J9.3

ASSIMILATING RADAR DATA FOR REAL-TIME SHORT TERM SNOWSTORM FORECASTING

Mei Xu[1], N. Andrew Crook, Yubao Liu and Roy Rasmussen
National Center for Atmospheric Research[2], Boulder, Colorado

1. INTRODUCTION

A mesoscale, real-time four-dimensional data assimilation and short-term forecasting system (RTFDDA) has been developed at NCAR (Cram et al., 2001; Liu et al., 2002). Built upon a high-resolution MM5 and an observational nudging scheme, the system continuously assimilates observations from various sources and provides updated 3-dimensional analyses and short-term forecasts in a cycling fashion. The RTFDDA system is now being adapted for real-time short term (1-12 h range) forecasting of snowbands in the airport terminal area. A major enhancement to the system for airport applications is the addition of a radar data assimilation component to incorporate multi-radar observations.

There are several methods to assimilate radar observations into a mesoscale model. Using simulated data as well as real data, we have previously tested the feasibility of using the four-dimensional variational data assimilation (4DVAR) technique to assimilate Level II radar data into MM5 (Xu et al. 2001). The results show that assimilating Level II radar reflectivity data using 4DVAR improves 1-4 h forecast of snowbands. In order to be more applicable to real-time operations, a less expensive method based on the analysis nudging technique, is now tested. The nudging method has been shown effective in assimilating synoptic scale observations, however, it is relatively untested for high resolution data and model grid.

In this work, feasibility of using the RTFDDA system to assimilate radar data for snowstorm forecasting is investigated. Case studies are conducted for snowstorm events that occurred in northeastern U.S. A series of assimilation and forecasting experiments are conducted to evaluate the performance of RTFDDA and the impact of radar data assimilation. The following section contains a brief introduction to the real-time system. Section 3 describes the CIWS radar observations and the data assimilation schemes in RTFDDA. Lastly, preliminary results from a case study are presented.

2. THE REAL-TIME ANALYSIS AND FORECASTING SYSTEM

The RTFDDA system was initially developed as a quick cycling FDDA system to provide real-time local scale analyses and short term forecasts. The data assimilation engine of the RTFDDA system is based on observational nudging. Each observation is ingested into the model at the observed time and location, with proper space and time weights. The system runs in three-hour cycling mode and is cold started once a week. Currently, traditional observations (rawinsonde, metar, ship and buoy reports), as well as non-traditional observations (mesonet, aircraft reports, profilers and satellite wind) are nudged in this manner. NIDS VAD profiles can also be nudged at the radar sites.

There has been an extensive effort on testing and evaluating the RTFDDA system. Briefly, both RTFDDA analysis and short term forecasts appear to perform reasonably better than the simpler or coarse-resolution analyses and conventional cold-start model forecasts. The RTFDDA results describe additional details of local circulations forced by thermal contrasts and/or topographic influence of synoptic weather systems.

In the current operational systems, no cloud or precipitation observation is directly assimilated. Qualitative comparison of the model cloud and precipitation with satellite images and NCEP “STAGE V” surface precipitation analyses generally shows good cloud and precipitation distributions in the RTFDDA final analysis, indicating an improved interaction between the model dynamics and physical processes with the nudging of wind, temperature and humidity observations. However, verification also reveals the need for assimilating high resolution observations on the fine meshes.

The RTFDDA system provides a framework for both case studies and real-time operations for 1-12 h snowband forecast. To adapt the system for airport applications, we are attempting to add an assimilation component to ingest Level II radar data into the model. We are currently focusing on the New York City airports. A three-grid configuration, with grid resolution of 3.3 km, 10 km and 30 km, is used (Figure 1). The second grid

---

[1] Corresponding author address: Mei Xu, NCAR/RAP, P.O.Box 3000, Boulder, Colorado 80307. Email: meixu@ucar.edu

[2] The National Center for Atmospheric Research is sponsored by the National Science Foundation.

covers an area similar to the Corridor Integrated Weather System (CIWS) NE domain, over which real-time level II WSR88D observations are available. The mesh sizes for the inner and outer grids are 106x124, 79x157 and 84x98 points, respectiviely. There are 36 levels in the vertical. Model physics schemes, including Dudhia simple-ice microphysics, Grell CPS (on grid 1 and 2) and MRF PBL, are used.

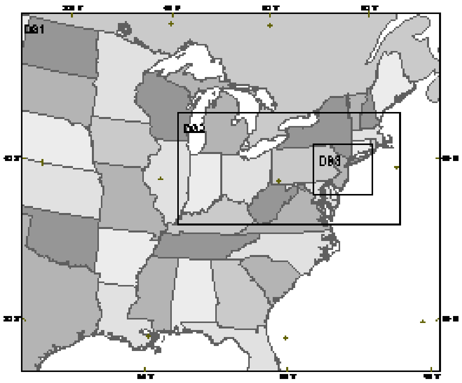

Fig. 1 The model grid used in RTFDDA for snowfall forecast in New York City area.

3. ASSIMILATING CIWS DATA USING RTFDDA

Recently, real-time Level II radar observations in the CIWS NE domain have become available via the Collaborative Radar Acquisition Field Test (CRAFT, Droegemeier et al., 2002) network. The domain has more than 20 radars, and covers an area of approximately 1500km x 900 km. Three-dimensional mosaic reflectivity for the region, as well as radial velocity from the individual radars, are accessible in real-time. To produce the mosaic reflectivity, reflectivity observations from the individual radars are mapped to a common Cartesian grid, then they are combined to form a unified 3D reflectivity field (Zhang et al., 2002). The grid resolution for the mosaic reflectivity is 1 km in the horizontal and 0.5 -1 km in the vertical. The datasets are updated every 5 minutes. An example of the CIWS mosaic reflectivity field is given in Figure 2.

Our goal is to enhance the RTFDDA system by fully utilizing the CIWS radar observations. As a first step, we have added an analysis nudging scheme to assimilate the mosaic reflectivity data. The mosaic reflectivity is first converted to 3D rainwater or snow mixing ratio (q_r) field and interpolated to MM5 grid 2 and 3 (see Fig. 1). Then the mixing ratio field, together with the corresponding latent heat, are nudged on the two inner meshes. The data insertion are performed at an interval of 30 minutes on grid 2 and 15 minutes on grid 3 in the case studies.

Previously we have found from simulated data experiments that both wind and thermodynamic fields are important for the evolution of snowbands. Nudging reflectivity alone for 6 hours has only marginal effect on the 3-6 hour forecasts. Given these results, one may expect very limited improvement without assimilating wind information from the radars. Nevertheless, assimilating reflectivity data in RTFDDA is a worthwhile attempt based on at least two considerations: (1) When the history of the storm is observed, continuous nudging may produce a cumulative effect. (2) RTFDDA is already assimilating some wind observations. The model wind field might be close enough to reality to support some of the assimilated q_r.

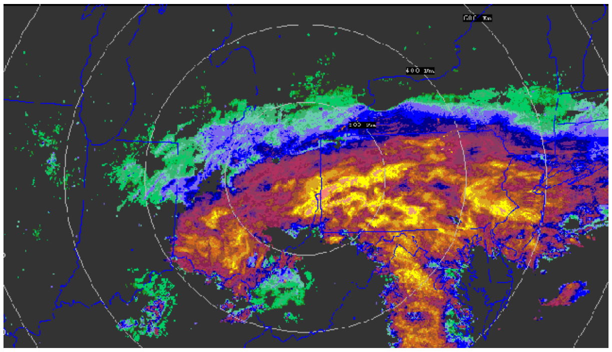

Fig. 2 Mosaic reflectivity data at 15 Z on Dec. 11, 2002.

4. A CASE STUDY USING RTFDDA

A snowstorm occurred in the northeastern U.S. on December 11, 2002. The storm formed in Central Texas at the early hours of Dec. 9 and moved northeastward. The system started to show in the CIWS network around 0 Z of Dec. 11, 2002 and was covered by CIWS radars for more than 24 hours. Snowfall started in the NYC airports around 14 Z of Dec. 11. The system is associated with relatively strong large-scale forcing.

Performance of RTFDDA

The model is cold started at 12 Z of December 9, 2002. The formation and general movement of the system is well simulated. When the storm moves into the CIWS domain (approximately same as model grid 2), the modelled system is slightly behind the observed storm. By 15 Z of Dec. 11, there are two major snowbands in the observations (Fig. 2) with the first one reaching NYC area. The RTFDDA forecast at this time, however, shows only one principal band and no precipitation in northern New Jersey and NYC area. In the model forecast, there are some convective activities in the region a few hours earlier, but they dissipate quickly without producing any signficant snowfall.

Point verification is extremely challenging to a numerical model. A distinquished feature in the radar observed snowfall at the NYC airports is the two-band structure separated by a period of no snowfall (Fig. 3). When no radar data is used, the RTFDDA analysis, though significantly better than the cold start forecast (not shown), show a delayed (~ 4 h) and much weaker first band. The second band is relatively well modeled. The 3-6 h forecasts from these analyses (without radar data) predict a further weakened first band (not shown).

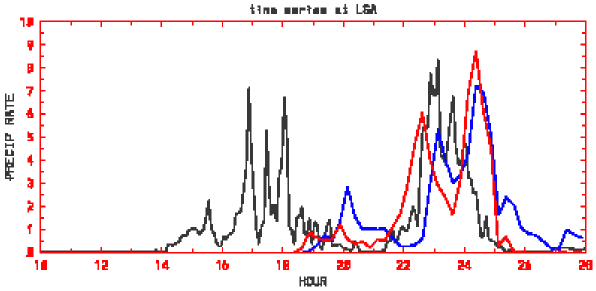

Fig. 3 Snowfall rate at New York La Guardia airport. Plotted are radar observations (black), RTFDDA analysis without CIWS data blue), and RTFDDA 3-6 h forecast with CIWS reflectivity nudging (red).

Effect of assimilating CIWS reflectivity data only (no latent heat)

The 3-6 h forecasts from RTFDDA with radar data assimilation show slightly earlier onset of both bands (Fig. 3). The magnitude of the first band is comparable to the 3-6 h forecast from RTFDDA without radar data (not shown). Since q_r is directly nudged, the model shows near-perfect snowfall during the assimilation stage when CIWS reflectivity is used. However this result does not last into the forecast stage. No dramatic improvement by radar data is seen in the snowfall forecast at the La Guardia airport.

A further examination of the snow mixing ratio field reveals that when the reflectivity data alone (converted to q_r) are nudged, at the end of the assimilation the qr field is comparable to the observed. After the forecast period starts, a major portion of the added qr disappears within an hour, while a small effect remains. An example of this effect is given in Fig. 4, which shows the reflectivity field at 15 Z of Dec. 11, from radar observations and 3-6 h forecasts of RTFDDA. Since the RTFDDA analyses are updated in 3-h cycles, the 3-6 h forecast at 15 Z represents a 5-h forecast following the analysis at 10 Z. The forecast from RTFDDA assimilating CIWS reflectivity show a slightly better agreement with the observations, especially at the northern and northeastern edges of the storm.

The RMS error and correlation coefficient between the observed and forecast snow mixing ratio fields are calculated. Fig. 5 shows that the forecast has an improved correlation with the obsevations when the CIWS reflectivity is nudged.

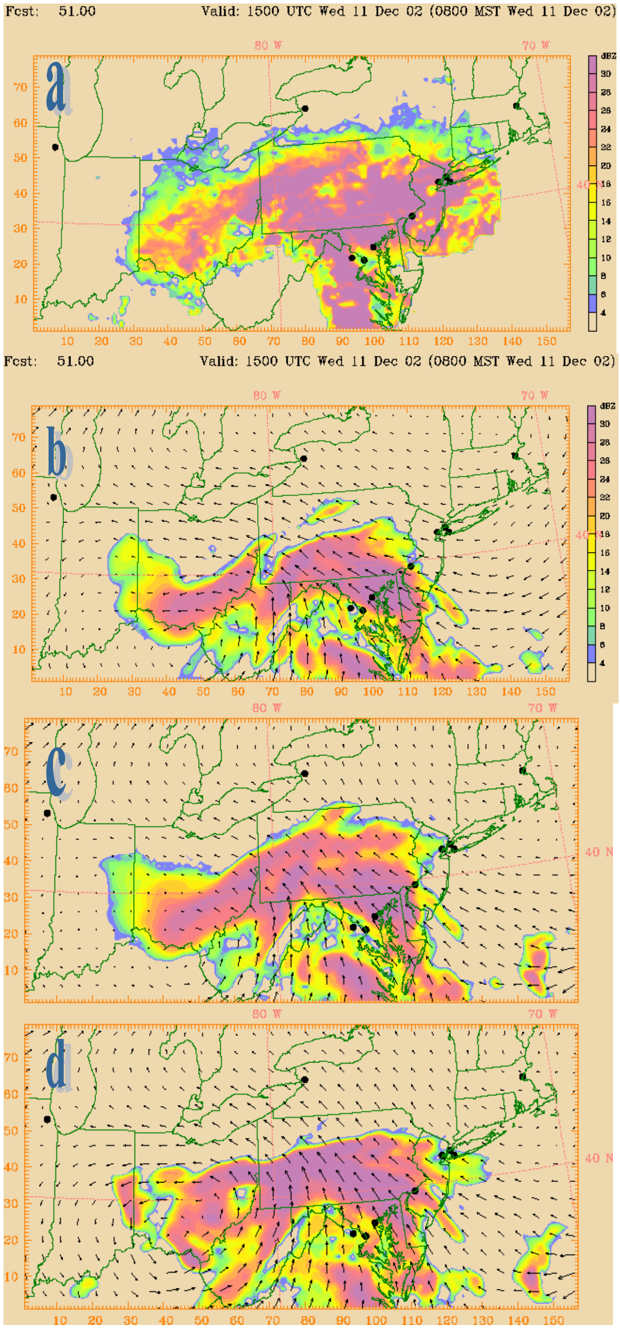

Fig. 4 Column-averaged reflectivity at 15 Z, December 11, 2002. (a) CIWS observations. (b) 5-h forecast without assimilating CIWS data. (c) 5-h forecast assimilating CIWS q_r. (d) 5-h forecast assimilating q_r and latent heat. Black dots indicate major airports.

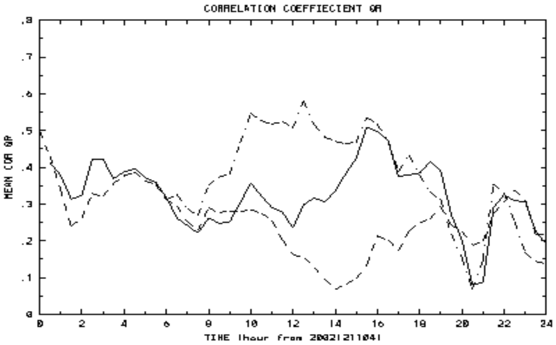

Fig. 5 Domain-average correlation between the modelled (3-6 h forecasts) and observed q_r fields. The curves are for RTFDDA without CIWS data (solid); RTFDDA without any data asaimilation (dashed); and RTFDDA with CIWS data nudging and observational nudging (dotted dashed).

Effect of assimilating latent heat

Generally, slightly more improvement is seen when the latent heat is added in addition to nudging q_r. Nudging the latent heat has a significant and lasting effect on the temperature and wind fields. The changes in temperature and wind, while noisy, are in the direction of reproducing the observed snowband (which is missing in the model forecasts). The vertical velocity produced by latent heat nudging is in general consistency but not in exact balance with the added qr. As a result, there is a period (~3 h) of spin-down/spin-up after nudging: a time of hydrometeor fallout and rebuilding. There are also times when the latent heat is added to the grid points where q_r is observed, it induces some local vertical motion instead of persistent, organized structures, thus limiting the overall positive effect of latent heat nudging. Effective filtering of the latent heat may be needed to further improve the forecast in a consistent manner.

Effect of adjusting water vapor based on reflectivity

Excessive evaporation can be a cause for error in the RTFDDA forecast. An experiment is therefore conducted to adjust the model water vapor field based on the observed reflectivity, in addition to analysis nudging the reflectivity and adding the latent heating. Using an estimated cloud based height, the adjustment scheme gradually saturates the regions of upward motion above the cloud base where q_r is observed. Results from the test show that even with the adjusted water vapor, the model forecast lacks the dynamics to support the added q_r. Instead, the resultant heating from the additional water vapor excites new convective activities and causes noise in the forecasts.

Our tests reveal the importance of correctly simulating the wind fields at high resolution. Even though the RTFDDA system assimilates wind observations from surface and upper air stations, profilers, etc., the data are insufficient for accurately specifying the wind fields at scales that are important for individual snowbands. To correctly predict the snowbands, modelling the vertical motion field is crucial. The results point to the need for assimilating velocity data from the radars.

5. SUMMARY

The RTFDDA system that NCAR developed for Army Test Ranges was tested for short-term forecast of snowfall. A radar data assimilation scheme based on analysis nudging was added to RTFDDA for assimilating level II data from multiple radars. Data ingest modules were developed to make use of the CIWS mosaic reflectivity datasets. The system was designed to run efficiently in real-time.

Case studies of winter storm events show that the RTFDDA system was skillful in predicting the storm's occurrance, though not very accurate at predicting the individual bands. Some improvement was achieved by analysis nudging the CIWS reflectivity data. Effect of assimilating radar reflectivity is yet to be evaluated in a statistical sense.

The future work will focus on the methods for assimilating CIWS radial velocity data. We also need to improve our understanding of the mechanisms that determine the small-scale structures in order to better model them.

ACKNOWLEGEMENT

This research is funded by the Federal Aviation Administration (FAA) and Army Testing and Evaluation Command (ATEC).

Cram, J., et al., 2001: An operational mesoscale RT-FDDA analysis and forecasting system. Preprints, 18th WAF and 14th NWP confs. Ft. Lauderdale, Florida. 30 July-3 August, 2001. AMS.

Liu, Y., et al., 2002: Performance and enhancement of the NCAR/ATEC mesoscale FDDA and forecasting system. Preprints, 15th Conf. on Numerical Weather Prediction. San Antonio, Texas. 10-16 August, 2002. AMS.

Droegemeier, K., K. Kelleher, et al., 2002: Project CRAFT: A test bed for demonstating the real-time acquisition and archival of WSR-88D base (Level II) data. Preprints, 18th Int. Conf. Meteor. Ocean. Hydrology, Orlando, Florida. AMS.

Xu, M., N.A. Crook, J. Sun and R. Rasmussen, 2001: Assmilation of radar data for 1-4 hour snowband forecasting using a mesoscale model. Preprints, 14th Conf. on Numerical Weather Prediction, Ft. Lauderdale, Florida. 30 July-3 August, 2001. AMS.

Zhang, J., J.J. Gourley, W. Xia and K. Howard, 2002: 3D multi-radar reflectivity mosaic for the CIWS domain. Preprints, 10th Conf. on Aviation, Range and Aerospace Meteorology. Portland, Oregon. 13-16 May, 2002. AMS.