Indirect reflectivity assimilation approach using radar simulator in JMA non-hydrostatic model based variational data assimilation system

Yasutaka Ikuta and Yuki Honda
Numerical Prediction Division, Japan Meteorological Agency
E-mail: ikuta@met.kishou.go.jp

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Ⅰ. Introduction

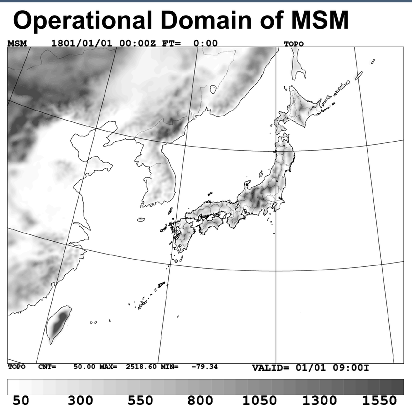
Japan Meteorological Agency (JMA) has been operating meso-scale model (MSM) mainly to enhance the disaster prevention weather information, especially the very-short-range precipitation forecast. The initial condition of MSM has been providing by 4DVAR data assimilation system (JNoVA; JMA non-hydrostatic model based variational data assimilation system (Honda et al. 2005)). In this work, we developed a radar reflectivity assimilation system to improve analysis of water vapor in JNoVA. 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 environment of hydrometeors prediction and the precipitation forecast improve significantly.

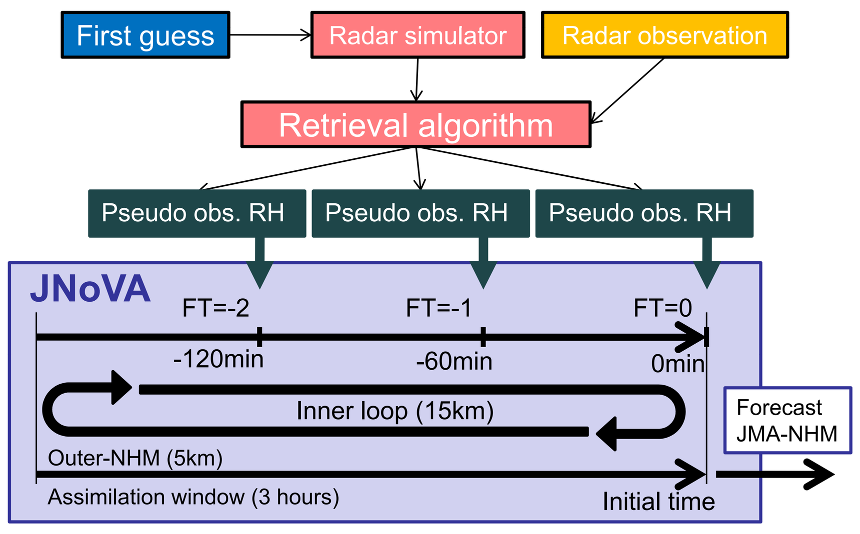
Ⅱ. NWP model and experimental design

The environment of experiment is built into JNoVA 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 added 1D retrieval to conventional 4DVAR. In this 1D retrieval, pseudo observation of relative humidity is estimated by observed reflectivity and radar simulator as observation operator. The estimated pseudo observation data are assimilated in FT=0, FT=-1 and FT=-2 as conventional observation data.

- ☐Analysis (JNoVA)
  - ☐ Data assimilation window: 3 hours
  - ☐ Outer (JMA-NHM)
    - ☐ Grid spacing : 5km
    - ☐ Experimental domain (grid): 721X577X50.
  - ☐ Inner (NLM, TLM/ADM)
    - ☐ Grid spacing : 15km
    - ☐ Experimental domain (grid): 241X193X40.
- ☐Forecast (JMA-NHM)
  - ☐ Grid spacing: 5 km.
  - ☐ Experimental domain (grid): 721X577X50.
  - ☐ Boundary condition: an operational GSM.
  - ☐ Convective parameterization : K-F scheme
  - ☐ Cloud microphysical process: 3-ice bulk microphysics process (BMP) scheme; rain, snow ,graupel and cloud water are 1-moment BMP scheme, and cloud ice is 2-moment BMP scheme.

Operational Domain of MSM





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 of beam path, 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 antenna 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 enough than the wavelength of the C-band radar.

- ☐Measurement of virtual antenna: Gaussian function to represent main lobes.
  It is calculated by Gauss-Hermit quadrature but the shape of the horizontal beam and side lobe is neglected.
- ☐ Back scattering: Rayleigh approximation or T-matrix.
- ☐ Effective hydrometeors: The rain water, the snow and the graupel.
- ☐ Attenuation: Only the contribution of the rain water.

BMP scheme for radar simulator

■ Intercept parameter

$$N_{0X} = N_X \lambda_X \quad (X = r, s, g)$$

■ Slope parameter

$$\lambda_X = \left(\pi \frac{\rho_X}{\rho_a} \frac{N_X}{Q_X} \right)^{\frac{1}{3}} \quad (X = r, s, g)$$

■ Reflectivity

$$Z_e = Z_r + Z_s + Z_g$$

$$Z_r = 720 \frac{N_{0r}}{\lambda_r^7}$$

$$Z_X = 720 \frac{|K_i|^2 \rho_X^2}{|K_w|^2 \rho_i^2} \frac{N_{0X}}{\lambda_X^7} \quad (X = s, g)$$

$|K_w|^2$ Dielectric factor for water　　ρ_a Air density

$|K_i|^2$ Dielectric factor for ice　　N_X Number concentration

Beam path bending

The beam path is calculated from the earth curvature and the refractivity of atmosphere. The refractivity is computed from the temperature, the pressure and the water vapor partial pressure.

$$N = \frac{77.6}{T} \left(p + 4810 \frac{e}{T} \right)$$

Ⅳ. Retrieval algorithm

Directly assimilating hydrometeors estimated from radar reflectivity is attended with some difficulties. For example, the dynamical balance of the hydrometeors and the momentum cannot be easily adjusted. Furthermore, it is difficult to calculate individual hydrometeors from the radar reflectivity for the reason that the relation between the reflectivity and these hydrometeors is strongly nonlinear. A 1D Bayesian inversion method is one of the methods to circumvent these difficulties.

1D Bayesian inversion

This method doesn't estimate hydrometeors from reflectivity. It retrieves the RH of pseudo observation from the observed reflectivity and the simulated reflectivity based on Bayesian inversion.

■ estimation equation

$$E(\mathbf{x}) = \int \mathbf{x} \, \mathrm{pdf}(\mathbf{x}) d\mathbf{x}$$

■ provability density function

$$\mathrm{pdf}(\mathbf{x}) \propto P(\mathbf{x} = \mathbf{x}_{true} \mid \mathbf{y} = \mathbf{y}_0) \quad \text{Bayes's theorem}$$

$$\propto P(\mathbf{y} = \mathbf{y}_0 \mid \mathbf{x} = \mathbf{x}_{true}) P(\mathbf{x} = \mathbf{x}_{true})$$

■ 'a posterior' probability　　conditional probability　　a priori probability

Probability of state x occurs, given observation y can be made for non-linear problem is;

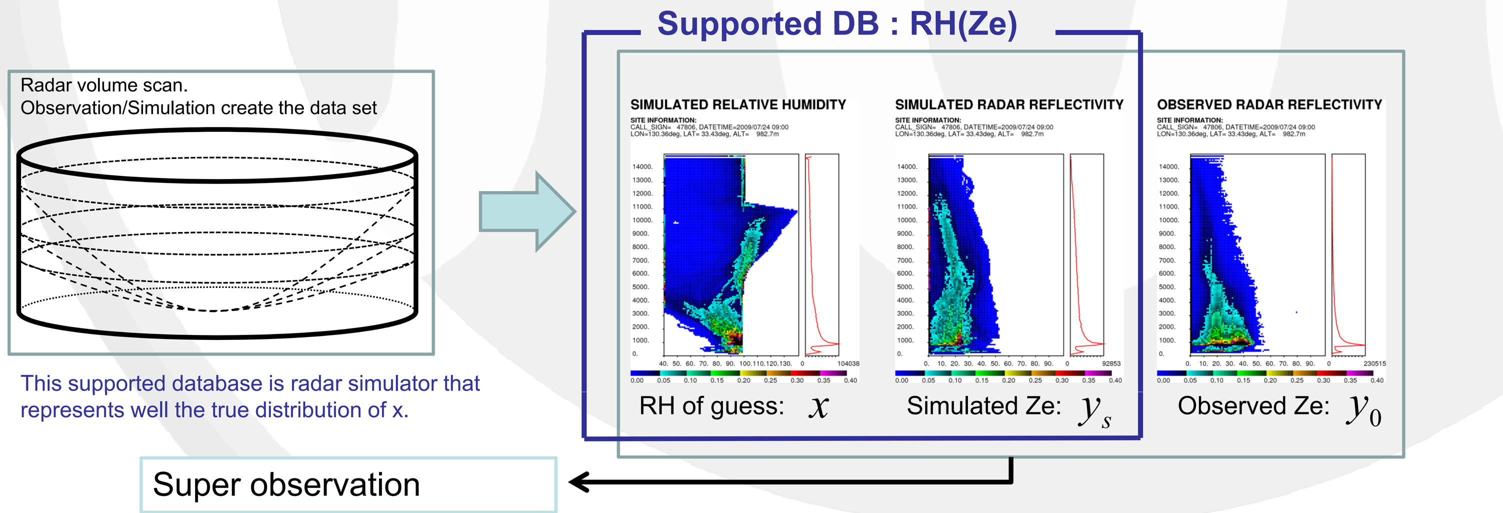
$$P(\mathbf{y} \mid \mathbf{x}) \propto \exp\left[-\frac{1}{2} (\mathbf{y}_o - \mathbf{y}_s(\mathbf{x}))^T \mathbf{R}^{-1} (\mathbf{y}_o - \mathbf{y}_s(\mathbf{x})) \right]$$

P(x|y) is assumed probability that the set of observation y0 deviate from the set of simulated observation ys by a certain amount, given state x.

☐ Following Olson(1996) and assuming xi database of atmospheric

This database is radar simulator that represents sufficiently well the true distribution of x. The Integral which the right-hand side of the estimate equation is replaced by summation over all state, contained in the database.

Where ys is simulated reflectivity by the radar simulator, R is the error covariance matrix.



The supported DB is updated in a usual radar volume scan.

■The optimum estimation of state x is the mean state averaged over the probability distribution;

$$E(x_i) = \frac{\sum_j^n x_j \exp\left[-\frac{1}{2} (y_{0i} - y_{sj})^T S_{ij}^{-1} (y_{0i} - y_{sj}) - J_{pij} \right]}{\sum_j^n \exp\left[-\frac{1}{2} (y_{0i} - y_{sj})^T S_{ij}^{-1} (y_{0i} - y_{sj}) - J_{pij} \right]}$$

Normalize factor

Penalty term Jp of height dependency to control the contribution of hydrometeors types.

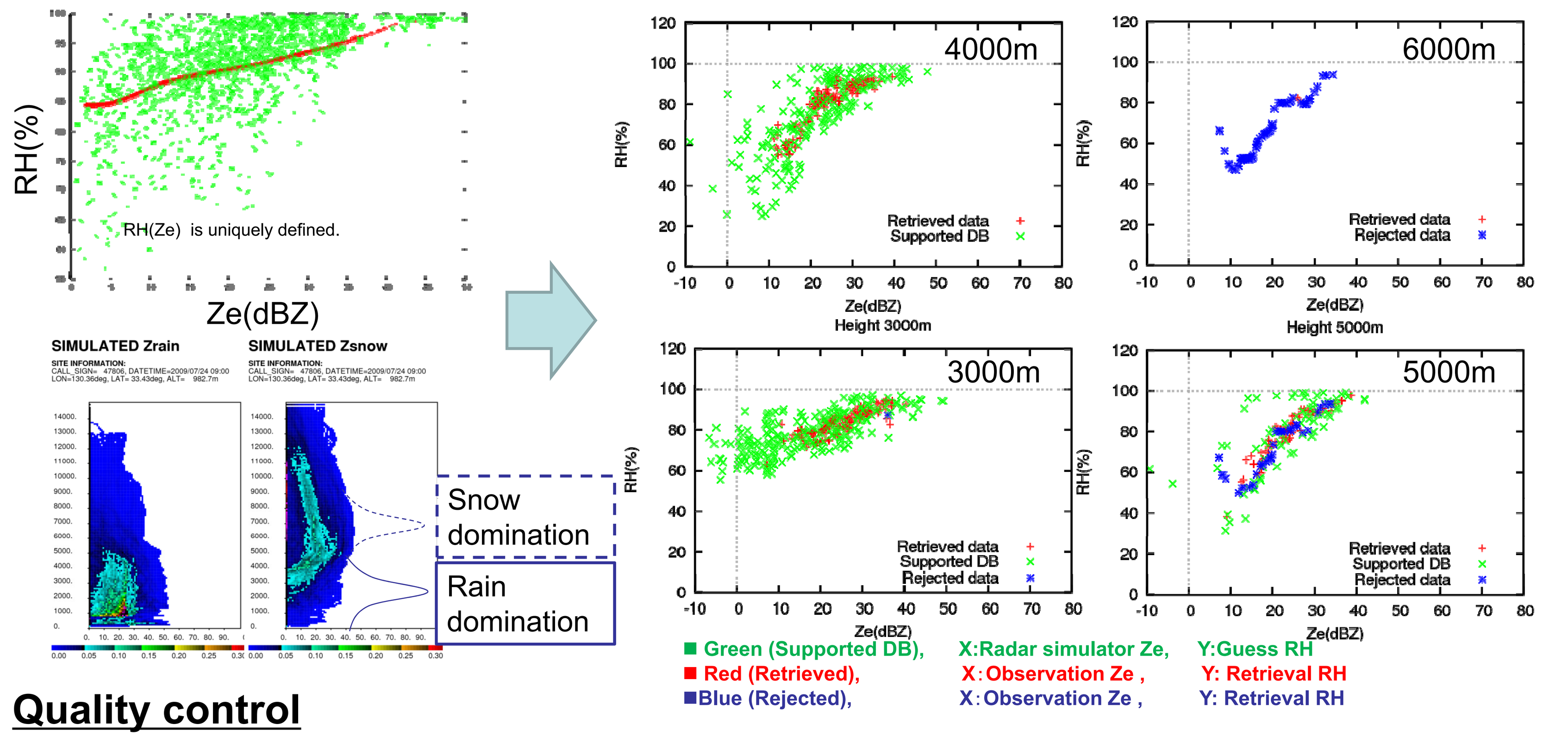
$$J_p = \frac{1}{2} (h_O - h_F)^T S^{-1} (h_O - h_F)$$

Ⅴ. Performance of retrieval algorithm

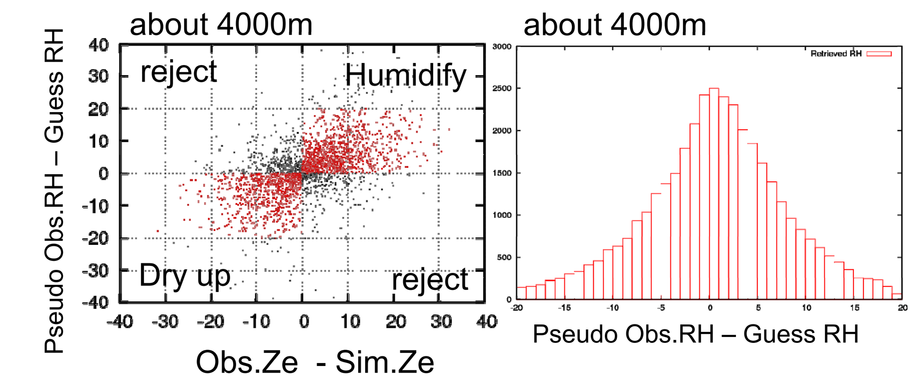
Efficiency of penalty term

The pseudo observation of RH is defined uniquely without penalty term of spatial restriction in the retrieval algorithm. To add the penalty term provides an appropriate dependency of beam height, and that represents difference of hydrometeors type. This approach avoids a positive bias of solid phase in the retrieval. Because, it has been known the reflectivity of snow is overestimated in 1-moment BMP scheme (Eito and Aonashi 2009), and such bias is unsuitable for retrieval method.

■ Independent of height　　■ Addition of penalty term



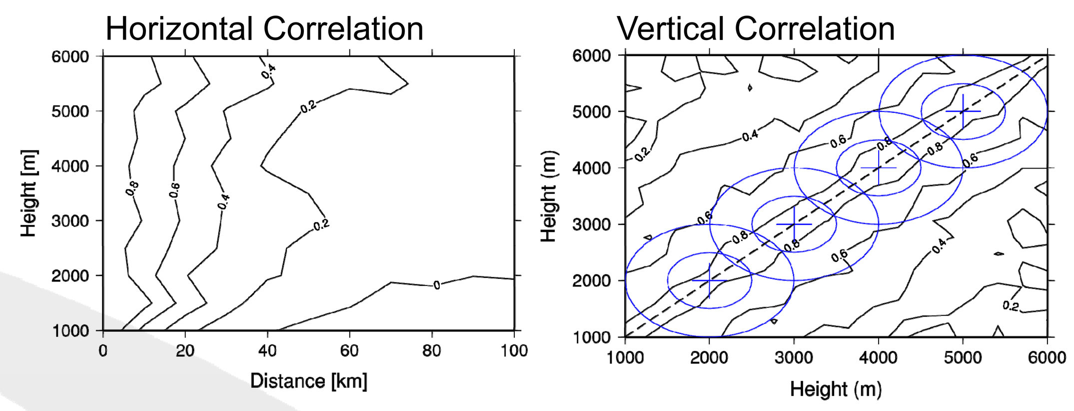
Quality control



The pseudo observation is rejected when increasing Ze error (Obs.Ze–Sim.Ze) and decreasing RH error (Pseudo Obs RH – Guess.RH). This QC prevents the unusual dry up and humidify in the analysis (Caumont et al. 2010). After this QC, the error histogram of pseudo observation becomes convenient the Gaussian distribution for 4DVAR.

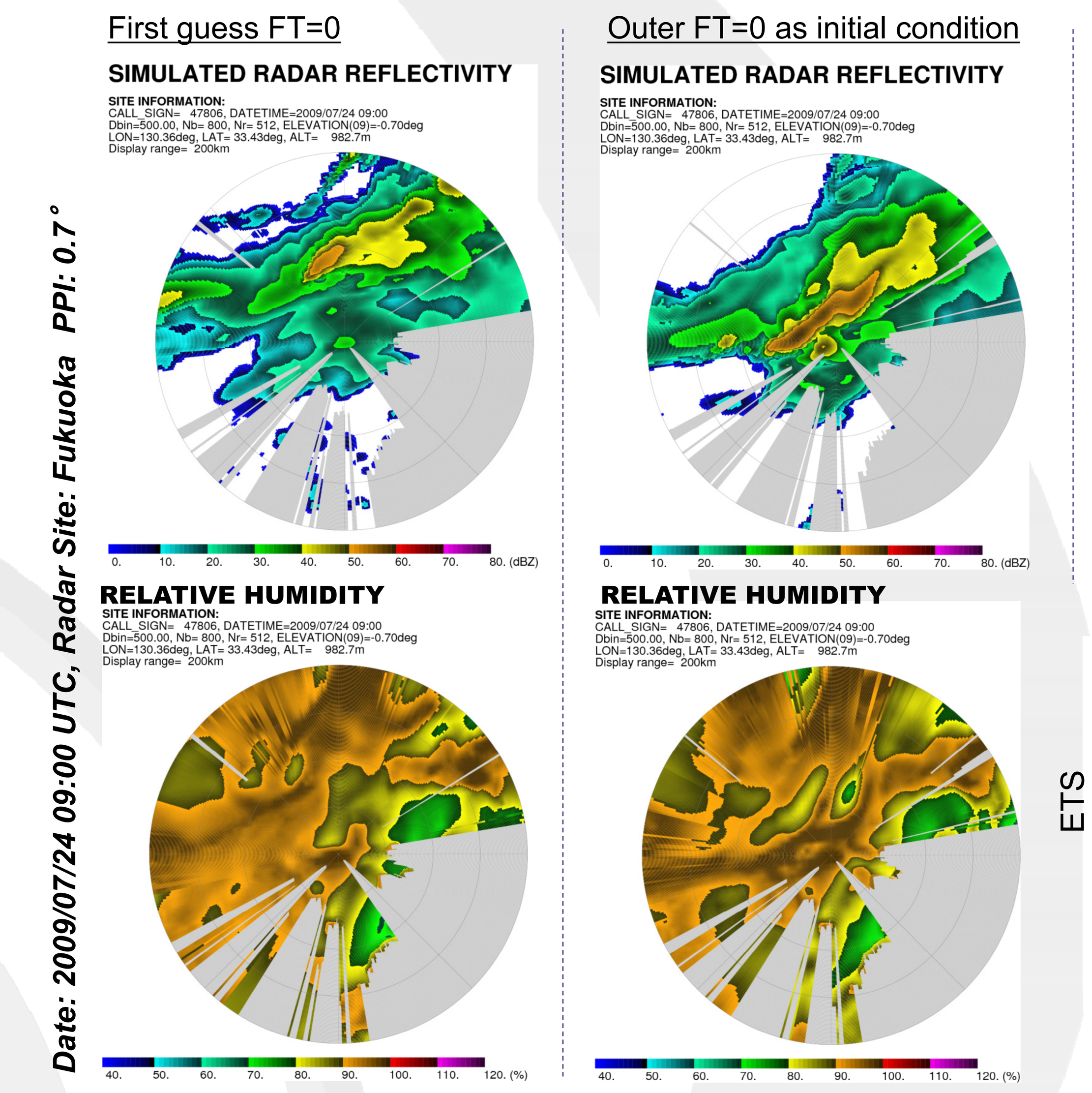
The horizontal correlation and vertical correlation of the RH error in each altitude are statistically calculated. The distance of horizontal thinning to regard as uncorrelated is found 60 km which is a multiple resolution of the inner model.

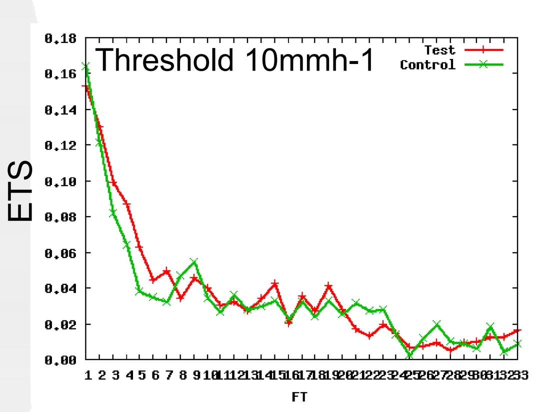
The pseudo observation data exists at a rate of one every 1000m in a column. We assume that the correlation between the data in column is allowed to a certain degree. However, to avoid overlapping data is necessary. Thus the overlapping data is rejected based on the observational error that depends on the distance from the site.



Ⅵ. Impact of 1D+4DVAR

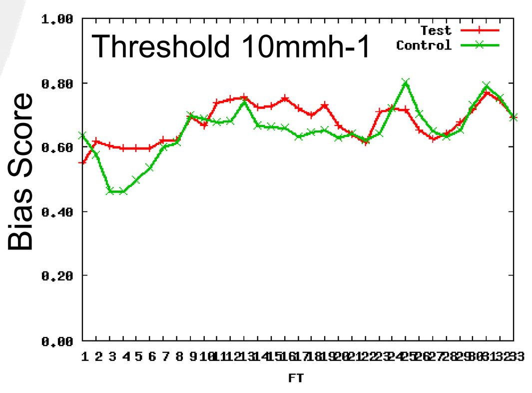
The analysis-forecast cycle experiment demonstrated the improvement of hydrometeors representation in initial condition. For example, the following figures represent the simulated reflectivity, RH and observed reflectivity of Fukuoka radar, and the gray color region in figure is beam blockage by topography. This first guess has displacement error of hydrometeors position, however the displacement error is recovered on outer FT=0 after 1D+4DVAR.





Verification of precipitation forecast

The MSM forecast experiment was performed using initial condition provided by 1D+4DVAR. The verification period of this experiment is 7days, 20 July to 26 July 2009. The ETS and bias score of 1D+4DVAR(Test) show the improvement of precipitation forecast than only JNoVA(Control) in very short-range forecast. Especially Control has the sudden drop of precipitation frequency on FT=3 that is improved in Test.



Ⅶ. Summary

☐ The new indirect assimilation of radar reflectivity, 1D+4DVAR, is developing in JMA. This new system is composed of the radar simulator, the 1D retrieval and JNoVA.
☐ The penalty term of the spatial restriction that controlled the contribution of the hydrometeors was introduced into the optimization technique for the performance gain of the 1D retrieval algorithm.
☐ In the analysis-forecast cycle experiment, the 1D+4DVAR approach demonstrates the improvement of heavy rain forecast, because the atmospheric environment in the initial condition for the hydrometeor is improved by assimilation of pseudo observation RH.

Ⅷ. Reference

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