J6.3

RECENT ADVANCES IN THE DIABATIC INITIALIZATON OF A NON-HYDROSTATIC NUMERICAL MODEL

Keith A. Brewster*
Center for Analysis and Prediction of Storms
University of Oklahoma, Norman, OK

1. INTRODUCTION

It is desirable to initialize nonhydrostatic storm-scale models in conditions of ongoing convection with a complete specification of the hydrometeor fields, temperature perturbations, and winds using high resolution data including surface data and Doppler radar winds and reflectivity.

Work has been done to obtain such information using time-series of Doppler velocity winds and numerical techniques such as the Single Doppler Velocity Retrieval method (SDVR, e.g., Weygandt et al. 2002) and four-dimensional variational data assimilation (e.g., Sun and Crook 1994). Such schemes can be very computationally demanding, and require three to five volume scans of radar data, which themselves take up to 25 minutes to collect. In the case of the SDVR scheme, calculation of spatial derivatives can also reduce the amount of information available near the storm edge.

It is of interest to investigate techniques that are of a simpler nature, that use only one volume scan of data, and could be used for diagnostics, forecast initialization, or generation of first-guess fields to aide the convergence of variational schemes.

One such method is the ADAS system that has been developed at the Center for Analysis and Prediction of Storms (Brewster 1996). For analysis of state variables ADAS uses a successive-correction Bratseth (1990) scheme with a telescoping correlation parameter that allows for the use of a variety of data sets with varying spatial resolution. The scheme includes a method for utilizing the radial velocity data to provide increments to the horizontal wind by estimating the Cartesian component increment from the radial wind and using a corresponding correlation to communicate the value of each component estimate based on the radar viewing angle. With such radial velocity corrections it is not possible to accurately reproduce the complete wind field, but the updated wind can indicate the location and relative strength of any convergence features having a component of convergence in the along-beam direction. When there are two or more radars observing the same location, an even better estimate can be made.

. *Corresponding author address: Dr. Keith Brewster, CAPS/Univ. of Oklahoma, 100 E. Boyd, Suite 1110, Norman, OK 73019. e-mail:kbrewster@ou.edu

2. HYDROMETEOR ANALYSIS

The cloud analysis portion of ADAS was initially derived from that of LAPS (Albers et al. 1996) with a number of initial modifications as described by Zhang et al. (1998). Additional improvements have subsequently been made, the most notable are described in this section.

The radar data are brought from the observed polar coordinate system to the model's Cartesian coordinate through a three-dimensional polynomial interpolation, where the data are assumed to vary quadratically in the horizontal and linearly in the vertical. This is an improvement to the original local averaging scheme, which used simple grid-box averaging, followed by gap filling. This method better preserves detailed storm structure, while still providing small-scale filtering where the data are denser than the model grid. At the same time, the technique is still computationally efficient for real-time use with domains including multiple radars.

The equations of Ferrier et al. (1995) are used to convert the observed reflectivity to the model's precipitating hydrometeors (rain, snow and hail).

Cloud water is initially assigned as in LAPS through the use of the Smith-Feddes technique. Recently, it was found in separate testing by the author that the cloud variables may be overestimated in regions of precipitation. As an initial attempt to avoid double-counting cloud water that was subsequently converted to precipitating hydrometeors, and accounted for by the reflectivity, the cloud water in regions of observed precipitating hydrometeors is limited to no more than 20 percent of the precipitating hydrometeor quantity. This is meant to represent the tail of the hydrometeor distribution. Further research is planned to more accurately define this limit considering typical drop-size distributions.

3. DIABATIC INITIALIZATION TECHNIQUES

It is well known that diabatic effects can have an impact on the forecasting of storm systems from thunderstorms to large convective systems, including monsoon circulations. Space constraints prohibit a complete review, but some past assimilation work used rainfall data and a prescribed parabolic heating curve, but this has evolved to where one can describe the heating within the storm based on the storm's actual hydrometeor distribution and its internal circulation. Zhang (Zhang et al. 1998, Zhang 1999) used the following equation to assign a temperature perturbation based on the hydrometeors diagnosed in bation based on the hydrometeors diagnosed in a storm analyzed at 10-km resolution:

$$\Delta\theta' = \beta_\theta L_v(\Delta q_c + \Delta q_i)/(c_p\pi)$$

$$\pi = (p/p_0)^{\frac{R_d}{c_p}}$$

where $\Delta\theta'$ is the temperature perturbation increment, Δq_c is the cloud water increment and Δq_i is the cloud ice, increment with hydrometeors given in kg/kg. L_v is the latent heat of vaporization for water, p is pressure, p_0=100 kPa, R_d is the gas constant for dry air and c_p is the specific heat of air. β_θ is a tuning parameter, which in this case is set to unity.

While this formulation (named herein the LH, for latent heat, method) produced excellent results in one of the modeled storm systems examined by Zhang (1999), but it had trouble in a region of large-scale ascent where other observations already had produced a moist adiabatic profile. This required adjustments in β_θ to avoid excessive temperature perturbations.

Reducing the cloud-sized hydrometeors to correct for the possible double counting impacts the LH method of estimating the diabatic temperature perturbation. To address this potential problem, a modified scheme is proposed where the temperature is assigned to the moist adiabatic temperature profile (based on the cloud base equivalent potential temperature) within convective clouds in the presence of upward vertical velocity. Vertical velocity is determined from wind data, notably from the radial velocities on the storm-scale. This approach is labeled the theta-e method in the following text.

4. EXPERIMENT DESIGN

In order to gauge the effectiveness of the initializations, short-term forecasts were made using the Advanced Regional Prediction System (ARPS) model (Xue et. al. 2000, Xue et al. 2001). The model was run with a horizontal grid spacing of 2-km covering an area of 200 x 200 km. 53 levels were used in the vertical with an average grid spacing of 400 m and a minimum grid spacing of 20 m, putting the first grid level at 10 m AGL. The high resolution forecasts used boundary conditions specified from a 12-km ARPS model run initialized at 1800 UTC 3 May 1999. To minimize contamination from the lateral boundaries, the 12-km run used no convective parameterization, and no hydrometeor variables were passed to the inner grid. To isolate the effects of initialization, the high-resolution prediction used relatively smooth terrain (interpolated from 12-km) and homogeneous soil and vegetation cover.

Level-II (base-data) WSR-88D data from the Oklahoma City (KTLX) radar are used along with the Oklahoma Mesonet, visible and IR satellite data from GOES-8.

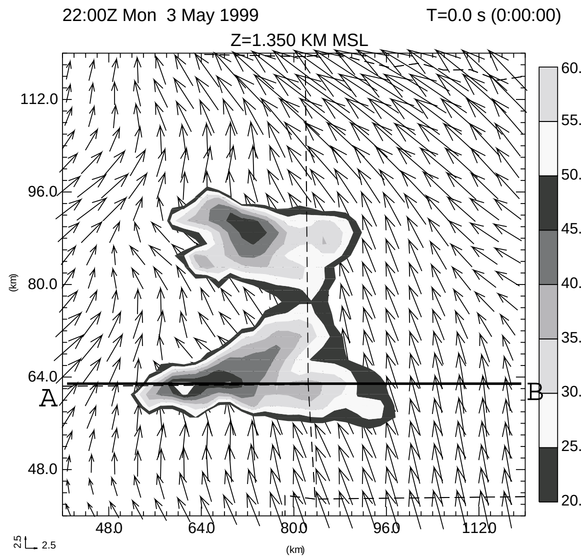

Fig 1. Low-level (0.5 degree) reflectivity (dBZ) from the Oklahoma City (KTLX) WSR-88D radar and 1.0 km AGL perturbation winds from analysis.

5. RESULTS AND DISCUSSION

The initial analysis was performed at 2200 UTC using a 4-hour 12-km forecast as a background. Fig 1 shows the initial low-level wind field overlaid on a remapped 0.5 degree scan reflectivity from the Oklahoma City (KTLX) WSR-88D radar. KTLX is located at x=156, y=116 km in this coordinate system. It can be seen that the radial velocity data was sufficient to depict low-level convergence with the cells. An updraft with maximum velocity of 10 ms^{-1} (not shown) is analyzed in the southern cell.

Figure 2 depicts cross sections across line A-B in Fig 1. Temperature perturbations, including those from the background forecast, surface data and diabatic enhancement are shown. The diabatic enhancement with the LH method is largely seen near x=70 km where the maximum cloud water has been analyzed in the updraft. Temperature excesses over 3 K are found. The location of the maximum is at about 5 km MSL. Without the recent cloud-water limitation in areas of reflectivity (not shown), the maximum is higher (7.1 K), but the location is similar. Using the theta-e method, a temperature excess of 6.3 K is found at 11 km.

Conditions in the updraft after it has reached an approximate steady state for both cases are depicted in Fig. 3. By this time the updraft has accelerated to nearly 50 ms^{-1}. Despite their initial differences, the result after the spin-up in this region are quite similar, but the initial condition produced by the theta-e method more closely matches the "spun-up" updraft condition, and the LH method takes somewhat longer to reach this state.

A longer forecast may reveal other impacts of the initialization method. Figure 4 shows the low-level reflectivity from the KTLX radar at 2256 UTC.

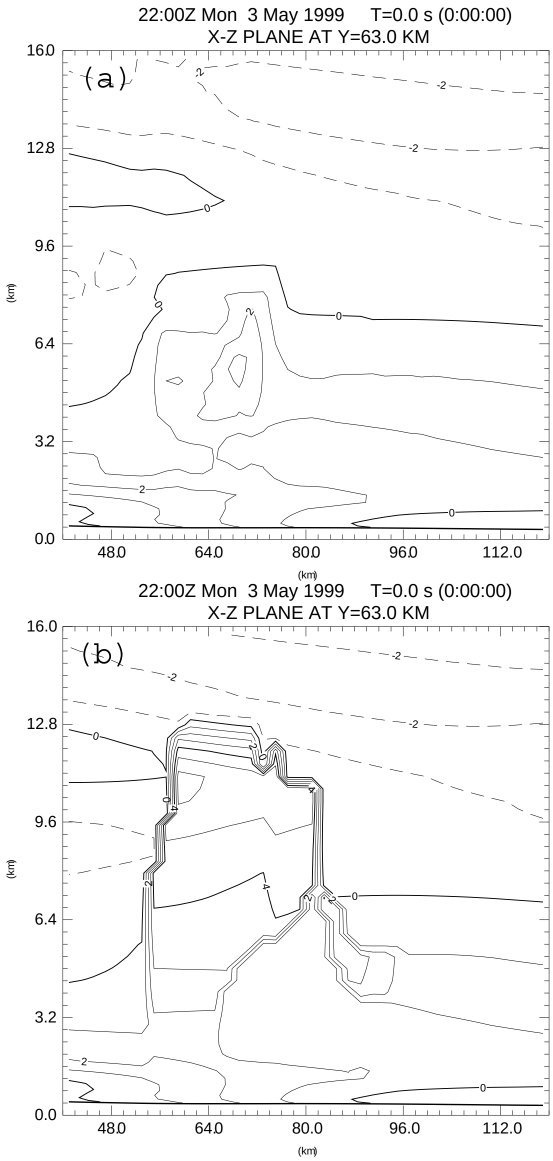

Fig 2. Perturbation potential temperature (K) cross-section through the storm (A-B in Fig 1) at the initial time for the a) LH and b) theta-e methods.

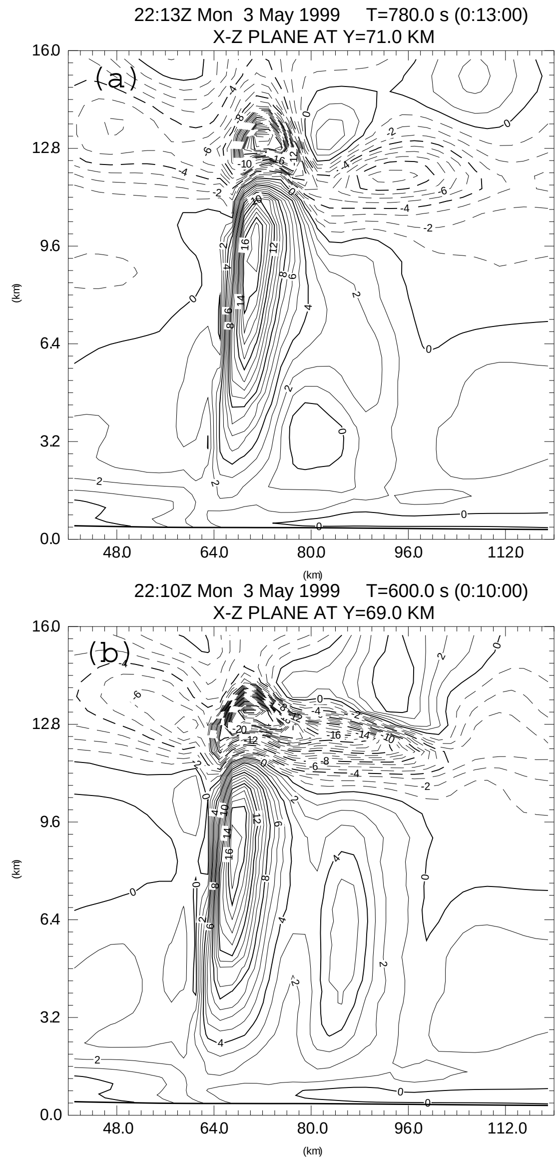

Fig 3. Perturbation potential temperature (K) cross-section (A-B in Fig 1) through the storm for the at the time of reaching near-steady-state condition for forecasts from the a) LH and b) theta-e methods.

Figure 5 shows the one-hour forecasts (valid at 2300 UTC). Both methods forecast a similar location for the southern (tornadic) cell, displaced about 8 km east of the observed. The general structure of this storm is quite similar among the two forecasts and the radar display. There are some differences seen in the forward flank where the theta-e method's forecast fits the observations closer, as it forecasted a secondary reflectivity maximum there. Good forecasts are produced to beyond two hours (not shown) though differences between the runs are harder to discern as other storms appear.

It has been demonstrated that a severe storm can be successfully simulated when a model is initialized using surface data, Doppler radial velocities, radar reflectivities, and geostationary satellite data.

A profile of temperature matching a moist adiabat is a reasonable initial condition in the updraft of the storm. The Doppler radial velocities, though insufficient to describe the complete storm circulation, are sufficient to identify the updraft region of the storm. In this case it appeared that the initial updraft and conditional instability were strong enough that the two diabatic initialization methods led to similar solutions by 13 minutes into the forecast, and also produced similar long-term forecasts. However, there is less spin-up required of the model with the theta-e method because its initial temperature profile was closer to the near-steady state updraft condition that evolved.

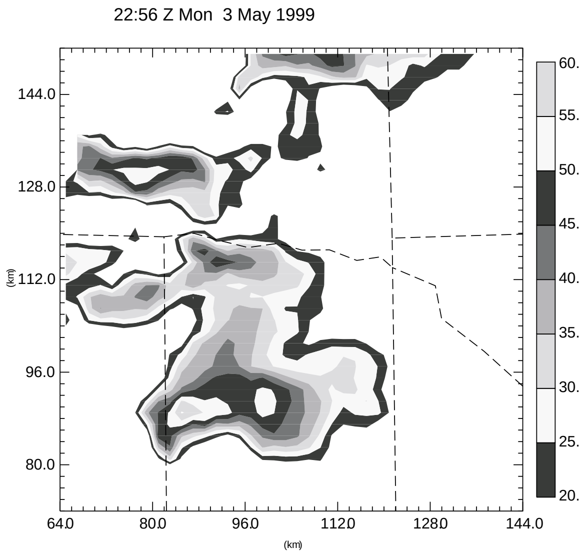

Fig 4. Low-level reflectivity (0.5 degrees) from the Oklahoma City (KTLX) radar at 2256 UTC.

Future work will explore the sensitivity of the updraft spin-up to initial value of the vertical velocity with the two diabatic initialization methods. Modification of the theta-e method to account for entrainment in towering cumulus will be studied. Also, the limitation on the cloud water and cloud ice amounts to be a fraction of the precipitation-sized hydrometeors will be more formally investigated.

6. ACKNOWLEDGMENTS

Discussions with Ming Xue, Fanyou Kong and Eric Kemp contributed to this work. This work is supported by grants from the National Science Foundation (ATM9909007) and from the Federal Aviation Administration (NA17RJ1227).

7. REFERENCES

Albers, S.C., J.A. McGinley, D.A. Birkenhuer, and J.R. Smart, 1996: The local analysis and Prediction System (LAPS): Analysis of clouds, precipitation and temperature. *Wea. and Forecasting*, **11**, 273-287.

Brewster, K., 1996: Application of a Bratseth analysis scheme including Doppler radar data. Preprints, 15th Conference on Weather Analysis and Forecasting. Amer. Meteor. Soc., Norfolk, VA, 92-95.

Ferrier, B. S., W.-K. Tao, and J. Simpson, 1995: A double-moment multiple-phase four-class bulk ice scheme. Part II. *J. Atmos. Sci*., **45**, 3846-3879.

Sun, J, and A. Crook, 1994: Wind and thermodynamic retrieval from single-Doppler measurements of a gust front observed during Phoenix II. *Mon. Wea. Rev.*, **122**, 1075-1091.

Weygandt, S. S., A. Shapiro, and K. K. Droegemeier, 2002: Retrieval of Model Initial Fields from Single-Doppler Observations of a Supercell Thunderstorm. *Mon. Wea. Rev.*, **130**, 433-453.

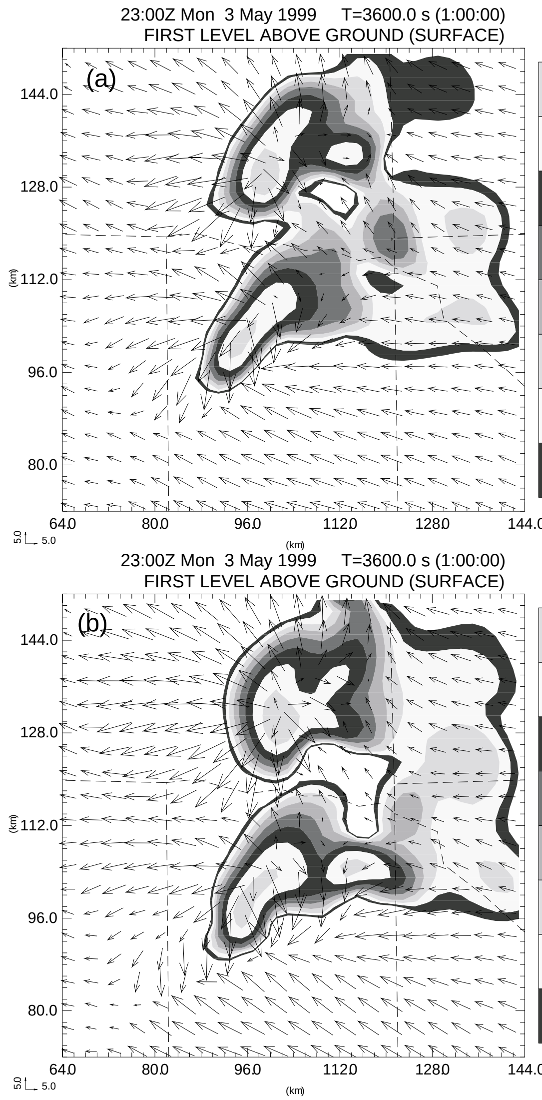

Fig 5. Forecast reflectivity at one hour for the a) LH and b) theta-e methods.

Xue, M., K. K. Droegemeier, V. Wong , 2000: The Advanced Regional Prediction System (ARPS) - A multiscale non-hydrostatic atmospheric simulation and prediction tool. Part I. *Meteor. Atmos. Physics*, **75**, 161-191.

Xue, M., K. K. Droegemeier, V. Wong , A. Shapiro, K. Brewster, F. Carr, D. Weber, and D. Wang 2001: The Advanced Regional Prediction System (ARPS) - A multiscale nonhydrostatic atmospheric simulation and prediction tool. Part II. *Meteor. Atmos. Physics*, **76**, 161-191

Zhang, J., F. Carr and K. Brewster, 1998: ADAS cloud analysis. *Preprints, 12th Conf. on Num. Wea. Prediction*, Phoenix, AZ, Amer. Meteor. Soc., Boston, 185-188.

Zhang, J. 1999: *Moisture and Diabatic Initialization Based on Radar and Satellite Observations*. Ph.D. Dissertation, Univ. of Oklahoma, School of Meteorology, Norman, OK, 73019.