J1J.2 IMPROVING VERY-SHORT-TERM STORM PREDICTIONS BY ASSIMILATING RADAR AND SATELLITE DATA INTO A MESOSCALE NWP MODEL

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1. INTRODUCTION

Radar observations contain rich information about the mesoscale and storm-scale structures of the atmosphere and hydrometeors with high spatial resolutions and frequent update rate, and therefore have the potential to become a major data source for high-resolution NWP model initialization. Before radar data is fully used for this purpose, however, an understanding of how the assimilated radar data affects the model forecast is needed. At the Naval Research Laboratory (NRL), a high-resolution data assimilation system is under development for nowcasting purposes. The objective of this development is to assimilate high-resolution data, especially those from Doppler radars and satellites, into the Navy's Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS®, Hodur 1997) to improve the model capability and accuracy in very-short-term prediction of severe weather events. A variational approach is used to retrieve three-dimensional wind fields from radar observations of radial velocity from multiple radars in a limited area and the thermodynamic perturbations associated with the retrieved winds. In parallel, a data fusion technique is used to combine satellite, radar reflectivity, and surface observations to update the model 3D cloud forecasts. The retrieved fields are then assimilated into the model to improve model initial conditions. The system has been tested with severe storm cases. A verification system has also been developed to assess the data assimilation impact. The objective of this paper is to give a description of the data assimilation procedures used in this study and to show some results from our recent data assimilation experiments.

2. DATA ASSIMILATION SYSTEM

The three-and-half-dimensional variational (3.5dVar) system developed by Xu et al. (2001a, 2001b) and Gu et al. (2001) used in this study performs a two-step retrieval of the three-dimensional winds and thermodynamical perturbation fields for NWP model data assimilation

2.1 Wind analysis

The wind analysis estimates the velocity increment $\mathbf{v^i} \equiv (u^i, v^i, w^i)$ to the model forecast

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background velocity $\mathbf{v^f} \equiv (u^f, v^f, w^f)$ by using two consecutive volume scans within the wind analysis time window (about 10 min) from each radar inside the analysis domain. The model grid field of $\mathbf{v^i}$ is estimated at the model time level nearest to the middle of the wind analysis time window by minimizing the following costfunction:

$$J = J_{bk} + J_{ob} + J_{ms} + J_{rm} \qquad (1)$$

where the four terms on the right-hand-side of the equation are the weak constraints (in the sense of least squares) provided by the forecast background, observations, mass continuity, and radial-velocity advection equation, respectively.

2.2 Thermodynamic perturbation analysis

After two consecutive wind retrievals, the estimated fields of $\mathbf{v^i}$ are then used as input data for the thermodynamic analysis. Similar to Gal-Chen (1978) and Hane and Scott (1978), the thermodynamic analysis computes the perturbation pressure increment $\boldsymbol{\pi}^\mathbf{i}$ and perturbation temperature increment $\mathbf{q^i}$ by minimizing the following costfunctions:

$$J_\pi = |\boldsymbol{\pi}|^2 + [[E_u^2 + E_v^2]]q_{uv} \qquad (2)$$

$$J_q = |\mathbf{q}|^2 + [[E_w^2]]q_w \qquad (3)$$

Where $\boldsymbol{\pi} = \mathbf{B}_\pi^{-1/2}\boldsymbol{\pi}^i$ and $\mathbf{q} = \mathbf{B}_q^{-1/2}\mathbf{q^i}$, [[ ]] denotes summation over all grid points, $\mathbf{B}_\pi$ is the background error covariance matrix for $\boldsymbol{\pi}^i$, $\mathbf{B}_q$ is the background error covariance matrix for $\mathbf{q}^i$, $\boldsymbol{\pi}$ is the state vector of the grid field of π, $\mathbf{q}$ is the state vector of the grid field of q, E_u and E_v are the constraints provided by model horizontal momentum equations, q_{uv} is the weight that normalizes and balances $[[E_u^2 + E_v^2]]$ with respected to the background term, E_w is the constraint provided by the model vertical momentum equation, and q_w is the weight that normalizes and balances $[[E_w^2]]$ with respected to the background term.

2.3 Precipitation retrieval

Radar observations of reflectivity are used for retrieval of rain, snow and graupel mixing ratios (Kessler 1969; Rogers and Yau 1989):

Rain water:

$$Z_O = 1.73\text{x}10^4(\mathrm{r}q_r)^{1.75} \qquad (4)$$

Snow and graupel:

$$Z_O = 3.8\text{x}10^4(\mathrm{r}q_s)^{2.2} \qquad (5)$$

Where Z_O – observed radar reflectivity, r is air density, and q_r and q_s are rain and snow (or graupel) mixing ratios.

3. EXPERIMENTS AND RESULTS

Real data from a squall line event on 9 May 2003 along the east coast of the United States were used to test the data assimilation system. WSR-88D data showed that this storm system entered the study area at about 1800 UTC and reached its mature stage at about 2300 UTC 9 May with strongest reflectivity of more than 70 dBZ. Data from three WSR-88D radars in that area were collected for the data assimilation study. COAMPS® model was started at 1200 UTC 9 May to provide background fields for the retrievals. Five experiments were conducted as shown in Table 1. Figure 1 illustrates the procedures in which data assimilation was cycled to assimilate the retrieved wind, thermodynamic, cloud, and precipitation fields into COAMPS® every hour during the data assimilation period from 1900 UTC to 2200 UTC. After that, a 14-hour forecast was executed.

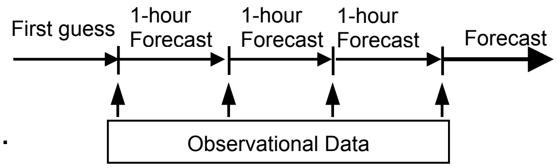

Fig. 1. Illustration of data assimilation procedures

Table 1. Data assimilation experiments

CNTL	No data assimilation
CLD	Satellite IR and vis data
CLD+PR	Satellite IR and vis data, radar reflectivity
WIND	Radar radial velocity
ALL	All data above

To study the impact of the data assimilation on model forecasts, root-mean-square (RMS) differences of model forecasts between each of data assimilation experiment and the control run were calculated as a function of forecast time. Figure 2 gives the results for the fields of u-wind component (u), temperature (T), water vapor mixing ratio (q_v), and rain water mixing ratio (q_r). It is obvious that all model forecasts responded significantly to the data assimilation in all data assimilation experiments. It is also interesting to note that the data assimilation impacts stayed in the model forecasts for the whole forecast period except the rain water mixing ratio, in which the data assimilation impact disappeared right after the storm system moved away from the model domain.

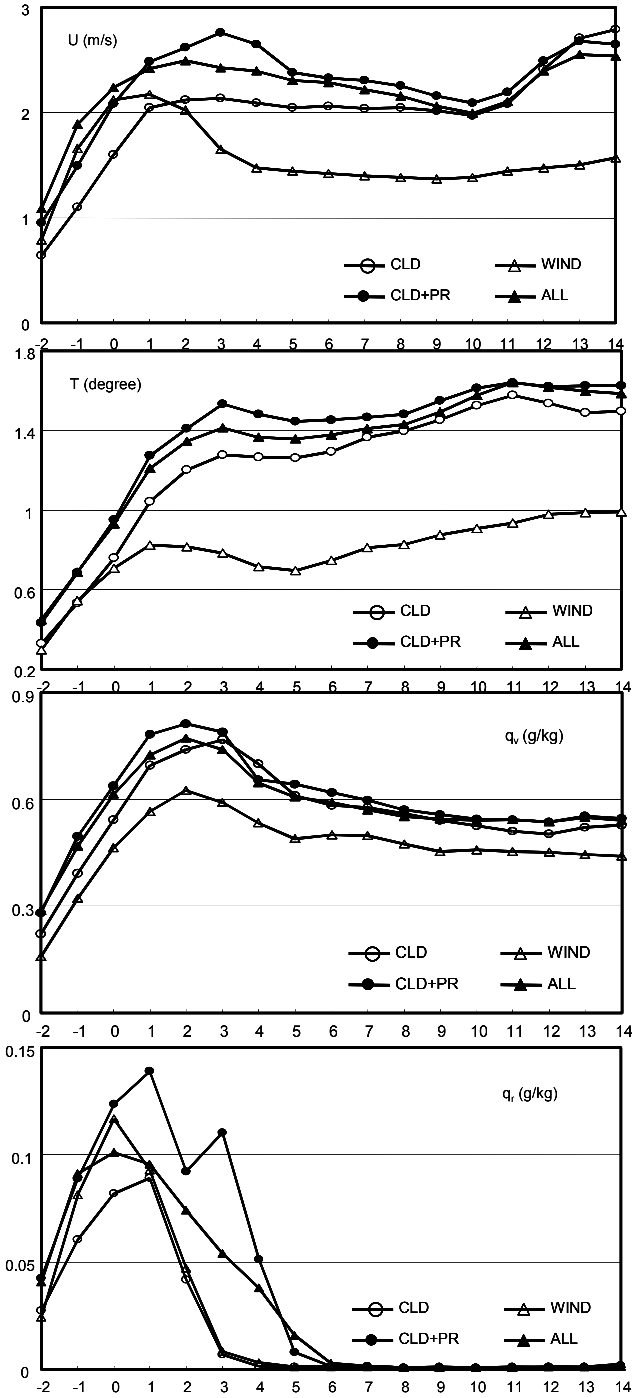

Fig. 2 Root-mean-square differences of model forecasts between the data assimilation experiments and the control run.

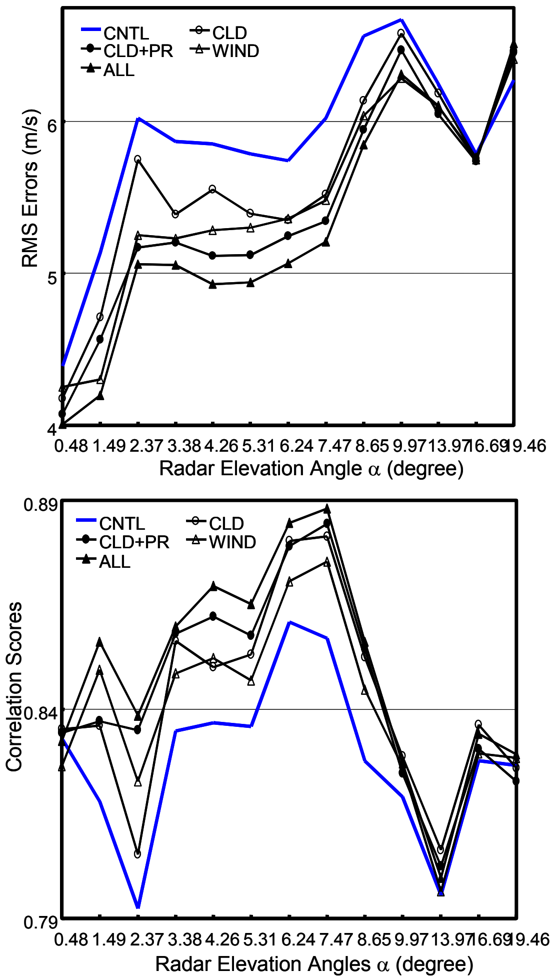

Fig. 3 Root-mean-square errors and correlation coefficients of radial velocities calculated from model 1-hour forecasts of three-dimensional winds verified against radar observations.

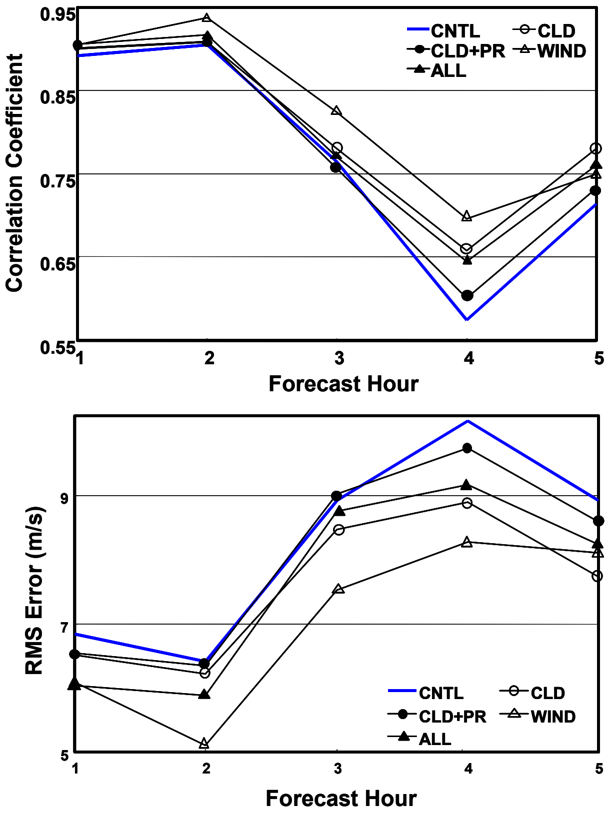

Fig. 4 Time variation of root-mean-square errors and correlation coefficients of radial velocities calculated from model forecasts of three-dimensional winds verified against radar observations at elevation angle of 2.37 degree.

A system has also been developed to verify model wind forecasts against radar observations of radial velocity. This system calculates the model-predicted radial velocities, at radar observational grids, from model three-dimensional wind forecasts (u, v, w) and then compares the calculated radial velocities with radar observations. Statistics of RMS errors and correlation coefficients are computed for each radar scan elevation. Figure 3 shows the calculated correlation coefficients and RMS errors for the first hour wind forecasts from all experiments as a function of radar scan elevations while Fig. 4 gives the time variations of the RMS errors and coefficients from one particular radar elevation scan. The improvements in model wind forecasts by all the data assimilation experiments can be seen clearly in Figs. 3 and 4, with the biggest improvement from the combined data assimilation at the first forecast hour and from the radial velocity assimilation experiment for rest of the forecast time. Accompanying the wind improvement, our results (not shown) also indicated notable improvements in storm location and intensity prediction.

4. CONCLUSIONS

The improvement in very-short-term storm prediction by assimilating radar and satellite observations into a mesoscale NWP model has shown the potential of using mesoscale NWP models in nowcasting not only storms but also other atmospheric parameters. Currently, there still are some scientific and technical challenging issues in mesoscale data assimilation, especially those associated with data quality, data assimilation algorithms, and the estimation of model uncertainty and observational errors. These are the major reasons for the small improvements, and sometimes even negative impacts, founded in some of our data assimilation studies. However, as the developments in high-resolution observational data and data assimilation algorithms continue, further improvement in very-short-term prediction of the atmospheric conditions from mesoscale NWP models are expected.

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