4B.1 # WIND AND THERMODYNAMIC RETRIEVALS IN A SUPERCELL THUNDERSTORM: 4DVAR RESULTS

N. Andrew Crook, David Dowell and Juanzhen Sun

National Center for Atmospheric Research*, Boulder, Colorado

1. INTRODUCTION

At the present time, operational NWP models exhibit minimal skill at forecasting the development and motion of convective storms. The primary tool for observing such convection is Doppler radar. It therefore makes sense that to increase the skill in convective scale forecasting it is necessary to assimilate observations from Doppler radars into NWP models. In this paper, we describe some recent research in the area of convective-scale assimilation and forecasting.

We have chosen for study a case of an isolated supercell storm observed near Arcadia, OK on 17 May 1981. A dual Doppler analysis of this storm was performed by Dowell and Bluestein (1997). This storm has also been the subject of a single Doppler retrieval study by Weygandt et al. (2002), Parts I and II. The assimilation technique used by Weygandt et al. (2002) is sequential in nature; first a single-Doppler velocity retrieval is performed, followed by a variational adjustment, a thermodynamic retrieval and finally a moisture specification step. In the present study, we use a 4DVar technique in an attempt to simultaneously retrieve the velocity, thermodynamic and microphysical fields. Finally, in a companion study by Dowell et al. (2002), the Ensemble Kalman Filter method is applied to the same dataset.

2. DATA

For a detailed description of the Arcadia dataset the reader is referred to Dowell and Bluestein (1997). Briefly, the storm was observed by two Doppler radars (at Cimarron and Norman). The baseline between the two radars is approximately 40 km oriented in a NW-SE direction (Cimarron in the northwest). The reflectivity and radial velocity observations from both radars were interpolated to a common Cartesian grid with a horizontal grid spacing of 2 km and a vertical grid spacing of 500 meters. The interpolation was achieved by using a Cressman scheme with a radius of influence of 2 km in the horizontal and 1 km in the vertical. In this study, 4 volumes of radar data will be assimilated, at t = 1630, 1634, 1638, 1643 UTC.

The sounding that is used to specify the large-scale environment is shown in Fig. 1. Details on the construction of this sounding can be found in the paper by Dowell et al. (2002) in this volume.

3. METHOD

The method we have used to assimilate radar data is the 4DVar data assimilation technique described in Sun and Crook (1997). Briefly, the analysis system finds a model solution that fits the data and a background field as closely as possible over a specified time period. The numerical model that is used as the constraint in the assimilation is a nonhydrostatic, storm-scale model (Sun and Crook, 1997). The prognostic variables include the three velocity components, the perturbation liquid-water potential temperature, rain water mixing ratio, and total water mixing ratio. By fitting the model to observations over a specified time period, a set of optimal initial conditions of the constraining numerical model can be obtained. The reader is referred to Sun and Crook (1997) for further details of the technique.

4. RESULTS

A series of single-Doppler assimilation experiments have been performed first using data from the radar at Cimarron and then data from the Norman radar. Each experiment consisted of three cycles, each cycle assimilating two radar volumes. A timestep of 5 seconds was used for the forecast and adjoint models.

The retrieved wind fields at z = 2.25 km and t = 1634 UTC are shown in Fig 3(a), using Cimarron data and 3(b) using Norman data. For comparison, a dual Doppler analysis at the same time and level is shown in Fig. 2. All analyzed/retrieved fields are shown in a storm relative frame of motion by subtracting a storm motion vector of U = 9.0 m/s and V = 6.0 m/s. The dual Doppler analysis shows two updrafts, a primary updraft to the south and a weaker one to the north. At z = 2.25 km the maximum vertical velocity in the primary/secondary updraft is 11.3/7.0 m/s.

Both single Doppler analyses capture the southern updraft reasonably well. Using Cimarron data, the vertical velocity reaches 8.5 m/s at z = 2.25 km while the Norman retrieval has a max vertical velocity of 11.3 m/s at this level. The retrieval of the northern updraft is not as successful.

* The National Center for Atmospheric Research is sponsored by the National Science Foundation. This research is sponsored by NSF through an Interagency Agreement in response to requirements and funding by the Federal Aviation Administration Aviation Weather Development Program.

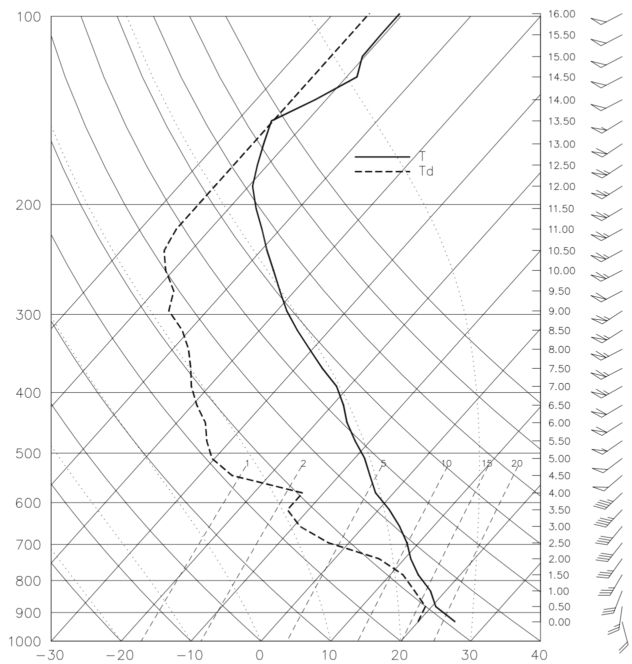

Figure 1. Sounding used to specify the large-scale environment.

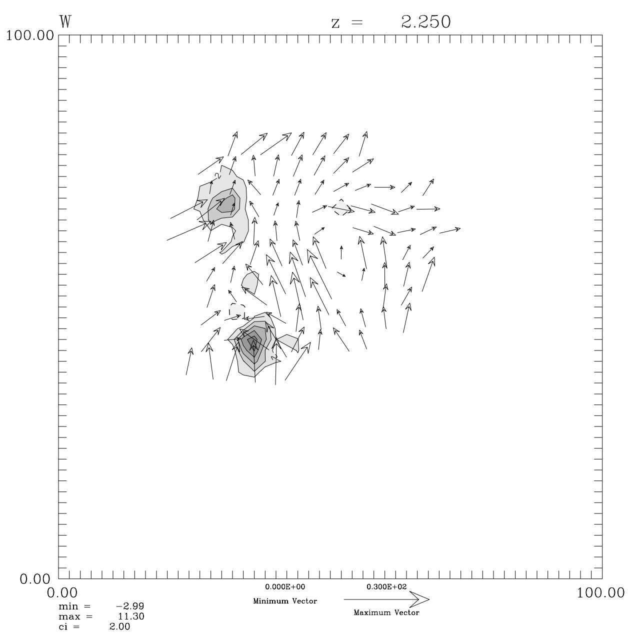

Figure 2. Dual Doppler analysis at z = 2.25 km and t = 1634 UTC. Winds are storm relative.

The assimilation using Cimarron data does not capture this updraft at all, while the assimilation using Norman data captures only 1/3 of the strength of the updraft (~2.5 m/s). The reason for this lack of success with the northern updraft is currently being examined.

In Table 1 we list the maximum vertical velocity throughout the storm from the dual Doppler, Cimarron-only and Norman-only retrievals. These values are averaged over 3 time levels at t = 1634, 1638 and 1643 UTC The dual Doppler analysis indicates an average maximum vertical velocity of 34.2 m/s. The Cimarron only analysis retrieves 73% of that value, whereas the Norman only analysis retrieves 69% of the max value.

Table 1: Maximum vertical velocity averaged over 3 time levels, t = 1634, 1638, 1643 UTC.

Dual Doppler	Cimarron-only	Norman-only
34.2 m/s	25.0 m/s	23.7 m/s

We now examine the contribution to the vertical velocity by the retrieved azimuthal divergence. In Fig. 4(a) we plot the azimuthal divergence from the Norman-only retrieval at z = 2.25 km and t = 1634 UTC. This is to be compared with the azimuthal divergence from the dual-Doppler analysis, Fig. 4(b). Although the dual Doppler azimuthal divergence is rather noisy, it does exhibit two maxima in the regions of the primary and secondary updrafts. As can be seen, the Norman-only retrieval captures some of the cross-beam convergence (just under 50% of the maximum) in the region of the primary updraft. This illustrates an important aspect of the 4D-Var technique for retrieval. By fitting a numerical model to the data, the observed radial convergence can drive convergence in the cross-beam direction through the equations of motion. This process is not possible in retrieval techniques which don't use the equations of motion.

We now analyze the retrieval of the cross beam component of the horizontal velocity. As verification we use the cross-beam component from each radar calculated from the dual Doppler analyses. The rms difference between retrieved azimuthal velocity and dual-Doppler azimuthal velocity is plotted for each vertical level in Fig 5((a) Cimarron and (b) Norman). Also plotted by the dashed curve is the fit of the retrieved to observed radial velocity. The statistics shown in Fig. 5 are averaged over the three analyses at t = 1634, 1638, and 1643 UTC.

Figure 5 indicates that with two exceptions the rms difference in azimuthal velocity is in the range of 4 -7 m/s. The first exception is in the Norman retrieval below 1.25 km where the rms difference reaches almost 10 m/s. The reason for this large difference is probably due to

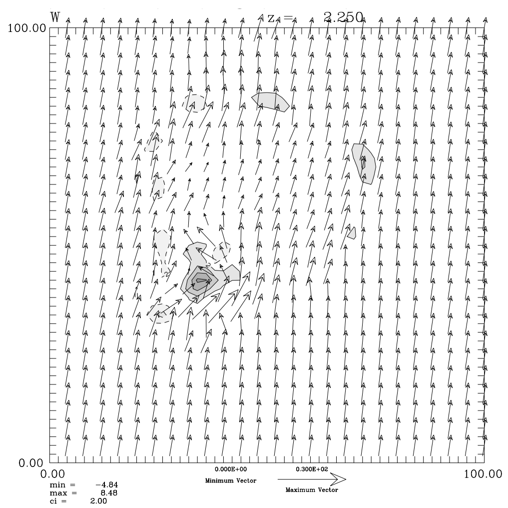

Figure 3(a) Vertical velocity (contours) overlaid on velocity vectors for the analysis using just Cimarron data. Analysis is at z = 2.25 km and t = 1634 UTC. Contour interval is 2 m/s.

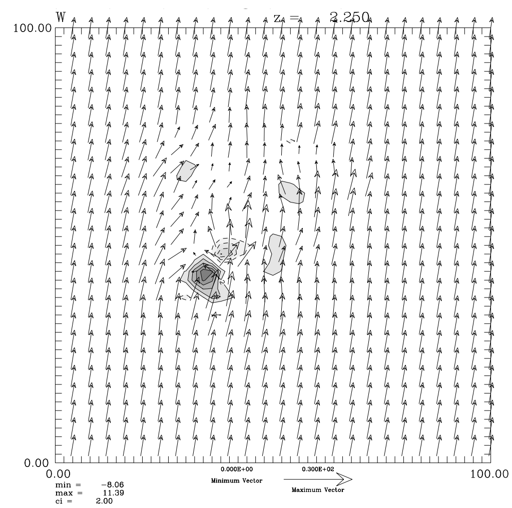

Figure 3(b) Same as 3(a) except using Norman data.

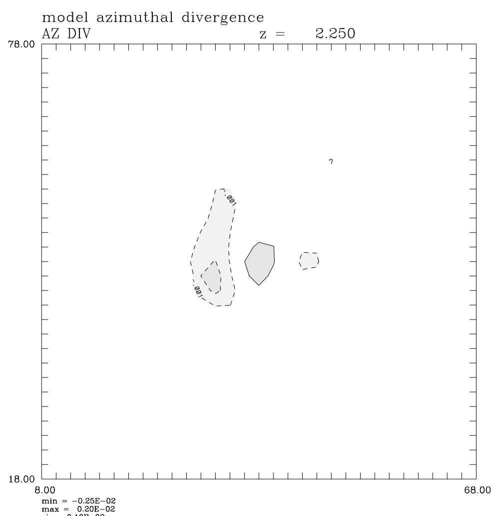

Figure 4(a) Azimuthal divergence for Norman-only case at z = 2.25 km, t = 1634 UTC. Contour Interval, .001 s^{-1}.

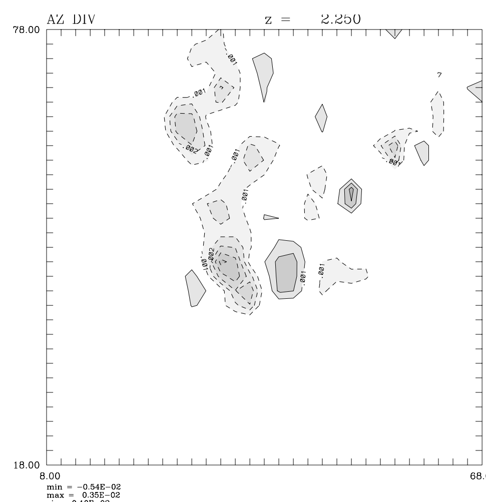

Figure 4(b) Azimuthal divergence from dual-Doppler analysis at z = 2.25 km, t = 1634 UTC. Contour Interval, .001 s^{-1}.

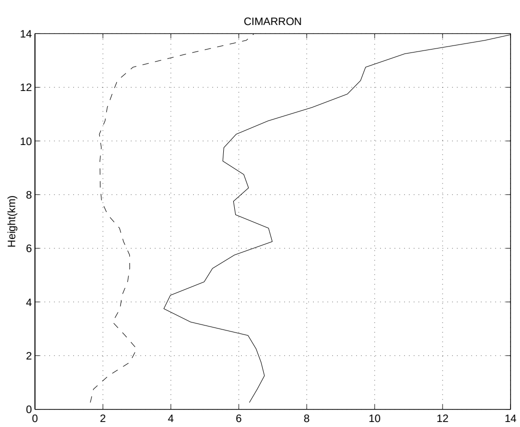

Figure 5(a). Vertical profile of R.M.S. difference between azimuthal velocity from Cimarron retrieval and dual-Doppler analysis. Statistics are averaged over three analyses at t =1634, 1638, 1643 UTC.

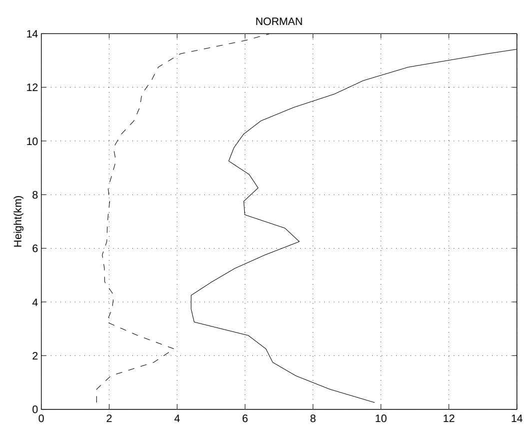

Figure 5(b). Same as Fig. 5(a) except for Norman data only.

the fact that a fairly large error has been introduced by extrapolating radar data down to the lowest model levels (especially in the case of the Norman radar which was farther from the storm). The second region where fairly significant differences exist is above 10 km in both retrievals. These difference appear to result from the fact that the sounding we are using is not very representative of the ambient flow at these levels.

Finally, we have conducted a number of forecast experiments using the retrieved fields as initial conditions. One of these experiments, initialized at t = 1634 UTC with the Norman-only analysis is shown in Fig. 6. The first panel shows a 40 minute forecast of rainwater mixing ratio and storm relative winds at z = 2.25 km. The second panel shows the observed rainwater field (converted from reflectivity) and dual Doppler winds at the verifying time. The first point to note is that the position of the forecast storm is fairly close to the observed location, indicating that the numerical model has been able to replicate the storm motion reasonably well. However, a number of difference exist, the first being that in the forecast a new cell has developed to the north of the original storm, which does not exist in the observations. Another difference is that the forecast storm maintains a maximum vertical velocity of around 30 m/s whereas the maximum vertical velocity in the observed storm has decayed to 18 m/s at this time. We are currently examining the reasons for these differences and will present further results at the Conference.

5. SUMMARY

We have performed assimilation and forecast experiments of the Arcadia, OK tornadic supercell using a 4Var adjoint technique applied to single-Doppler radar data. Preliminary results indicate that the 4DVAR technique retrieves approximately 70% of the maximum vertical velocity obtained in a dual-Doppler analysis. There is a significant contribution of the retrieved azimuth divergence to the vertical velocity. The rms difference between retrieved and dual-Doppler analyzed azimuthal velocity is in the range of 4-7 m/s. However, larger differences exist above 10 km and at low levels in the Norman retrieval. Finally, preliminary forecast experiments have indicated that the numerical model can replicate the storm motion reasonably well, but not all of the details of the storm structure.

REFERENCES

Dowell, D. C., and H.B. Bluestein, 1997: The Arcadia, Oklahoma, storm of 17 May 1981: Analysis of a supercell during tornadogenesis. *Mon. Wea. Rev.*, **125**, 2562-2582.

Dowell, D.C., F. Zhang, L. Wicker, C. Snyder, B. Skamarock and N.A. Crook, 2002; Winds and thermodynamic retrievals in a supercell thunderstorm: Ensemble Kalman Filter results (in this volume).

Sun, J. and N. A. Crook, 1997: Dynamical and microphysical retrieval from Doppler radar observations using a cloud model and its adjoint. Part I: Model development and simulated data experiments. J. Atmos Sci. **54,** 1642-1661.

Weygandt S. S., A Shapiro, K.K. Droegemeier, 2002: Retrieval of Model Initial Fields from Single-Doppler Observations of a Supercell Thunderstorm. Part I: Single-Doppler Velocity Retrieval.

Weygandt S. S., A Shapiro, K.K. Droegemeier, 2002: Retrieval of Model Initial Fields from Single-Doppler Observations of a Supercell Thunderstorm. Part I: Single-Doppler Velocity Retrieval. Part II: Thermodynamic Retrieval and Numerical Prediction.

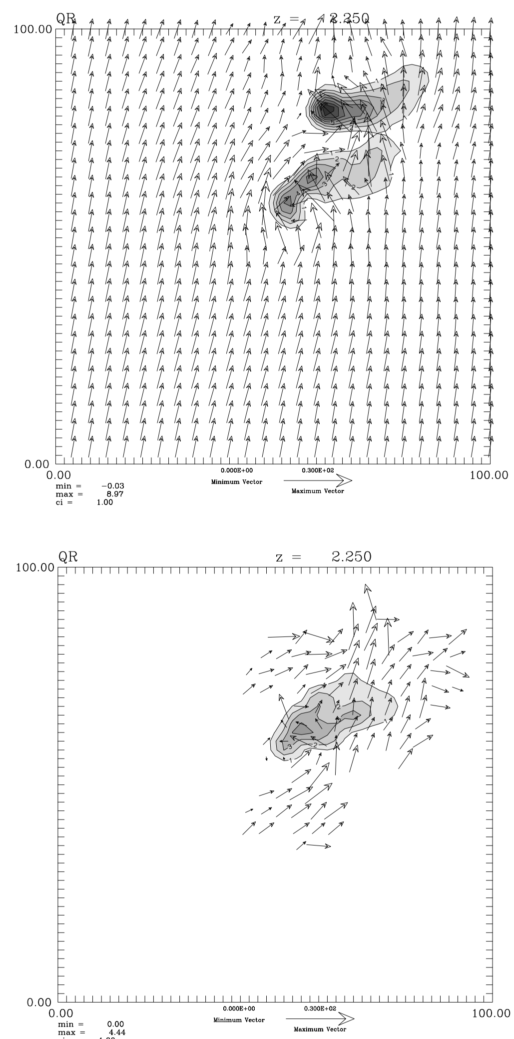

Figure 6. (a) 40 minute forecast of the Arcadia storm. Rainwater mixing ratio and storm-relative winds at z = 2.25 km. (b) Observed rainwater and dual Doppler winds at verifying time.