Data Assimilation with Adjoint Model including Three-Ice Bulk Cloud Microphysics

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1. Introduction

JMA operates NWP models for weather forecasting and disaster prevention information providing. To make the initial condition of NWP model, many kinds of observation data are assimilated. Recently, JMA plans to more effectively utilize remote-sensing observation about hydrometeors in data assimilation.

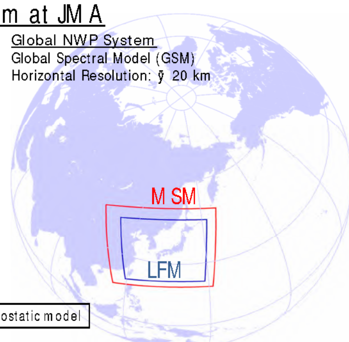
Main Operational NWP System at JMA

Meso-scale NWP System
- Meso-Scale Model (MSM)
  - Main Purpose: Providing of Disaster Prevention Information, Aviation forecast
  - Forecast Range: 39-hour
  - Forecast Model: JMA-NHM
  - Horizontal Reolution: 5km
- Meso-scale Analysis (MA)
  - Data Assimilation System: JNoVA

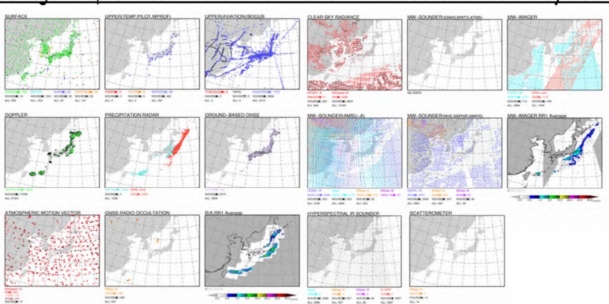
Local NWP System
- Local Forecast Model (LFM)
  - Main purpose: Providing of Disaster Prevention Information, Airport forecast
  - Forecast Range: 9-hour
  - Forecast Model: ASUCA
  - Horizontal Resolution: 2 km
- Local Analysis (LA)
  - Data Assimilation System: ASUCA-Var

New non-hydrostatic model

Global NWP System
- Global Spectral Model (GSM)
- Horizontal Resolution: ~ 20 km



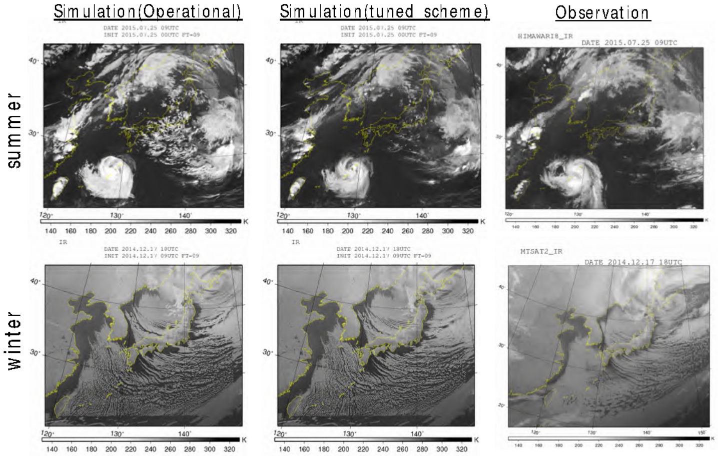
Coverage map of assimilate observation in Meso-scale NWP system



Recent updates: GPM/DPR, GPM/GMI, GNSSRO, Himawari-8/AMV, Himawari-8/AHI are started to assimilate operationally from March 2016.

2. Cloud microphysics for DA

Model bias interfere with accurate data assimilation. In our model, cloud forecast has large bias, thus the bias of cloud processes must be removed for accurate assimilation relating hydrometeors.



6-class 3-ice 1-moment bulk scheme

Prognostic variables
Qv, Qc, Qr, Qi, Qs, Qg

Tuning for bias reduction

Number concentration of ice is diagnosed by mixing ratio of ice, and number concentration of snow defined as function of temperature (Hong and Lim, 2006). Correction coefficients in accretion process are tuned to match as the satellite radiance image.

TL/AD cloud microphysics is simplified to keep linearity

For example: No perturbation variables
- Thermal dynamics coefficients in melting and accretion process
- Terminal velocity in accretion process
- Temperature for phase changing

Verification of adjoint code is satisfied with O(10^-15).

3. Single Column TL/AD Model

	Single column TL/AD model based on KiD*
Variables	P(pressure), T(temperature), Qv(specific humidity), Qx(mixing ratio of hydrometeors x) x=cloud, rain, ice, snow and graupel
Vertical resolution / number of level	160 m / 100 levels
Time step	5 sec

* KiD v2.3 (Shipway and Hill 2012)

Observation operator

Equivalent reflectivity factor (Z)

Simple formation of reflectivity factor for C-band radar using Rayleigh approximation.

$$Z_r = 720\frac{N_{0r}}{\Lambda_r^7}, \quad Z_s = 1.18\frac{|K_i|^2}{|K_w|^2}720\frac{N_{0s}}{\Lambda_s^7}, \quad Z_g = \frac{|K_i|^2}{|K_w|^2}720\frac{N_{0g}}{\Lambda_g^7}$$

$$H_{z_e} = 10\log_{10}\left[10^{18}\left(Z_{rain}+Z_{snow}+Z_{graupel}\right)\right]$$

Brightness temperature (Tb) of microwave imager

RTTOVSCATT (rttov11.3 by EUMETSAT)

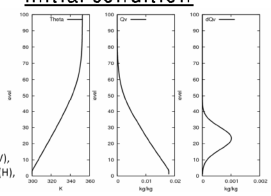
Satellite: GPM, Sensor: GMI, Frequency: 1) 10.65 GHz(V), 2) 10.65 GHz(H), 3) 18.7 GHz(V), 4) 18.7 GHz(H), 5) 23.8 GHz, 6) 36.5 GHz(V), 7) 36.5 GHz(H), 8) 89.0 GHz(V), 9) 89.0 GHz(H), 10) 165.5 GHz(V), 11) 165.5 GHz(H), 12) 183.31± 3 GHz, 13) 183.31± 8 GHz

Radiation transfer model is including rain and snow flux.

Rain and snow flux

$$F_r = \rho Q_r U_{Q_r}, \quad F_{sp} = \sum_x \rho Q_x U_{Q_x} \quad x= \text{snow, graupel}$$

Initial condition

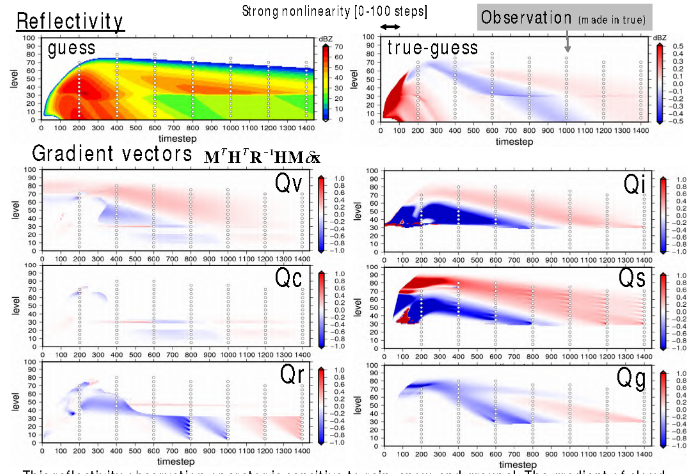


Surface variables is constant.
e.g. U_{srf}, V_{srf} = 0.01

4. Sensitivity of reflectivity and brightness temperature

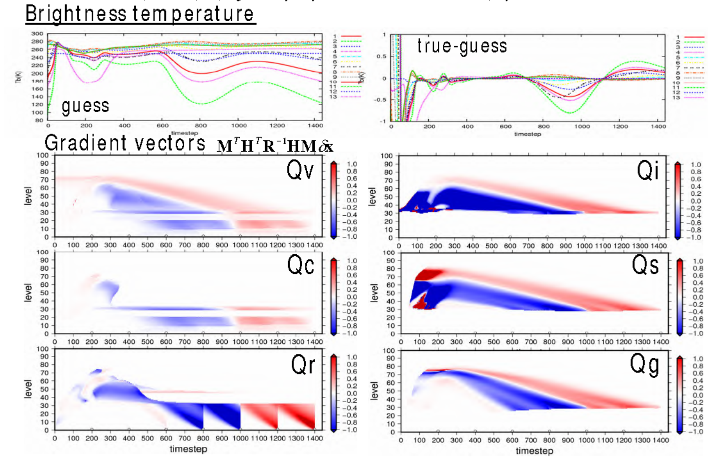
Test Case "deep2" in KiD. Observations are assimilated every 200-step.

Reflectivity



This reflectivity observation operator is sensitive to rain, snow and graupel. The gradient of cloud, ice and water vapor are propagated by adjoint model of cloud microphysics.

Brightness temperature



This Tb is sensitive to all hydrometeors. Adjoint of rttovscatt gives fuzzy and continuity of ice-phase gradient to vertical direction.

5. Summary

Adjoint of ice-phase process is important for assimilation relating hydrometeors.
- Adjoint process including graupel propagates information to upper air. The graupel at upper air influence the snow and ice distribution in analysis. The effects of ice and snow analysis is kept long lead time than the analysis of rain only.

Ice-phase gradient of Tb is fuzzier than the that of reflectivity.
- Reflectivity observe three-dimensional fields of hydrometeor.

To assimilate Z and Tb, BG error of hydrometeors have to be depended on BG flow.
- Climatological background error is not enough to take the correlation of hydrometeors.
- JMA plans to operate Hybrid DA system, thus control variables of hydrometeors will be assimilated using ensemble estimated background error.