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NIDS-BASED INTERMITTENT DIABATIC ASSIMILATION AND APPLICATION TO STORM-SCALE NUMERICAL WEATHER PREDICTION

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1. INTRODUCTION

The lack of accurate moisture/cloud initial conditions is one of the major causes for the spinup problem in explicit cloud and precipitation forecasting models during the first a few hours. Although many studies have sought a remedy by using satellite or/and radar data, the lack of detailed information on initial moisture, cloud water and latent heating fields is still a key problem. NEXRAD data can provide the three-dimensional precipitation field with high spatial and temporal resolution, though in a model, other conventional variables (i.e., water vapor, temperature and wind) may not be consistent with the cloud and precipitation analysis fields. Thus, evaporation processes may quickly kill convective storms present at the start of the model forecast.

To address this problem, a diabatic initialization scheme has been improved to provide a latent heat forcing in the model thermodynamic equation and to force vertical circulations and the associated divergence that is consistent with the observed precipitation. The 28 March 2000 Fort Worth/Texas tornado storm was chosen to explore options for applying the diabatic initialization technique, which essentially involves forcing the model over some time period with a heating field based upon NIDS (NEXRAD Information Dissemination Service, Baer, 1991) radar reflectivity, using an intermittent diabatic assimilation (IDA) technique.

2. INTERMITTENT DIABATIC ASSIMILATION (IDA)

The initialization analysis tool for this study is based on the cloud analysis of the ARPS Data Analysis System (ADAS, Brewster, 1996; Zhang et al., 1998). It can provide the detailed moisture initialization for the model and support the basis for moisture data assimilation. It incorporates cloud reports from surface observations, satellite and radar data to construct three-dimensional cloud and precipitation fields.

Based on the ADAS cloud and precipitation analysis, we have developed and improved a diabatic initialization scheme to provide the latent heating forcing in the model thermodynamic equation, and to force vertical circulations and the associated divergence that are consistent with the realitic precipitation field. In the scheme, the temperature field is adjusted first in cloud and precipitation regions to account for latent heating release from cloud condensation; the amount of latent heating is related to the amount of cloud liquid water content that is inserted in the ADAS cloud analysis. The relative humidity is adjusted to saturation in the analyzed cloudy regions. A simple latent heating adjustment is defined by (Zhang, 1999):

$$\Delta\theta' = \beta \bullet L_v(\Delta q_c + \Delta q_i)/(c_p\pi) ,$$

where $\Delta\theta'$, Δq_c and Δq_i are the differences between the potential temperature, the cloud liquid water mixing ratio, and the cloud ice mixing ratio before and after the adjustment, respectively; L_v the latent heat of vaporization/condensation of water, c_p the specific heat of dry air at constant pressure, π the Exner function, and β a weighting factor ranging from 0 to 1.

To take advantage of the availability of various observational data (especially radar data) near the storm initiation time, an intermittent diabatic assimilation (IDA) procedure is performed during the pre-forecast period. With this procedure, the model is integrated forward from an initial condition for a specified period (15 minutes for this study), and a new analysis and diabatic adjustment are then obtained by combining the model predicted fields with various observations. The cycle is repeated for several times until an assimilated initial condition is obtained, after which the model is integrated forward. Figure 1 shows the procedure, in which NIDS radar data are assimilated every 15 minutes for a period of one hour.

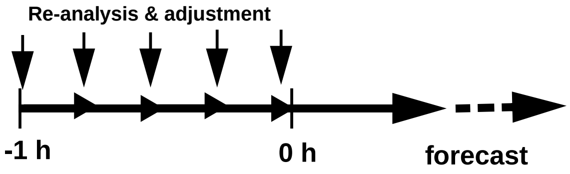

Fig. 1. The procedure of intermittent diabatic assimilation.

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3. THE STORM-SCALE NWP MODEL

The storm-scale numerical weather prediction (NWP) model used for this study is the Advanced Regional Prediction System (ARPS). A full description of the model can be found in Xue et al. (1995; 2000; 2001). The ARPS was developed at the Center for Analysis and Prediction of Storms (CAPS) at the University of Oklahoma. It is a multi-scale three-dimensional nonhydrostatic compressible forecast system with comprehensive physics. It was designed from the beginning to serve as an effective tool for basic and applied research and as a system suitable for explicit prediction of convective storms and weather systems at other scales.

4. A TORNADO STORM CASE

A tornado, reported as causing F2 damage on the Fujita Scale, passed through the downtown region of Fort Worth, Texas (TX), during the early evening of March 28, 2000. The tornado was reported as starting around 6:20pm LST March 28 (0020 UTC, March 29), and its path length was about 3 miles. Severe damage to clad buildings in the downtown was reported. Strong wind, softball hail, and torrential rain accompanying the tornado damaged many interior areas that had withstood the actual tornado winds. The tornado took five lives, injured over 100 people, caused $450 million in damage and closed the downtown for five days. A second F3-scale tornado from the same storm system touched down in Arlington, TX, some 15 miles further east of Fort Worth about 30 minutes later.

The synoptic condition related to this storm system is as follows. Above the 700 hPa level on March 28, a powerful broad low-pressure trough was located over the Great Lakes and northeastern US. The north central US was dominated by a weak ridge of high pressure. Another weaker trough was found over the western US. At 250 hPa, a very strong westerly stream jet with a maximum speed of over 90 m/s was located from northern Mexico across TX and Louisiana to southern Mississippi. The surface features included a distinct north-south oriented dryline in western TX in the morning. At 12Z March 28, the surface location of the dryline was from the TX panhandle to Mexico. It moved easterly during the morning. Figure 2 shows the surface dewpoint temperature, surface convective available potential energy (CAPE), and surface wind at 18 Z, March 28. Associated with the dryline, there were strong southwesterly winds on the west side and south-to-southeasterly winds on the east side. A zone of high CAPE values was situated on the east side of the dryline, with maximum CAPE exceeding 3000 J/kg.

The earliest convective cells appeared over Shackelford County, TX, just ahead of the dryline and about 150 km west of Fort Worth between 20 and 21Z, March 28. These cells developed and organized into supercell storms and moved eastward to Fort Worth to produce deadly tornadoes in the next couple of hours. Between 22 and 23 Z, more convective cells developed along the dryline, and then evolved into a strong convective line oriented along a north-south axis. A series of individual severe storms in the line moved eastward or northeastward with a trailing stratiform precipitation region (Fig. 3a).

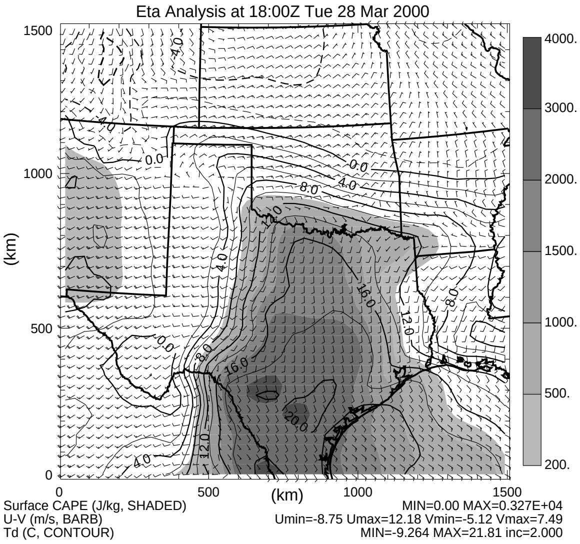

Fig. 2. The surface dewpoint temperature (interval 2.0 C) and surface wind (m/s) at 18 UTC, March 28, 2000. Negative contours are dashed.

5. FORECAST EXPERIMENTS AND RESULTS

The ARPS model was used in a one-way nested mode with a 9-km coarse horizontal grid spacing and a 3-km fine grid spacing. Fifty-three levels were used in the vertical, and the vertical grid space varied from 20 m at the ground to 980 m at the top. The physical domain is 1000 km x 1000 km and 450 km x 300 km for the coarse and fine grids, respectively. The coarse grid covers the entire Oklahoma and Texas, and the fine domain centers on Fort Worth.

Identical model physics options are used on the both coarse and fine grids except for cumulus parameterization for the coarse grid. They include the 1.5-order TKE-based subgrid-scale turbulence and PBL parameterization, two-layer land surface model, explicit grid-scale ice microphysics, and NASA/GSFC radiation package. The Kain-Fritsch cumulus parameterization scheme is used with the explicit ice microphysics only on the coarse grid.

Starting from 18Z March 28 2000, the 9-km coarse grid was run for 12 hours with the NCEP Eta analysis as the first guess and combining rawinsonde, wind profiler, NWS surface and Oklahoma Mesonet data via ADAS analysis. The lateral boundaries of the 9 km grid were forced by linearly interpolating the 3-hourly Eta forecasts that started from 18Z. Neither radar data nor data assimilation was performed on the 9-km grid.

Three forecast experiments were performed on the 3-km fine grid (Table 1). Using the ADAS analysis at 22Z, the 4-hour forecast from the 9-km grid was used as the background, into which were assimilated NWS surface data and NIDS radar data (including KFWS, KDYX, KGRK and KFDR WSR-88D radars). The model was used to produce 5-hour forecasts starting from 22Z with this analysis as EXP1. For the control simulation, a 1-hour intermittent diabatic assimilation is performed from 22Z to 23Z as EXP2. During the 1-hour assimilation period, NIDS radial velocity and reflectivity at 15-minute intervals were incorporated into the cloud analysis and diabatic adjustment (see Fig. 1). For this case, the model produced a 4-hour forecast starting from 23Z with additional 1-hour pre-forecast/assimilation. EXP3 is same as EXP1 but starting from 23Z with the 5-hour 9-km forecast as the background, and also the NIDS radar data was put in at this initial time. For this case, a 4-hour forecast was made. The 3-km grid lateral boundaries for three experimental cases all come from the 9-km hourly forecasts.

Table 1: Summary of experiments

Exp.	Start time	Data Assimilation
EXP1	22Z	Cold start
EXP2	22Z	IDA every 15 min for 22-23Z
EXP3	23Z	Cold start

Figure 3 shows the model-predicted composite reflectivity fields and surface winds (actually at the first model vertical level which is 10 m above ground) valid at 00 UTC 29 March 2000, for all three experiments. The corresponding observed radar composite reflectivity image from Fort Worth is also shown in Fig. 3a. Note that it is really a 2-hour forecast for EXP1 (Fig. 3b) at this time; 1 hour forecast for EXP3 (Fig. 3d); but 1 hour forecast and additional 1 hour data assimilation cycle for EXP2 (Fig. 3c). It is found that only EXP2, which used 1 hour IDA at 15-minute intervals, predicted very well the thunderstorm (marked by the arrow in Figs. 3a and 3c) which spawned the Fort Worth tornado after about 20 minutes. In the observation of Fig. 3a, one supercell with a maximum reflectivity of 72 dBZ was located inside Tarrant County, and just northwest of downtown Fort Worth. The model captured this tornadic storm with a maximum reflectivity of 70.4 dBZ (Fig. 3c). Associated with the predicted severe thunderstorm, the surface/low-level features of strong convergence, strong divergence, strong cool pool and high vorticity were also captured in EXP2 (not shown). Although both EXP1 and EXP3 partly captured some thunderstorms north and south of Fort Worth, they both missed the Fort Worth tornadic storm at this time (Figs. 3b and 3d).

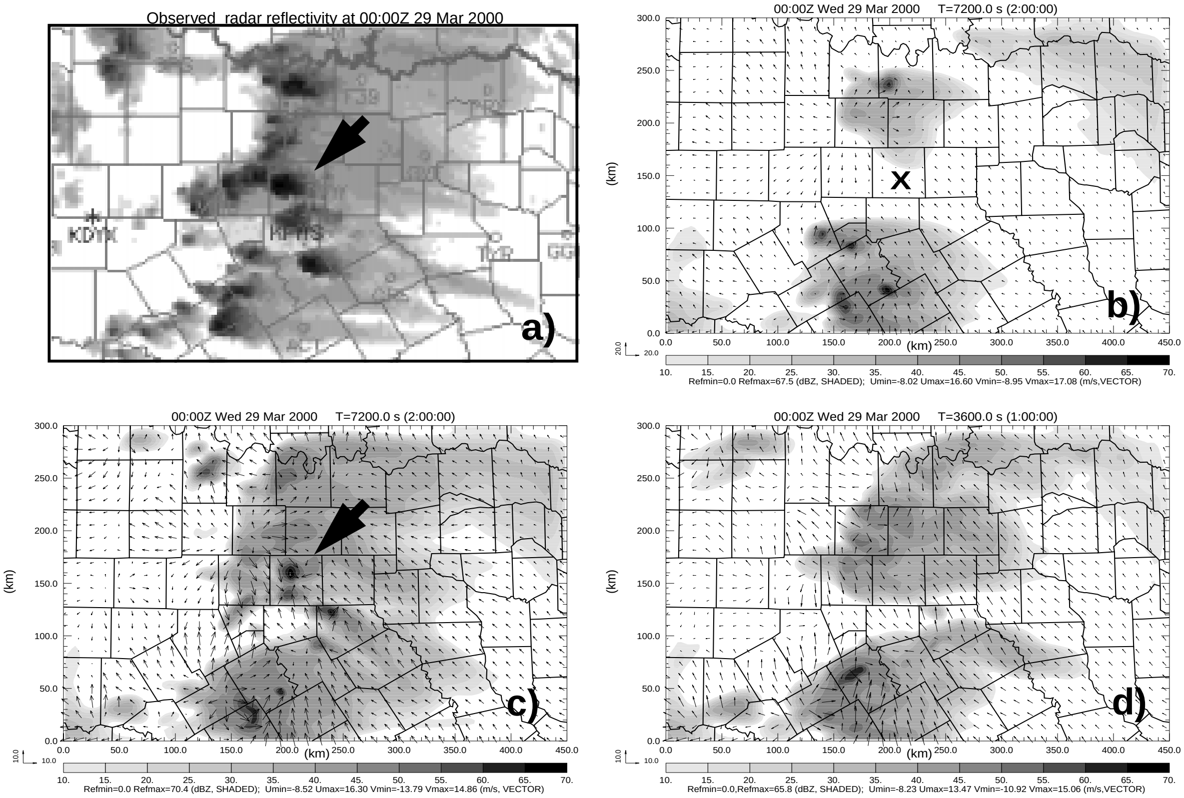

Fig. 3. Model-predicted composite (maximum in a vertical column) reflectivity fields and surface wind vectors valid at 00 UTC 29 March 2000 from EXP1 (b), EXP2 (c), and EXP3 (d), and corresponding observed radar composite reflectivity image from Fort Worth, TX (a). The location of Fort Worth was marked by "X" in (b).

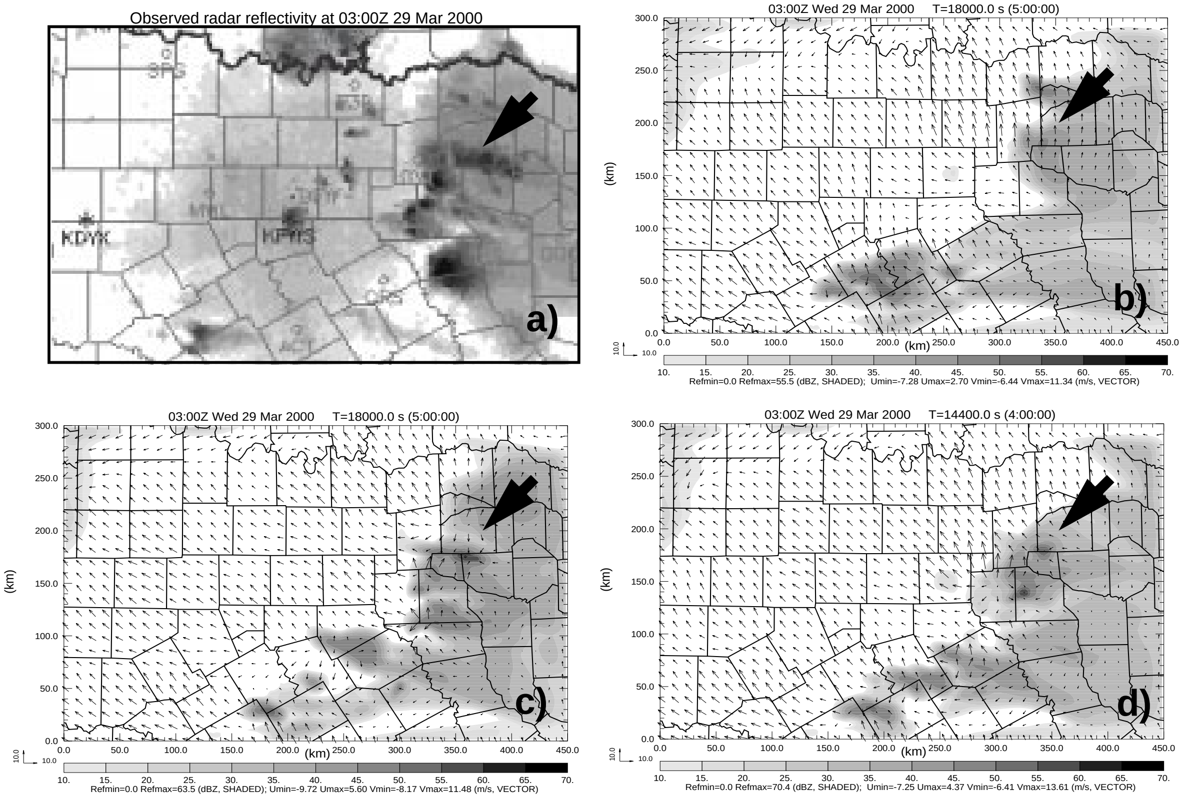

Fig. 4. As in Figure 3 but for 0300 UTC 29 March 2000.

The observed tornadic thunderstorm moved across downtown Dallas and continued east-northeasterly in the next couple of hours, as shown in Fig. 4a for the radar observation at 0300 UTC 29 March. The control experiment, EXP2, reproduced reasonably well the storm evolution during the entire 4-hour forecast period and 1-hour assimilation cycling (Fig. 4c). Even for the no-data assimilation experiments of EXP1 and EXP3, the model took some spinup time, and then was able to produce comparable forecasts at 0300 UTC 29 March, as shown in Fig. 4b for the 5-hour forecast of EXP1 and Fig. 4d for the 4-hour forecast of EXP3.

6. SUMMARY

Based on NIDS radar data (WSR-88 level-III data), which is available for public access for all US national radars in real time, an intermittent diabatic assimilation scheme has been developed and improved to solve the storm-scale NWP spinup problem. This assimilation scheme was used to perform the prediction of a deadly tornadic thunderstorm case. The results show that data assimilation indeed has a significant positive impact on the storm forecast. The model can reasonably predict the severe thunderstorms that in reality spawned at least two tornadoes over the area of Fort Worth, TX on 28 March 2000. Of notable importance is the model's ability to capture storm timing, location, intensity and evolution, and some supercell storm characteristics in the tornadic environment. We now plan to conduct further experiments with higher horizontal resolution and more detailed analysis to better understand how the intermittent diabatic assimilation impacts the storm-scale spinup problem, and also to investigate tornado dynamics.

7. ACKNOWLEDGMENTS

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