2B.8   ASSIMILATION OF RADAR OBSERVATIONS INTO A HIGH-RESOLUTION NUMERICAL WEATHER ANALYSIS AND PREDICTION SYSTEM AT NRL

Qingyun Zhao*, John Cook, Larry Phegley, Keith Sashegyi
Marine Meteorological Division, Naval Research Laboratory, Monterey, California
Qin Xu
National Severe Storm Laboratory, Norman, Oklahoma
Paul Harasti
University Corporation for Atmospheric Research, Boulder, Colorado
Mike Frost
Computer Sciences Corporation, Monterey, California

1. INTRODUCTION

Doppler radar observations of radial velocity and reflectivity have been successfully used for decades to detect and monitor severe storms and other hazardous weather and to issue warnings. Use of radar observations for model data assimilation, however, had not started until recent years. Processing the large amounts of radar data with appropriate data quality control and extracting meteorological information from radar observations with the accuracy needed by numerical models are still facing many challenging issues. As the mesoscale model resolution increases, the need for three-dimensional, high-resolution observational data will increase greatly. Doppler radar observations contain information about the three-dimensional structure of atmospheric winds and hydrometeors and therefore should be used as a new data source for high-resolution model data assimilation. Recent developments in data assimilation technologies and the fast increase in computing power will pave the way for radar data assimilation in the next few years. In turn, these high-resolution wind fields will then be needed to drive applications such as chemical/biological dispersion models.

A high-resolution radar data assimilation system is under development at the Naval Research Laboratory for the Navy's Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS™, Hodur, 1997). The data assimilation system uses a variational approach, together with other data fusion technologies, to retrieve three-dimensional cloud and wind fields from radar observations of radial velocity and reflectivity from multiple radars inside an analysis domain. This system also uses satellite data and surface observations for retrieving cloud and precipitation information. The products from this system are used to initialize the high-resolution COAMPS model, and at the same time, to provide detailed dynamical and hydrological structures of the three-dimensional atmosphere for the NOWCAST program at the Naval Research Laboratory. The high-resolution winds from the data assimilation system as well as from the COAMPS model forecast have been used to drive chemical/biological (CB) dispersion models (Hazard Prediction and Assessment Capability (HPAC) and Vapor, Liquid, and Solid Tracking (VLSTrack)) for CB defense.

Extensive testing of the system has been conducted with NEXRAD level-II data and the Navy's experimental SPY-1/TEP shipboard radar data. The results from the tests have showed positive impact of radar observations on wind and cloud analyses. The objective of this paper is to give a brief description of the systems and data we used for the studies. Results from our experiments will also be discussed.

2. DESCRIPTION OF DATA ANALYSIS SYSTEMS

The three-dimensional radar wind analysis system was developed by Xu et al. (1995, 2001). This system uses a three-and-half-dimensional variational (3.5DVAR) technology to retrieve the three-dimensional wind increment to the model background by minimizing the costfunction

$$J = J_1 + J_2 + J_3 + J_4$$

where the four terms on the right hand side of the equation represent the constraints of observations, background, radial momentum and mass continuity, respectively. Detailed descriptions for J_1, J_2, J_3 and J_4 can be found in Gu and Xu

---

* *Corresponding author address*: Qingyun Zhao, Naval Research Laboratory, Monterey, CA 93943;
e-mail: zhao@nrlmry.navy.mil

(2001). Also built in with this system is a radar radial velocity de-aliasing algorithm that corrects errors in observed radar radial velocities caused by range folding and velocity aliasing. Nyquest velocity and model background velocity are used in the radar data quality control. Background fields in this study were from COAMPS model forecasts.

A three-dimensional cloud analysis system, originally developed at the Forecast Systems Laboratory (FSL) as a part of the Local Analysis and Prediction System (LAPS) (Albers et al., 1996) and modified and used by the ARPS Data Assimilation System (ADAS) at the University of Oklahoma, was also used in this study for retrieving cloud information. This system uses a model forecast as a first guess, merges satellite data, radar reflectivity, and surface reports to analyze three-dimensional cloud liquid water, ice particles, precipitation, temperature and moisture fields (Zhang et al., 1998). This system has been further modified recently in order to directly use the satellite data, surface observations, and the background forecast fields from the Navy's Operational Tactical Environmental Data System (TEDS) database and from the COAMPS model. A verification system has also been developed at NRL to automatically determine the accuracy of the cloud products for quality control.
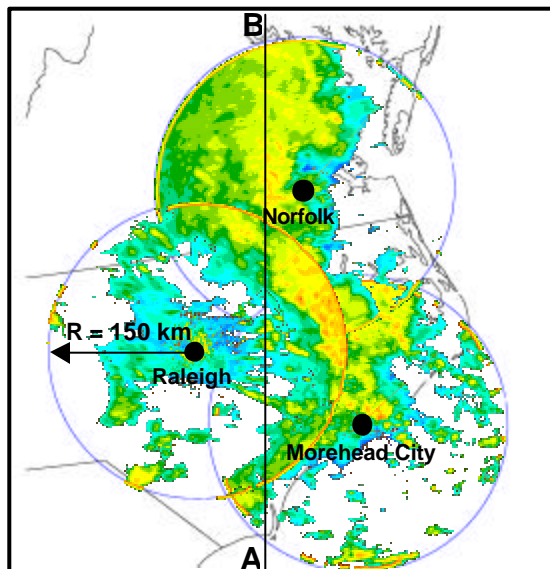

Fig. 1 Locations and coverage of three Doppler radars at Norfolk, VA, Raleigh and Morehead City, SC, together with base radar reflectivity observed by these radars during the storm on October 29, 2002.

3. WIND AND CLOUD ANALYSES

Level-II volume scan data from three Doppler radars at Norfolk, Virginia, Raleigh and Morehead City, North Carolina were collected during a storm on October 29, 2002. Figure 1 gives locations of these three radars and their coverage (with maximum data range of 150 km). Base radar reflectivity images of the storm observed by these radars are also given in this figure. At the same time, satellite data from GOES-8 IR and visible channels and surface observations of cloud amount and cloud base in the storm region were collected for this study. The COAMPS model 24-hour forecast with 3 km resolution provided background fields for the analyses.
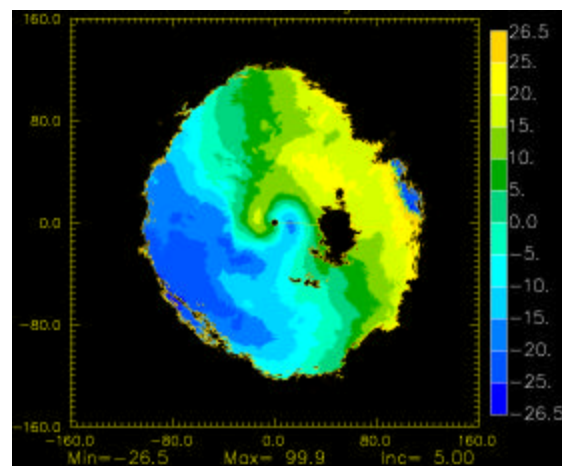

Fig. 2 Radar Radial velocity observed by the Doppler radar at Norfolk, VA at 16 UTC on October 29, 2002 with radar elevation angle of 3.45 degrees.

Radar radial velocity observations (Fig. 2) showed strong vertical shear within the storm, with a lower-level onshore flow that brought moisture from the ocean into the storm while strong westerly winds were observed at upper levels. This feature can also be seen from the retrieved three-dimensional winds from the 3.5DVAR system. Figure 3 shows the retrieved horizontal winds at three different levels from the same radar observations. The wind direction changed mainly between the 1 km and 2 km levels.

One important feature of the 3.5DVAR radar wind analysis system is the capability of using radar observations from multiple radars. This increases both the radar data coverage and the accuracy of wind analysis in areas covered by more than one radar. To highlight this effect, experiments were conducted with data from three radars shown in Fig. 1. In these experiments, winds were first retrieved using data from each of these three radars individually, then the retrieval was run again

with data from all these three radars. Figure 4 gives the horizontal wind increments (which show the impact of radar observations on wind analysis) at about 4 km level from these experiments. It was found that the major effect of using data from multiple radars was to increase the data coverage. For this limited study, however, the impact on quality of the wind analysis was found to be relatively small except for the area near the Norfolk radar.
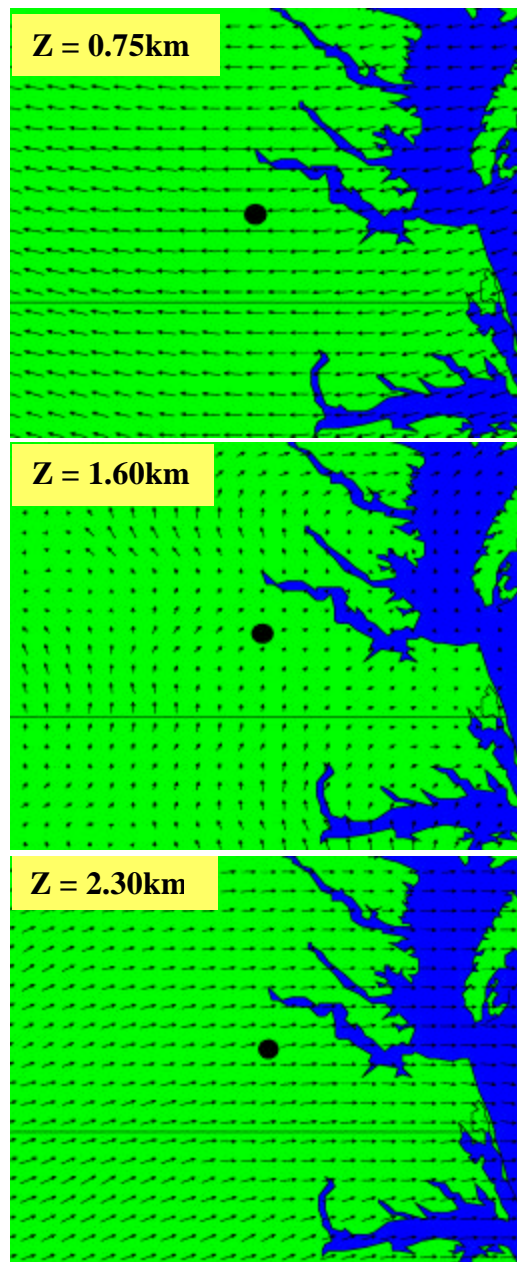

Fig. 3 Retrieved horizontal winds at three different levels using the data observed by the Doppler radar at Norfolk, VA at 16 UTC on October 29, 2002.

Studies were also performed to investigate the vertical motion from the radar wind analyses inside the storms. The ADAS cloud analysis system was used to analyze the three-dimensional clouds. A vertical cross-section of cloud water and ice mixing ratio from ADAS through the center of the storm along the AB line in Fig. 1 is shown in Fig. 5, together with wind increments from the 3.5DVAR radar wind analyses. As expected, radar observations of winds did show some positive impact on increasing upward motion and lower level convergence inside the storms. This is really an encouraging sign for radar wind data assimilation into the COAMPS model since the control COAMPS run (without using radar wind data) could not predict the strength of the storm system as evinced by the lack of upward motion inside the storms.

4. RADAR DATA ASSIMILATION INTO COAMPS MODEL

Both the ADAS cloud analysis and the 3.5DVAR radar wind analysis systems are running at NRL Monterey with real-time data to provide three-dimensional cloud and wind fields for an NRL nowcasting system and to drive chemical/biological (CB) dispersion models. Another goal of this research is to assimilate radar observations into COAMPS to improve initial conditions of cloud and wind fields and to study the impact of radar observations on improving model prediction. As the combined 3.5DVAR/ADAS data analysis system has been successfully tested with results showing improvement in wind and cloud analyses, our next step is to incorporate the results from these analyses in real-time into the COAMPS data assimilation system. Future research will study the impact of the assimilation of these radar-data-derived analyses on improving model prediction. As the research project continues, more results will be shown at the conference.
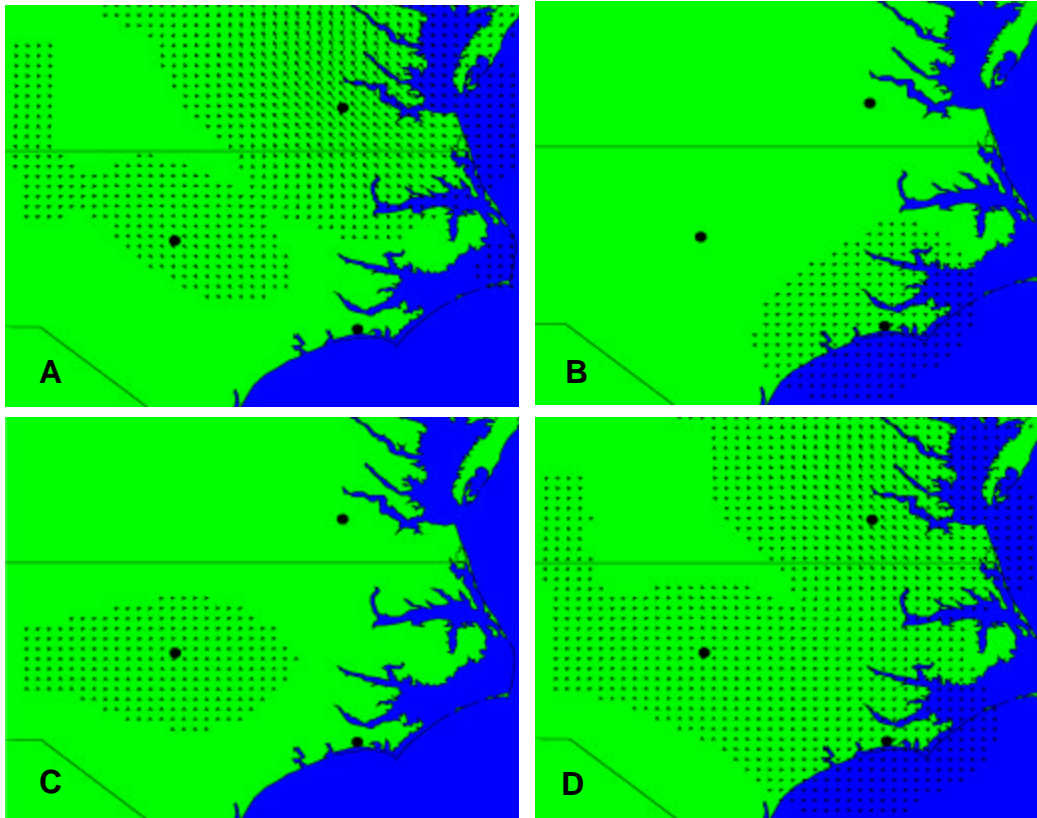
Fig. 4 Retrieved horizontal wind increments at level with z = 3.9 km with data observed by (A) the Norfolk radar, (B) Morehead City radar, (C) the Raleigh radar, and (D) all the three radars at 16 UTC on October 29, 2002.

REFERENCES

Albers, C. Steve, J.A. McGinley, D.L. Birkenheuer, and J.R. Smart, 1996: The Local Analysis and Prediction System (LAPS): Analyses of clouds, precipitation, and temperature. *Wea. and Forecasting*, **11**, 273-287.

Gu, W., H. Gu, and Q. Xu, 2001: Impact of single-Doppler radar observations on numerical prediction of 7 May 1995 Oklahoma squall line. Preprints*, Fifth Symposium on Integrated Observing Systems*, 14-19 January 2001, Albuquerque, New Mexico, Amer. Meteor. Soc., 139-142.

Hodur, R.M., 1997: The Naval Research Laboratory's coupled ocean/atmosphere mesoscale prediction system (COAMPS). *Mon. Wea. Rev.*, **125**, 1414-1430.

Xu, Q. S. Yang, and H. Gu, 1995: New simple adjoint method for three-dimensional wind and temperature retrievals from single-Doppler data. Preprints, *27th International Conference on Radar Meteorology*, Vail, Colorado, Amer. Meteor. Soc., 806-807.

Xu, Q., H. Gu, and W. Gu, 2001: A variational method for Doppler radar data assimilation. Preprints, *Fifth Symposium on Integrated Observing System*, 14-19 January 2001, Albuquerque, New Mexico, Amer. Meteor. Soc., 118-121

Zhang, J., F. Carr, and K. Brewster, 1998: ADAS cloud analysis, Preprints, *12th Conf. on Numerical Weather Predictions*. Phoenix, AZ., Amer. Meteor. Soc., 185-188.
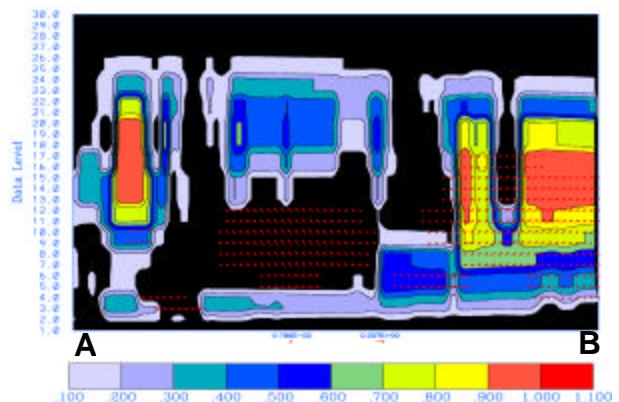
Fig. 5 Vertical cross-section of retrieved clouds and wind increments along the AB line in Fig. 1 at 16 UTC on October 29, 2002.