**P15.13 DETECTION OF HAZARDOUS WEATHER PHENOMENA USING DATA ASSIMILATION TECHNIQUES**

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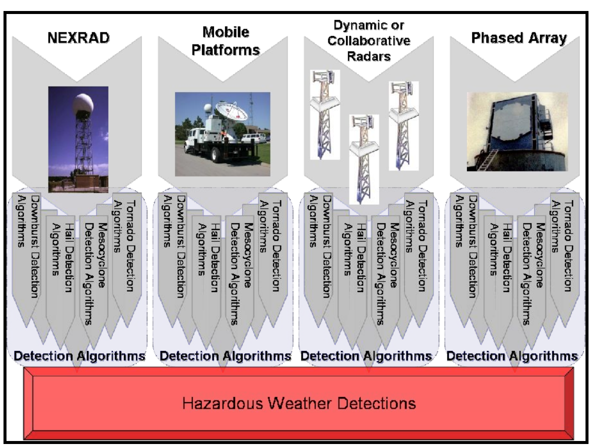
## 1. INTRODUCTION

Currently, the most widely used paradigm for the automated detection of tornadoes and other hazardous weather events involves identifying patterns in Doppler radar reflectivity and velocity data. The patterns include gate-to-gate shear, strong convergence oriented in lines, descending areas of high reflectivity, etc. The Warning Decision Support System-Integrated Information (WDSS-II), a highly developed detection suite by the National Severe Storms Laboratory, uses this general methodology, incorporating near storm environment analyses for hail detection, satellite data for clutter suppression, and a variety of other advanced tools. The major limitation of tools such as WDSS-II, however, is that new detection algorithms must be created, or existing ones adapted, each time a new observation system is deployed (e.g., TDWR). Further, they operate principally on data directly measured by the sensor (e.g., radial velocity and reflectivity) and thus cannot make use of fine-scale fields that are potentially available (e.g., pressure deviation and temperature fields within the storms). Finally, such systems are limited in their ability to synthesize data from other observing platforms in a dynamically consistent manner.

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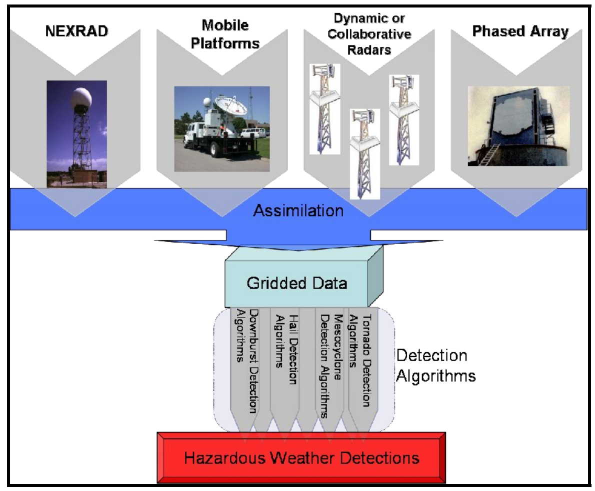


Figure 1: Block diagrams of a) the current detection paradigm (top) and b) the paradigm introduced by detection through data assimilation and gridded data sets (bottom). Note the number of detection algorithm sets in each.

An alternative approach that has the potential to overcome these limitations involves using advanced data assimilation and retrieval techniques, applied to all available observations – especially those collected at fine scales by Doppler radar – to generate dynamically consistent, 3D gridded analyses of all key observed and unobserved meteorological quantities to which detection tools can be applied. The potential advantages include the ability to interrogate quantities not available from radar data alone and the use of geometrically simple 3D grids.

A great deal of motivation for this project lies in the fact that, in the current detection paradigm, a new set of algorithms must be developed for each new observation platform (Figure 1a). Scientists and engineers need to continue developing and maintaining a set of detection algorithms for each individual radar system, as many hazardous weather features will be detected differently by each. If data assimilation is utilized, and a physically consistent 3D grid of the observations from all platforms is produced, only one set of algorithms is needed to perform detection on the gridded set (Figure 1b). Deployment of a radically new observation system would then require only a new assimilation process, but the current detection algorithms can be employed just as before. In addition, the incorporation of data from other observing systems improves the quality of the analysis.

Another significant motivation rises from current detection algorithms being based on the radar data (e.g., reflectivity and radial velocity), not the physical structure of the storm. For example, a tornado/parent mesocyclone will look very different when viewed by a WSR-88D with a gate size of 1km, as supposed to a mobile radar with a gate size of 50m. In many cases, vortex detection (mesocyclone and tornado) is performed simply by comparing velocity of one (or more) gate(s) with the velocities of its(their) neighboring gates, and correlating those shear zones with ones at different elevations, identifying regions of vertically contiguous rotation (e.g., Mitchell et al. 1998). However, if data assimilation through the use of an ensemble Kalman filter is performed, environmental parameters are developed through optimal combinations of model physics and observations, allowing for retrieved fields such as temperature, and environmental winds (Dowell et al. 2004). Additional state variables such as pressure, vorticity, various water mixing ratios, etc. allow for a much more physically-based detection of hazardous weather. In addition to estimating the environmental state, the filter also allows for estimation of model and observation error covariances, providing even more information when considering the state variables.

To examine the tradeoffs in hazardous weather detection between conventional sensor-based algorithms and the potential of applying algorithms to assimilated, gridded analyses, we compare detections produced by WDSS-II to features in analyses that are generated using ensemble Kalman filtering for an observed tornadic storm that occurred on 29 May 2004 and that was observed at reasonably close range by NEXRAD radar.

## 2. METHODOLOGY

We seek to explore the value added to hazardous weather detection through the use of assimilated data sets. To do this, we have decided on performing several case studies on supercell events, where a wide variety of hazardous weather occurred. Initially, we will compare detections produced by automated algorithms to features in assimilated analyses that are generated using ensemble Kalman filtering for an observed tornadic storm that occurred on 29 May 2004 and that was observed at reasonably close range by NEXRAD radar. This case was chosen for several reasons, including that it consists of a well-observed, cyclic supercell that produced large hail, high winds, and at least 16 tornadoes of varying intensity in its approximately nine hour lifetime. Comparison between detected features in WDSS-II and features manually identified in the assimilated analyses, and their subsequent relation to surveyed ground truth data will allow for a good assessment of relative skill of hazardous weather phenomena detection.

In exploration of a “simple” case, such as that of a well developed supercell thunderstorm, we hope to make use of several resources not available for other, less-detectable tornado cases. First, we want to demonstrate the ambiguity in current detection algorithms, both in placement of the detection and in the number of detections, in cases where the tornado location is already relatively well-placed by current detection algorithms. Second, we want to analyze the assimilated analysis for features common in tornadic suprecells. Third, we want to demonstrate the potential for reduction in ambiguity of tornado detections with the use of additional data made available through the assimilation process. Finally, the behavior of the assimilation system being used has been well-tested, and we know how well it will perform. Introducing more marginal cases may require more work on the assimilation system and modifications of it's forward prediction component, which is well beyond the scope of this study.

The general EnKF data assimilation procedure that produced the results seen in the following section (along with more in-depth analysis of retrieval performance) are described in detail in Tong and Xue (2005). Major differences include a reduction here in the radius of influence to 6km and a decrease in ensemble members to 40. The forward-prediction component of the assimilation is provided by the Advanced Regional Prediction System, a compressible non-hydrostatic model. A full description of the model physics and performance are available in Xue et al. (2000, 2001).

The initiation of the forward-prediction component of the simulation consisted of a horizontally homogeneous grid, with initial conditions provided by a single sounding from KOUN (released at 0000 UTC). For this study, the ARPS model was configured to run in 3D cloud model mode.

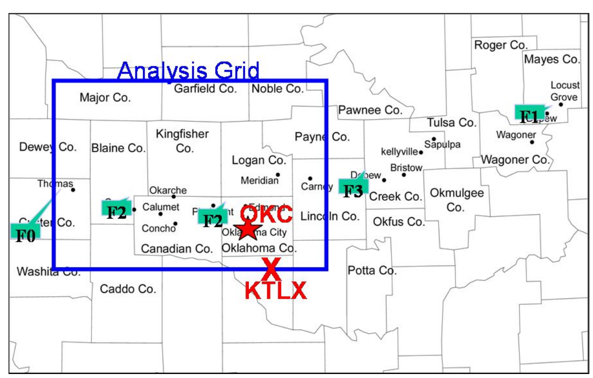


Figure 2: The analysis area used in this May 29th, 2004 case study. Tornado touchdowns, and the location of Oklahoma City and the KTLX radar are provided.

The analysis grid is 180km by 120km by 16km, with a horizontal grid spacing of 1km. The analysis is performed for a 60 minute period, with reflectivity and radial velocity observations from the KTLX WSR-88D assimilated every five minutes. The state RMS error becomes tolerable after about 60 minutes of observation, so that is the time we will be considering (0100UTC, 8pm CDT) in our comparisons.

## 3. RESULTS

At the times being considered (~0100 UTC), the supercell is fully mature, has already produced multiple tornadoes, and is about to produce an anticyclonic tornado at 0105 UTC. An occluded mesocyclone has moved tword the rear of the storm and is no longer discernible on radial velocities or on the assimilated data. However, a new and very intense anticyclonic rotation is maturing and is associated with the main storm updraft. This is what spawns the anticyclonic tornado minutes later.

Figure 3: WDSS-II display of reflectivity with overlay of Tornadic Vortex Signatures (yellow and red triangles). Time is 0102 UTC.

Figure 3 shows the WDSS-II display of reflectivity at a 0.5 degree tilt at the time 0102 UTC. Overlaid are the detections of Tornadic Vortex Signatures. Note that there are five individual signatures, but there is only one tornado imminent. This is where we hope to improve on detections by narrowing down areas of potentially hazardous weather through the use of retrieved fields. Instead of relying on only shear regions, we could consider placement of baroclinic zones, vertical vorticity maxima (and in this case minima), updraft maxima, and pressure deviations all in relation to one another, indicating the most likely area for tornadic development.

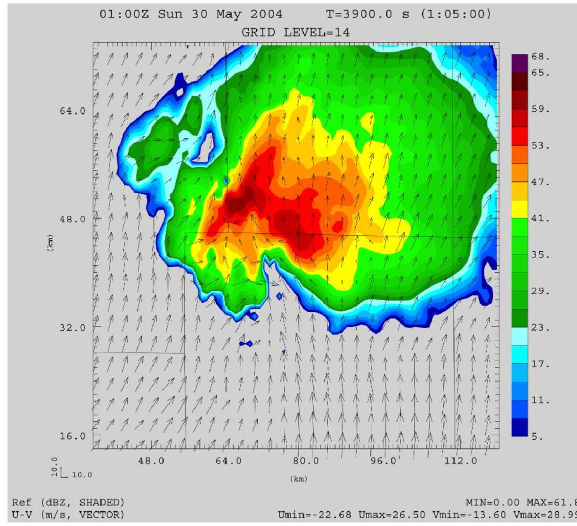


Figure 4: Cross-section of radar reflectivity derived from the assimilated data. Note the structure as compared to that displayed in figure 3. Time is 0100 UTC.

Comparing figures 3 (actual reflectivity from KTLX) and 4 (reflectivity derived from assimilated storm) reveals very similar structure. Of major importance is placement of the hook, and expanse of the forward-flank and rear-flank precipitation cores. The assimilated storm must have these features in proportion; otherwise we can assume low-level baroclinic zones and thus the storm's structure is erroneous. The assimilation, in this case, displays characteristics very close to the NEXRAD observations.

We now examine the assimilated analysis to see what sort of features are apparent. The initial assumption was that a vorticity maximum (or in this case a minimum) would indicate an area of rotation, and discriminating true, longer-lived mesocyclones or tornadoes, versus more transient phenomena such as gustnadoes, would involve those maxima or minima associated with a significant updraft. This signature is very evident (Figure 5), and is actually the first indication that the imminent tornado was anticyclonic (we initially thought there was some sort of error because the negative vorticity was associated with the updraft, but later review of damage surveys and storm reports indicated this tornado was actually anticyclonic).

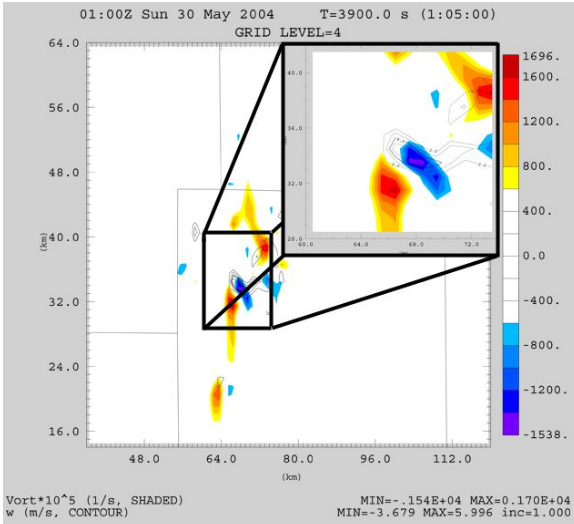


Figure 5: Low-level cross-section of vertical vorticity with overlaid contours of strong positive vertical velocities (updrafts). Note the strong updraft is associated with negative vorticity, indicating a anti-cyclone. Several minutes later a anticyclonic tornado touched down. Time is 0100 UTC.

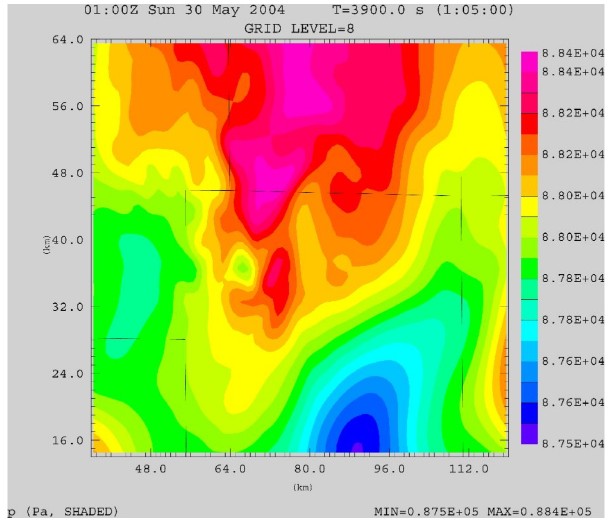


Figure 6: Low-level cross-section of pressure with. Placement of the local minimum in pressure is in agreement with placement of the main anticyclonic updraft. Time is 0100 UTC.

Further interrogation of the data involved considering the structure of typical supercells and ways to pinpoint tornadic circulations. Figure 6 illustrates the pressure field of the supercell and its surrounding environment. There is a quite pronounced low pressure center that coincides with the previously identified updraft and vertical vorticity minimum. At this point, we have eliminated all but one of the vertical vorticity maxima/minima and have essentially narrowed down any signatures of tornadoes to a single location. However, to illustrate another technique for locating hazardous areas of the storm, we examine the air temperature at the surface to identify the cold pool (Figure 7). This could be useful for rear-flank downdraft identification, as well as for mesocyclone identification and tracking.

One of the most surprising aspects of these results to us is the ability to retrieve some of the gradients associated with the mesocyclone. We did not expect such a strong gradient and low-center to be shown in the assimilated data. Additionally, we did not expect that coupling vorticity maxima/minima would have narrowed down the circulations to only one possibility. We are encouraged by the ability for the EnKF assimilation's ability to retrieve some of the strong gradients at scales applicable to storm-scale hazardous weather detection, and feel that using these retrieved fields has the potential to further reduce the ambiguity in detections of hazardous weather phenomena.

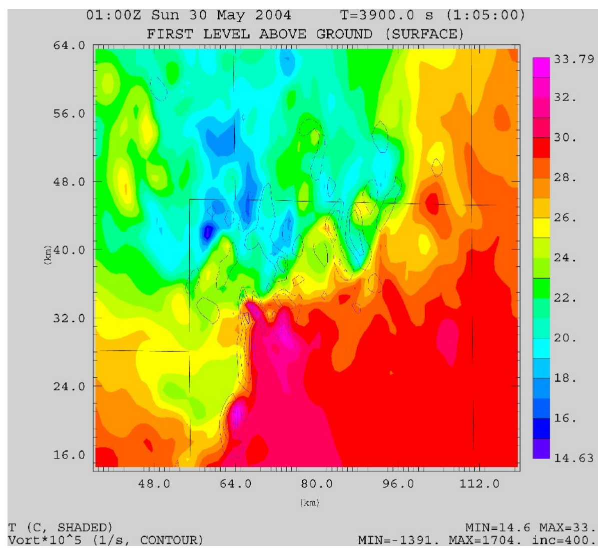


Figure 7: Cross-section of surface temperature with overlaid contours of vertical vorticity. Note that the intersection of the strong temperature gradients (mini-fronts) is associated with the strong negative vorticity area. Time is 0100 UTC.

## 4. SUMMARY AND FUTURE WORK

Although no particular "algorithm" has been set for detection of tornado signatures or other hazardous weather phenomena using the EnKF output, the ability to detect such features has definitely been demonstrated. Of particular importance is the ability to differentiate between transient features located in improper areas of the storm (i.e. vorticity maxima region in the forward flank of the storm) and those in proximity to other features, indicating a true hazard. This "detection by structure," rather than detection by Doppler velocity gradients and reflectivity features, could potentially result in more accurate tornado, hail, and high wind identification and tracking.

The initial results of this evaluation of hazardous weather detection using assimilated data are encouraging to say the least. We were not expecting such well-defined features to be uncovered, giving us great enthusiasm for continuing the research.

Future work will be concentrated in three main areas. First, we want to continue to evaluate the qualitative ability of this assimilation method to render data representative of actual storm structure, and of quality high enough to develop some sort of process for detection of hazardous weather using its output gridded data set. This will consist of running the assimilations with different sizes, resolutions, etc. Second, we want to develop standard methods for detecting the hazardous weather phenomena for our comparisons to the WDSS-II detections and damage surveys (e.g. what signature is a tornado, what constitutes large hail, what do we look for to indicate a damaging wind event, etc.). Third, we would like to evaluate the complexity involved in the filtering process, and the time requirements needed to run such a assimilation system for detection purposes.

This study promises to investigate some of the basic reasons as to why the EnKF application to real-time assimilation, and the development of grid-based detection algorithms will be a costly, but worthwhile, long-term endeavor.

## 5. REFERENCES


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