P2.8 An Evaluation of 3DVAR, Nudging-based FDDA, and a Hybrid Scheme for Summer Convection Forecasts Using the WRF-ARW Model

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1. INTRODUCTION

Recently, an "observation-nudging"-based FDDA scheme has been implemented in the Weather Research and Forecasting (WRF) model (Liu et al., 2005). Verification of operational forecasts during Summer 2005 using the "observation-nudging" FDDA initialization approach showed superior performance in very short-term forecast of summer convection (Yu et al, 2006). The WRF modeling system also includes a "grid-nudging" FDDA capability (Stauffer et al, 1990, 2005) and a 3DVAR package developed at NCAR. In this paper we compare the three different data-assimilation schemes for short-term forecasts of a summer convection event during IHOP-2002. The purpose of this study is to assess WRF 3DVAR, grid-nudging, observation-nudging and a combined approach in terms of their ability to produce initial conditions for very short term forecasts of convective precipitation. The model precipitation forecasts are verified against the NCEP STAGE IV analysis.

2. MODELING SYSTEMS AND EXPERIMENTAL DESIGN

A convective storm during IHOP-2002 from 1200 UTC 13 June 2002 to 2000 UTC 13 June 2002 in Oklahoma and Kansas is chosen for the case study. At 0700 UTC 13 June 2002, after a squall line moved out of Oklahoma and Kansas, a storm initiated in eastern Colorado, developed, and moved to the southeast. It reached maximum intensity around 1800 UTC, and then began to dissipate while moving out of Oklahoma and Kansas. The model domain is chosen as in Figure 1 where domain 1 has a grid increment of 30 km, domain 2 is 10 km, and domain 3 is 3.3 km.

All experiments designed for this study are shown in Figure 2. CF12Z is the control experiment, which exhibits the model's capability in terms of a very short term forecast with a cold start. The model started at 1200 UTC from 1 degree global analysis. CF06Z is also a cold-start forecast, but began its forecasts 6 hour earlier.

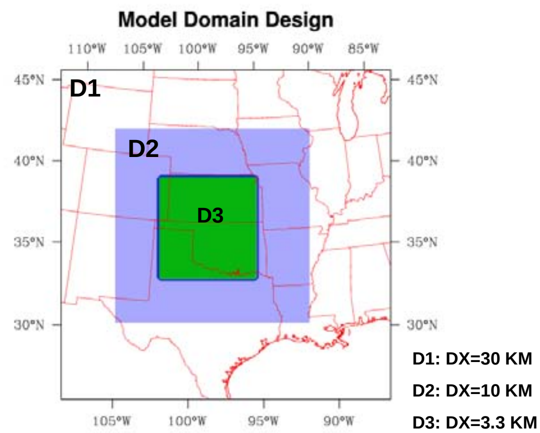

Figure 1 Model Domains

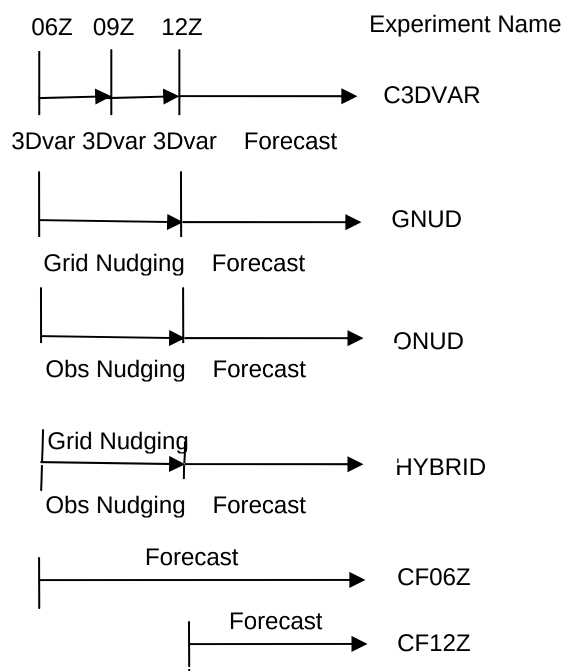

Figure 2 Experiment Design

The model initial conditions/background and boundary conditions were derived from a 1 degree 6-hourly global analyses. C3DVAR applies the 3DVAR cycling method to add observation data during the model spin-up period. C3DVAR is cycled from 0600 UTC 13 June 2002 to 1200 UTC 13 June 2002 with a 3 hour interval. Model forecasts started at 1200 UTC 13 June 2002 for both methods. GNUD uses a grid-nudging method from 0600 UTC 13 June 2002 to 1200 UTC 13 June 2002 with 1 degree global analysis data. It examines the effect of dynamic initialization by applying large-scale analysis data. ONUD uses observation-nudging. It assimilates all of the observation data from 0600 UTC to 1200 UTC for both coarse and fine mesh grids. Finally, a hybrid method is tested by combining the grid-nudging and observation-nudging methods as experiment HYBRID. Here, grid-nudging was applied from 0600 UTC to 1200 UTC using the global analysis at coarse mesh. The model forecast started at 1200 UTC 13 June 2002 with the initial data from hybrid results. As a convenience for comparison, all tests were set up so that there was no feed back between coarse- and fine-mesh grids.

3. RESULTS AND ANALYSIS

Figure 3 showed the precipitation structure and evolution of the observed storm based on the Stage IV analyses. At 1300 UTC, there were two convective clusters, one located in Kansas and the other in Oklahoma. In the next 6 hours, this system developed and reached maximum strength in a typical “bow”-shape at 1800 UTC, and then moved southeast out of the IHOP domain.

Figure 4 compares the 1-hr accumulated precipitation forecasted by the experiments. At 1300 UTC, CF12Z showed weak precipitation since the model had not spun up the precipitation processes yet. All other experiments showed two strong precipitation areas, one located in western Oklahoma, and another located in Kansas. The position of the forecasted storm in northern Kansas GNUD and CF06Z were very similar. The forecasted precipitation areas were all displaced northwestward. GNUD showed some improvement, while the C3DVAR, ONUD and HYBRID appear to perform the best compared to the Stage IV observation. For the convective cluster in Oklahoma, GNUD and CF06Z had very similar precipitation structures, and were biased a bit toward the northwest, while C3DVAR, ONUD and HYBRID produced a larger area precipitation and extended it a bit to the north.

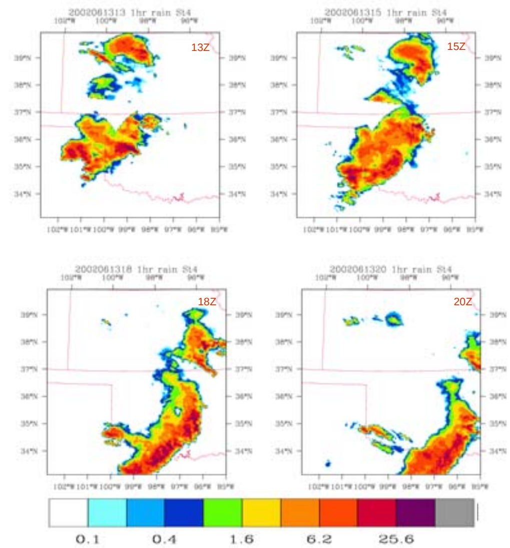

Figure 3 Stage IV analyses of 1hr accumulated precipitation on 20020613. Top-left at 1300 UTC, top-right at 1500 UTC, bottom-left at 1800 UTC, bottom-right at 2000 UTC.

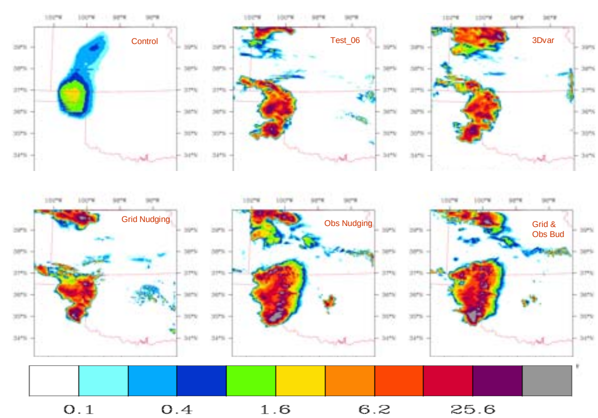

Figure 4a, 1 hr precipitation valid at 1300 UTC 13 June 2002. Top-left is CF12Z, top-middle is CF06Z, top-right is C3DVAR, bottom-left is GNUD, bottom-middle is ONUD, bottom-right is HYBRID.

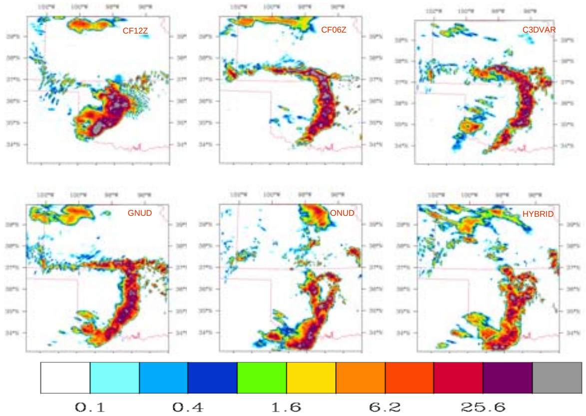

Figure 4b, 1 hr precipitation valid at 1800 UTC 18 June 2002. Top-left is CF12Z, top-middle is CF06Z, top-right is C3DVAR, bottom-left is GNUD, bottom-middle is ONUD, bottom-right is HYBRID.

At 1800 UTC, the differences among the experiments are much more obvious. All of the experiments forecasted strong precipitation in Oklahoma. The storm in CF12Z moved slower. C3DVAR, GNUD, ONUD and HYBRID represented improvements in the precipitation forecast comparing with both CF12Z and CF06Z. The storm structures in southwest Oklahoma were similar to the Stage IV analysis. It is worth pointing out that C3DVAR and GNUD both had a tail-like precipitation band along the border of Oklahoma and Kansas, and the main part of the storm was located further north than the observation. ONUD and HYBRID apparently cleared this tail-like precipitation band, and moved the major storm further south. Therefore they were much more consistent with the Stage IV observations. ONUD had a rain gap in the main band in the central north of the Oklahoma, while the HYBRID did not.

All experiments forecasted poorly for the convective storm located in the southeast region of Kansas. CF12Z, C3DVAR, GNUD, and CF06Z completely missed the storm. It should be noted that the "observation-nudging" approach corrected the false convection in northern Kansas that was produced by all the other schemes.

To further understand the precipitation forecast

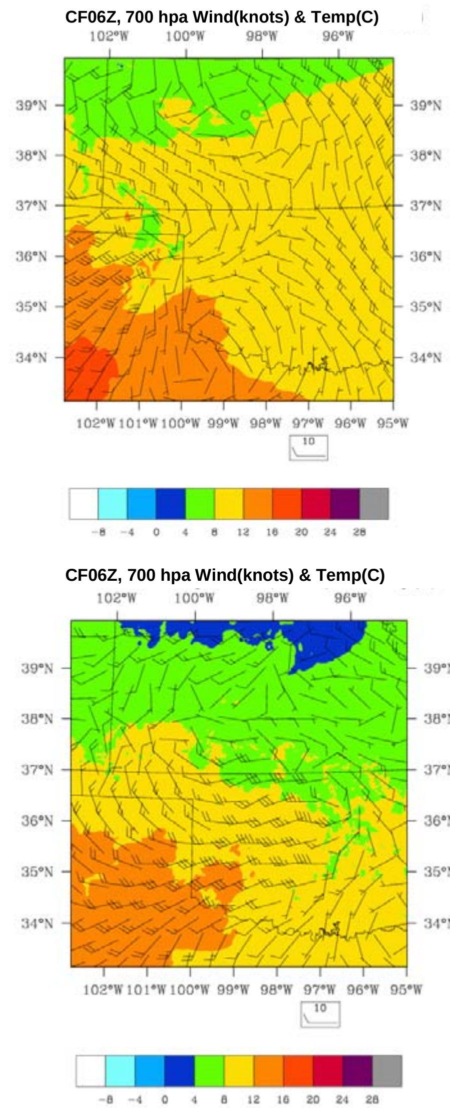

Figure 5, 700 hpa wind and temperature fields of CF06Z. Top panel is validated at 1200 UTC 13 June 2002, bottom is validated at 1800 UTC 13 June 2002.

differences, the wind circulations, temperature and moisture fields have been examined. Among all experiments, the surface wind and dew point temperature at 1200 UTC presented a moisture gradient from west to east and a more moist area along Oklahoma and Kansas at 700mb. The moisture condition was enough for the development of the storm, as long as the large scale perturbation could initiate and enhance the convection. Therefore, the related surface cold front and high level trough determined the differences in the position and shape of the storms.

At 700mb, at 1200 UTC, 3DVAR, GNUD and CF06Z were similar in that all of them had very strong southwesterly flows. The ridge extended further northwest. Especially, the strong warm temperature advection in front of the ridge prevented the cold air from moving south. This was consistent with the development of the system in the later hours. As shown for 1800 UTC, the north wind could not reach further south. The cyclone center was located in southern Kansas. In Oklahoma beyond the cold front, there were strong west winds. The system moved mainly to the west. That was the reasons that the precipitation position in Oklahoma, shown in Figure 4b, was biased north compared with the Stage IV analysis. Along the state border of Oklahoma and Kansas, there was an obvious wind shear, which caused the tail-like strong precipitation (Figure 5).

ONUD and HYBRID are obviously different from other experiments. At 1200 UTC, the southwest flow is relative weak. The related ridge was located a little bit south. The system moves mainly to the southeast. As shown in Figure 6 at 1800 UTC, the north wind prevailed in north Texas, with cold temperature advection. The cyclone center, which was related to the storm in Oklahoma, was located further south comparing to other experiments. This was consistent with the results in Figure 4b, that ONUD and HYBRID cleared the tail-like precipitation band, and the storm position in Oklahoma was biased south and more close to the Stage IV, relative to other experiments.

As discussed above, ONUD and HYBRID had better results for the storm in Oklahoma. This is because the "observation nudging" could modify both the coarse and fine mesh grids with all available data and created better initial fields, which resulted in the difference in the precipitation prediction in the following hours. It was not surprising that the precipitation and circulation of C3DVAR, CF06Z and GNUD were similar, since the affect of the C3DVAR and GNUD on the fine mesh grid was through the

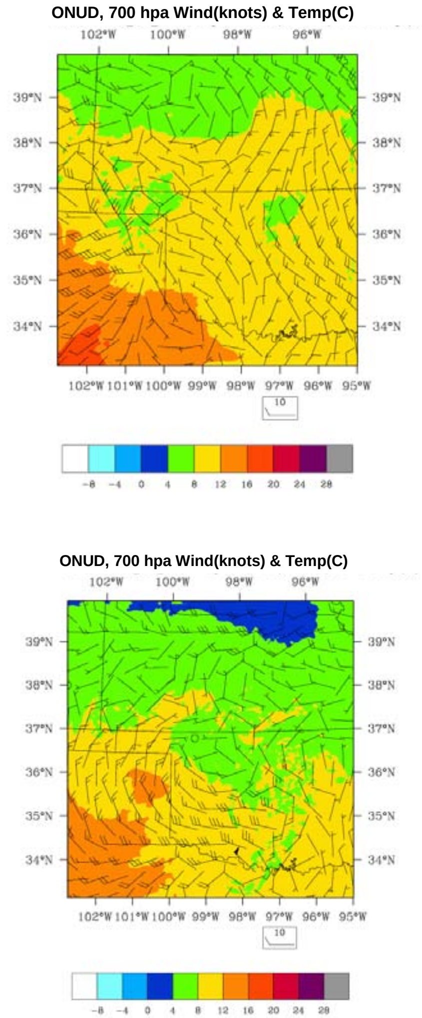

Figure 6, 700 hpa wind and temperature fields of ONUD. Top is validated at 1200 UTC 13 June 2002, bottom is validated at 1800 UTC 13 June 2002.

boundary. On the other hand, in this study, C3DVAR used only Aircraft (ACARS) data and sounding data. We chose a 20 minutes window for flight data, and the sounding data were only available at 1200 UTC with 3 stations in Domain 2. Lack of enough data to correct the circulation field is another reason for the poor performance of C3DVAR in this study.

All of the experiments, except for ONUD, simulated a erroneous convective band near the north boundary of the fine mesh domain. This may be due to amplification of disturbances generated by inconsistence between the coarse and fine grids.

4. CONCLUSION

WRF data-assimilation schemes including 3DVAR and "observation-nudging" are evaluated in forecasting an IHOP-2002 severe convection event. For the June-13 squall-line case, while the storm had already been present at the model initial time, all data assimilation schemes appear to greatly outperform the model cold-start forecasts. In fact, for cold-start forecasts, 0 to 6 hour forecasts were poorer than that of 6 to 12 hour forecasts.

3Dvar, grid-nudging and observation-nudging methods forecast the basic features of the storm development and movement for 0 – 12 hour forecasts. "Observation-nudging" performs the best with its advantages of assimilating observations on both the coarse and fine mesh grids and having a close interaction (dynamical adjustment) between observations and model equations.

Continuing work will be conducted to improve the hybrid method. In this study, the hybrid experiment only adds large-scale (more like background) information through "grid-nudging", to complement the observation-nudging. For future operational application, the hybrid method that combines the grid analyses of 3DVAR that assimilates remote sensing and Radar data and "observation-nudging' will be developed to improve forecasts of summer convection.

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5. REFERENCES

Liu, Y., A. Bourgeois, T. Warner, S. Swerdlin and J. Hacker, 2005: Implementation of Observation-nudging Based FDDA into WRF for Supporting ATEC Test Operation. WRF/MM5 Users' Workshop June 27 - 30, 2005. Boulder, CO.

----, T. Warner, W. Yu, R.G. Bullock and B.G. Brown, 2006: Very short-term QPFS for summer convection over complex terrain areas using the NCAR RTFDDA system: a comparison with NCEP NAM and RUC operational forecasts in New Mexico and Arizona. 12th Conference on Mounrain Meteorology. Aug. 27-31, 2006.

Stauffer, D.R., N. Seaman, 1990: Use of Four-Dimensional Data Assimilation in a Limited-Area Mesoscale Model. Part I: Experiments with Synoptic-Scale Data. Mon. Wea. Rev., 118, 1250-1277.

----, D.R., A. Deng, J. Dudhia, and T. Otte, 2005: Update on Development of Nudging FDDA for Advanced Research WRF. WRF/MM5 Users' Workshop June 27 - 30, 2005. Boulder, CO.

Yu, W., Y. Liu, T. Warner, R. Bullock, B. Brown and M. Ge, 2006: A Comparison of Very Short-term QPFS for Summer Convection over Complex Terrain Areas, with the NCAR/ATEC WRF and MM5 Based RTFDDA Systems. WRF/MM5 Users' Workshop June 19 - 22, 2006. Boulder, CO.