUND 900 PM CST.
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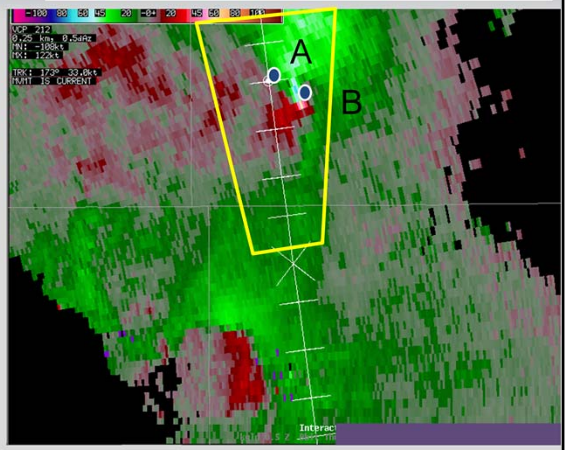
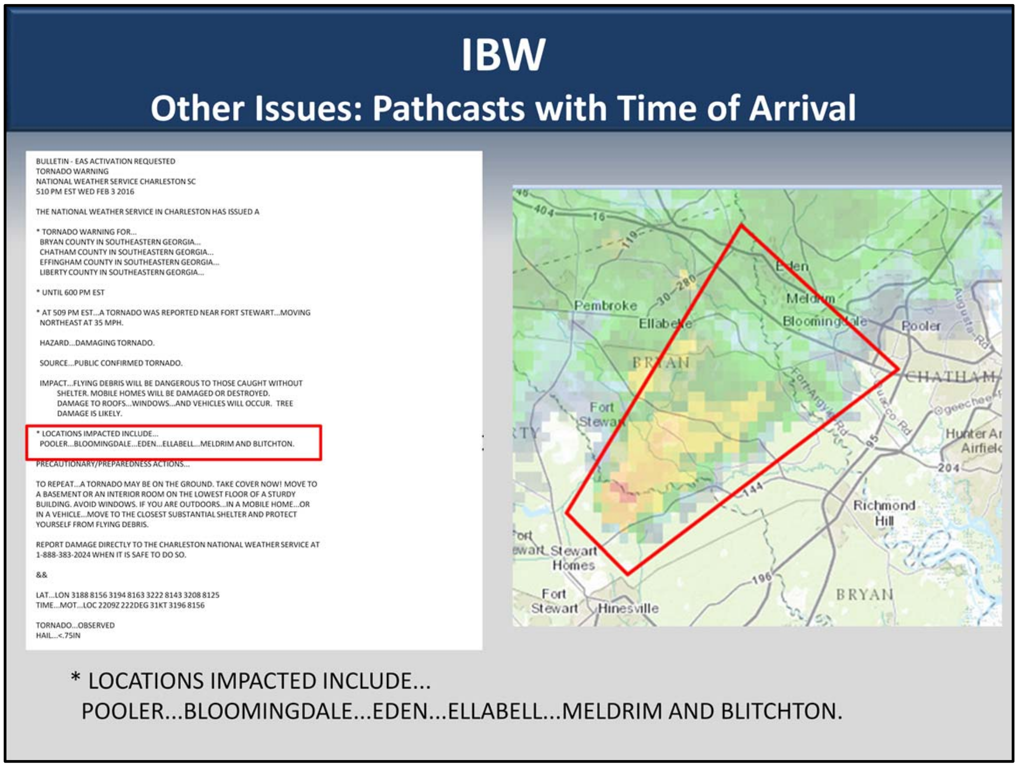


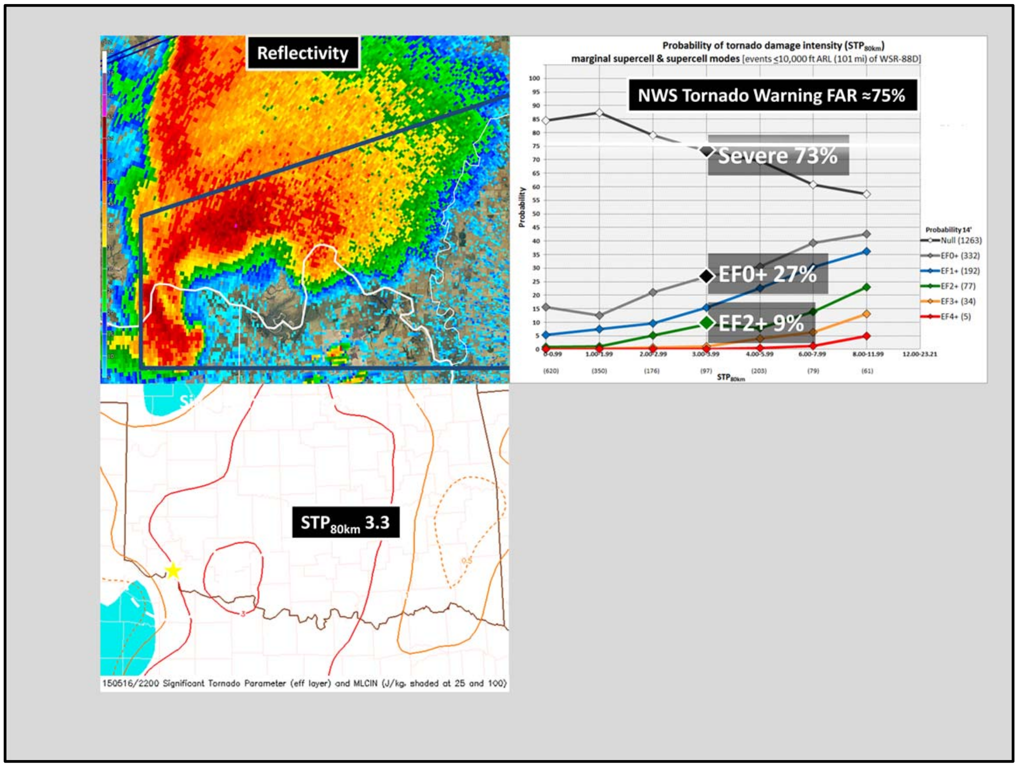
Town “A” is in the pathcast; Town “B” is not.

Since pathcasts are turned on with the default setting in WarnGen IBW templates, you will need to be very careful with using the time of arrival option version. Recall the technological limitations due to radar resolution and range, issues when you don't place the “Drag Me To Storm” dot correctly, and of course, all the problems caused in the shapefiles due to large and/or irregularly shaped cities. In addition, there are known meteorological limitations with using specific time of arrival locations in warnings such as non-linear storm motion, and conveying multiple threats from a single storm. Please review some of the specific best practices regarding the use of pathcasts at wdtd.noaa.gov.



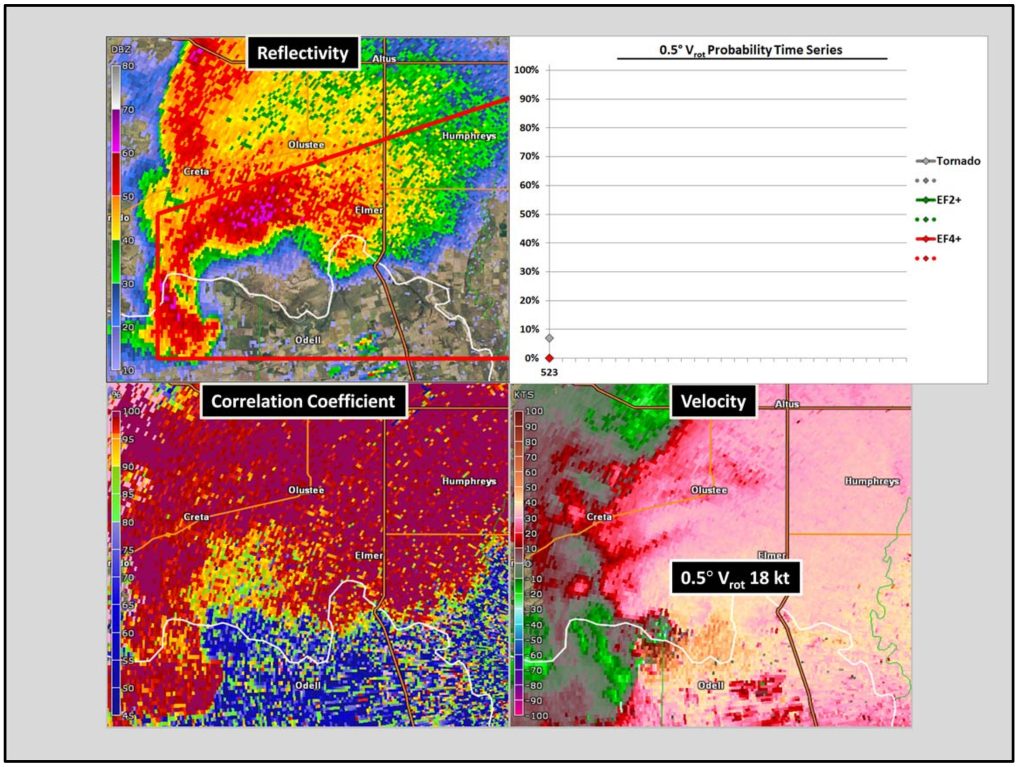
Some best practices of using pathcasts, as reiterated from previous storm-based warning training from WDTD are:

- Always keep your storm track vector accurate (this keeps your threat motion attributes in the best possible location)
- Issue frequent SVS updates (keep trimming back unnecessary areas)
- Configure your WarnGen customization files for the best local configuration of cities and towns to be included along a track.
- And finally, when in doubt about time of arrival, leave it out.

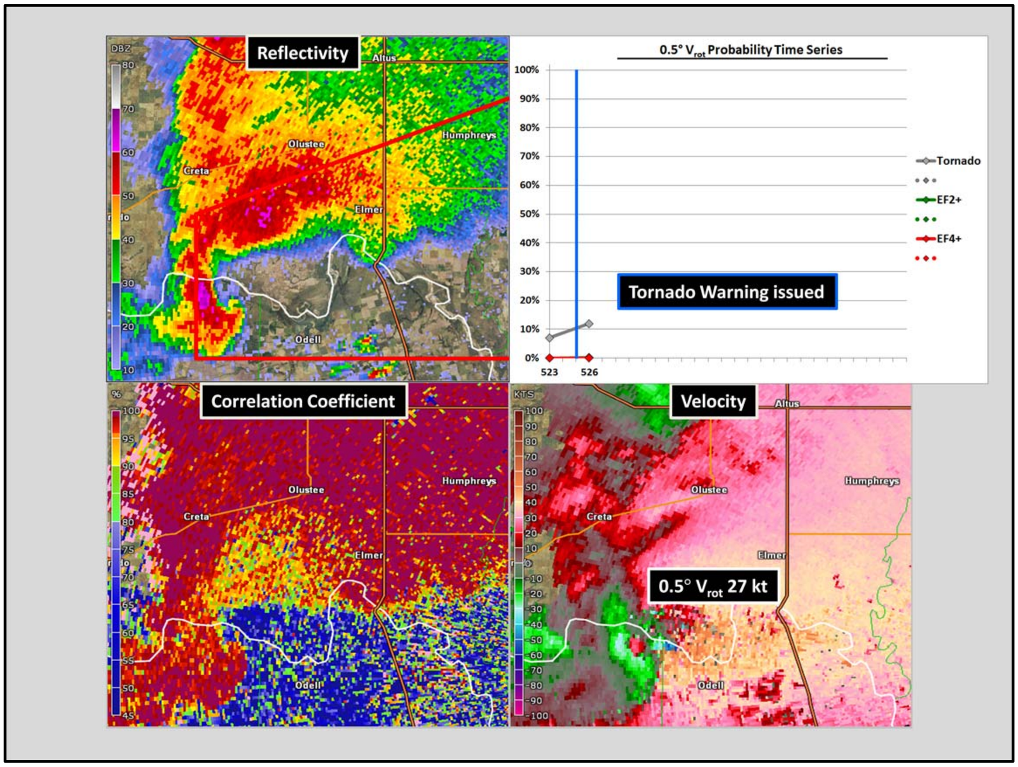


Finally, we're going to demonstrate a way in which the probability information can be applied. Only a few snapshots in the evolution of a tornadic storm are going to be shown for training purposes. Obviously more information would be available in a real-time setting and we recognize that the warning meteorologist is considering more than 0.5° reflectivity/velocity/CC data. Focus on the application of the probabilities and the resulting decision-making process. Keep in mind this is a basic example to illustrate how to apply the underlying concepts.

In this case, the STP is rather low and the probability of an EF2 or greater occurring in the region is quite low. There is an isolated supercell in southwest Oklahoma that will be the focus of the IBW decision. Distance to the radar is less than 40 miles, so 0.5 Vr relationships to EF-Scale potential are pretty reliable. Note there is already a SVR issued for this storm based on a detection of a severe updraft.



At 523 PM probabilities are very low and low level Vrot is pretty paltry. Nonetheless, strengthening was anticipated and a tornado warning was issued at 525.



At 525 PM the tornado warning is issued and by 526 pm Vrot was 27 knots and probabilities have risen slightly but are still pretty low.

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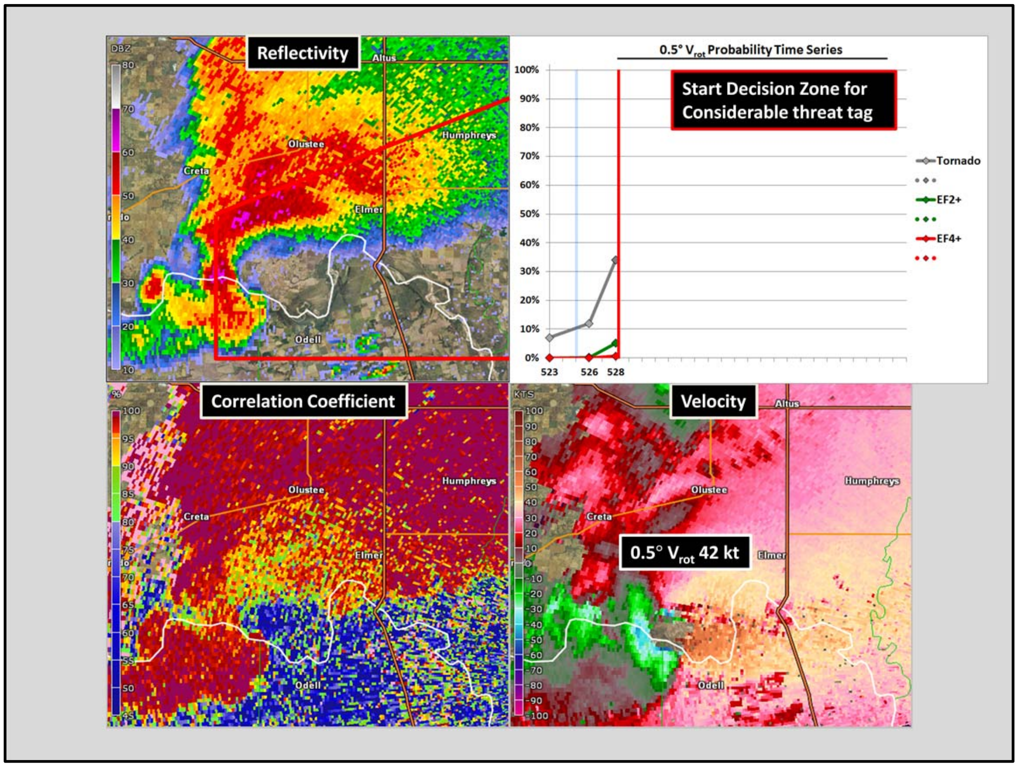
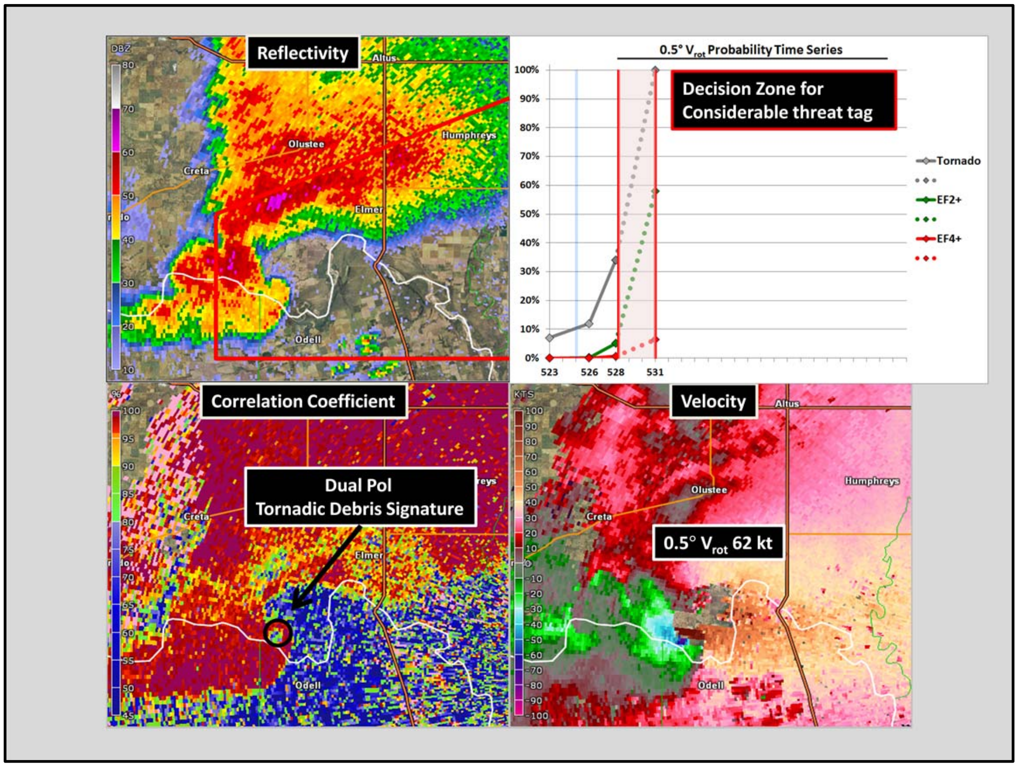
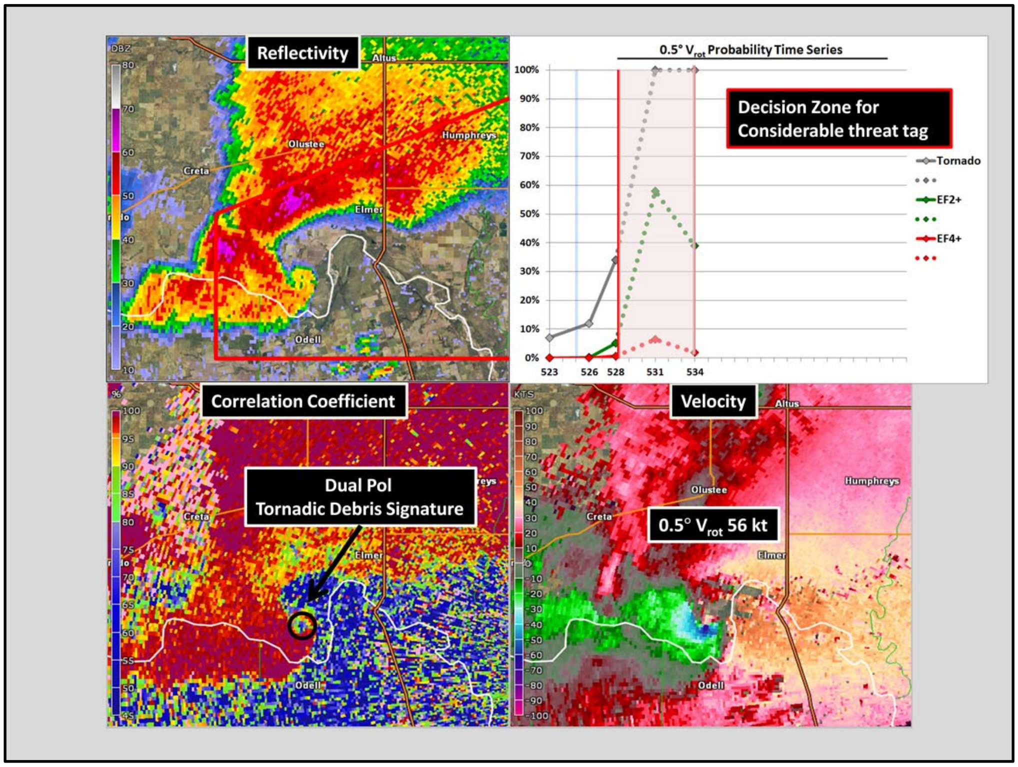


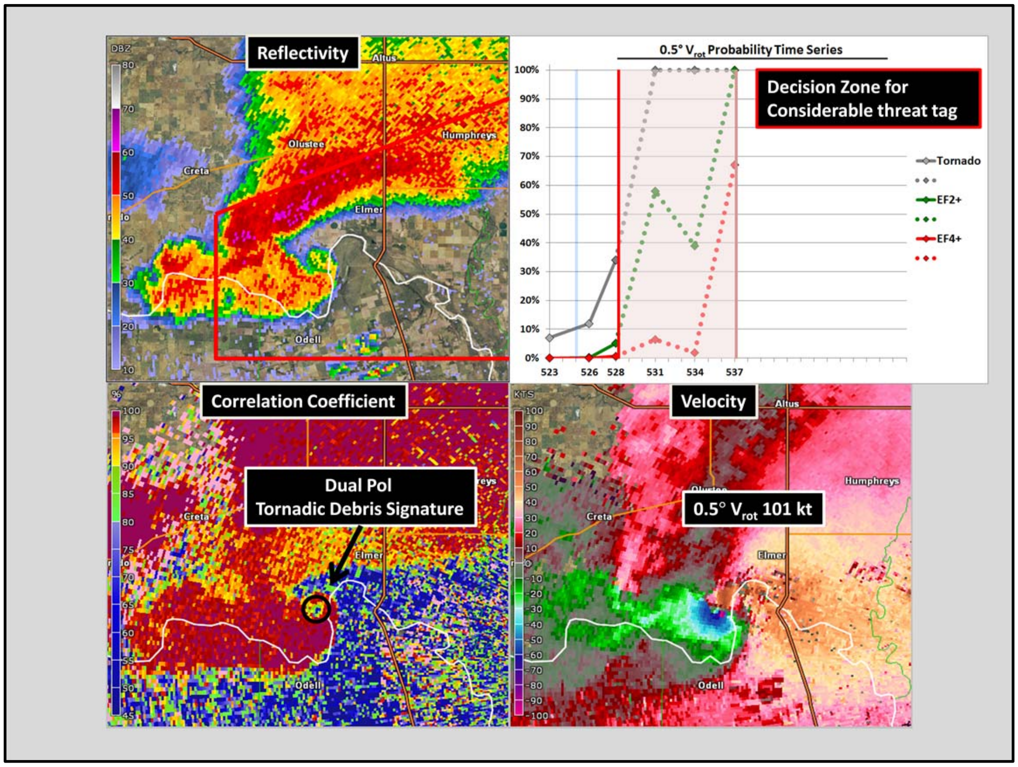
At this point, full attention should be paid toward the potential need for a considerable tag. Vrot is 42 knots and probability of a tornado is 35% and probability of a stronger tornado is 5%. Things are trending upward though and you should be anticipating very closely.



At the 531 PM CDT volume scan, the first sign of a CC minima is evident, at which point probability source should switch to the conditional probability graph. Vrot has risen substantially and quickly to 62 knots and the probability of a strong tornado has climbed to 60%. At this point the most likely outcome is an EF2 or stronger tornado. If you haven't already done so, a considerable tag upgrade is a likely choice.



At the 534 PM CDT volume scan, TDS signature continues with Vrot at 56 kt. If you haven't already done so, once again, the considerable tag upgrade is a likely choice.



At the 537 PM CDT volume scan, TDS signature continues with Vrot now up to 101 kts. If you haven't already done so, once again, the considerable tag upgrade is a likely choice.

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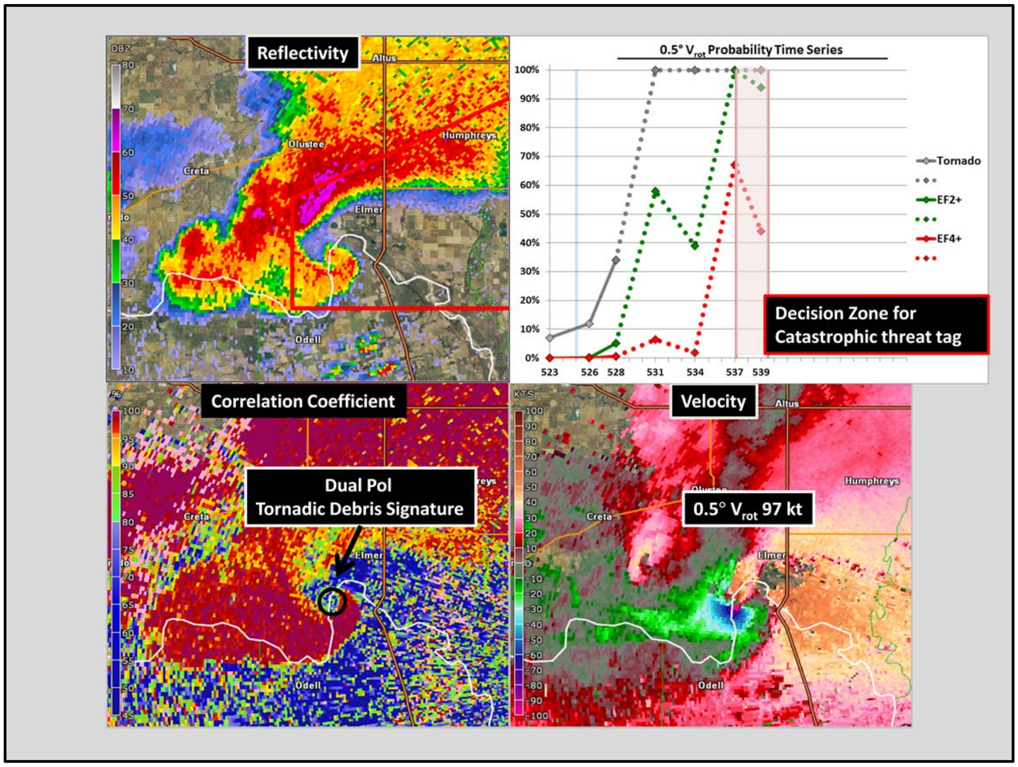
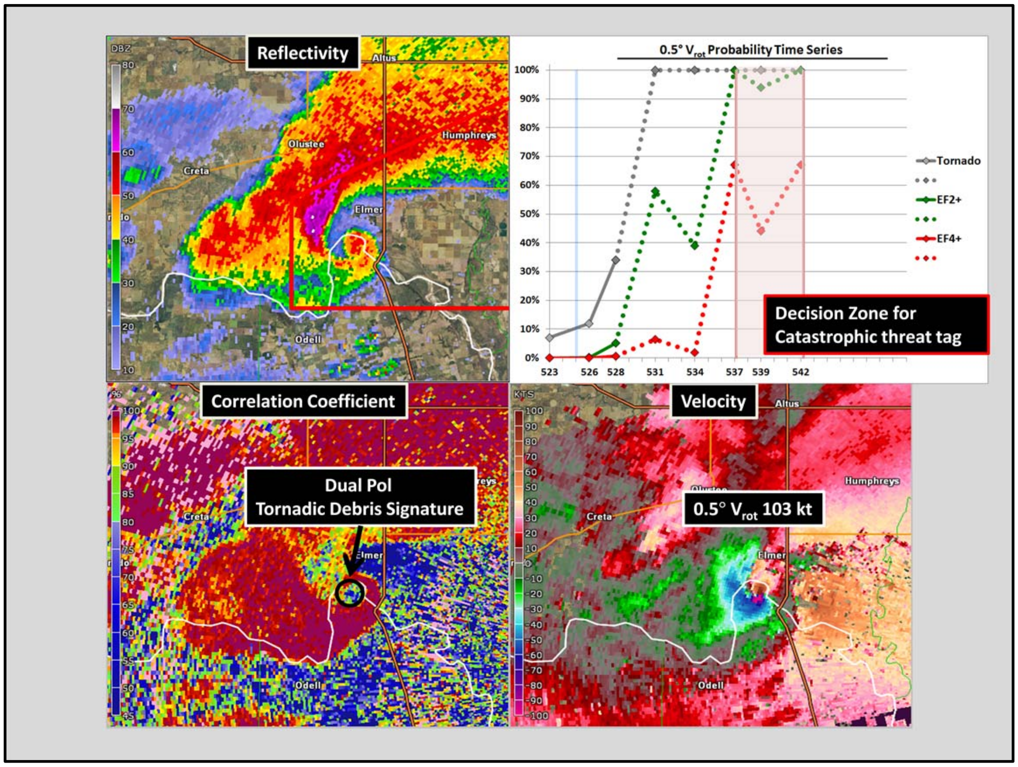


At the 539 PM CDT volume scan, TDS signature continues with Vrot now at 97 kts. As the tornado is approaching Elmer, you should start considering upgrading to a catastrophic threat tag.



At the 542 PM CDT volume scan, TDS signature continues with Vrot now at 103 kts. As the tornado is approaching Elmer, you should start considering upgrading to a catastrophic threat tag

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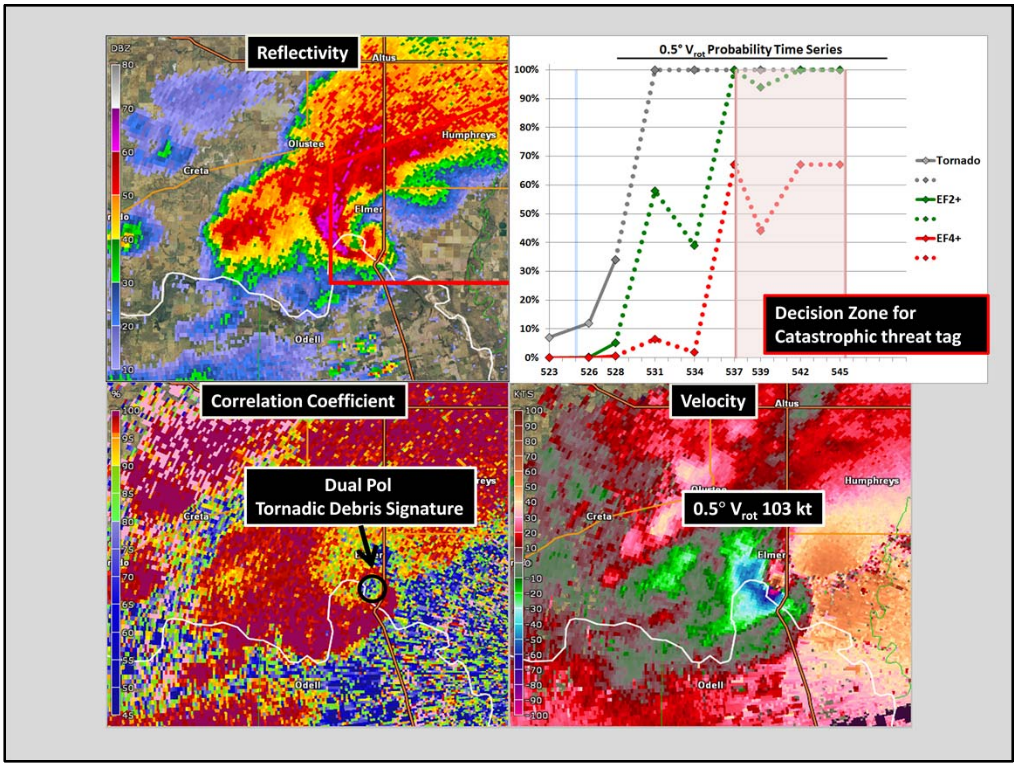

At the 545 PM CDT volume scan, TDS signature continues with Vrot still at 103 kts. As the tornado is entering Elmer, you should start considering upgrading to a catastrophic threat tag.

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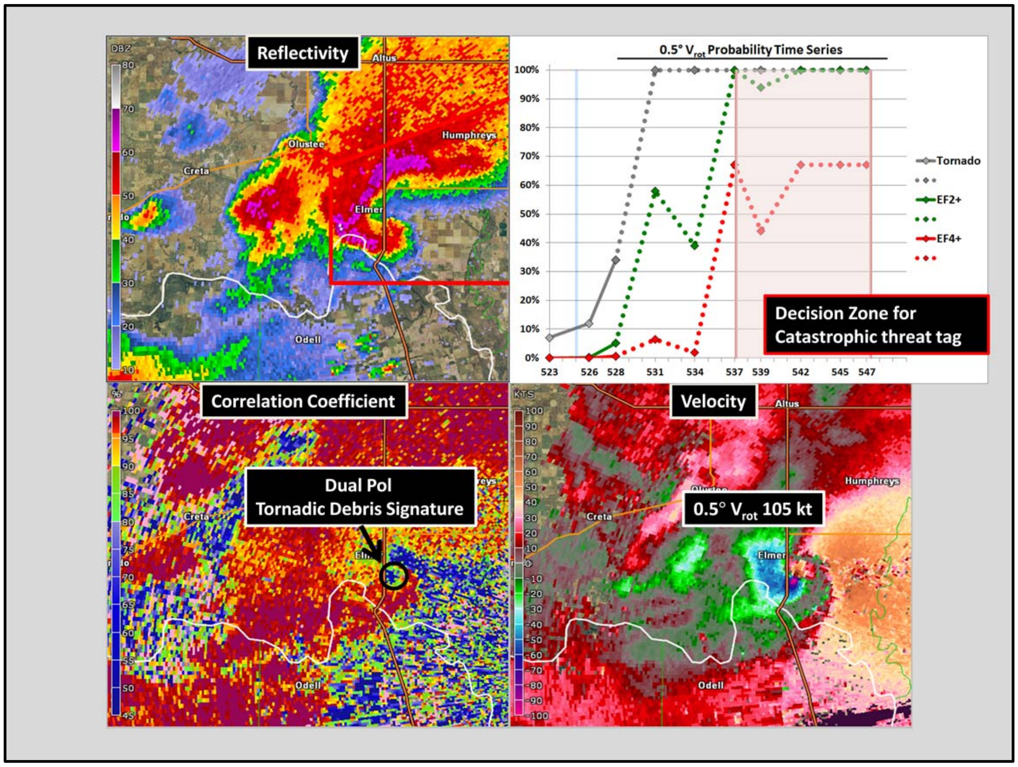

At the 547 PM CDT volume scan, TDS signature continues with Vrot up to 105 kts. As the tornado is entering Elmer, you are in the decision zone for considering a catastrophic threat tag.

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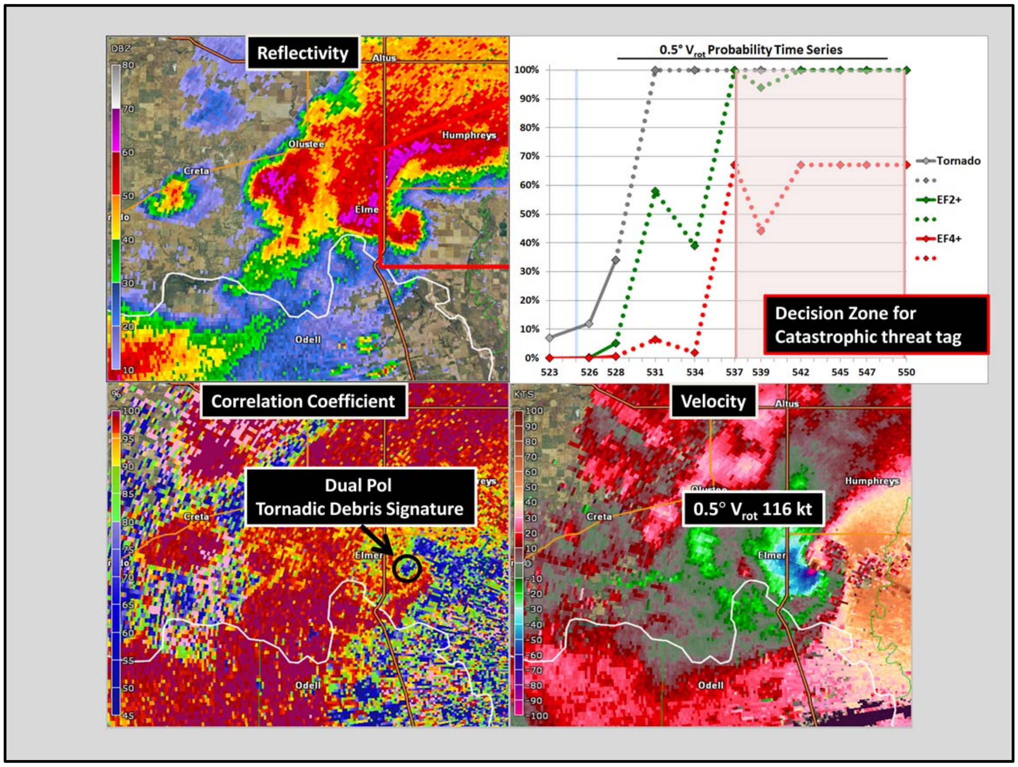

The 116 kt 0.5° V_{rot} is the 3rd highest of the super-resolution radar era (mid 2008–present). The Elmer, OK tornado was 1 mile wide and the sparse density of damage indicators yielded EF3 damage. The Norman Forecast Office in their damage assessment mentioned the tornado was likely violent (EF4+) based on video and radar presentation.

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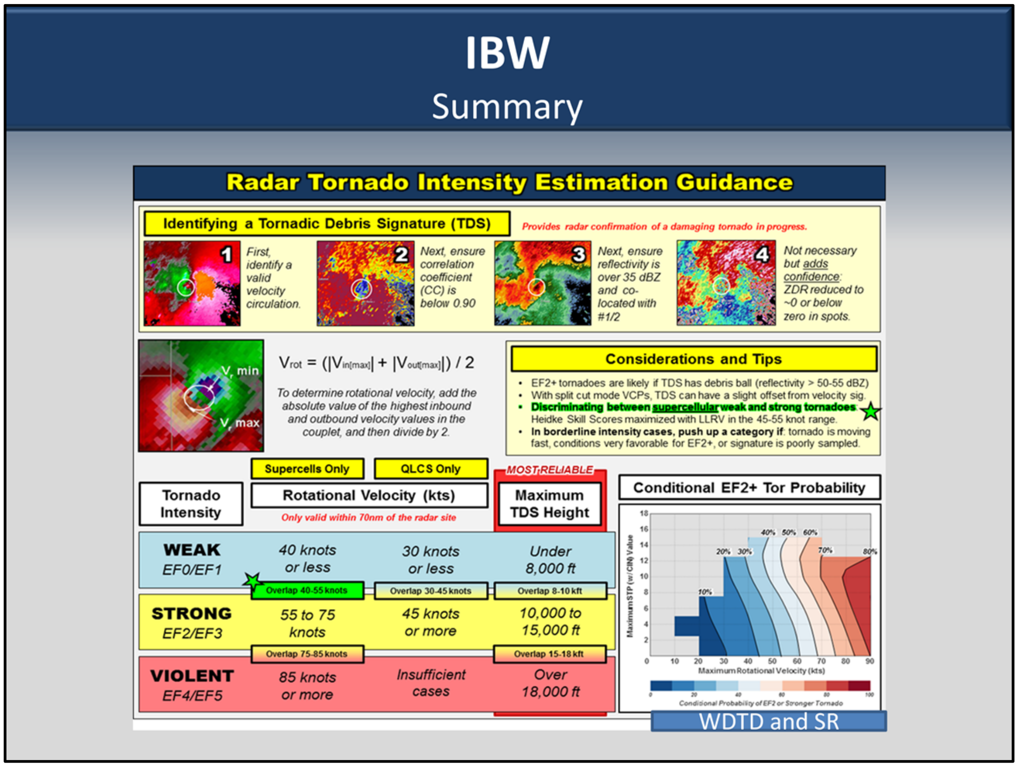

Finally, IBW is not just some half-baked policy update. The warning paradigm shift brought about by IBW is based on sound observational research which show a degree of skill in discriminating between tornado intensity. The use of STP along with other near-storm environment considerations, rotational velocity, and tornado debris signatures in a probabilistic sense should be used to develop your warning methodology to better anticipate and warn for situations where the most intense and destructive tornado events can occur.

A complete list of references used in this presentation are available at http://www.wdtd.noaa.gov/courses/ibw/references.php.