I. Introduction

Japan Meteorological Agency (JMA) has been operating meso-scale model (MSM) mainly to enhance the disaster prevention weather information, especially the very-short-range forecast precipitation. The initial condition of MSM is obtained by 4D-VAR data assimilation system (JNVAR) which is non-hydrostatic model based variational data assimilation system (Hongo et al., 2005). In this work, we developed a radar reflectivity assimilation system to improve analysis of water vapor in JNVAR. This reflectivity data assimilation is 1D+4DVAR which composed of a one-dimensional (1D) retrieval of relative humidity and the conventional 4DVAR system. An application of this 1D+4DVAR method is expected that the observation of hydrometeors precipitation and the precipitation forecast improve significantly.

II. NWP model and experimental design

The environment of experiment is built into JNVAR and JMA-NHM (Saito et al., 2006) which is a forecast model of MSM similar to operational system. For experiment of new approach, the reflectivity assimilation is varied 1D retrieval to conventional 4DVAR. In this 1D retrieval, pseudo observed reflectivity of relative humidity is estimated by observed reflectivity and radar simulator as observation operator. The estimated pseudo observed data are assimilated in FT=0, FT=1 and FT=2 as conventional observation data.

III. Observation operator (Radar simulator)

The radar simulator is an observation operator to generate the reflectivity from model output. This radar simulator provides more accurate position and an equivalent reflectivity factor which is computed from the size-distribution of precipitation particles on beam path through the geometry of the pointing angle of the virtual antennas in the MSM forecast field. The distribution of the particle is diagnosed by the BMP scheme similar to the forecast model. The cloud particle is disregarded in this simulator, because the diameter of the clouds is smaller more than the wavelength of the C-bands.

- Measurement of virtual antenna: Gaussian function to represent main lobes.
- Filtering by Gauss-Hermite statistics of the horizontal beam and side lobe is neglected.
- Back scatting: Rayleigh approximation or T-matrix.
- Effective hydrometeors: The rain water, the snow and the graupel.

BMP scheme for radar simulator

\[
\begin{align*}
\text{Beam path bending} & \quad R = \frac{Z}{Z_0} \\
\text{Beam path} & \quad z = \frac{Z}{Z_0} \\
\text{Slope parameter} & \quad \frac{Z}{Z_0} = \frac{Z_0}{Z} \\
\text{Effective factor for dielectric} & \quad \frac{Z}{Z_0} = \frac{Z_0}{Z} \\
\text{Effective factor for ice} & \quad \frac{Z}{Z_0} = \frac{Z_0}{Z} \\
\text{Number concentration} & \quad X = \frac{Z}{Z_0} \\
\text{Beam path} & \quad z = \frac{Z}{Z_0} \\
\text{Slope parameter} & \quad \frac{Z}{Z_0} = \frac{Z_0}{Z} \\
\text{Effective factor for dielectric} & \quad \frac{Z}{Z_0} = \frac{Z_0}{Z} \\
\text{Effective factor for ice} & \quad \frac{Z}{Z_0} = \frac{Z_0}{Z} \\
\text{Number concentration} & \quad X = \frac{Z}{Z_0} \\
\end{align*}
\]

IV. Retrieval algorithm

Directly assimilating hydrometeors estimated from radar reflectivity is attended with some difficulties. For example, the retrieval balance of hydrometeors and the momentum cannot be easily estimated from the observed reflectivity and the simulated reflectivity based on Bayesian inversion. Thus, a 1D Bayesian inversion is one of the methods to circumvent these difficulties.

1D Bayesian inversion

The method doesn’t make hydrometeors from reflectivity, it retrieves the RH of pseudo observation from the observed reflectivity and the simulated reflectivity based on Bayesian inversion.

\[
\text{Bayesian's theorem} \\
\text{P(y|x) = P(x|y)P(y)P(x)}
\]

In the above probability, \(P(y|x)\) is a posterior probability of the state given observation, \(P(x|y)\) is the likelihood function, \(P(y)\) is the prior probability, \(P(x)\) is the prior density function. Thus, the posterior density function is obtained by the combination of the likelihood function and the prior distribution.

\[
\text{P(y|x) \propto P(x|y)P(y)}
\]

\(P(y|x)\) is assumed to be positive density function of the set of observation y derived from the simulated observation y. In other words, \(P(y|x)\) is defined as the probability density function of the error of \(y\).

Verification of precipitation forecast

The MSM forecast experiment was performed using initial condition provided by 1D+4DVAR. The verification period of this experiment is from 12/30/2009 to 01/05/2010. The ETS and bias score of 1D+4DVAR(TOT) show the improvement of precipitation forecast than only JNVAR(TOT) in every observation. Especially, this result has the sudden drop of precipitation prediction on FT=5 that is improved in Test.

V. Performance of retrieval algorithm

Efficiency of penalty term

The pseudo observation of RH is defined uniquely without penalty term of spatial restriction in the retrieval algorithm. The penalty term provides an appropriate dependency of beam height, that represents the difference of hydrometeors type. This approach avoids a possible bias of solid phase in the retrieval. Because, it has been known the reflectivity of anechoic is overestimated in 1D+4DVAR scheme (Eito and Akaishi, 2005), and such bias is unsuitable for retrieval method.

\[
\text{Penalty term of height dependency to control the contribution of hydrometeors types.}
\]

\[
\text{Penalty term of height dependency to control the contribution of hydrometeors types.}
\]

VI. Impact of 1D+4VAR

The analysis/forecast cycle experiment demonstrated the improvement of hydrometeors precipitation in initial condition. For example, the following figures represent the simulated reflectivity RH and observed reflectivity of Fukuba radar, and the grey color region in figure is beam blockage by topography. This first guess has displacement error of hydrometeors position, however the displacement error is recovered on outer FT=1 after 1D+4DVAR.

VII. Summary

The new indirect assimilation of radar reflectivity, 1D+4DVAR, is developed in JMA. This new system is composed of the radar simulator, the 1D retrieval and JNVAR. The penalty term of the spatial restriction that controlled the contribution of hydrometeors was introduced into the optimization techniques for the performance gain of the 1D retrieval algorithm.

VIII. Reference