A SURVEY OF REAL-TIME 3DVAR ANALYSES CONDUCTED DURING THE 2010 EXPERIMENTAL WARNING PROGRAM SPRING EXPERIMENT

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1. Introduction

A dynamically-adaptive three-dimensional variational data assimilation (3DVAR) system was run in real-time as part of the 2010 Experimental Warning Program (EWP) spring experiment conducted in the NOAA Hazardous Weather Testbed (Stensrud et al. 2010). The EWP brings scientists and operational forecasters together to provide feedback and enable collaboration on research projects related to improving National Weather Service warning services for severe convective weather events. The real-time 3DVAR system has the ability to automatically detect and analyze severe local hazardous weather by identifying mesocyclones at high spatial resolution (1km horizontal resolution) and high time frequency (every 5 minutes) using data primarily from the national WSR-88D radar network, and NCEP's North American Mesoscale (NAM) model product. It is a first step in the long-term "Warn-on-Forecast" research project to enhance tornado warning lead times by assimilating multiple data sources into a dynamically consistent analysis that provides the initial conditions for storm-scale numerical model forecasts.

For this initial real-time experiment, one user-controlled domain and three automated domains were used. Some representative samples of the analyses that demonstrate performance and capabilities are shown here, including:

- May 10, 2010 - tornados in Central Oklahoma (near-radar)
- May 16, 2010 - $500M hail storm in Central OK (near-range)
- June 16, 2010 - multiple tornados near Dupree, SD (far-range)

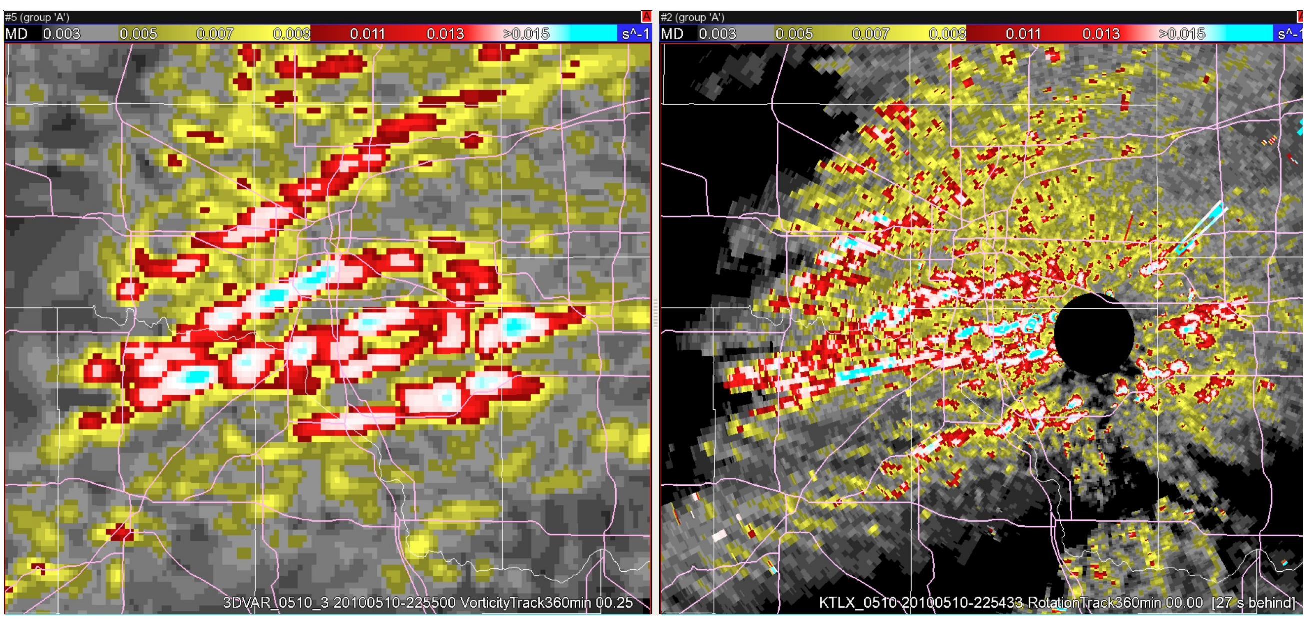


Figure 1: 3DVAR maximum vorticity (left) and maximum Azimuthal Shear derived from KTLX Doppler Velocity (right) accumulated over the period from 2130 UTC to 2300 UTC on May 10, 2010 in Central Oklahoma for the 3-7 km vertical layer.

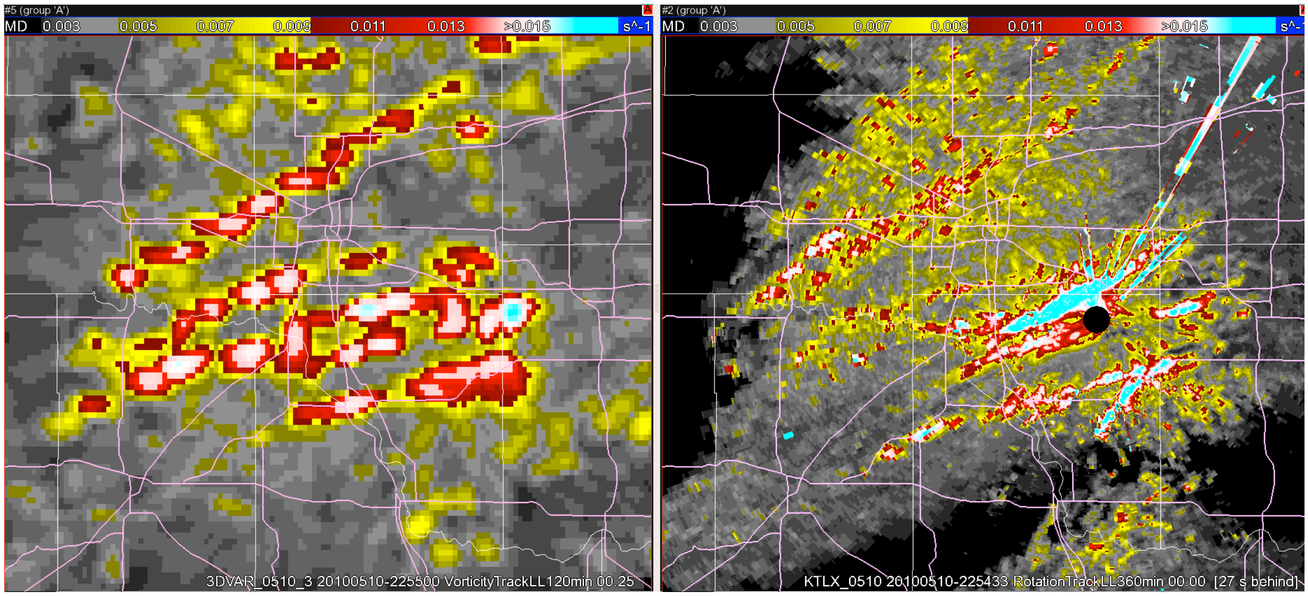


Figure 2: Same as Figure 1, for the 0-3 km (near-surface) vertical layer.

As this project is in the early stages, the data generated in spring 2010 provide the first opportunity to examine how this information may be used in operations to improve the understanding of the structure and behavior of severe storms. We evaluate the realism of the assimilated data fields and their derivatives, such as the 3D wind field, vorticity, and divergence. Trends in these fields are compared to radar and other sensors to determine the strengths of the 3DVAR analysis as well as areas where improvement is needed.

2. May 10, 2010 tornados

Figure 1 and Figure 2 show the 3DVAR vorticity compared to an Azimuthal Shear field (essentially half the true vorticity; Smith and Elmore 2004) derived directly from Doppler velocity from the KTLX radar, both showing the maximum values over a 1.5-hour time period at different elevations. The KTLX data have a horizontal resolution of 0.5° by 250 m, so the tracks of smaller circulations may appear in those data while not appearing in the 3DVAR field. Although the radar-derived Azimuthal Shear values should, in theory, be approximately one half the true value of vorticity in the storm, the smoothed 3DVAR data show maximum values that are smaller than expected due to the larger grid spacing than the radar data. A 250m-resolution 3DVAR analysis is needed, in this case, to do a direct comparison of values.

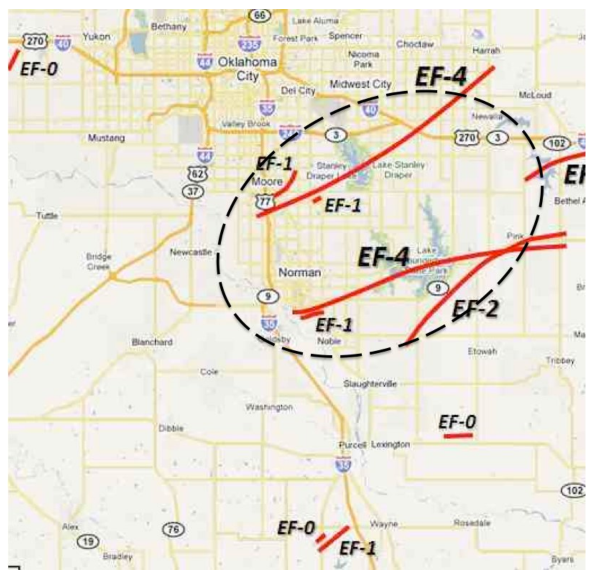


Figure 3: A summary of tornado damage paths from May 10, 2010 (courtesy the Norman, OK, National Weather Service Forecast Office).

Figure 3 shows reported tornado tracks and intensities for this event, with the tornados that occurred during the time period of Figures 1 and 2 circled. The larger-scale 3DVAR vorticity tracks match up well with the tracks of mesocyclones that occurred during the event; however, it does not detect a shallow circulation

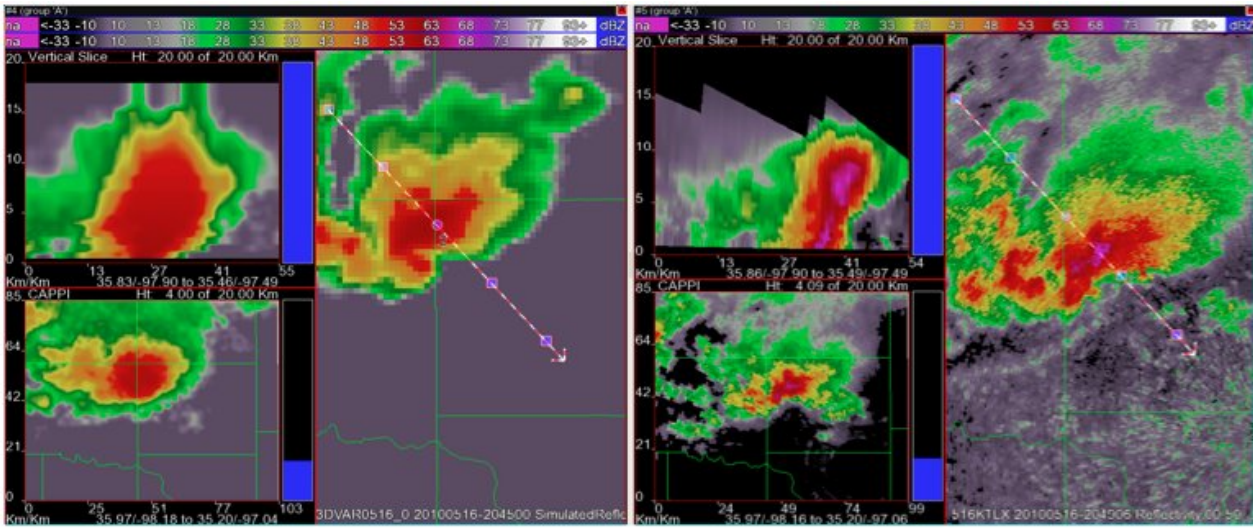


Figure 4: The left (3DVAR simulated reflectivity) and right (KTLX observed reflectivity) half of the image each contain three subpanels: top-left is a vertical cross section; lower-left is the reflectivity at 4 km MSL; right is the near-surface reflectivity (lowest height or elevation angle) showing the location of the vertical cross-section.

that produced and EF-2 tornado in the SE part of the circled area. The 3DVAR analysis does filter out some bad data caused by radar radial velocity dealiasing failures in the top-left of Figure 2. Because the resolution of the 3DVAR analysis in this case is four times that of the radar data, the circulation paths are much broader than for the Azimuthal Shear field, but the overall performance of the 3DVAR matches very well with the tornado and mesocyclone tracks.

3. May 16, 2010 hail storm

Figure 4 shows a simulated reflectivity field (left) from the 3DVAR analysis that is based on the analyzed moisture (Kessler 1969) compared to the observed radar reflectivity from the KTLX radar (right). At this time, the storm was producing observed 2-inch (> 50 mm) hail stones on the ground, and shortly thereafter produced 4.25-inch (> 110 mm) hail. There are several differences between the modeled storm structure and the structure observed via radar. Because the 3DVAR assimilation occurs in near real-time and can take up to four minutes to process, there is a slight lag – for the southeastward-moving storm, the 3DVAR analysis is slightly behind the radar observation. The vertical structure shows a broader core due to the contributions of multiple nearby WSR-88D radars that are not time-synchronized. Finally, the extremely high reflectivity values that appear in the radar observations are much lower in the assimilated cloud analysis.

Data fields that are unique to the 3DVAR analysis and not directly available in the radars observations may also be indirectly assessed with independent data fields. A radar reflectivity-based hail swath – Maximum Expected Size of Hail (MESH; Ortega et al. 2010) for the 4-hour period from 19 UTC to 23 UTC – is compared to the trend of updraft intensity (vertical component of the wind) for the same time period in Figure 5. In this case, strong pulses of high vertical velocity values are followed, as would be expected, by observations of larger hail sizes. Even though large hail is not detected directly by the assimilation, the derived vertical velocity field may be correlated to very large hail.

4. June 16, 2010 tornados

Multiple tornados occurred with a slow-moving storm at far range from the nearest radar. The circulation signature, in this case, was sometimes in the radar "2nd trip" band where range folding occurred. The storm is approximately 150 km from the nearest radar, with mid-beam of the lowest radar elevation scan about 2.5 km above ground level.

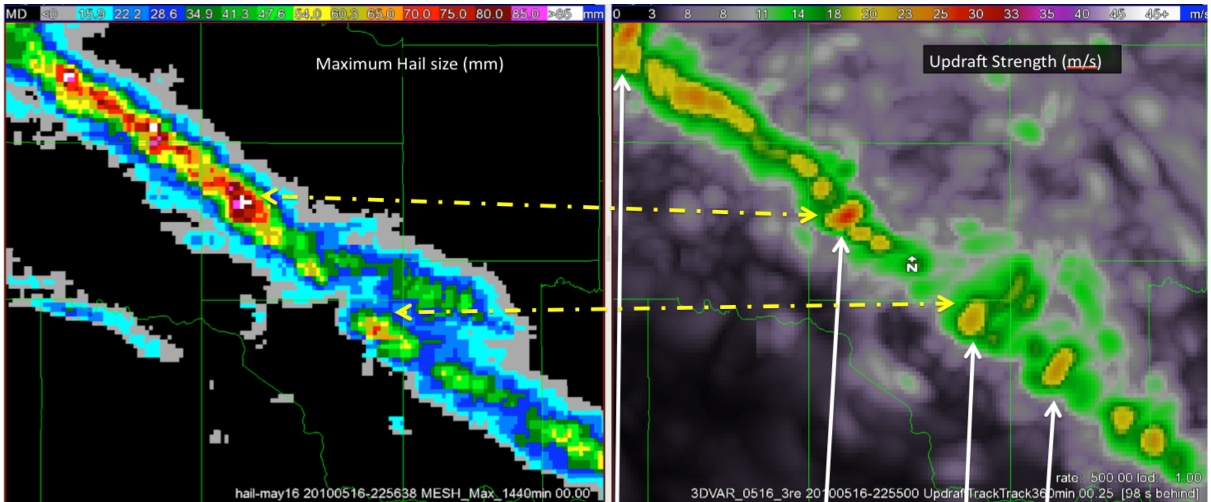
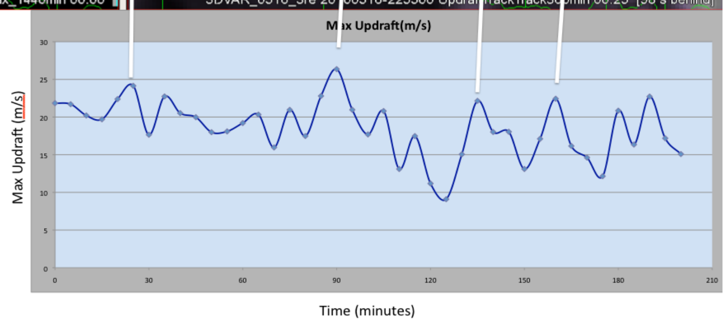


Figure 5: Radar-estimated maximum hail size swath (above), accumulated maximum updraft intensity (top-right), and the time trend of updraft strength versus storm age (right) for the May 16, 2010 Central Oklahoma hail storm,. Data are for the 4-hour period from 19 UTC to 23 UTC.



A mesocyclone was detected in the 3DVAR vorticity field, although it was sometimes weaker than shown by the radar-derived azimuthal shear field (Figure 6).

Updraft strength (not shown) was also affected by the poor radar sampling at longer ranges, resulting in lower values of updraft strength than likely occurred in the storm. However, the overall performance matched very closely with radar observations.

5. Summary

Analysis of 3DVAR updraft strength and vorticity show the correct trends when compared with independent validation. Mesocyclones and updrafts are observed well at near ranges. Poor radar resolution may result in weaker-than-expected velocity values when a storm is located at long range from all radars.

Small-scale, near-surface circulations may be smoothed out of the 1 km analysis. Testing with finer horizontal resolution is needed, as are comparisons with multi-Doppler analyses.

6. Acknowledgements

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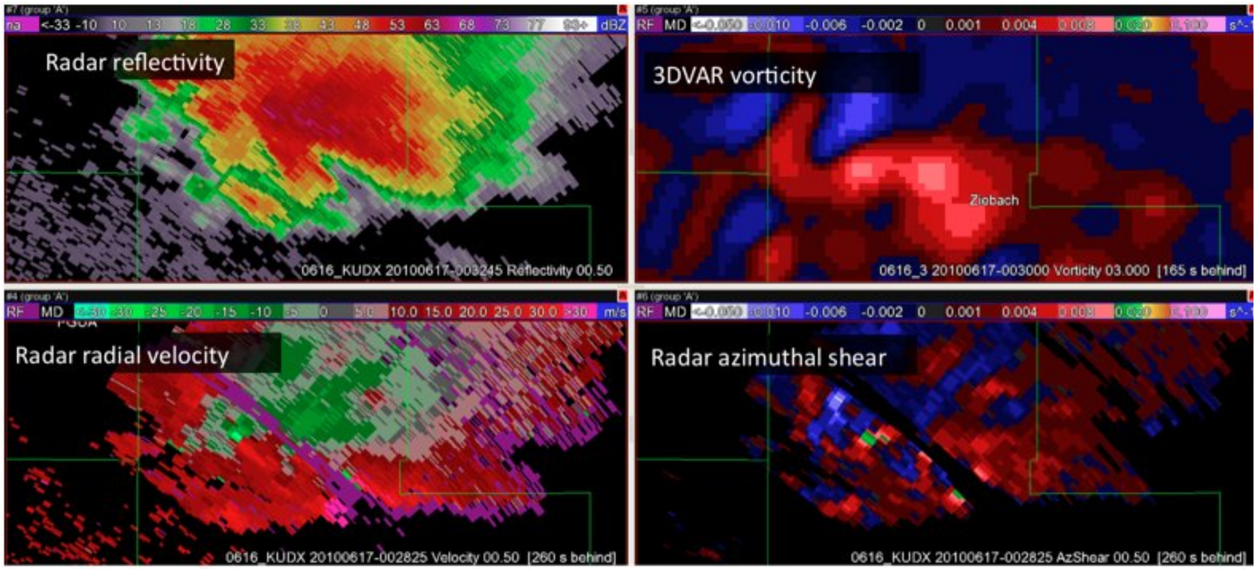

Figure 6: Radar reflectivity, radial velocity, and azimuthal shear fields, along with 3DVAR vorticity, for May 16, 2010 near Dupree, SD. The radar is located about 150 km to the southwest of the center of the image.

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