Dual-frequency Precipitation Radar (DPR) for NWP data assimilation

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Meso-scale NWP system at JMA

- **Main purpose**
  - Disaster risk reduction and aviation weather forecast

- **Forecast model**
  - Meso-Scale Model (MSM)
    - Non-hydrostatic model
    - Grid spacing: 5 km

- **Data assimilation**
  - Meso Analysis (MA)
    - Incremental 4D-Var
    - Outer grid spacing: 5 km
    - Inner grid spacing: 15 km
Current State of GPM/DPR Assimilation at JMA

- Current our 4DVAR
  - Hydrometeors are “not” analysis variables.

- GPM/DPR assimilation method
  - Indirect assimilation (1D+4DVAR)
  - Assimilation of relative humidity profile retrieved from reflectivity

Radar/Raingauge-Analyzed Precipitation

Assimilated as precipitation
Further Utilization of GPM/DPR

• Characteristics of DPR observation
  – 3-D information of hydrometeors
  – Sensitivity to snow particles

• Benefit of the direct assimilation of DPR in DA
  – Improvement of hydrometeors in initial time
    • Elementary processes (evap. / depo., conversion, melting, latent heating …) work well on early time.
    -> Water vapor, temperature and precipitation become more accurate.
    -> Improvement of precipitation forecast

JAXA/EORC Tropical Cyclone Database
(http://sharaku.eorc.jaxa.jp/TYP_DB/index_j.html)
Next step of GPM/DPR Assimilation

Future Plan: Implementation of Hybrid-4DVar with control variable of hydrometeors into the operational Meso-Analysis

Indirect assimilation
using retrieved RH profiles in traditional 4DVAR

Direct assimilation of GPM/DPR
using reflectivity (KuPR, KaPR) profiles in new Hybrid-4DVAR
Tangent Linearization of Microphysics Scheme

Single column TL/AD model based on KiD. (KiD, Shipway and Hill (2012))

Init. of Qv

$\mathcal{M}_t(x_0)$

$\mathcal{M}_t(x_0 + \delta x) - \mathcal{M}_t(x_0)$

Nucleation is a strongly nonlinear process.

Snow error is originated from difference in ice perturbation

Perturbation of Qv

$M_t \delta x$

TL is almost consistent with NL.

Fixed variables on background trajectory
- Air density and pressure
- Diffusivity of water vapor, thermal conductivity of air

Nucleation is a strongly nonlinear process.

Snow error is originated from difference in ice perturbation
Analysis Increments

**observation**
- KaPR (35.5GHz)
- KuPR (13.6GHz)

**Traditional DA**
Climatological (100%) + Ensemble (0%)

**Hybrid DA**
Climatological (50%) + Ensemble (50%)

Color shade: Total Precipitable Water
Barbs: Surface Wind

Localization radius was set to 300 km.

Nens: 12+1

Widely changed
Traditional DA vs. Hybrid DA

**CNTL**
Forecast from Traditional DA

**TEST**
Forecast from Hybrid DA

**Forecast**
Grid spacing: 2 km

**TEST – CNTL**
Color shade: Total Precipitable Water
Barbs: Surface Wind
Precipitation of Forecast

Observation
Lead time: 9-hour

Traditional DA
Climatological(100%) + Ensemble(0%)

Hybrid DA
Climatological(50%) + Ensemble(50%)
• Only liquid phase data were assimilated in this experiment.
  • Assimilation of ice phase leads to poor forecast accuracy because simulation has a bias.

• To reduce the bias between simulated and observed reflectivity, we developed the radar simulator and cloud microphysics.
Artificial noise filtering to simulate corrected reflectivity

The probability of noise filtering is estimated by CDF function

\[ P = \max\left(0, 1 - \exp(a(x - b))\right) \]

The coefficients \(a\) and \(b\) of the function are obtained by fitting to a frequency distribution of observation.

Noise is reduced using flagEcho.
Mixed-Phase Particles

The backscattering coefficient of melting particle is calculated as a mixture of ice and water.

It will be possible to simulate bright bands in the melting layer.

Fabry, F., and W. Szyrmer (1999)
July 7th, 2018 GPM/DPR KuPR range=160
KuPR

OBSERVATION

OLD SIMULATOR

NEW SIMULATOR

Ze > 0 dBZ
CFADs of KuPR

OBSERVATION
OLD SIMULATOR
NEW SIMULATOR

Bright band

Artificial noise filtering
CFADs of KuPR: Observation - Forecast

OLD SIMULATOR

NEW SIMULATOR
Weak rain is underestimated in the current model. Reflectivity by solid precipitation above the melting layer is weak.
PSD of rain:

\[ n(D) = N_{0r} \exp(-\lambda_r D) \]

\[ N_{0r} = n_{ar} \lambda_r^{n_{br}} \]

\[ \lambda_r = \left( \frac{\pi \rho_r n_{ar}}{\rho_a q_r} \right)^{1+b_r-n_{br}} \]

Abel and Boutle (AB) has many small particles when Q_r is small compared to Marshal-Palmer (MP)
GMI Simulation

Definition of hydrometeors in MSM
Density, max/min diameter, slope parameter …

PSD
Cloud ice: Exponential distribution with slope parameter dependent on temperature.
Rain: Abel and Boutle (2012)
\[ n(D) = N_{0r} \exp(-\lambda_r D) \]
\[ N_{0r} = n_{ar} \lambda_r^{n_{br}}, \lambda_r = \left(\frac{\pi \rho_r n_{ar}}{\rho_a q_r}\right)^{1+b_r-n_{br}} \]

Variables
P, T, Qv, Qc, Qr, Qi, Qs, Qg, Cloud fraction
T_surf, Qv_surf, P_surf, U_surf, V_surf, SST

Particle shape
Cloud ice: thick hex plate
Snow: sector-like snowflake
Graupel, rain and cloud: sphere

Updating \([mietable_gpm_gmi.dat]\)

RTTOV-SCATT

Radiance
Cloud ice is almost not.
Issues of conversion from cloud ice to snow

① Diagnostic for the fractionation rate of cloud ice to snow

\[ f_{aggr} = 1 - \exp[-T_{scaling}(T - T_{CT})q_i/q_{cf0}] \]

② Autoconversion from cloud ice to snow

\[ QCNi_s = K_1 H(Q_i - Q_{i0}) \]
\[ K_1 = 0.001 \exp[0.025 T_c] \]
\[ Q_{i0} = 1.0 \times 10^{-4} \]

① + ②

\[ QCNi_s = \max(QCNi_s, f_{aggr}) \]

However, \( f_{aggr} \) is dominant and cloud ice is very quickly converted to snow.
Rain and cloud ice terminal velocity, accretion (considering cloud ice terminal velocity), and diffusion growth are also changed in this modification.
Impact Experiment

Address problems by comparing with GPM.

Observation | Current Model | Modified model

A

B

C
Impact Experiment

Observation

89.00V

Current Model

89.00H

Modified Model
Verification of Precipitation

M002_a029_sum_07196_001 M002_a028_sum_07192_002
Num of init: 328, Period: 201806130000-201807232100
Precipitation

ETS

Bias Score

Best

Good

Poor

Test-Control

Test-Control
Verification against SONDE  
Lead time 39-hour

**Mixing ratio**

- **me**
- **me(Test-Control)**

- **rmse**
- **rmse(Test-Control)**

- The current model has incorrectly compensated for this error.

**Temperature**

- **me**
- **me(Test-Control)**

- **rmse**
- **rmse(Test-Control)**
Summary

We have been developing the direct assimilation technique for DPR. However, simulated reflectivity has a large bias.

In order to resolve the issues, the radar simulator is enhanced and the cloud microphysics scheme is corrected.

As a result, accuracy of the simulation and forecast was improved.

Next Step:
Assimilation (re)experiment using the new simulator and cloud microphysics.
Thank you for your attention.
Single Column Model

Case of warm2 in KiD

Evaporation (MP-AB)

Qc (MP-AB)

Qr (MP-AB)

Terminal Velocity of rain (MP-AB)
Hydrometeors profiles

Current Model

Modified Model

Modified Model – Current Model