VERIFICATION OF LOW LEVEL VORTICITY IN A HIGH RESOLUTION FORECAST MODEL USING RADAR DATA

Kyle Howe[1], Keith Brewster[2], Jerry Brotzge[2]

[1]Collabrative Adaptive Sensing of the Atmosphere Research Experience for Undergraduates
University of Oklahoma, Norman Oklahoma
and
McGill University, Montreal, Quebec

[2]Center for Analysis and Prediction of Storms
University of Oklahoma, Norman, Oklahoma

ABSTRACT

The Center for Collaborative Adaptive Sensing of the Atmosphere (CASA) first integrative project (IP1) has provided researchers with radar data having high temporal and spatial resolution. These data are currently assimilated to produce short-term mesoscale forecasts of severe weather events. This case study considers a tornadic event that passed within range of the CASA network; multiple high-spatial and temporal resolution forecasts of these severe weather areas are examined. Five model runs were done, each using various combinations of NetRad (CASA) reflectivity, NEXRAD reflectivity, and Doppler radial velocity data. These high-resolution forecasts include areas of low-level vorticity, which were subsequently tracked and compared to verification data from the NEXRAD and CASA radar networks.

This case study provides a baseline for future research in this area as well as showing a direct and useful application of CASA radar data. Most of the models were skilled in predicting the location of these low-level rotation areas even two or three hours out. While it is hard to statistically verify these results, it does show that a high resolution forecast assimilating high-resolution radar data can do quite well in predicting severe weather.

1. INTRODUCTION

1.1 *CASA IP1 Test Bed*

The Center for Collaborative Adaptive Sensing of the Atmosphere (CASA) first integrative project (IP1) test bed is an array of four X-band radars, funded by the National Science Foundation, located in southwestern Oklahoma (Brotzge et al., 2007: McLaughlin et al., 2005). Covering an area of about 7000 km^2 and spaced about 25km apart, the area was chosen for its high frequency of tornadoes and proximity to WSR-88D radars (Brewster et al., 2005). CASA radars are designed to provide spatial resolution on the order of 100 meters and updates at least once per minute, which is a considerable improvement over the current operational NEXRAD WSR-88D radar system, which has 250 meter gate spacing updating every 5 minutes in storm mode. Since CASA radars are closely spaced, the beam is able to scan the lowest parts of the atmosphere that the NEXRAD system overshoots due to the curvature of the earth and spacing on the order of 250 kilometers (Brotzge et al., 2005). The spacing of the radars was also chosen in order to optimize the use of dual Doppler allowing for three dimensional wind structure to be extracted (Brewster et al., 2005).

IP1's four radar nodes are steered using a technique called Distributive Collaborative Adaptive Sensing (DCAS), which utilizes a software package called the Meteorological Command and Control (MC&C). Using DCAS allows end users, including the National Weather Service, emergency managers, and researchers, to specify their needs as to where they want the radars to scan. Balancing all the end-user needs, the radars collaborate with each other through the MC&C to provide the most optimized scan possible to satisfy all requests. Each group of users has a distinct set of rules and priority assigned to them. The rules are used in tandem with feature detection algorithms to determine the best use of the radars' time. Each decision cycle takes 60 seconds and is guaranteed to provide a 360 degree scan at the two degree elevation angle, as well as satisfying as many other requests as possible (McLaughlin et al., 2005).

1.2 *Case Study*

On May 8th 2007, a squall line formed in Texas, moved east into western Oklahoma, then merged with cells moving north, and developed into a Mesoscale Convective Vortex (MCV). The complex was within range of three of the four radars, Lawton (KLWE), Cyril (KCYR), and Chickasha (KSAO). The NWS issued eight tornado warnings associated with the MCV, three of which were inside the CASA domain, and a damage survey by CASA confirmed a tornado touched down near Minco, Oklahoma within range of KSAO. Curving of the couplet to the northwest is observed between 03 UTC and 04 UTC on the KSAO velocity data with three distinct areas of rotation present.

1.3 *Numerical Weather Model*

As part of the Spring Experiment, which occurred in the Hazardous Weather Test Bed at the University of Oklahoma, five different runs of the model were performed each with different data assimilated: no radar reflectivity, NEXRAD reflectivity, NetRad (CASA) reflectivity, a combination of NEXRAD and NetRad reflectivity, and NetRad and NEXRAD combined reflectivities with NetRad Doppler velocity. The use of NetRad data presents a unique problem in that there is no longer a guaranteed full volume scan, and most of the data consist of sector scans at each level. An algorithm was devised to combine these data into a pseudo volume for proper use in the model. Another challenge is the use of the extremely high resolution NetRad Doppler velocity data due to the large number of data (Brewster et al., 2007).

Data are assimilated into the CAPS Advanced Regional Prediction System (ARPS) Model (Xue, M. et al., 2000: Xue, M. et al., 2001) using incremental analysis updating (IAU) during a 40-minute period that starts 10 minutes before the top of the hour (corresponding to the METRAR observation), consisting of four 10-minute assimilation periods. After this 40-minute period, a 5.5 hour forecast is produced. For May 8th 2007, the model was initialized at 0050UTC and the assimilation continued until 0130UTC at which point the forecast continues unaided. This case study will only focus on the first three hours of the forecast from 0100UTC to 0400UTC. Currently it takes 8 hours in real-time to produce a pair of 6 hour forecasts (Brewster et al., 2007).

The focus of this case study is to analyze a series of high-resolution short-term forecasts of significant severe weather and set a baseline for future work on this subject. This case study will also serve to illustrate some of the potential strengths and weaknesses of the CASA radar network in the prediction of hazardous weather through the use of a numerical weather model.

2. DATA

Reflectivity and velocity data from WSR-88D radars in Oklahoma City (KTLX) and Fredrick (KFDR), and CASA radars near Lawton (KLWE), Cyril (KCYR), and Chickasha (KSAO) were examined using the WDSS-II system for verification. The areas of interest to this study were outside the range of the Rush Springs radar and therefore no data were used from this site. Circulation areas were tracked on all of the radars by looking for the signature couplet on the raw velocity data. The 2-degree elevation scan was used from CASA since it is the only elevation guaranteed to have a full 360-degree scan every minute. For NEXRAD the .5-degree raw velocity data was used, as it is the lowest elevation available from NEXRAD. KTLX data between 02UTC and 03UTC were not available because an experimental volume coverage pattern was used that evening and caused some of the data to be lost from the Level II archive. In addition, only Level III data were available from KFDR during this time.

Once the forecasts were produced for each of the five different types of data assimilated, plots of forecasted vertical vorticity and wind were produced on a Cartesian grid using ARPS Plot. For this case study, the tracks and intensity of any rotations are the parameters to be evaluated. In order to track rotations on these forecasts, contours of constant vertical vorticity on the 7th model level (about 600m AGL).

3. METHOD

Only the first three hours of the forecast are analyzed since all observed low-level circulations were out of range of KSAO after 0400 UTC with only rain persisting in the CASA network after this time. When viewing the model output, the center of rotation was estimated and an x,y pair was recorded from 0100 UTC to 0400 UTC. This model is of such high resolution that using a subjective method to find the center of rotation should have little if any effect on the results. Main

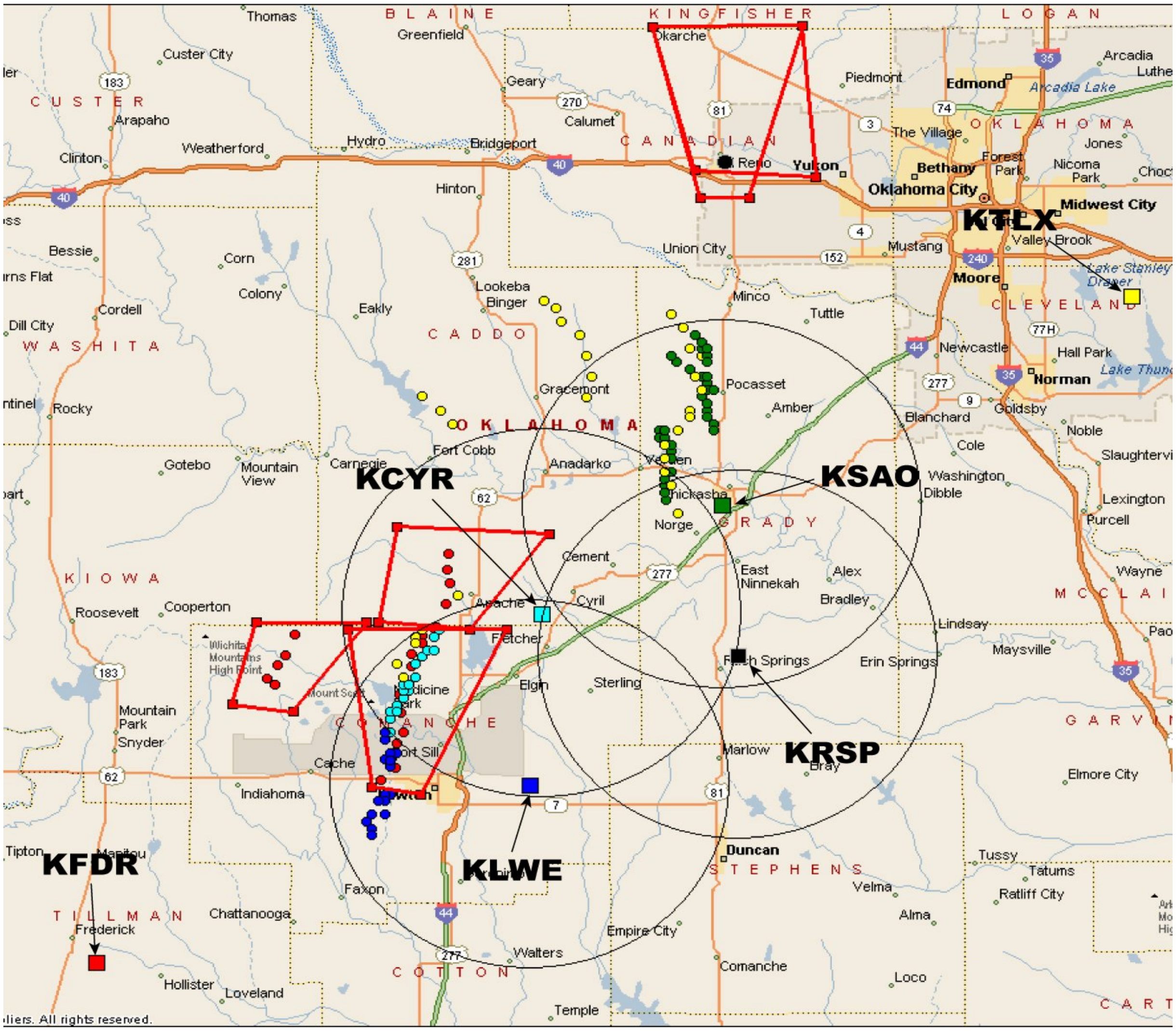

Fig 1. *Location of NEXRAD (KFDR and KTLX) and CASA IP1 test bed (KLWE, KRSP, KSAO, KCYR) in southwestern Oklahoma and tracks of mesocyclones as detected by each radar. The range rings on the IP1 radars are 30km in radius and represent the outer edge of the IP1 range while the polygons illustrate the warnings issued by the NWS.*

areas of rotation were tracked and are considered areas that underwent significant intensification and lasted for periods of time longer then 10 minutes. The threshold at which it becomes a mesocyclone or tornado is still up for interpretation and would require looking at vertical continuity, change in pressure and other atmospheric values.

In order to statistically analyze the results, four parameters were chosen to describe the tracks of the various forecasts (Harold Brooks personal communication). Linear fits were performed on all the tracks from 03UTC to 04UTC in order to obtain a slope, which were then displayed as a directional vector. All but one of the forecasted tracks of mesocyclones was linear, with the non-linear track being excluded from this analysis. The second parameter used is the starting point of the rotation as represented by it's x,y pair. The third parameter is the time at which the rotation initially appeared and the final parameter is calculating the vector distance ($d = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2}$) between the starting point of the model and the KSAO rotations. These four parameters are used to analyze which model performed the best.

4. RESULTS

Results are discussed in one-hour increments corresponding to the first three hours of the forecast.

4.1 *01 UTC – 02 UTC*

The first 30 minutes of this period was part of the assimilation process meaning that the model was still working to assimilate new information. The forecast using radial velocity data struggled through this time period to produce coherent rotations and many of the rotations produced quickly dissipated, which is likely due to the assimilation. The earliest rotation was produced by the NetRad velocity model forecast at around 0120UTC and even at that point the rotation was weak. A tornado warning was issued at 0139UTC by the NWS and three of the forecasts had rotations that touched the warning box at some point (Fig. 2). The NEXRAD forecast placed the rotation approximately 17km to the northeast and the NetRad velocity was approximately 7km to the east. It should be noted that these are very small scales and what appears on this scale to be a large deviation may actually be quite good relative to operational models that have, at best, 12-kilometer grid spacing. As seen in Figure 2 the only other model that produced an area of vorticity was the NetRad/NEXRAD combined reflectivity forecast.

4.2 *02 UTC – 03 UTC*

An evaluation of the forecast from 02 UTC to 03 UTC is difficult to produce primarily due to a lack of verifying data from both KTLX and KCYR. This lack of data was due to large amounts of data being dropped from KTLX and attenuation limiting effective range of tornado detections, which is not an unanticipated problem (Brewster et al., 2005). While an evaluation of the entire forecast window is ideal, there were no tornado warnings issued during this time from the NWS. The reason for choosing this event as a case study was to see if the model is able to predict small-scale vorticity signatures, which were not present at this time. All of the forecasts produced areas of vorticity with varying intensity and were able to sustain these areas throughout the period (Fig. 3).

4.3 *03 UTC – 04 UTC*

All of the forecasts, including the no radar data run, had at least one rotation during this time period. The main area of the storm left the range of the CASA network at 04UTC but did continue north to produce another tornado in El Reno, Oklahoma at 0445 UTC according to an SPC storm report. Figure 4 shows the tracks taken from the forecasts and plotted against the true mesocyclone track seen by KSAO.

The most interesting results come from the forecast that utilized Doppler radial velocity data in conjunction with NEXRAD and NetRad reflectivity. Figure 5 shows this forecast plotted with the KSAO rotations. This forecast had four rotations during this hour that were all fairly significant. Note that the area of the graph is only 30km by 50km or $1500km^2$.

In addition to these tracks, table 1 contains the four parameters described in the methodology section computed for each of the forecast and is used to assess the best forecast. Highlighted in grey are the values that did the best at predicting the true value.

5. DISCUSSION

There was some spin-up delay in the models as they had difficulties in producing initial areas of rotation, taking nearly a half hour but note that 12-km models often have a 3-6 hour spin up to produce rain. After an initial area of rotation was produced it generally continued well into the 03UTC-04UTC hour where the most significant weather occurred. There was severe weather occurring in the CASA network before 01UTC with 3 tornado warnings issued by the NWS Norman office between 00UTC and 0130UTC. Analyzing this time period is difficult since the models were still dealing with a large influx of initialization data. The next "outbreak" occurred around 03UTC with a tornado produced after 04UTC outside of the CASA network. Interestingly, there were no warnings issued during this time even though there were multiple rotations in the thunderstorm complex.

As discussed before, the MCV played a major role in the track of the rotations and may explain why all the forecasts except for the NetRad velocity forecast moved the mesocyclones to the northeast instead of curving them to the northwest. There is little indication except in the NetRad velocity forecast that a mesoscale rotation exists suggesting that the MCV was missed.

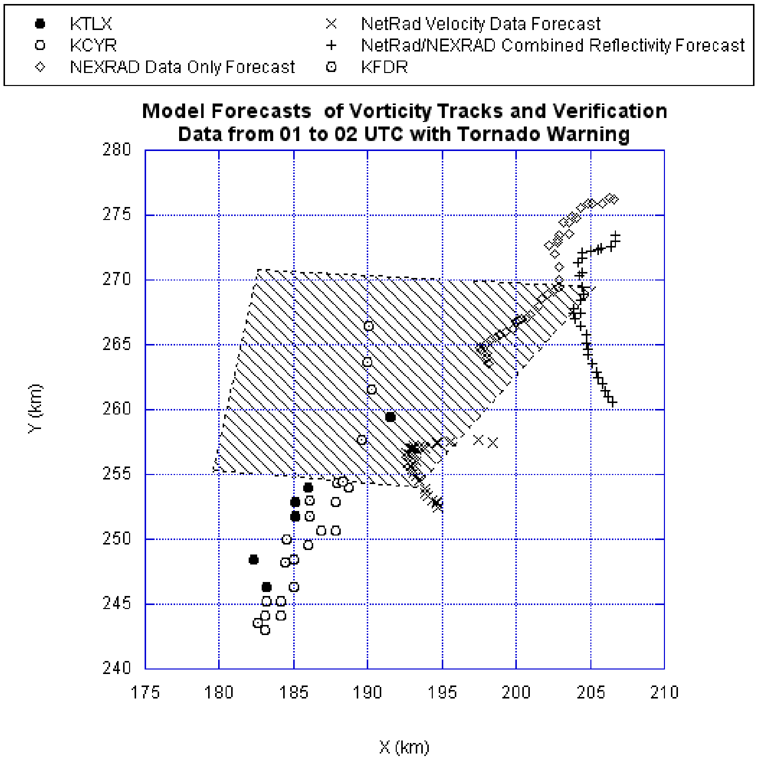

Fig 2. *Forecast rotations with verification data from 0100UTC to 0200UTC and the only tornado warning issued in this time (0139UTC)*

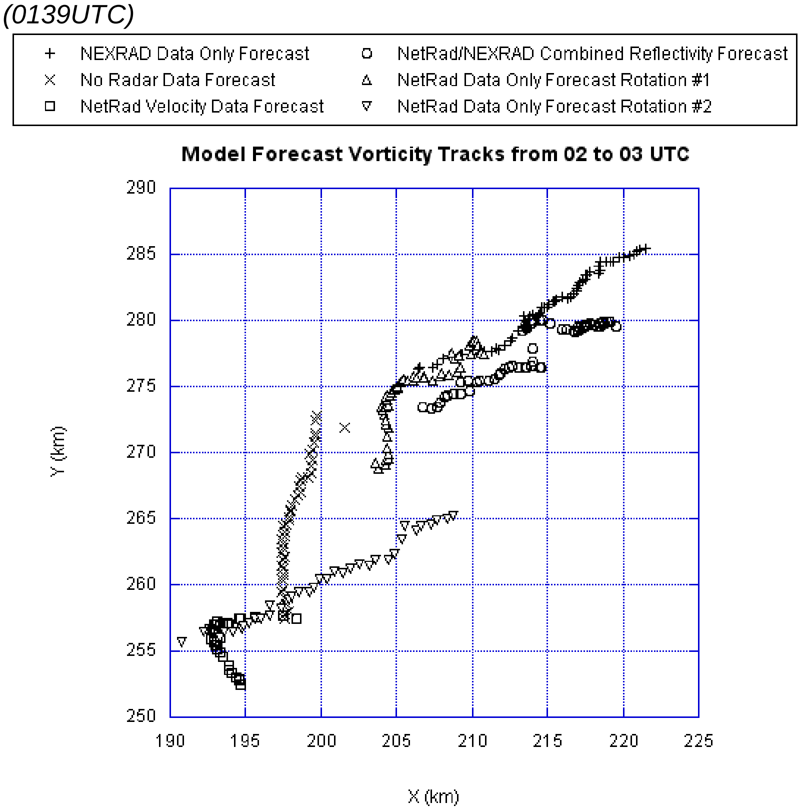

Fig 3. *Forecast tracks of areas of rotation from 0200UTC to 0300UTC. All of the forecasts have now produced some level of rotation.*

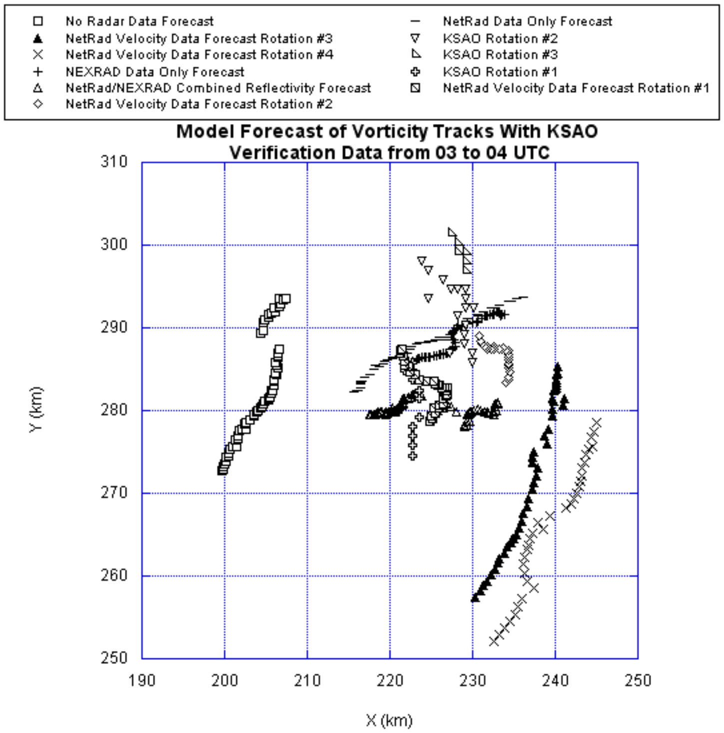

Fig 4. *Forecast tracks of areas of rotation from 0300UTC to 0400UTC with verification data from KSAO also plotted (open squares). Note the curving of the actual rotations to the Northwest before dying due to the presence of an MCV*

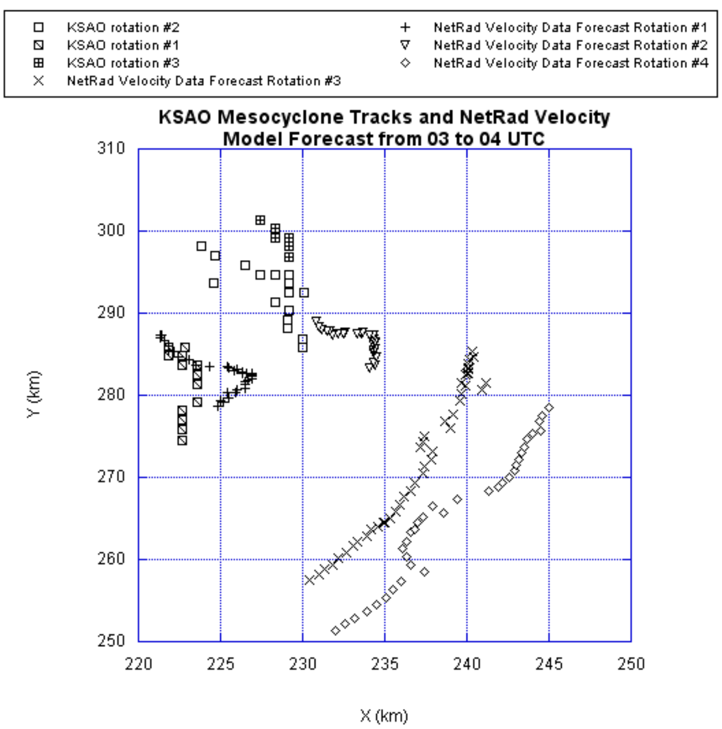

Fig 5. *Forecast tracks from NetRad velocity data plotted against KSAO (squares) verification data.*

Model Forecast	Starting Point		Starting Time	Slope	Distance from KSAO Starting Point		
	X	Y			Rotation 1	Rotation 2	Rotation 3
No Radar	199.7	272.7	3:00	2.26	23.1	33.0	38.2
NEXRAD ONLY	221.6	285.6	3:00	0.60	11.2	8.4	13.6
NetRad ONLY	215.7	282.3	3:00	0.54	10.5	14.7	19.9
NetRad/NEXRAD Combined Reflectivity	219.5	279.6	3:00	-0.03	6.0	12.2	19.8
NetRad Velocity Rotation 1	224.8	278.7	3:11	-0.91	4.7	8.8	18.7
NetRad Velocity Rotation 2	234.1	283.4	3:36	-0.84	14.5	4.8	14.4
NetRad Velocity Rotation 3	230.4	257.5	3:17	2.81	18.6	28.3	39.4
NetRad Velocity Rotation 4	232	251.3	3:26	1.94	25.0	34.6	45.7
Chickasha Observed Data Rotation 1	222.7	274.48	2:57:46	-1.01			
Chickasha Observed Data Rotation 2	230	285.8	3:25:57	-1.36			
Chickasha Observed Data Rotation 3	229.2	296.9	3:43:59	-1.70			

Table 1. *Starting point, starting time, slope of linear fit, and distance from start of verification data (KSAO) rotation for each forecast*

From the statistics table, the velocity forecast performed the best having all the parameters closest to the actual track. This forecast produced four rotations and was able to get two of the within 6km of the true track. The time is also only off by about 10min for each rotation, significant for a forecast 3 hours from start and 2.5 hours from the end of data.

Overall the models performance in predicting low-level vorticity was improved with the addition of low-level CASA velocity data. When looking at the tracks from 03UTC - 04UTC all of the tracks (including the surface observation only forecast) are within a 1500km^2 area which is still less than the average tornado warning area from the new polygon warning system, about 2000km^2 to 2500km^2 (Paul Schlatter personal communication). It is also important to point out that this forecast is 3 hours after data was assimilated into the model meaning that the potential lead times for warnings could be increased.

Figure 1 also illustrates an interesting point in that NEXRAD and CASA may be detecting different features of the same storm simultaneously. The most striking difference between the two is the absence of a track from KCYR when clearly KTLX has a strong couplet that was warned upon and was within range of Cryil. Analysis of the data reveals difficulty in distinguishing between noise and true data. Also, the Cryil data showed almost no “couplet” at the location where KTLX was showing one and in order to not bias the results, no rotation was recorded if it could not clearly be seen from the data. There is another discrepancy when the storm passed near KSAO, which indicated 3 areas of rotation while KTLX detected what appeared to be a single continuous area of rotation is an important point, which the CASA program will need to deal with if this high-resolution data is to be implemented in forecasting operationally.

6. FUTURE RESEARCH

Additional cases will need to be collected in order to draw statistically significant conclusions. There was another tornadic system that passed through the network on April 10th 2007, which will be analyzed in the future. Further research will also need to be done in how this forecast can be modified so a forecaster can accurately use the model outputs to warn the public.

The processing of CASA velocity data is also being modified now so that the resolution at which it is assimilated can be increased using this computer. A lot of memory is required to run the model with this high-resolution data but with the increased resolution comes a much more accurate model.

A final question that will need to be addressed is how a forecaster is to use these model forecasts in order to issue warnings. Due to the high resolution of the model there are obviously certain small-scale features that may be too hard to model and will therefore throw the model off. The best way to deal with this is to run the model with different data, as in this case study, essentially producing an ensemble forecast.

7. CONCLUSION

The model may be able to predict with good accuracy the position of low-level vorticity in this single case. If this high resolution forecasting is to be used operationally questions about how long in advance and with what certainty the forecaster should issue warnings will need to be examined thoroughly.

It is obvious that it is difficult to statistically verify the results of this case study due to insufficient data. The results obtained here are intriguing and act as a baseline for further studies in this area. It shows that there is the potential that a high-resolution model can forecast small-scale severe weather events, which has the potential to increase current lead times for severe weather warnings. Obtaining more data depends soley on having more tornadic storms pass through the IP1 test bed, which may be a potential hindrance.

8. ACKNOWLEDGEMENTS

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