An Assimilation Experiment of a Heavy Rainfall Event around Tokyo with a Cloud-Resolving Nonhydrostatic 4D-Var Assimilation System

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1. Introduction

The Forecast Research Department of the Meteorological Research Institute (MRI) has been developing a high-resolution nonhydrostatic 4 dimensional variational assimilation system (NHM-4DVAR) based on the Japan Meteorological Agency nonhydrostatic model (JMA-NHM). The aim is to apply a 4DVAR technique to the mesoscale convective cloud system with a cloud resolving resolution less than 2 km. NHM-4DVAR was applied to a heavy rainfall event occurred at Tokyo on 21 July 1999 (Kawabata et al. 2007), and the NHM-4DVAR quantitatively well reproduced compared with the observations. In this case, perturbations to the dry dynamics and the advection of water vapor are considered in the NHM-4DVAR, and the Doppler Radial Wind (RW) data, GPS precipitable water vapor (GPS-PWV) data, surface wind and surface temperature data were assimilated. After this successful result, the NHM-4DVAR has been modified further in order to assimilate the radar reflectivity data, and an assimilation experiment has been underway for the heavy rainfall event around Tokyo on 4-5 September 2005.

2. NHM-4DVAR

A forward model of NHM-4DVAR is a full nonlinear JMA-NHM, while a tangent linear and an adjoint model consider perturbations to the dynamics and the warn rain cloud microphysics process. Control variables are horizontal wind (u, v), vertical wind (w), nonhydrostatic pressure, potential temperature, surface pressure and total water (mixing ratios of water vapor + cloud water), rain water / saturation pressure of water vapor. Last two variables are new control variables to introduce perturbations to the water substances to the NHM-4DVAR. These are chosen in consideration of the characteristics of their error statistics and the correlation with other variables.

The Z-Qr relation (eq.1, Sun and Crook 1997) is adopted as the observation operator for the assimilation of the radar reflectivity data. Because the Z-Qr operator is linear equation, it is better than other operators. The observational error is set to 15 dBZ. This value is much larger than the measurement error of the radar. In general, the observational error includes the measurement error, the representativeness error and the conversion error. Furthermore conversion error is consists of the error of the model error and the observation operator. Since only warm rain cloud microphysical process is implemented to the adjoint model and the observation operator does not include the effect of the snow, hail and graupel, the conversion error is considered large.

$$Z_{qr} = 10 \times \log 10\left(cqr \times (dns \times qr)^{1.75}\right) \qquad (1)$$

3. Assimilation experiment

NHM-4DVAR was applied to a heavy rainfall event around Tokyo on 4-5 on September 2005. The assimilation area is about 240 km x 240 km which covered the Kanto plain on the middle part of Japan Island. The assimilation window is set to 10-minutes during 20-21 JST on 4 Sep. 1-hour assimilation window was conducted in the heavy rainfall event described above, while it is not available in this case, because of the nonlinearity. 6 assimilation windows were conducted during 1 hour and the results were compared with the observations.

The Radial Wind data (RW) and the radar reflectivity derived by the Doppler radars, the GPS Precipitable Water Vapor (PWV) data and the surface observation data are available as the high temporal and spatial resolution data. In NHM-4DVAR, RW data and the reflectivity data are assimilated with 1 minute interval by every elevation angle and both data from 0.7 to 5.4 degree elevation angle are used for assimilation to remove undesirable high elevation angle data. GPS-PWV data are assimilated with 5 minutes interval, and the surface wind and temperature data observed by the Automated Meteorological Data Acquisition System (AMeDAS) of JMA are assimilated with 10 minutes interval.

Figure 1 shows the comparison of radar reflectivity (dBZ) between the observations and the analysis. The locations, horizontal size and the intensity of the main rain band are well reproduced compared with the observations. Except for the main rain band, another convective cell easterly located on the main rain band is also reproduced. The rainfall intensity is shown in Fig. 2. As well as the reflectivity, the precipitaion intensity is well reproduced. The agreement of the reflectivity fields shows that the assimilation procedure works well. On the other hand, the agreement of the precipitaion intensity fields shows that the structure of the rain band is basically reproduced.

4. Assimilation of “0 dBZ”

The numerical models often produce false precipitation in their simulation. If “0 dBZ” observations are assimilated at the false precipitation area, these areas will be eliminated in the assimilation result and the forecast fields will be improved. But this method includes some troubles. On the one point of view, small reflectivity is not clear that these are reflected by rain water. Consequently, only the reflectivity over 10 dBZ is assimilated in the NHM-4DVAR. On the another point of view, assimilation of “0 dBZ” provides the result that most convections in the assimilation area are eliminated, because the number of grids of “0 dBZ” is much larger than one of “over 10 dBZ” in the assimilation field and the costfunction converges to the “0 dBZ” field. To deal these problems, we introduce following method: If the reflectivity is over 10 dBZ in the first guess field and under 10 dBZ in the observations, the grid is regarded as the false precipitation to be eliminated, and “0 dBZ” observations are assimilated. The observational error of “o dBZ” is set to 4 times of the normal one, because “0 dBZ” is not real observations. Result is shown in Fig. 3.

5. Conclusion

A cloud-resolving nonhydrostatic assimilation system with warm rain cloud microphysics called NHM-4DVAR, was developed. The system was applied to a heavy rainfall event and reproduced observed rain band both in the reflectivity and the rainfall intensity. “0 dBZ” assimilation technique was introduced to the NHN-4DVAR.

References

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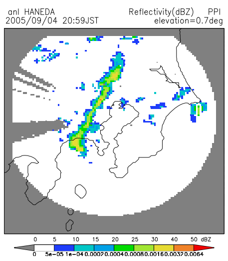

Fig. 1 Radar reflectivity(dBZ). Left: assimilation. Right: observation.

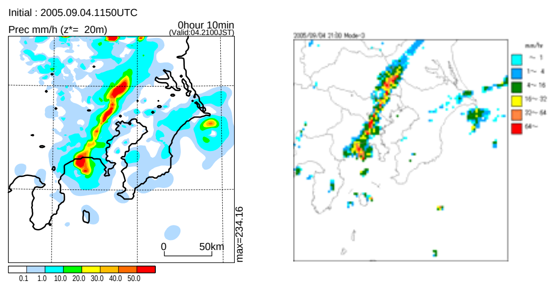

Fig. 2 Precipitaion intensity(mm/h). Left: assimilation. Right observation.

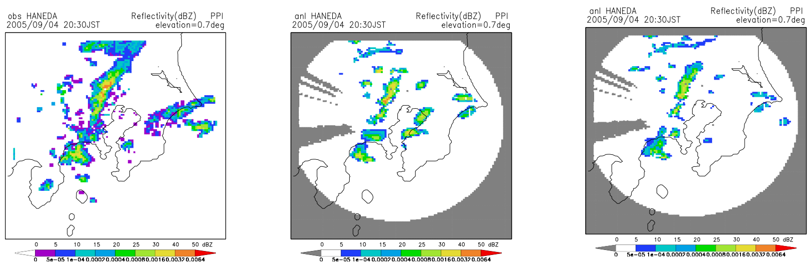

Fig. 3 Assimilation “0 dBZ”. Left: observation. Middle: first guess. Right:assimilation.