14.2

ASSESSING THE UTILITY OF SEVERAL ANALYSIS SCHEMES FOR DIAGNOSING PRECURSOR SIGNALS FOR CONVECTIVE INITIATION AND NON-SUPERCELL TORNADOGENESIS ALONG BOUNDARIES
DRAFT VERSION

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1. INTRODUCTION

There have been remarkable advances in short-term numerical prediction down to increasingly better horizontal grid resolutions that have resulted in forecasts down to the convective scale. A number of these models are highlighted at this conference, and it is apparent from these presentations that forecasters have or will have a chance to use incredibly detailed forecasts. These forecasts often appear so realistic that it is difficult to distinguish them from actual data. Of course not all the forecasts will come true, and a good high-resolution analysis available in real-time is important for forecasters to have to monitor how well these model forecasts are performing, especially in regards to important surface boundaries.

A good analysis can serve many purposes in addition to monitoring model performance. For convective potential, forecasters typically use real-time analyses to monitor derived fields such as Convective Available Potential Energy (CAPE), Convective INhibition (CIN), and convergence. These are parameters that can be important to nowcasting and short-term forecasting but would be difficult to calculate without an analysis scheme. Another use for an analysis package would be to initialize a convection-resolving model, either on a local National Weather Service (NWS) Weather Forecast Office (WFO) scale, or a much larger scale. And of course an analysis serves as a record of what actually occurred.

At the Forecast Applications Branch (FAB) of the Global Systems Division (GSD) of NOAA/ESRL, we have been running an analysis scheme since the 1980s known as LAPS, for Local Analysis and Prediction System. The philosophy behind the creation of LAPS was to provide a real-time high-resolution analysis using all available data sources. The analysis scheme has been a part of the Advanced Weather Interactive Processing System (AWIPS) and available to forecasters in real-time for over twenty years. During this time a number of data sources have been added to the analysis, and the horizontal resolution increased from an original 10 km to 5 km, with the option to run at finer resolution at a WFO. Besides providing the forecaster with a high-resolution surface and three-dimensional analysis at hourly intervals, LAPS was envisioned as a starting point analysis to use for a local model that could be run even at a WFO.

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While LAPS over the years has been associated with the analysis system described above, in fact it is really a system composed of an analysis component and a predictive component. Within the analysis component, we have recently been testing LAPS at much higher space (down to 1 km in the horizontal grid) and time (every 15 min) resolutions. In addition, a different type of analysis scheme known as STMAS, for Space-Time Mesoscale Analysis System, has been developed and is being run at horizontal grid resolutions varying from 5 to 1 km.

STMAS is envisioned to one day replace the original "LAPS" analysis, and one of the motivations for this study was to compare STMAS analyses with those from "traditional LAPS" (hereafter we refer to this simply as LAPS). Since a typical forecaster use of an analysis scheme is to monitor boundaries and monitor conditions along a boundary, we concentrated the LAPS and STMAS comparisons to look at cases where boundaries were present. Further, in terms of applications to potential severe weather, a known and well-studied boundary that commonly occurs in Northeast Colorado called the Denver Convergence-Vorticity Zone (DCVZ, or "Denver Cyclone", Szoke et al., 1984) was chosen as a focus for the comparisons. We sought to find cases during the convective season when the DCVZ was present and conditions supported potential convection to compare analyses. Such cases will often have both the quasi-stationary DCVZ boundary and one or more smaller-scale outflow boundaries. The presence of boundaries with different scales provide an excellent opportunity to examine the various spatial and temporal scales of the analyses.

While the focus of this study is to compare the various LAPS analyses, we felt this would be a good opportunity to also examine another relatively new analysis that is available on AWIPS, the NCEP Real-Time Mesoscale Analysis (RTMA). Finally, for some of the cases we were able to include the 0 hour forecast time for the new High-Resolution Rapid Refresh model (HRRR), which is run in a predictive mode at 3 km resolution. There are caveats that must be considered when including the HRRR and RTMA in any comparison, and these are discussed further in the next section.

2. OVERVIEW OF THE VARIOUS SCHEMES

In this section we provide some background information on the various analyses that are compared in this study. There are a number of variations, including the purpose or goal of each, which should be considered before any conclusions can be drawn from the comparisons.

As noted earlier, LAPS is a long-standing analysis scheme whose original purpose was to provide a rapid, high-resolution surface and 3-D analysis on an hourly basis on a WFO type scale. The analysis could then be used to initialize a local-scale model for short-term forecasting applications. The original LAPS used a 10-km horizontal grid spacing and one-hour time resolution. The LAPS schemes used in the study here have the following characteristics:

- Horizontal grid resolutions varying from 5 km to 1 km.
    - Most operational versions are at 5 km at this time.
- Temporal resolution down to 15 min.
    - Operational versions generally at 1 h intervals.
- Full 3-D analysis.
- Available on AWIPS on WFO to sub-Regional scales, but not CONUS.
- Uses all available observations including Doppler winds, satellite, METARs and mesonet, profilers, and ACARS.
- Utilizes variational methods and Kalman filtering techniques.
- Fairly liberal QC in order to catch smaller-scale features.

The STMAS scheme was motivated by work with the FAA to provide a quick, high-resolution surface analysis. As such, the goal is to provide a larger-scale analysis, which in the latest version is done down to 2 km horizontal grid resolution on the CONUS scale. Some of the characteristics include:

- Horizontal grid resolutions varying from 5 km to 1 km.
- Temporal resolution of 15 min.
- Full 3-D analysis.
- Goal is to use all observations, like LAPS, but currently does not use Doppler winds.
- Uses a multigrid technique combining the advantages of EnKF and 4DVAR.
- QC scheme similar but not identical to LAPS for this study.
- Not available on AWIPS.

The primary purpose of the RTMA is to provide a National Digital Forecast Database (NDFD) matching-resolution analysis to verify NWS digital forecasts. RTMA is available on AWIPS and has been running at a horizontal grid resolution of 5 km until a recent increase to 2.5 km. Although the primary purpose of the RTMA was for an "analysis of record", since it is available in real-time on AWIPS it can of course be used as an aide in nowcasting (as discussed in the COMET module available at http://www.meted.ucar.edu/nwp/RTMA/). A summary of the features of RTMA include:

- Horizontal grid resolution now at 2.5 km (was 5 km).
- Temporal resolution of 1 hour.
- Primary input is from surface METAR and mesonet data.
- 2-D surface analysis (no fields requiring 3-D input such as CAPE and CIN).
- Available on AWIPS up to the CONUS scale.
- Uses GSI (Gridded Statistical Interpolation) with downscaling from the 13 km RUC.
- Different QC scheme than LAPS or STMAS.

The HRRR is a fairly new high-resolution model whose development was motivated by FAA needs for improved short-term prediction on the convective scale. The model runs at a 3 km horizontal grid resolution every hour with forecasts out to 15 h. The model initialization is derived from the 13 km RUC. Therefore, it must be noted that the 0 h "forecast" is not a separate analysis on a 3 km horizontal grid scale, so we should not expect it to resolve smaller-scale boundaries, although these can be generated in the model forecast. The HRRR is not routinely available on AWIPS as it is an experimental model, but it is available online (at http://ruc.noaa.gov/hrrr/). Because it has become so popular with operational forecasters, many WFOs download a subset of the full 3D HRRR output for display on AWIPS. A summary of the features of the HRRR includes:

- Horizontal grid resolution of 3 km.
- Temporal resolution of 1 hour (forecasts are available on the web at 15 min intervals).
- Input is from the 13 km RUC and includes all types of data, similar to LAPS and STMAS.
    - Doppler winds are not used at this time but VAD winds are.
- Full 3-D analysis.
- Available online and on AWIPS at some WFOs.
- Uses GSI.
- Different QC scheme that is more restrictive than LAPS or STMAS.

As noted earlier, cases were chosen that focus on well-defined boundaries on days when there was convective potential. We were especially interested in quasi-stationary boundaries, since these types of boundaries have been shown to be important for the formation of nonsupercell or "landspout" tornadoes (Szoke et al. 1984; Brady and Szoke 199x, Wilson and Wakimoto 199x). Analyses from these and other studies indicate that there is typically an increase in convergence and cyclonic vorticity near a quasi-stationary boundary prior to convective development. Baumgardt (2006) used this knowledge together with the typical instability and low vertical wind shear characteristics of the environment associated with nonsupercell tornadoes to develop a real-time Non-Supercell Tornado parameter (NST) calculated using their LAPS analyses. Testing of the NST parameter in real-time on AWIPS at the LaCrosse, Wisconsin WFO showed some success in improving situational awareness for potential nonsupercell tornado development, which can be very difficult to predict using radar data alone since the parent convective cell typically shows little if any rotation prior to tornado development. In contrast to supercell tornadoes, rotation may be seen at very low levels using clear-air returns along the associated boundary, but this can be problematic when the boundary is too far (~100 km or less) from the radar.

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We had originally hoped to develop a similar parameter using the LAPS and STMAS analyses, as well as to display the real-time analyses on the AWIPS at the Boulder WFO for testing by the forecasters during the 2010 summer. We were not able to accomplish provide the fields on AWIPS or develop a similar NST parameter for the 2010 convective season, so displays were only available on the web (except of course for the standard LAPS and RTMA, which are on AWIPS). The HRRR was also available for part of the convective season on a separate experimental AWIPS workstation.

In the comparisons then we focus on the basic wind analysis, plus analyses of convergence/divergence and vorticity. The analyses are compared qualitatively and also assessed as to their potential value for helping to forecast convective potential and nonsupercell tornado potential along boundaries. There is no real "ground truth", since we are comparing analyses to analyses, so quantitative evaluation is difficult without a scheme whereby observations might be withheld, which was not done in this case. The derived fields of convergence and vorticity are also compared. The scale of any pre-existing low-level cyclonic circulations along a boundary that could spin up into a tornado will be relatively small, so one question is whether the 1 km analyses can depict any of the individual circulations. The other question though that is applicable to all the analyses is whether there is a signal of increasing larger scale cyclonic vorticity in areas along a boundary that may be more prone to nonsupercell tornado spinup. For example, this appeared to be the case from the analyses from the 3 June 1981 Denver tornadoes (Szoke et al. 1984).

3. CASES

Two cases are used for comparison of the various analyses and are discussed in Section 3. Both had a DCVZ boundary along with smaller-scale outflow boundaries. A probable tornado occurred with the first case while three or four nonsupercell tornadoes occurred with storms along the boundary for the second case.

3.1 *Case 1: 26 May 2010*

This was a very active severe weather day and actually turned out to be an excellent null case for VORTEX-2. It turned out the VORTEX armada arrived just after the storm along the DCVZ developed. The locations of the reported tornadoes are shown in Figure 1. This was actually a day with sufficient vertical wind shear to support supercell storms, as seen by the Denver 1200 UTC sounding in Figure 2, especially east of Denver by the afternoon, when the southeast surface flow had increased to about 20 knots, and in fact the VORTEX-2 armada followed a storm that initiated along a well-defined Denver Cyclone that was centered quite close to the Denver International Airport (DIA), with the storm fairly quickly becoming a supercell.

This case then is somewhat of a "hybrid" situation where the storm may have produced a tornado quite early in its lifetime, perhaps even before gaining supercell characteristics, because it developed over a tight low-level cyclonic circulation along the DCVZ. A

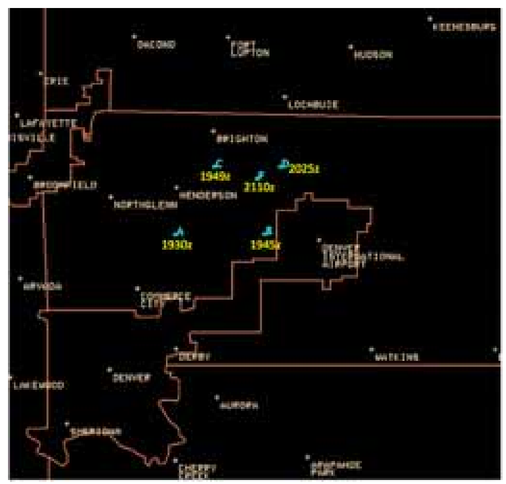

Figure 1. Locations and for the reported tornadoes on 26 May 2010.

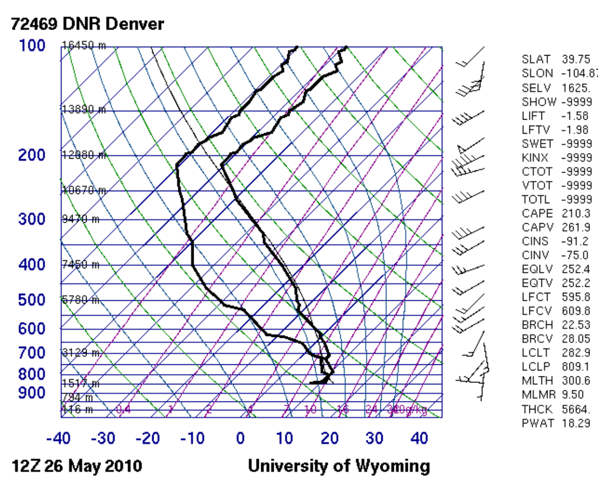

Figure 2. Denver sounding at 1200 UTC on 26 May.

paper discussing this type of interaction was presented by Szoke et al. at an SLS Conference in 1996.

Even though the storm of interest developed close to DIA and was observed by storm chasers and the general public, there is still some controversy as to whether there was even a single tornado touchdown. There was no apparent damage reported, although this is not unusual as the actual path that the core of the storm took was over a sparsely populated area near the airport. But the other issue adding to the confusion was that the distinctly lowered cloud feature that was likely reported as a tornado may well have been a lowered cloud base. Although of course not critical to the comparisons to be shown, it is interesting to see some of the photos taken of the storm, which are displayed in the montage in Figure 3. The storm was a prolific producer of hail as well, as seen by the two photos in Figure 3, with some of the hail reaching near baseball size.

As far as storm development and boundary evolution, this was a relatively straightforward case of a single DCVZ boundary, and storms initiating on the boundary without any type of other boundary collision. An overview of the visible imagery leading up to and including the time of rapid storm development is shown in Figure 4. Note that there is really no other convection developing when the first storm forms along the boundary near DIA near 1900 UTC.

The METAR and mesonet observations in Figure 4 show a typical flow pattern associated with the DCVZ; broad southeasterly flow on the eastern plains east of Denver, with lighter, more northerly flow along the Urban Corridor. The result is an approximate north-south zone of convergence as the southeasterly flow hits the weaker northerly or variable flow, forming the DCVZ. The flow then to the east of the DCVZ is fairly uniform out of the southeast.

Given that there is only the relatively lengthy and fairly stationary DCVZ boundary on this day, one would expect that all of the analyses should be able to resolve the feature. A comparison of the convergence/divergence fields from the various

Figure 3. Photos of the storm and possible tornado (or tornado look-alike?). The storm was also a prolific hail producer, covering the ground with cars getting stuck in the hail.

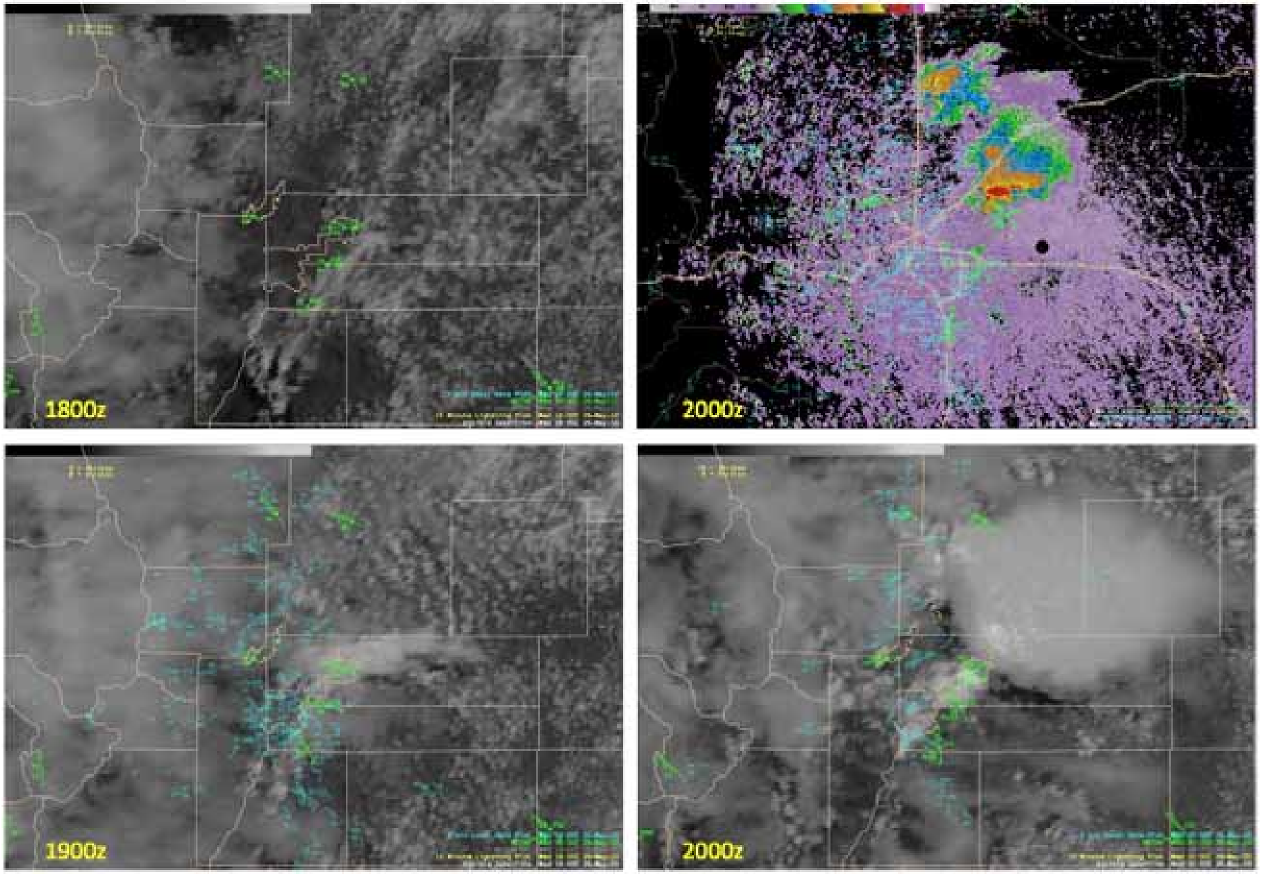

Figure 4. Overview of the conditions leading to storm development along the DCVZ boundary.

analyses (all except for the HRRR for this case) is shown in Figure 5. An identical comparison for surface vorticity is in Figure 6.

Given the observations that show a DCVZ boundary that is becoming increasingly well-defined prior and up until the initiation of the first convective storm near DIA just before 1900 UTC, ideally one would want to see a reflection of this in the analyses of convergence. That is, a gradual increase in convergence over time with a well-defined zone of convergence concentrated near the DCVZ. Examining the various analyses in Figure 5, the analyses from STMAS appear to best display the ideal behavior. The STMAS analyses show an increasing area of higher values of convergence that become more well-defined in an approximate south to north direction. There is even a concentration of convergence along the south to north DCVZ boundary near to where the storm develops (close to the plus sign in the figures).

The standard (5 km horizontal grid resolution) LAPS has a somewhat similar behavior, except that it also has an elongated area of convergence off to the east of the DCVZ boundary. This looks like it is a result of analyzing for a bad observation. This same eastward extension of convergence is also seen in the LAPS/1 km analysis, which makes sense given that it uses the same QC scheme as traditional LAPS. A closeup of the LAPS 5 km wind analysis in this area of convergence is shown in Figure 5, and one for the 1 km analysis in Figure 6.

The offending wind observation is the station with the northeast wind at 25 kts, labeled station CO072. This disagrees with the nearby station that has an east-southeast wind of 15 kts, which is similar to most of the nearby wind observations. Examination of a time series from the offending site shows that it consistently varied from the more generally southeast to east-southeast wind direction, but not always by the same amount. The wind analyses from both LAPS and LAPS/1 km show a distinct turning of the wind in a rather broad area, and the influence of this one observation clearly spreads out over a fairly large area. Given this wind analysis, one can see why there is the extended convergence area to the east of the DCVZ, with a turning of the winds creating a converging wind field that should not be present. The same wind difference in the observations exists all the way back through 1700 UTC, although at that time the wind speeds were less, so the erroneous convergence area does not become as apparent until 1800 UTC.

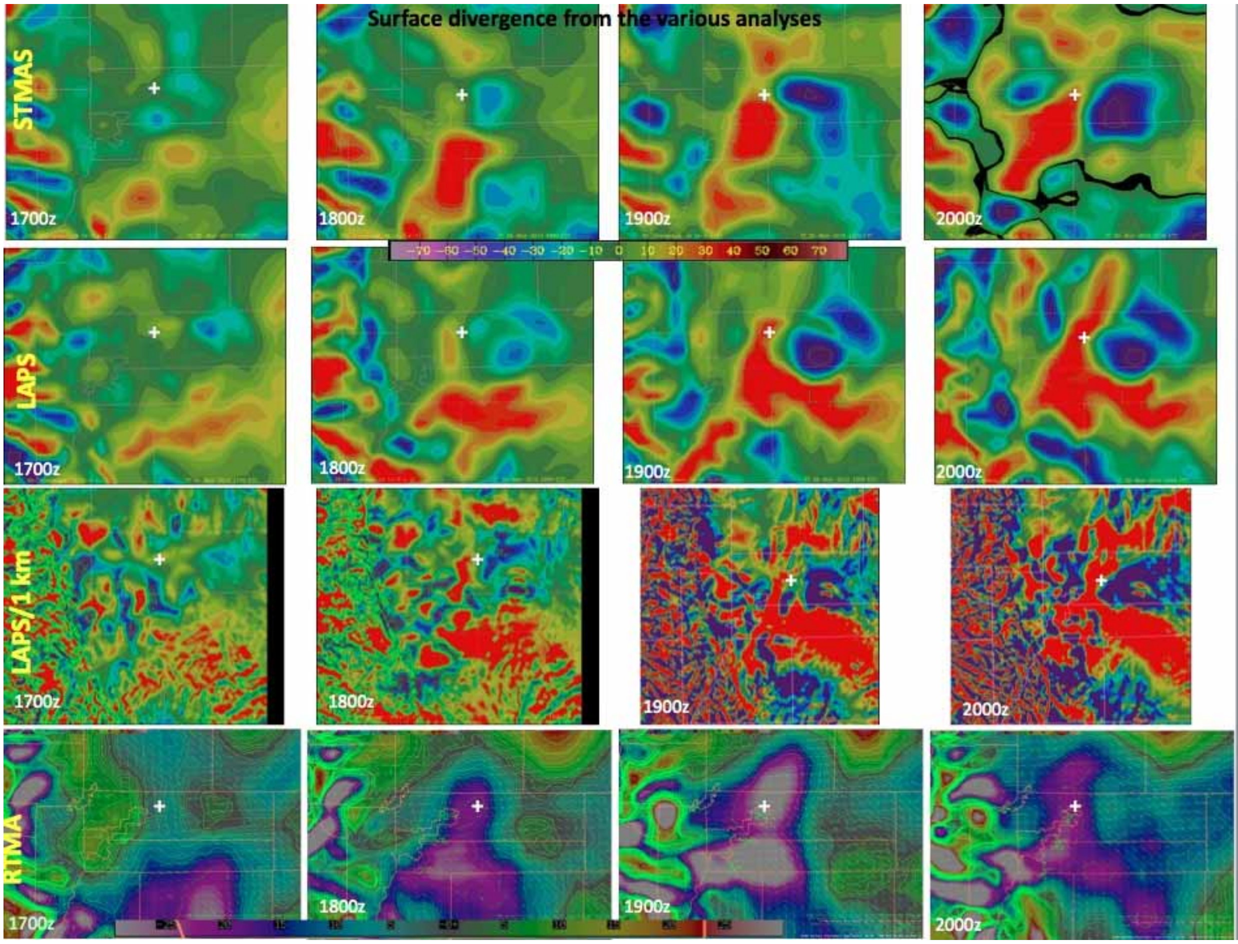

Figure 5. Comparison of the analyses of surface convergence (warm colors) and divergence (cool colors). For reference, the location of the possible tornadoes near DIA are marked by a plus sign. Note: scale is similar except for RTMA.

This was clearly not a case of a stuck sensor, since the speed and direction did vary. But presumably a "buddy check" type scheme should have flagged such a wind. The fact that the RTMA analysis did not analyze for this observation could mean that the QC scheme threw it out, or this particular mesonet may not have even been a part of the data base. The area of broad convergence that does show up in the RTMA analysis by 2000 UTC is a consequence of some broader turning in the RTMA wind field between a more SE flow and a more ESE flow.

The philosophy of the LAPS analysis is what really contributes to the offending observation making it into the analysis. That is LAPS tends to have a more liberal check on surrounding observation comparisons since it is desired to be able to identify smaller scale gust front type features. Such features at smaller scales would at times be reflected in significant changes between nearby stations, something that might get thrown out in a more stringent QC scheme. One way to get around this in LAPS would be to have an active and evolving "blacklist" of offending stations, which would also enable one to continue to allow other observations in from a similar mesonet that may well be fine.

One feature that is very apparent in the LAPS/1 km analyses is the increase in detail, which would be expected when going to a higher resolution. But a legitimate question is whether the detail is so overwhelming as to detract from its usefulness, at least as viewed by a forecaster. For this case, it seems that the detail distracts from the main message of increasing convergence near the DCVZ boundary, and the amount of detail is too much for the intended nowcast applicaton being considered here.

The RTMA by far has the broadest areas of convergence and divergence. There is still the right trend of increasing convergence with time up until 1900 UTC, but it is in a rather broad zone around the DCVZ.

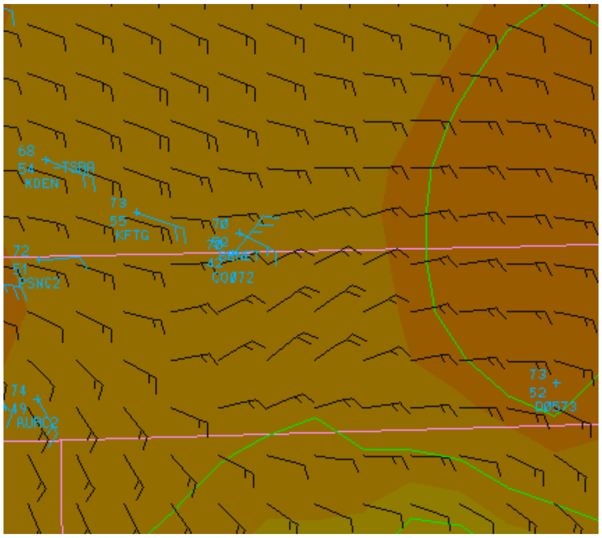

Figure 6. LAPS/5 km wind analysis with observations at 1900 UTC on 26 May 2010.

A similar comparison is made for the surface vorticity analyses in Figure 8. Considering the overall evolution of the wind field for this event, the DCVZ tended to wrap up into a cyclonic gyre ("Denver Cyclone") near DIA between 1700 to 1900 UTC, and especially in the hour between 1800 and 1900 UTC. The expected analysis of vorticity then would be to have an increasingly concentrated area of cyclonic vorticity focusing on the area of DIA, with the magnitude of cyclonic vorticity increasing with time.

Examining the analyses in Figure 8 indicates that STMAS certainly has a dramatic increase in cyclonic vorticity between 1800 and 1900 UTC just south of DIA, with this maximum inching closer to DIA by 2000 UTC. The unconfirmed tornadoes (Figure 1) were reported near DIA from 1930 through 2110 UTC. There are other, smaller areas of cyclonic vorticity that extend to the southwest along the DCVZ boundary but are of lesser magnitude. There are also other areas away from the DCVZ that have increasing areas of cyclonic vorticity, although this happens more by 2000 UTC when convection is underway and likely influencing the vorticity field.

The LAPS/5 km analyses have similar characteristics to the STMAS vorticity analyses, with an increasing concentrated area of cyclonic vorticity near DIA. There appears to be a more focused zone of cyclonic vorticity that extends back to the southwest along the DCVZ in the LAPS analysis than indicated in the STMAS analysis. The 1 km LAPS analysis is most distinct from LAPS and STMAS by having more concentrated areas of cyclonic vorticity that are separated in space along the DCVZ boundary. These may be resulting from actual instabilities spinning up along the boundary, as has been observed in some DCVZ tornado cases. The use of the Doppler winds by

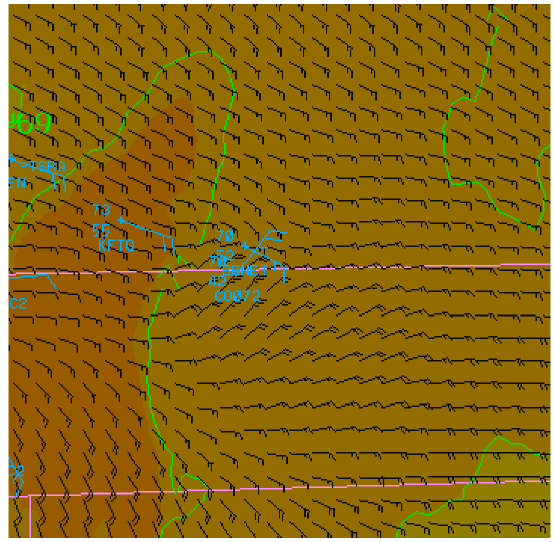

Figure 7. Same as Figure 6, but for the LAPS/1 km analysis.

LAPS and the 1 km horizontal resolution may be enabling such features to be resolved. However, we have not yet done a detailed radar cross-check to see if the locations of these individual features are also visible in the actual Doppler radar velocity and reflectivity fields. Of course, storms did not develop in this more southern area, so if these smaller-scale cyclonic features existed they were not important on this day. However, as we noted when discussing the 1 km LAPS convergence analyses, the amount of detail in the 1 km vorticity analysis may be too much in this case in terms of a nowcasting application at a WFO, with less of a noticeable concentration of cyclonic vorticity near DIA than is seen in the STMAS and LAPS/5 km analyses. These later analyses do a better job of focusing the forecasters attention on an area that later had either a tornadic or near-tornadic storm.

The RTMA analyses of vorticity tended to be quite broad, as was the case for convergence. There is an extension more to the east rather than along the DCVZ prior to 1900 UTC, reflecting more the broad cyclonic turning in the wind field in RTMA and not as sharp of a DCVZ boundary. By 1900 UTC and especially 2000 UTC the cyclonic vorticity does concentrate more and increase in magnitude, though not as much as in the LAPS and STMAS analyses that are also at 5 km horizontal grid resolution.

In summary for this case, there are some interesting tendencies revealed in the analyses that tended to focus on the area near DIA where there was an eventual severe and perhaps tornadic storm. However, as noted by one of the forecasters on this day, the area near DIA was certainly one to focus on based on the evolving Doppler reflectivity and velocity and looping these fields. This was aided by the fact that the area of interest was extremely close to the WSR-88D radar, located just to the southeast of DIA.

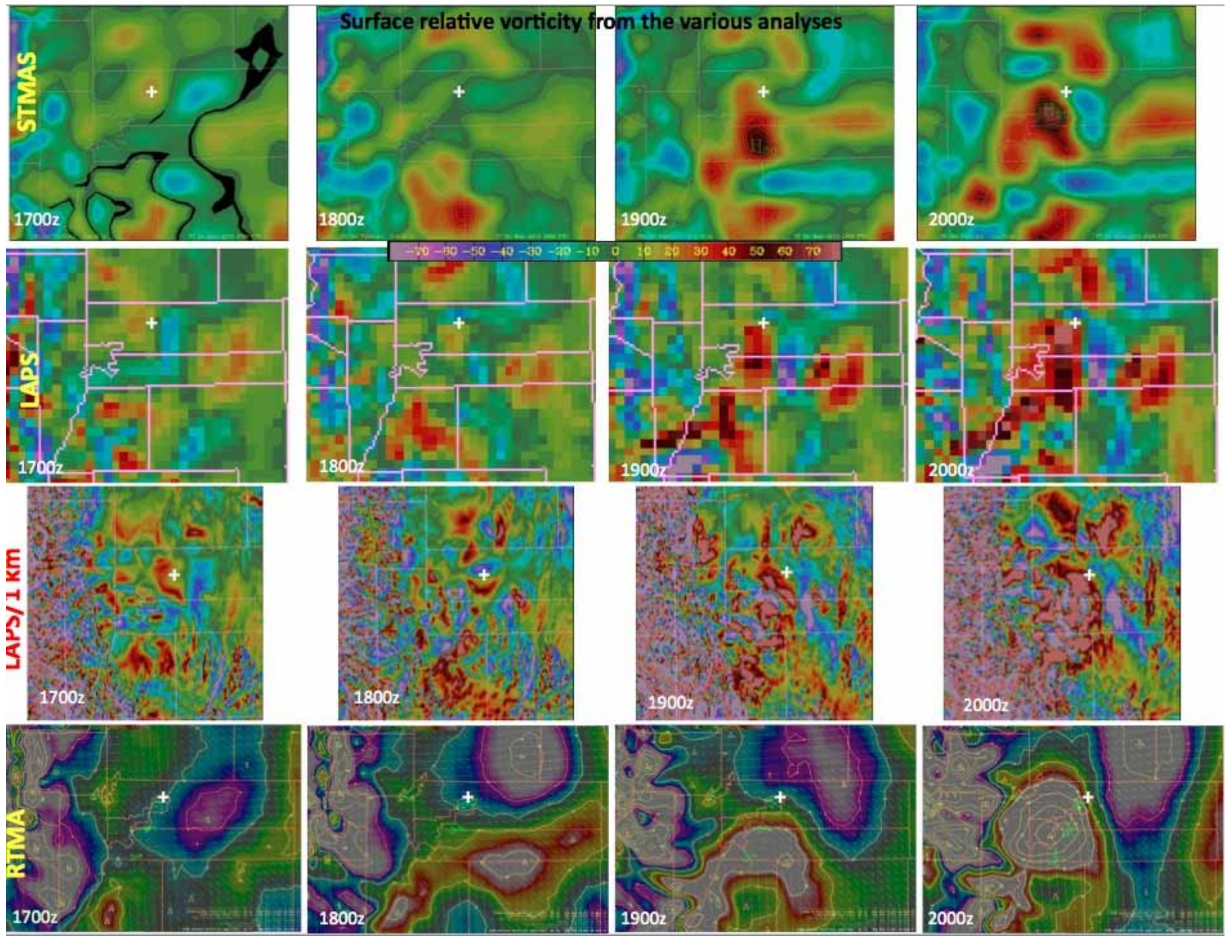

Figure 8. Surface vorticity analyses. In this case the color scheme is similar for all the analyses, in that warm colors denote cyclonic vorticity.

3.2 *Case 2: 16 August 2010*

This was a more typical "landspout" type case with several confirmed tornadoes developing right along a boundary. The storms were, at least initially, not nearly as dynamic as in case 1, with the main severe weather the tornadoes. The Denver 1200 UTC sounding (Figure 9) does show some vertical wind shear, but winds are more disorganized in the lower levels, and the stronger winds are more near the jet stream level. The tornado reports for this day are depicted in the map in Figure 10. The accompanying photos clearly show there were tornadoes, one eventually becoming quite ropelike with a lengthy condensation funnel. The northern tornado (or tornadoes, there were two reports that were separated in time) had more of a dust column without much of a condensation funnel. However, it struck a farmstead and demolished a relatively new barn that, ironically, had been destroyed previously by a tornado.

A radar overview of the storms is given in Figure 11. The main boundary was well-defined, and looked like

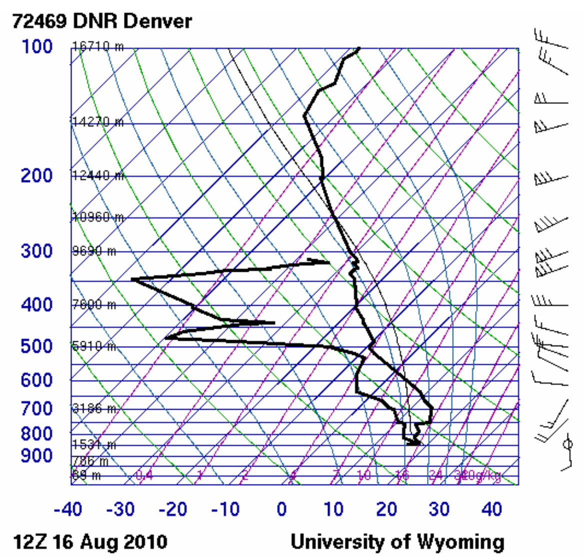

Figure 9. Denver sounding at 1200 UTC on 16 August.

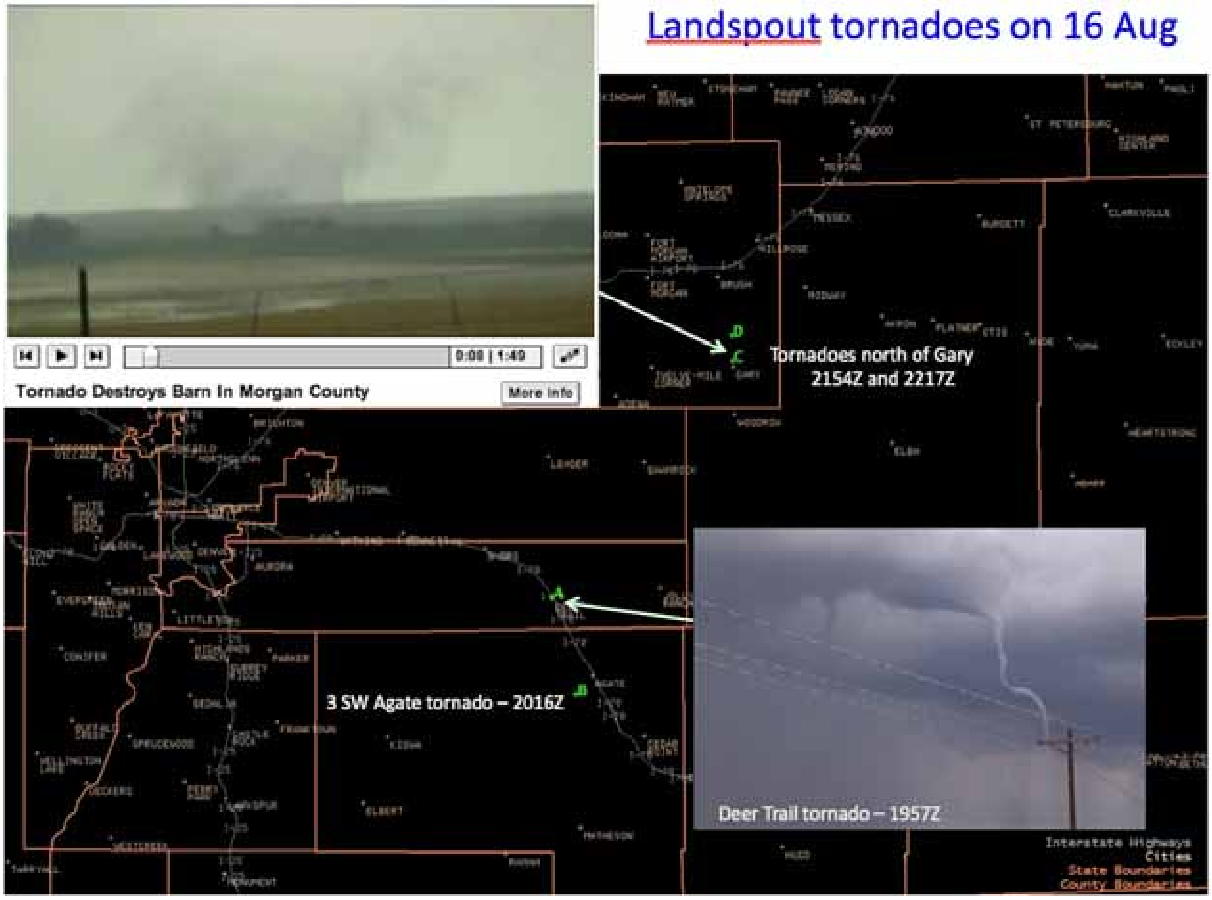

Figure 10. Locations and times of the reported tornadoes along with selected photos.

another DCVZ boundary, although it was displaced eastward from their typical location (more typically being in the location of the 26 May case). The general flow on either side of the boundary was similar to Case 1, with brisk southerly flow on the east side of the boundary and light, mainly northerly flow on the west side. The displacement of the boundary to the east put it farther away from the WSR-88D radar than in Case 1, but it was still close enough to be well observed as a radar fine line, with plenty of clear-air return to give a good coverage of Doppler winds. This was especially true for the area of the tornadoes to the southeast, with the on-duty NWS forecaster noting that looping of the reflectivity field revealed several misoscale circulations along the boundary well before any storms developed.

Overall the flow to the east of the boundary was weaker than in the first case, and since it was more southerly, one would expect for their to be somewhat less convergence. However, as noted by Roberts et al. (1990) in their study of the 15 June 1988 tornadoes, the configuration of a more southerly flow flow on one side of the boundary and more northerly on the other can have a tendency to increase the chance of smaller scale cyclonic vorticity centers forming along the boundary. These are features to be watched for when examining the vorticity and convergence analyses for this case.

The radar overview in Figure 11 shows that the main fine line existed for several hours prior to any storm development along it. The atmosphere was relatively capped (Figure 9), although there were some weak cells that did move off the mountains and foothills into the Urban Corridor during the morning. These were not significant at all, although they did produce some outflow boundaries, seen at 1900 and 2000 UTC. The outflows were most visible by looping the reflectivity fields but also were apparent as an increase in the flow away from the radar. The outflow which may have been important in helping to increase the convergence enough along the boundary and force the development of storms (also seen in the 15 June 1988 case (Roberts et al. 19xx) and in the study by Brady and Szoke 19xx).

Whether the outflow boundaries were resolved by any of the analyses is another question to be addressed, and is a nice complexity to this case. Do the analyses in fact show any increase in convergence just prior to the tornadic development?

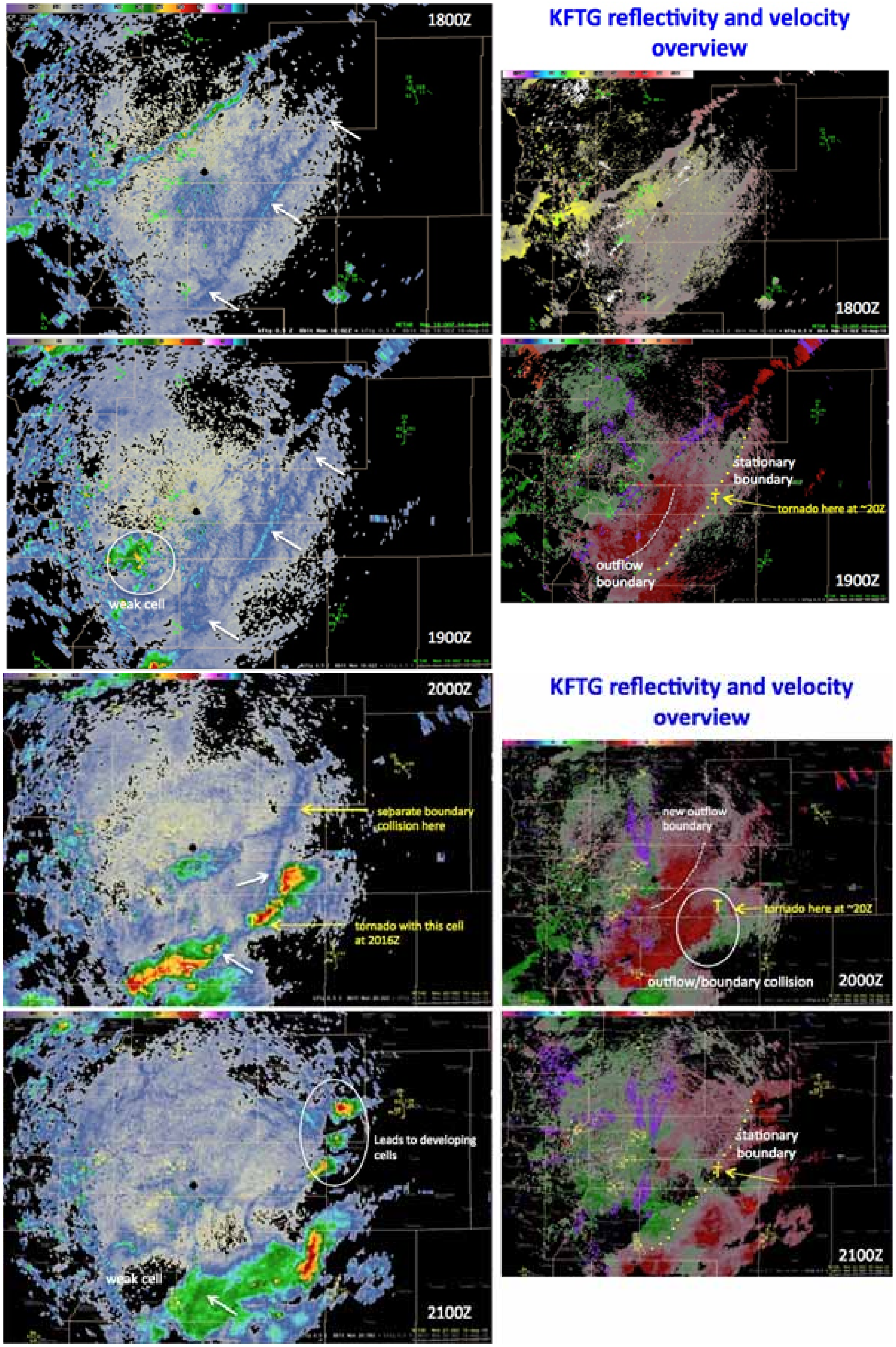

Figure 11. Overview of radar reflectivity (left column) and velocity (right column) from 1800 through 2100 UTC on 16 August 2010.

The convergence analyses are compared in Figure 12, and the vorticity analyses in Figure 13. The image in some of the panels of Figure 12 is of the temperature analysis, with a similar scale for all that have this as a background image. The analysis comparisons begin at 1700 UTC, except for RTMA, which is missing the first couple of hours. Since the boundary was present many hours prior to the tornadic development, we wanted to examine whether there was a trend in the precursor conditions that be of value to a forecaster.

All of the analyses tend to focus a zone of convergence aligned roughly with the main boundary. Note in Figure 12 that warm colors in all the figures represents convergence and cool colors divergence, although the magnitudes of the scales vary (they are the same for LAPS and STMAS at 5 km and for RTMA and HRRR). We are more concerned here with the patterns of convergence and divergence and the trends and not the magnitudes.

While all the analyses show convergence aligned with the boundary, there are certainly differences. STMAS and the two LAPS analyses have other smaller-scale couplets of convergence/divergence to the west of the main boundary that are not seen really seen in the other analyses. These reflect some of the smaller scale outflow boundaries that were present with the weak convection occurring near the Urban Corridor in the late morning and early afternoon hours. The fact that they tend to be stronger in the LAPS analyses likely reflects the contribution from Doppler winds that are not currently in STMAS. The LAPS/1 km generally shows these features more succinctly then in STMAS or the 5 km version of LAPS, which is a reasonable outcome.

In terms of the main boundary, STMAS appears to show the most concentrated increase in convergence near the two southern tornadoes through 1900 UTC, though just prior to the tornado development near 2000 UTC there is a bit of a decrease. On the other hand, the same area increases again by 2100 UTC, when the concern in terms of new tornado development shifts to the northeast. Both LAPS analyses tend to focus more on the northern tornado area, and are most different from STMAS in this regard at 1900 UTC. The 1 km LAPS has some interesting banded structure along the main boundary, but it is hard to say whether this is real or what is contributing to this without future study of this case. It does appear that the 1 km LAPS is picking up on the outflow boundary that at 2000 UTC is approaching the northern tornado area, as seen by the

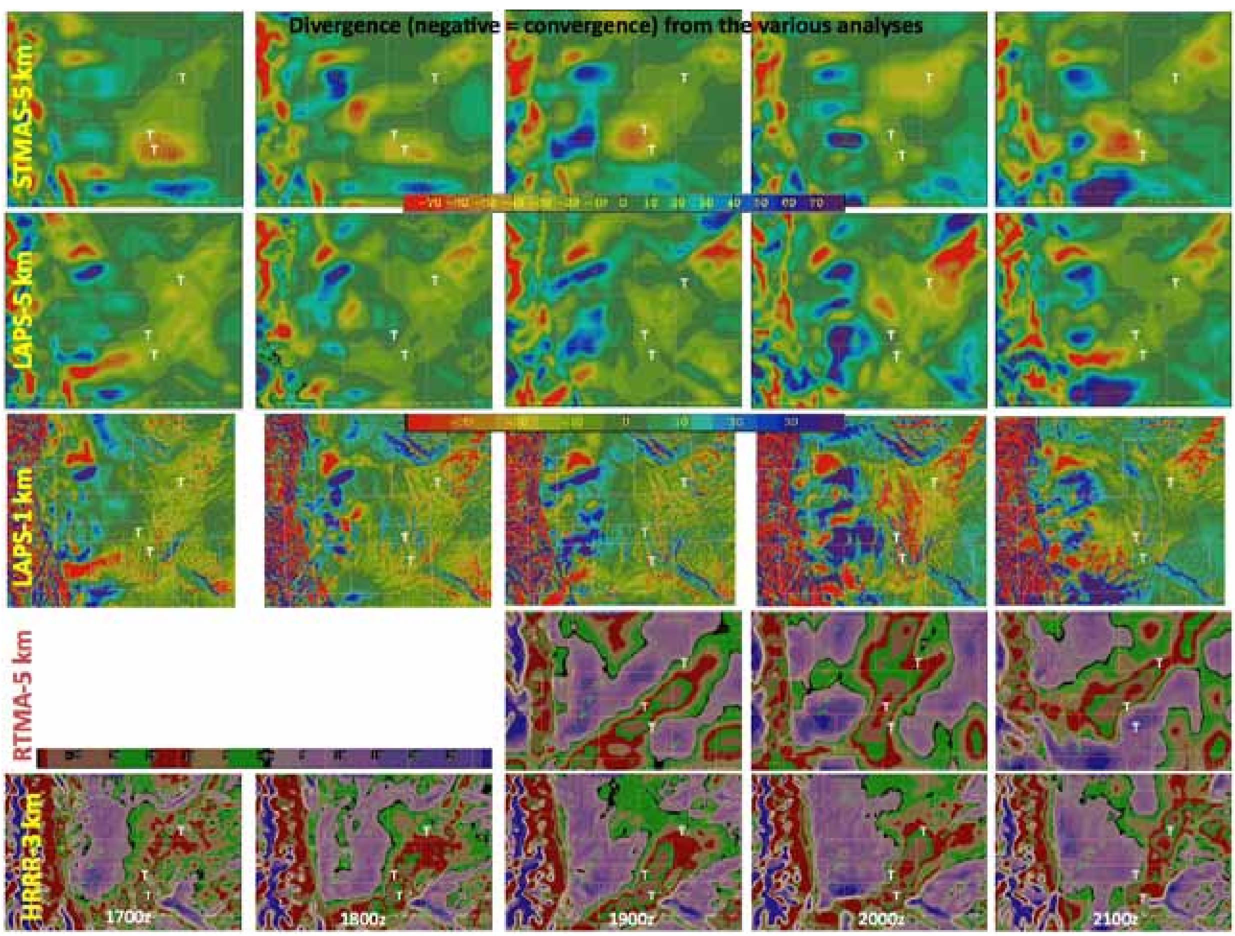

Figure 12 Comparison of the analyses of convergence/divergence on 16 August 2010.

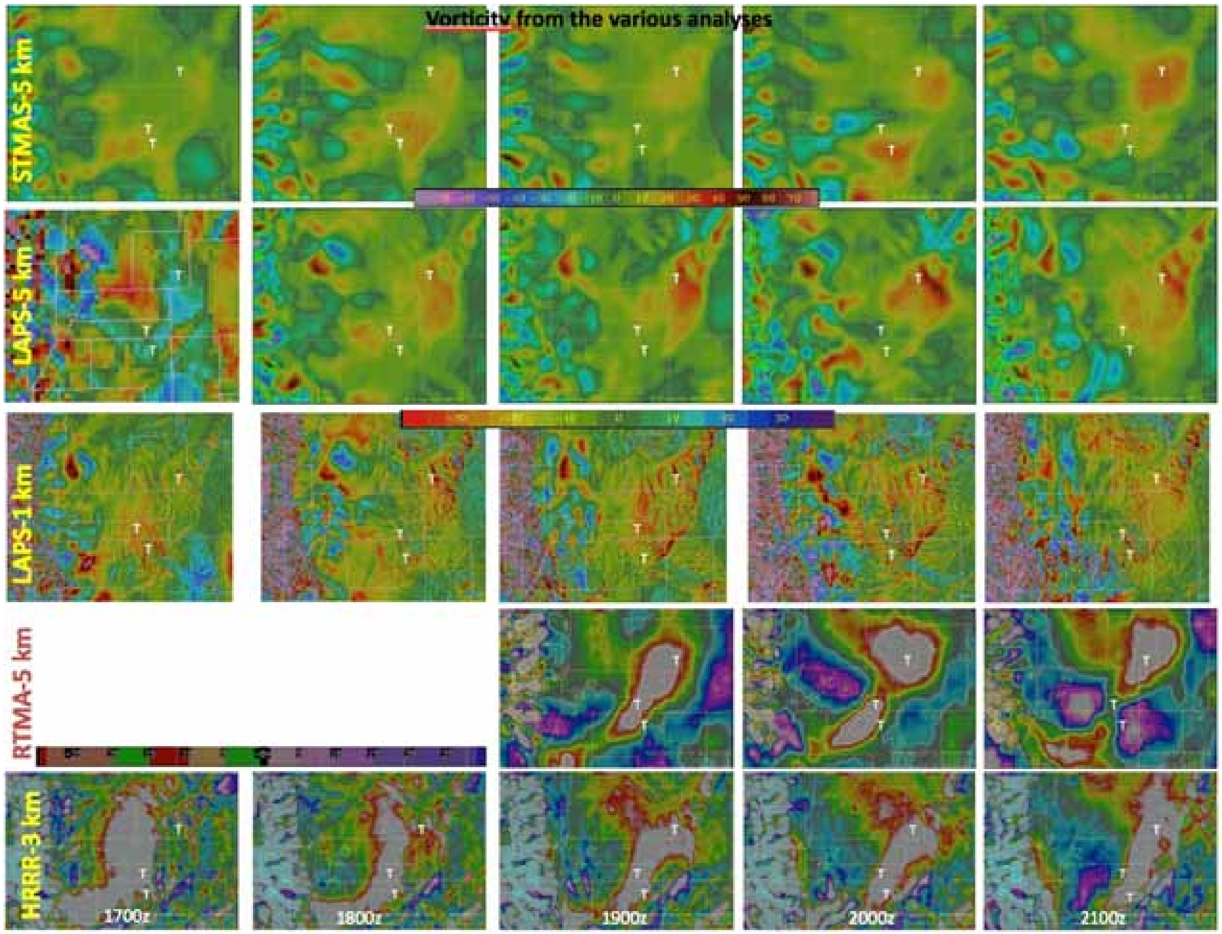

Figure 14. Comparison of the vorticity analyses for 16 August 2010.

smaller-scale north-south area of increased convergence to the west of the main boundary. This area is in a similar location to the outflow boundary depicted in Figure 11 at 2000 UTC.

In terms of the vorticity analyses, STMAS and LAPS/5 km both seem to have the most concentrated areas of increasing cyclonic vorticity in about the right locations prior to tornadic development. RTMA and the HRRR have a somewhat broader scale to the cyclonic vorticity, but both do focus it on the main boundary.

The 1 km LAPS has such fine detail that, in general, it would be more difficult for a forecaster to focus on the areas where the tornadoes occur and where the 5 km STMAS and LAPS tend to show their maxima. Looking in detail along the main boundary one does not get a sense that the 1 km analysis is resolving any of the smaller scale misovortices that the forecaster on duty for this event could see in a loop of the reflectivity and velocity fields. It would though be interesting to revisit this case with a closer look at the higher time resolution analyses (every 15 min) to see if such features did in fact exist in the analysis.

In summary, this is a good test in that there is a larger scale boundary and other, more subtle outflow boundaries. All the analyses resolve the larger scale boundary, while more wind observations and Doppler winds, which are in LAPS, appear to help better resolve the outflows. The trends and areas identified appeared to have some potential value for nowcasting.

4. SUMMARY

Two cases from last summer were compared, concentrating on the surface analyses of convergence/divergence and vorticity. Both cases had a well-defined and long-lived stationary boundary that played an important part in storm and tornado development. Smaller outflow boundaries were also found on the second case.

All the analyses resolved the main boundary in each case as an area of more concentrated convergence and cyclonic vorticity. These areas tended to be more focused in the 5 km STMAS and the 5 km version of LAPS, adding to their potential nowcast value in terms of alerting a forecaster to an area of increasing potential along a boundary. The 1 km version of LAPS had considerably more detail, especially in the vorticity field, but it was difficult to filter through this detail and determine the important features that were more easily seen in the other analyses. At 1 km, however, it appeared that smaller scale outflows could be better delineated. There were a number of questions that still can be addressed by a closer look at the fine scale analyses. Other analyses have recently been added, including a 2 km version of STMAS, and the horizontal grid resolution of RTMA has recently been reduced to 2.5 km. It would be interesting to compare these two analyses, especially for the August case, to see if a resolution between the possibly “too fine” (for the applications of nowcasting here) 1 km analysis and the broader 5 km analyses may add value.

5. REFERENCES

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