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USING AWIPS AND VORTEX FINDINGS TO FORECAST QUALITATIVE PROBABILITY OF SIGNIFICANT TORNADOES

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1. INTRODUCTION

One of the biggest challenges currently facing a National Weather Service operational forecaster is making an accurate warning decision for a potentially tornadic thunderstorm. The NWS WSR-88D radar has enabled forecasters to clearly observe mesocyclones within thunderstorms, but resolution of the actual tornado is seldom possible due to the relatively small scale of the tornadic circulation. The national false alarm ratio (FAR) for tornado warnings in 2001 was 72%, and the National Weather Service has identified the reduction of tornado warning FAR as a primary goal. Recent research results published by Dr. Paul Markowski and collaborators from VORTEX (Markowski et al., 2002) have given exciting new clues as to the possible ingredients for significant (F0-F1 lasting more than 5 minutes, and all F2 or greater) tornadoes. Many of these clues can be forecasted, directly observed, or inferred using AWIPS. Over the past 14 months, four significant tornado events have occurred within the Springfield, Missouri National Weather Service Forecast Office's county warning area, and all occurred in an environment containing the hypothesized necessary ingredients for significant tornadoes. This paper will review research results published by Dr. Markowski, and show how these concepts can be used in an operational setting via AWIPS.

2. TORNADO INGREDIENTS

Dr. Markowski and collaborator Erik Rasmussen have hypothesized that there are 3 primary ingredients necessary for tornado formation: a persistent, rotating updraft; enhanced storm-relative helicity; and the development of a relatively warm and moist rear-flank downdraft (RFD). While all 3 will be discussed, it is the development of a rear-flank downdraft with the special characteristics of being relatively warm and moist that is the mort recent finding from VORTEX and will receive the most discussion here

2.1 Development of a Persistent, Rotating Updraft

It has generally been accepted for a number of years that generation of a rotating updraft is the result of tilting and stretching of a horizontal vorticity tube into the vertical by an updraft.

The persistence of a rotating updraft can be tied to several features. First, the gust front along the edge of the RFD should not move too far away from the updraft. Large low-level ambient relative humidity is conducive to this. The proximity of the RFD to the updraft prevents the warm and moist inflow from being cut off. Second, most precipitation should be deposited well away from the updraft so as not to inhibit the updraft. Deep layer shear resulting in strong storm-relative winds has been shown to be an effective way to move precipitation out and away from the updraft.

2.2 Enhanced Storm-Relative Helicity

Only in rare cases is the meso-alpha scale storm-relative helicity (SRH) so large that locally enhanced SRH is not needed to generate significant tornadoes. Large outbreaks, where many supercells produce significant tornadoes, typically have background SRH at or above 300 m^2s^{-2} over the entire warm sector. It is not clear how much SRH is required for a supercell to become tornadic, in most cases however, tornadic supercells occur where SRH tends to be locally enhanced.

SRH is highly variable both spatially and temporally (Markowski et al., 1998a). Local enhancement of SRH can result from mesoscale boundaries such as convective outflow boundaries, anvil shadows (Markowski et al., 1998b), and the forward flank downdraft (FFD); acceleration of inflow parcels; and variations of vertical shear parameters

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due to small wind perturbations (wiggles in the hodograph). Of these, only mesoscale boundaries occur on the operationally observable scale. In VORTEX, two thirds of significant tornadoes occurred within 20 km of *conventionally detected* boundaries using platforms such as surface observations, satellite imagery, and WSR-88D imagery (Markowski et al., 1998c). This suggests that the operational forecaster can *infer* the existence of enhanced SRH near conventionally detected mesoscale boundaries.

2.3 Development of a Relatively Warm and Moist RFD

Research over the past several decades has shown that air parcels enter the actual tornado through the RFD. Observationally, the RFD has been equated with a radar indicated hook echo on the reflectivity product (Markowski, 2002). The hook echo is in turn co-located with the often observed clear slot, through which only a few large drops fall. It is important to note that not all hook echos result in tornadoes. In fact, VORTEX results showed many nontornadic supercells also had hook echos. This suggests that the WSR-88D reflectivity product may not give a clear picture in determining whether or not a supercell is tornadic.

Dual Doppler velocity data from VORTEX suggest that velocity fields also are not definitive in tornado detection. In addition, VORTEX mobile mesonet observations found that most mesocyclones actually exist all the way to the ground regardless of whether or not a tornado forms.

On a more encouraging note, the VORTEX results did show that most significant tornadoes had relatively warm and moist RFDs, while non-tornadic storms had RFDs that were relatively cold (low θ_v) as measured by the mobile mesonet. This relationship was shown to only have a .2% chance of occurring randomly. It is important to note that no differences were found between tornadic and weakly tornadic (F0-F1 lasting less than 5 minutes) supercells even with a dense mobile mesonet. It appears that even though these weak tornadoes account for 68% of all reported tornadoes (Grazulis, 1993), their detection is not possible using current technology. Fortunately, only 1% of all tornado deaths are caused by weak tornadoes (F0-F1).

While mesonets dense enough to measure θ_v in RFDs do no exist operationally, RFD buoyancy might be at least partially *inferred* based on conventional observations of surface-based dewpoint depressions. Observed dewpoint depressions in the storm inflow region during VORTEX showed a statistically significant relationship to mobile mesonet measured θ_v in RFDs. As dewpoint depressions in the inflow increased, RFD θ_v tended to decrease, and this seemed to be associated with a decreased likelihood for tornado genesis. Of course, in areas where convective inhibition (CIN) is large and dewpoint depressions are low (on the cold side of a boundary) sustained, surface-based upright convection and in turn tornadoes are very unlikely. It appears then that the dewpoint depression in the inflow seems to hold some promise for determining the buoyancy of the RFD *in a probabilistic sense*.

It is important to stress that the simultaneous occurrence of all 3 ingredients; a persistent, rotating updraft; enhanced storm-relative helicity; and a relatively warm and moist RFD is a very rare event. Dr. Erik Rasmussen has referred to tornadoes in many cases as "mesoscale accidents", and Dr. Markowski stated "We can't forecast significant tornadoes deterministically." Rotating updrafts can be observed, but enhanced SRH and buoyancy of the RFD can only be partially inferred through observations of mesoscale boundaries and dewpoint depressions.

3. AWIPS APPLICATIONS

AWIPS provides the operational forecaster the ability to examine numerical model output, WSR-88D data, and observations of the near-storm environment on one platform. Using these tools, the forecaster can examine the likelihood of occurrence of the 3 tornado ingredients, then in turn establish a qualitative probability of significant tornadoes.

3.1 Forecast and Detection of a Persistent, Rotating Updraft

Convective available potential energy (CAPE) is commonly used operationally as a measure of instability. CAPE, along with the strength of the deep layer wind shear, are tools a forecaster can use to estimate the potential intensity of convective updrafts. Numerical model forecasts of surface-based CAPE are available on AWIPS every 3 hours for the Eta Model out to 60 hours, and every hour for the RUC Model out to 12 hours.

Observations of CAPE on a regional scale based on satellite soundings in cloud-free areas are available on AWIPS. On the state scale, the Local Analysis and Prediction System (LAPS) from the Forecast Systems Laboratory gives hourly graphics of CAPE and CIN. The LAPS products are based on satellite data, ground-based observations, profilers, WSR-88D data, and numerical model initialized fields.

Forecasts of storm-relative helicity are commonly used by operational forecasters to determine the potential for persistent rotation in convective updrafts. The Eta Model yields graphics on AWIPS of 0-3 km storm-relative helicity every 3 hours out to 60 hours.. The helicity is calculated based on the Bunkers method (Bunkers et al. 2000). It is important to emphasize that this should be viewed as a background value. As stated before, it is rare that SRH will be sufficient (>300 m^2s^{-2}) over a wide area to generate significant tornadoes. Usually some type of local enhancement of SRH is needed.

Observed background SRH is available hourly on AWIPS via LAPS, however predicted storm motion is typically20 degrees or more to the left of storm motion calculated by the Bunkers method. This commonly leads to an underestimation of SRH as compared to SRH produced by the ETA.

On the storm scale, the WSR-88D has 4 algorithms for detection of rotation. Uncorrelated shear is defined as a 2 dimensional feature with no vertical correlation. The 3D correlated algorithm alarms when 2 or more vertically correlated 2D features are detected, but only one is symmetrical. A circulation will trigger a mesocyclone alarm when 2 or more vertically correlated, symmetrical elements are detected. The TVS (tornado vortex signature) will alarm when a 3D circulation exceeds a minimum threshold of gate-to-gate shear and has a base located on the 0.5 degree slice or at least 600 m AGL. The circulation depth must be at least 1.5 km, and the maximum gate-to-gate ΔV detected within the circulation must be at least 36 ms^{-1} or at least 25ms^{-1} at the circulation base.

3.2 Inferring Enhanced SRH

As stated in section 2.2, enhanced SRH can be *inferred* from observations of mesoscale boundaries. Outflow boundaries can often be detected as thin lines on the WSR-88D 0.5 degree reflectivity product; cumulus lines on visible satellite imagery; and surface temperature, dewpoint, and wind discontinuities on LAPS graphics. Spin-down time for enhanced SRH on an outflow-induced baroclinic boundary will vary according to stability, but for typical boundary layer atmospheric viscosities, enhanced SRH can exist for several hours after the thermal gradient has dissipated.

3.3 Inferring the Presence of a Relatively Warm and Moist RFD

VORTEX results have shown that the buoyancy of the RFD is an important ingredient for the genesis of significant tornadoes. Data from the VORTEX mobile mesonet was used to establish a statistically significant relationship between RFD θ_v and conventionally measured surface dewpoint depressions. It follows that conventional observations of dewpoint depression might allow the operational forecaster to infer RFD buoyancy and that forecasts of RFD buoyancy might be inferred through numerical model predictions of dewpoint depression. AWIPS allows one to display forecasts of surface dewpoint depression every 3 hours.

Hourly observations of dewpoint depression in AWIPS are available through the MAPS Surface Analysis System (MSAS). The MSAS analysis combines the previous analysis as a first guess with current surface observations including ASOS, any mesonets (through LDAD, a local ingest into AWIPS), and profilers. In data sparse areas, the Eta Model forecast dewpoint depression is used as a first guess.

4. CASE STUDIES

Four severe weather events containing significant tornadoes have occurred over the past 18 months within the county warning area covered by the Springfield, Missouri National Weather Service Forecast Office. Archived data from these cases show that in each case, the ingredients for tornadogenesis discussed here were present. The chart below lists these values, and in all cases dewpoint depressions were below 10^0F, possibly indicating a more favorable environment for a relatively warm and moist RFD.

Event	F-scale	CAPE	DPD	SRH
11/23	F2	400	5-9 F	400
4/27	F2	2000	5 F	400
8/12	F1	1500	7 F	150*
12/17	F2	1000	7 F	500

* An outflow boundary was present

It is possible that a source of enhanced SRH was necessary in only the 8/12 case, since background SRH was very high (>300 m^2s^{-2}) in the other cases. The 8/12 case involved a storm that crossed a well-defined outflow boundary and then merged with another larger storm. Shortly after crossing the outflow boundary, a strong mesocyclone and then a tornado formed.

5. SUMMARY

Results from VORTEX, together with previous research, have led Dr. Paul Markowski and collaborators to hypothesize that 3 key ingredients are necessary for genesis of significant tornadoes (F0-F1 lasting more than 5 minutes and all F2 or greater): a persistent, rotating updraft; enhanced storm-relative helicity; and the development of a relatively warm and moist rear flank downdraft. The WSR-88D is an effective tool for detection of persistent, rotating updrafts, however both enhanced storm-relative helicity and relative buoyancy of the RFD are not observable features using current observational systems. Fortunately for operational forecasters, AWIPS makes it possible to infer these quantities through observations of related features. Existence of enhanced storm-relative helicity can be inferred near mesoscale boundaries, and existence of a relatively buoyant RFD can be inferred through observations of low dewpoint depressions.

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