P4.10 ON THE USE OF RADAR OBSERVATIONS OF REFLECTIVITY IN VERIFYING MODEL HYDROMETEOR FIELDS

Qingyun Zhao*, John Cook, Jerome Schmidt
Marine Meteorological Division, Naval Research Laboratory, Monterey, California
Mike Frost
Computer Sciences Corporation, Monterey, California
Paul Harasti
University Corporation for Atmospheric Research, Boulder, Colorado
Brian Gaudet
National Research Council Postdoctoral Fellow at NRL, Monterey, California

1. INTRODUCTION

Explicit cloud microphysical processes have been included in most NWP models today. Verification of the three-dimensional distribution of hydrometeors (cloud liquid water, cloud ice, rain, snow, and graupel) from model forecasts, however, remains a big challenge to most modelers due to the lack of direct measurements of these fields. Efforts have been made in the past years to validate model hydrometeor fields against aircraft observations from field experiments (Heymsfield and Donner 1990; Moss and Johnson, 1994), satellite measurements (Pudykiewicz et al., 1992) and surface observations (Zhao and Carr, 1997). While these studies have shown successfulness and usefulness of field experiments, satellite data and surface observations in validating and improving numerical model parameterizations of hydrometeor fields, a three-dimensional picture of differences between model simulations and observations is still not clear basically because verifications in the studies above were done either along aircraft flight paths, at cloud top, or on the surface.

Doppler radar has been used for meteorological studies for decades (Doviak and Zrnic, 1984). The capability of measuring the three-dimensional dynamical and hydrological structures of storms with high-resolution makes Doppler radar a very useful tool in storm detection, tracking, nowcasting, and microphysical structure studies (Brandes et al., 1995). However, studies on using radar data for model verification have been very limited in past years. Quantitative verification of model predictions against radar observations has rarely been found. Several factors are thought to have limited the use of radar data for this purpose: 1) both radar radial velocity and reflectivity are not predictive variables in numerical models; 2) quality control issues that can affect the accuracy of radar data; 3) the difference between the radar polar coordinate and the model Cartesian grid system makes it inconvenient to compare model results with radar observations; 4) a single radar usually covers a small portion of a model domain. However, raw radar data is the only data currently available that can provide direct, high-resolution measurements of the three-dimensional kinematic and hydrometeor fields inside storms. Furthermore, full-volume, full-resolution radar data is now available in real-time from the NEXRAD network over most of the US, thus providing an invaluable data source for mesoscale and cloud-scale model validation.

At the Naval Research Laboratory, studies are under way to use radar data in mesoscale data assimilation and model verification for the Navy's Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS™, Hodur, 1997). One of the systems we have developed is a system that integrates and interpolates radar reflectivity data from individual radars inside the model domain to model grids. The interpolated radar reflectivity on model grids will then be used for both data assimilation and model verification. Radar raw data have been collected via the CRAFT project and experiments have been conducted for several storm cases. The objective of this paper is to give a brief description of this system and show the usefulness of radar data in quantitative model verification. Some results from our experiments will also be discussed.

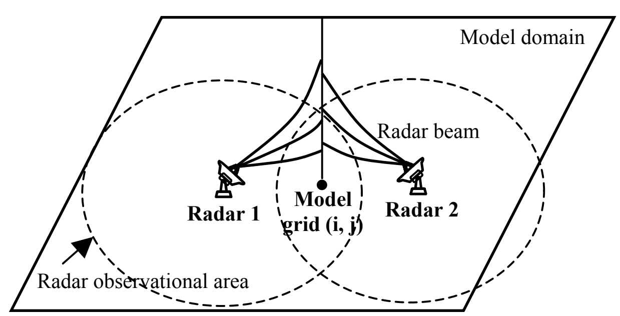

Figure 1. Schematic illustration of interpolation of observational data from multiple radars to model grids.

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

2. RADAR DATA PROCESSING

One of the important features of the system we developed is the capability of using radar data from multiple radars inside the model domain. Figure 1 illustrates a case in which two radars are located inside a model domain. As one can see in this illustration, the biggest advantage of this multi-radar data capability is the increase of radar data coverage. Another benefit we get from this feature is the increase in the number of observations and hence data resolution, especially in the vertical direction, in areas covered by multiple radars. Usually, the elevation angle resolution in NEXRAD volume scans is about one degree for most low-elevation tilts, which results in vertical data resolution of about 1 km at 55 km range and larger beyond this point in standard atmospheric conditions. This vertical resolution is larger than the vertical resolution of most mesoscale models, especially near the surface. If data from multiple radars are used, however, the vertical resolution of observational data at grid (i, j) has been significantly increased, sometimes even doubled (if three or more radar data are used) as shown in Fig. 2. The use of multiple radar data, however, also increases the complexity in radar data composition. To overcome this, a special interpolation algorithm has been designed that combines the nearest-neighbor interpolation with grid box average weighted by distance.

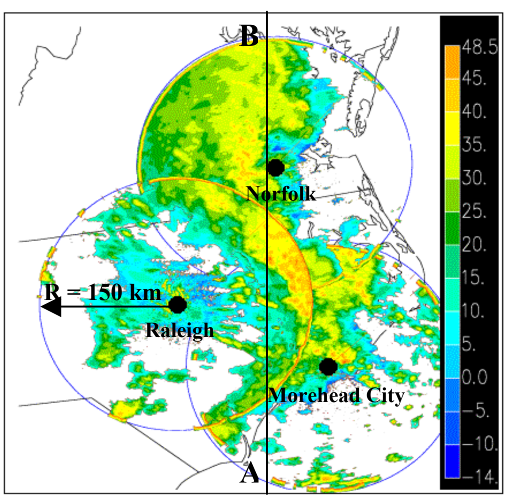

Fig. 2 Locations and coverage of three Doppler radars at Norfolk, VA, Raleigh and Morehead City, SC and base radar reflectivity observed by these radars during the storm at 16 UTC on October 29, 2002.

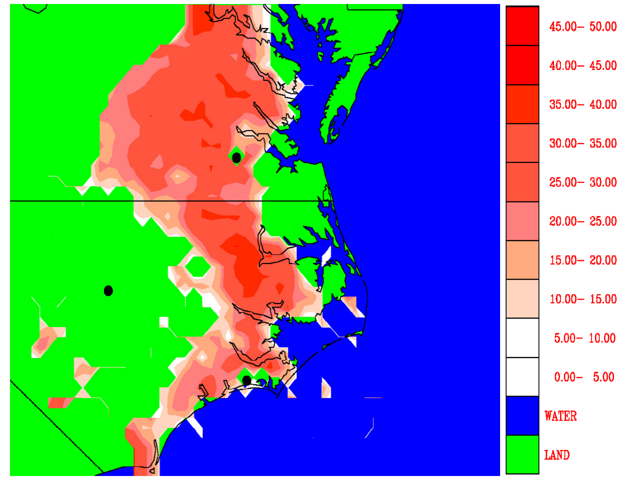

Figure 3. Horizontal cross-section of radar reflectivity (dBZ) observed by the three radars shown in Fig. 2 on COAMPS grids at 3.1 km level.

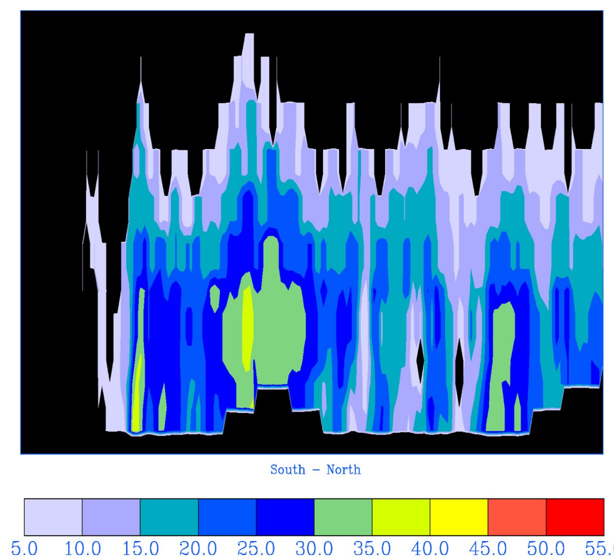

Figure 4. Vertical cross-section of observed radar reflectivity (dBZ) on COAMPS grids along the AB line in Fig. 1.

To demonstrate the effectiveness and accuracy of this interpolation procedure, a case from a frontal system in the coastal areas of Virginia and North Carolina on 29 October 2002 is selected, in which data from three radars at Norfolk, Virginia, Raleigh and Morehead City, North Carolina were collected and interpolated to COAMPS model grids with a horizontal grid resolution of 3 km. Figure 2 gives locations of these three radars, their coverage (with maximum data range of 150 km) and base radar reflectivity of the storm observed by these radars. Figure 3 shows radar reflectivity from these three radars interpolated to the COAMPS model grids at 3.1 km level at the same time. A good agreement between Fig. 2 and Fig. 3 has been found from these two figures. To further show the three-dimensional structures of the storms observed by these three radars, a vertical cross-section of radar reflectivity along the AB line in Fig. 2 is given in Fig. 4. Fine structures of the storm system can be seen clearly in this vertical cross-section.

3. CALCULATION OF RADAR REFLECTIVITY FROM MODEL HYDROMETEORS

The current version of the COAMPS model has five predictive variables in the cloud microphysics parameterization. They are cloud liquid water, cloud ice, rain, snow, and graupel. To be verified against radar observations, model simulations of hydrometeor fields need to be converted to radar reflectivity. This is done by using the following relationships between radar reflectivity factor Z (mm^6/m^3) for Rayleigh scattering and liquid water content M (g/m^3) (Atlas, 1954; Brown and Braham, 1963; Douglas, 1964)

Cloud liquid water:	$Z=4.8\text{x}10^{-2}M^{2.8}$
Cloud ice:	$Z=2.8\text{x}10^{-2}M^{2.8}$
Rain:	$Z=2.4\text{x}10^{4}M^{1.82}$
Snow aggregates:	$Z=3.8\text{x}10^{4}M^{2.2}$
Graupel (dry):	$Z_e=9.4\text{x}10^{5}M^{1.12}$
Gaupel (wet):	$Z_e=5.4\text{x}10^{6}M^{1.21}$

where Z_e is the effective radar reflectivity factor for Mie scattering with incoming radar wavelength of 10 cm (for NEXRAD). The values of liquid-water content M in above equations can be obtained from the model forecasts of different hydrometeors, and the calculated radar reflectivity factor Z (or Z_e) is then converted to the unit of dBZ used by radar observations.

A COAMPS simulation of the frontal case in Fig. 2 was used to test the radar verification system. Model radar reflectivity fields were calculated from model 4-hour forecast fields valid at 16 UTC 29 October 2002. A vertical cross-section of the calculated model radar reflectivity is shown in Fig. 5a, while Fig. 5b gives the observed values from the three radars in Fig. 2 at the same time. There were no observation data near the surface in Fig. 5b because the first PPI scans in these radar observations were made with an elevation angle of 0.5 degree, which leads to a cut-off height (a function of distance between the grid point and radar station in the standard atmospheric conditions) of about 1.0 to 1.5 km for most grid points on this cross-section. It is interesting to notice that the storm systems from model prediction agree quite well overall with radar observations in storm locations and radar reflectivity magnitude. The vertical structures from model forecast, however, look quite different from observations. It appears that the model overestimated the heights of the maximum reflectivity zones where most precipitable water can be found.

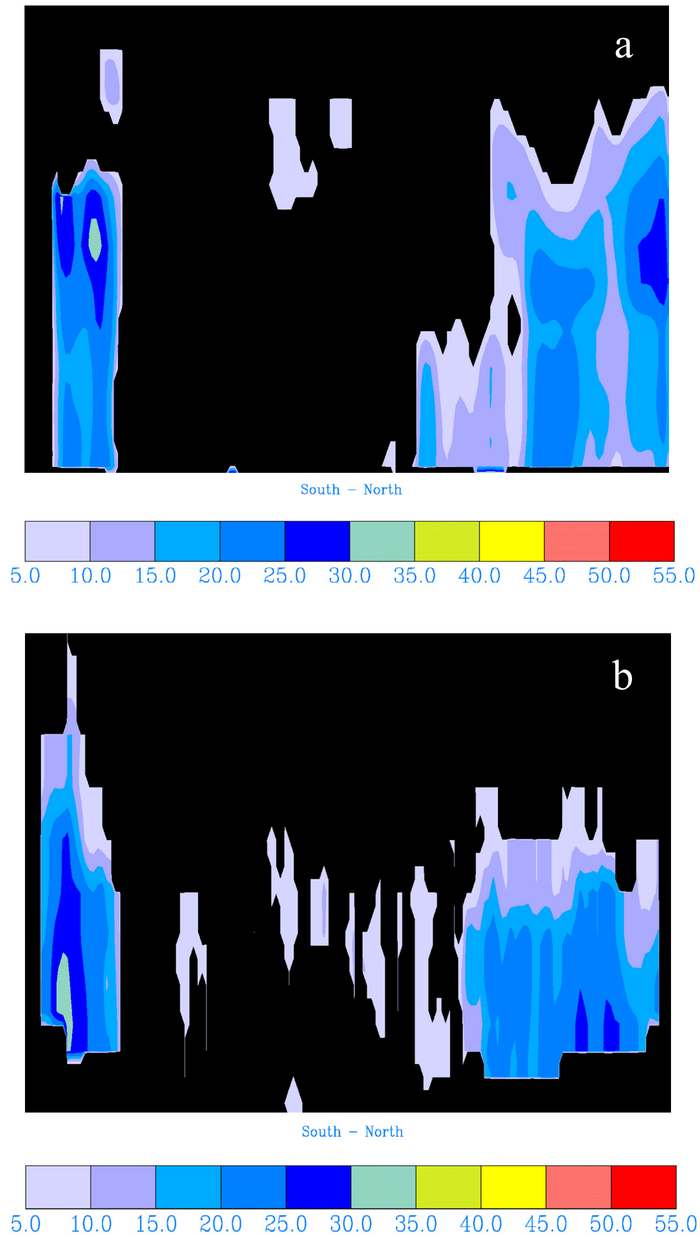

Figure 5. Vertical cross-sections of radar reflectivity (dBZ) from (a) COAMPS model 4-hour prediction and (b) observations at 16 UTC 29 October 2002.

4. SUMMARY

A system for verifying numerical model predictions of hydrometeor fields against radar observations of reflectivity has been developed at the Naval Research Laboratory. This system utilizes a new data source of high spatial resolution, and also provides a new method to quantitatively verify the three-dimensional hydrological structures of storms from mesoscale model forecasts. The biggest advantage of this system is the capability of using radar data from multiple radars that cover a much larger area than single radar and provide more data and higher data resolution in the overlapping areas. This system will be further tested, refined and used for COAMPS model development, moist physics parameterization and radar data assimilation.

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