Assimilation of GPM/DPR at JMA

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OUTLINE

1. Introduction
2. Operational NWP system at JMA
3. DPR data assimilation
    - Radar simulator
    - 1D+4DVAR
        - Relative humidity estimation
    - Quality control
4. Performance evaluation
5. Summary

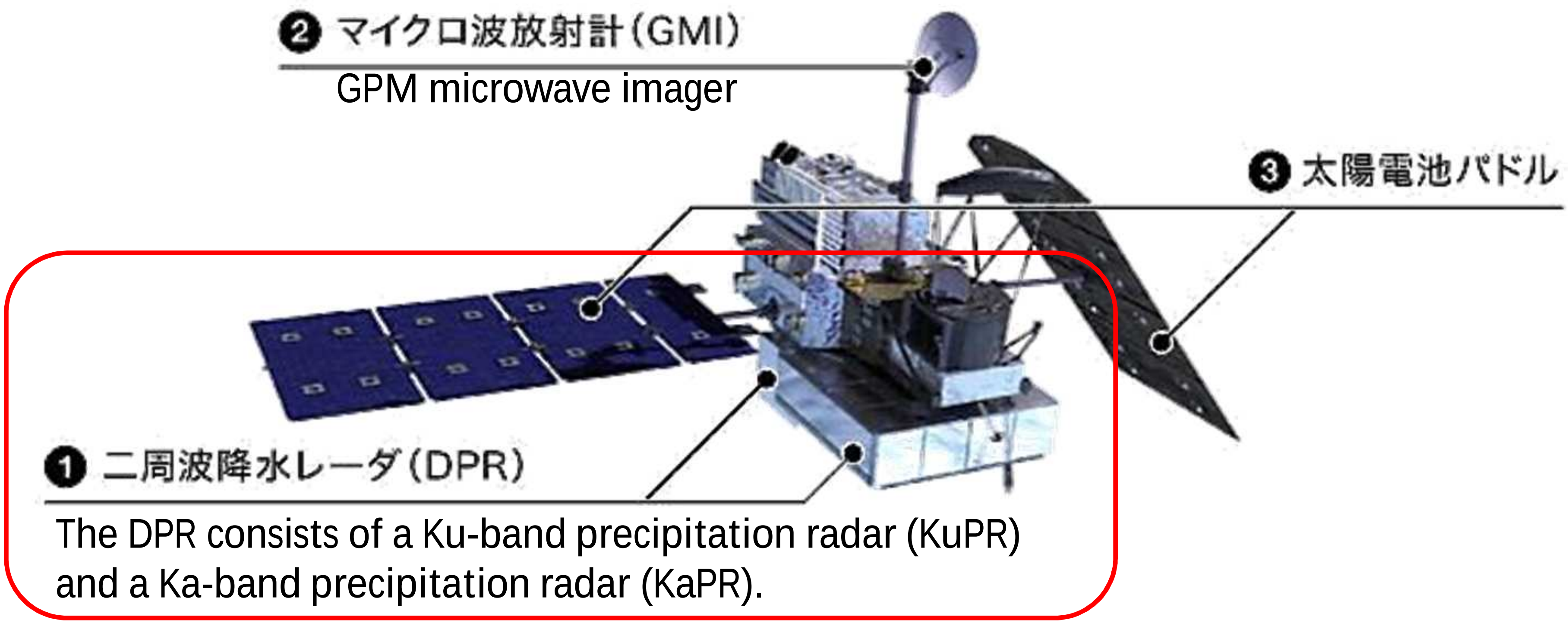
Introduction

- JMA has been operating NWP models for weather forecasting and disaster prevention information providing.
- To make the initial condition of NWP model, JMA assimilates many observation data. Especially, satellite data are most important data for improvement of the initial condition.
- Impact of GPM/DPR data assimilation at JMA
  - GPM/DPR was started to assimilate operationally in March 2016.

GPM core satellite

Global Satellite Mapping of Precipitation Global (GPM core)

- Dual-frequency Precipitation Radar (DPR)
  - Japan Aerospace Exploration Agency (JAXA)
  - National Institute of Information and Communications Technology (NICT)



JAXA HP (http://www.satnavi.jaxa.jp/project/gpm/) より

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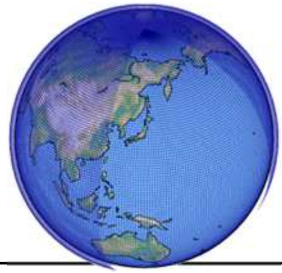
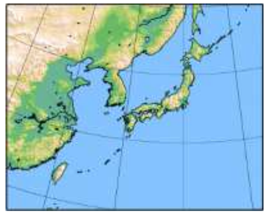
Current NWP models of JMA

	In Operation					In Test Operation (*)
	Deterministic					
	Global Spectral Model **GSM**	Meso-Scale Model **MSM**	Local Forecast Model **LFM**	One-week Ensemble **WEPS**	Typhoon Ensemble **TEPS**	Meso-scale Ensemble **MEPS**
objectives	Short- and Medium-range forecast	Disaster reduction Aviation forecast	Aviation forecast Disaster reduction	One-week forecast	Typhoon forecast	Uncertainty and probabilistic information of MSM
Forecast domain	Global 	Japan and its surroundings (4080km x 3300km) 	Japan and its surroundings (3160km x 2600km) 	Global 		Japan and its surroundings (4080km x 3300km) 
Horizontal resolution	TL959(0.1875 deg)	5km	2km	TL479(0.375 deg)		5km
Vertical levels / Top	100 0.01 hPa	48+2 21.8km	58 20.2km	60 0.1 hPa		48+2 21.8km
Forecast Hours (Initial time)	84 hours (00, 06, 18 UTC) 264 hours (12 UTC)	39 hours (00, 03, 06, 09, 12, 15, 18, 21 UTC)	9 hours (00-23 UTC hourly)	264 h (00, 12 UTC) 27 members	132 h (00, 06, 12, 18 UTC) 25 members	39h 11 members
Initial Condition	Global Analysis (4D-Var)	Meso-scale Analysis (4D-Var)	Local Analysis (3D-Var)	Global Analysis with ensemble perturbations (SV)		Meso-scale Analysis with ensemble perturbations (SV)

(* 予報部内での利用目的のため。外部にデータは提供されていない。)

Main Operational Forecast model

Global NWP System

Global Spectral Model (GSM)

Horizontal resolution:TL959(0.1875 deg)

Global Analysis (GA): 4D-Var

Meso-scale NWP System

Meso-scale model (MSM)

Forecast Model: JMA-NHM

Horizontal resolution: 5 km

Meso Analysis (MA): 4D-Var

Data assimilation system: JNoVA

Local NWP System

Local Forecast model (LFM)

Forecast Model: ASUCA

Horizontal resolution: 2 km

Local Analysis (LA):3D-Var

Analysis cycle

Data assimilation system: ASUCA-Var

Meso-scale NWP System

- Main purpose: Providing disaster prevention information
  - Accuracy of precipitation forecast is of very importance.
  - Hydrometeors in initial condition must be improved for forecast improvement.

- Cloud microphysics process
  - 3-ice 6-class bulk scheme
  - Prognostic hydrometeors
    - Water vapor, cloud, rain, ice, snow and graupel
  - Reflectivity calculation needs these hydrometeors in data assimilation system.

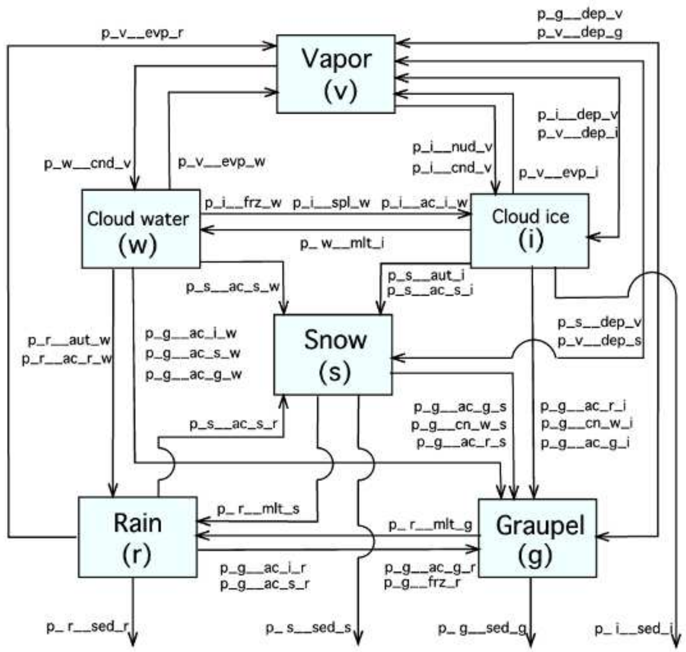
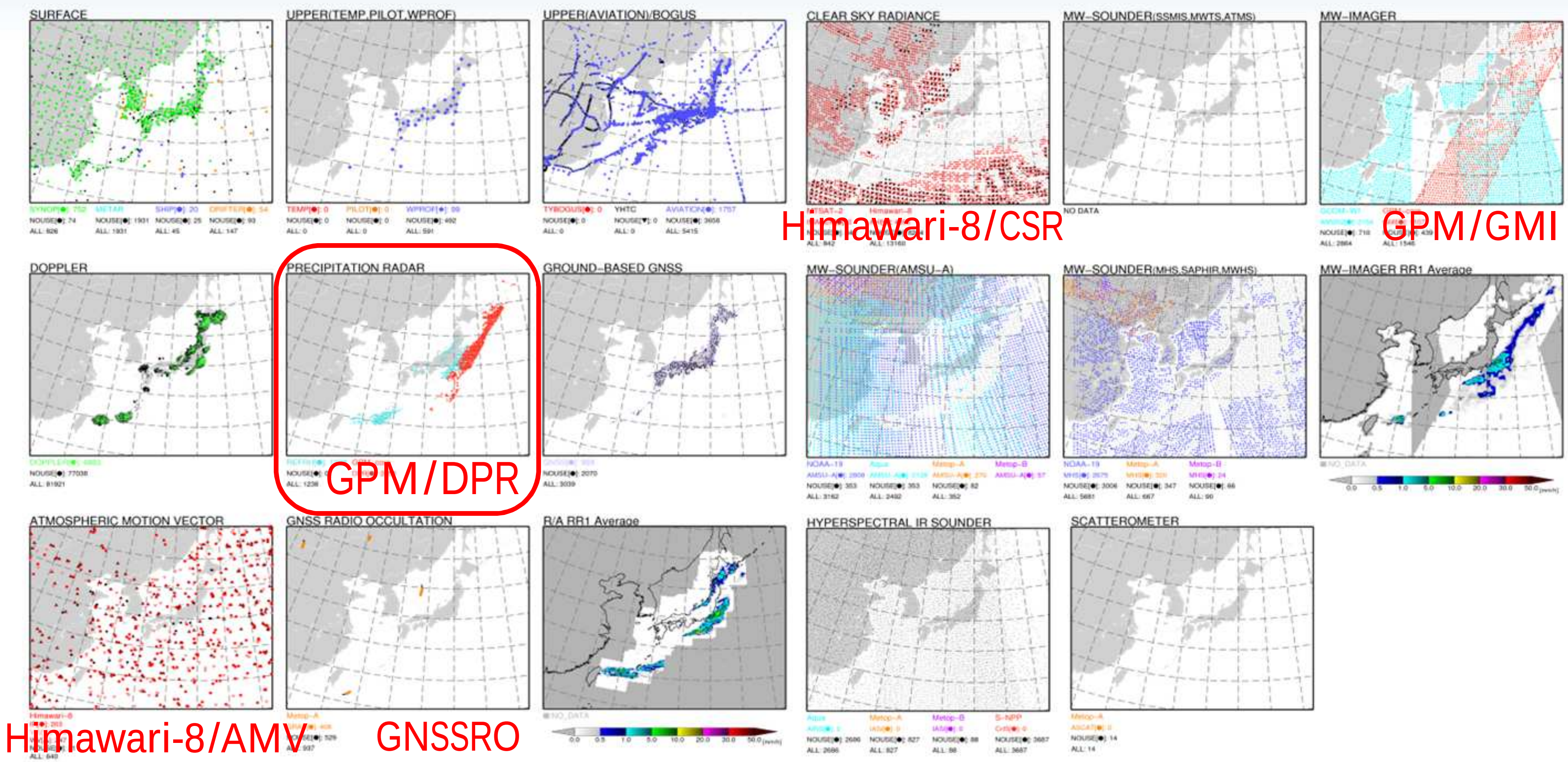


Figure 3.5.2: Cloud microphysical processes in the MSM. For a list of symbols, see Table 3.5.1.

JMA Outline NWP 2013

Coverage map of assimilated observation in Meso-scale NWP system

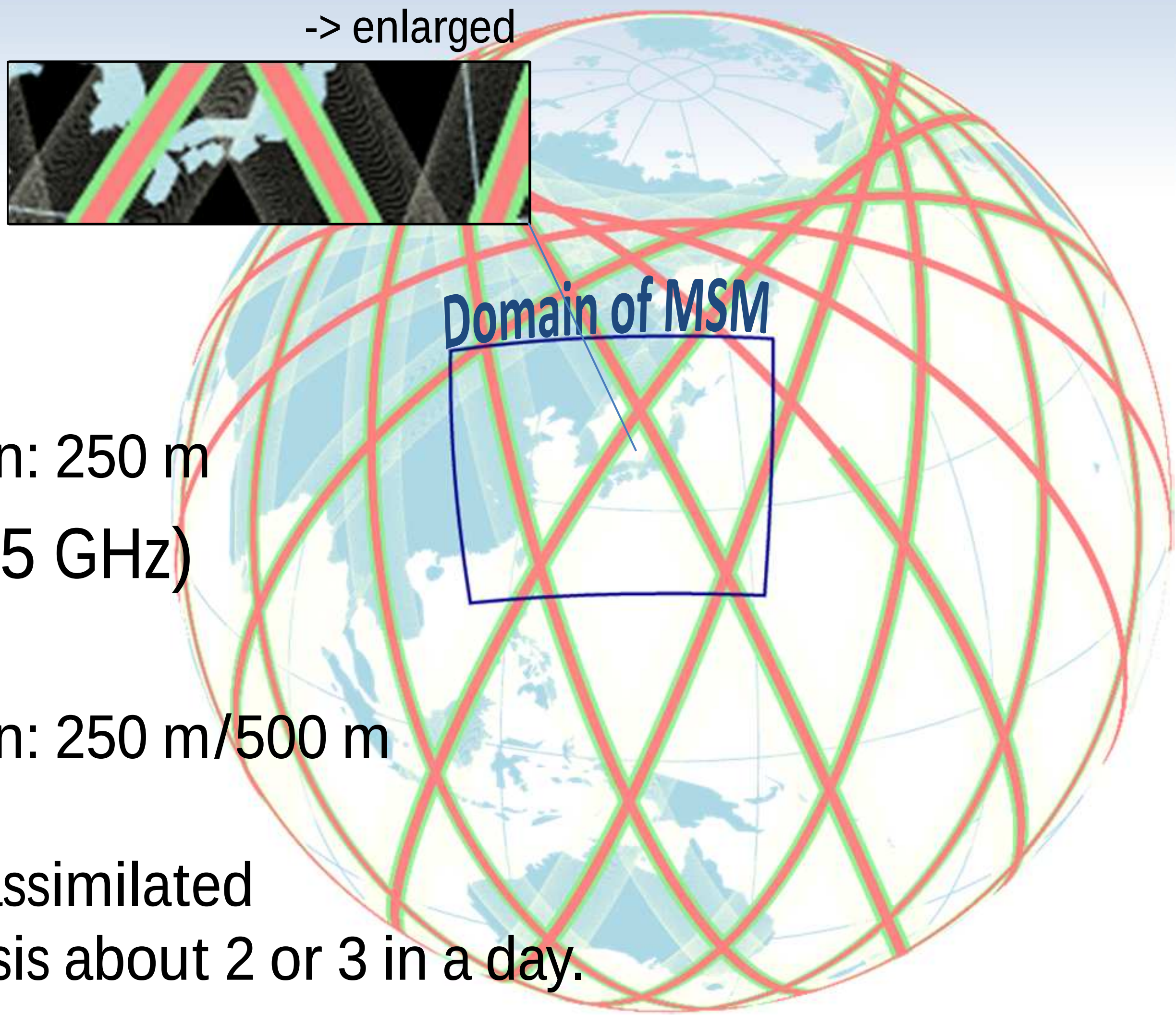


Recent updates: GPM/DPR, GPM/GMI, GNSSRO, Himawari-8/AMV, Himawari-8/CSR are started to assimilate operationally in March 2016.

GPM Data Coverage during 24-hour

- GMI
  - Width: 800 km
- KuPR(13.6 GHz)
  - Width: 245 km
  - Vertical resolution: 250 m
- KaPR MS/HS*(35.5 GHz)
  - Width: 125 km
  - Vertical resolution: 250 m/500 m

  * High sensibity mode
- KuPR and KaPR are assimilated
  by meso-scale analysis about 2 or 3 in a day.



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Ground-based Radar Simulator in JMA

- It was developed for weather radar assimilation.

☐ Beam bending
- Refraction index

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

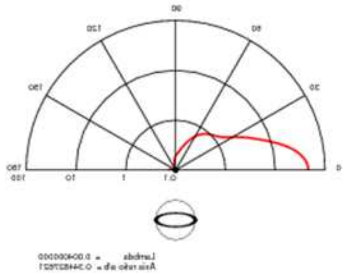
- The Earth curvature

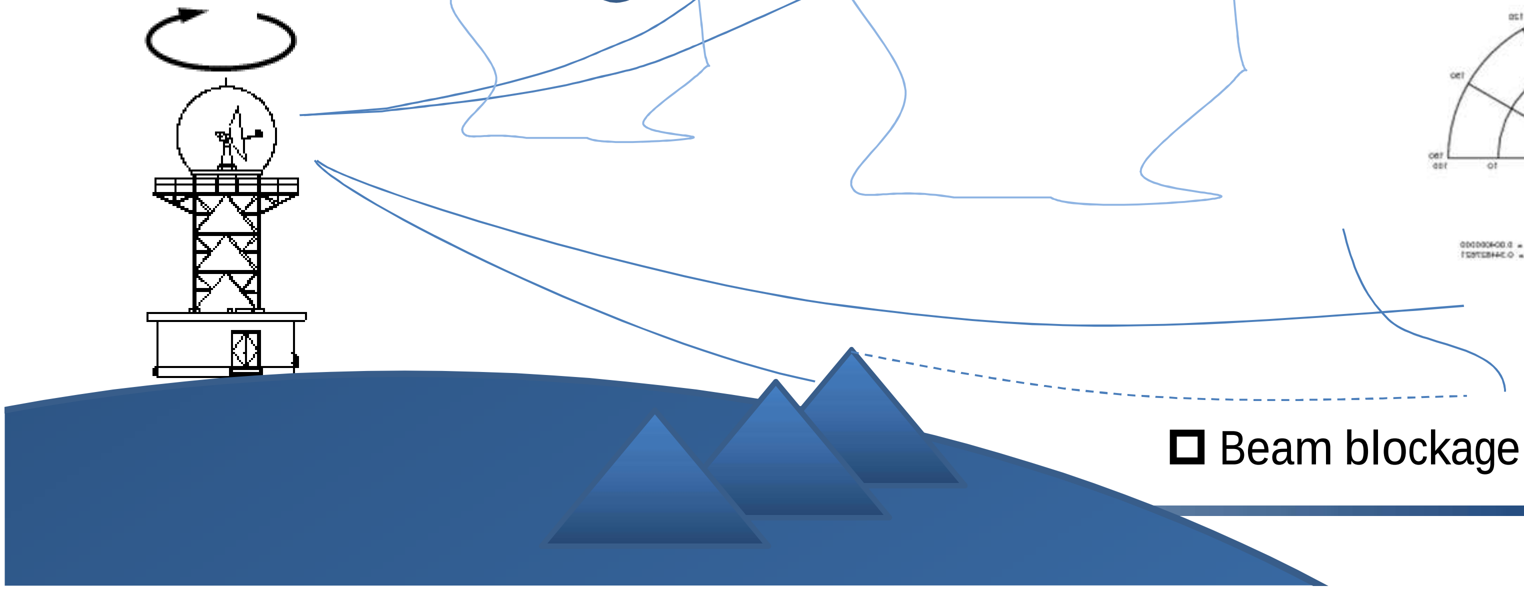
☐ Effective hydrometeors
- Rain, Snow and graupel.

☐ Beam shape
- Gauss-Hermite quadrature, quadrature order n = 5

☐ Virtual radar site
- Ex. Tokyo
- λ=5.7cm
- Resolution=500mX(360/512)°
- Number of elevation =28

☐ Scattering cross-section
Rayleigh (or T-matrix)

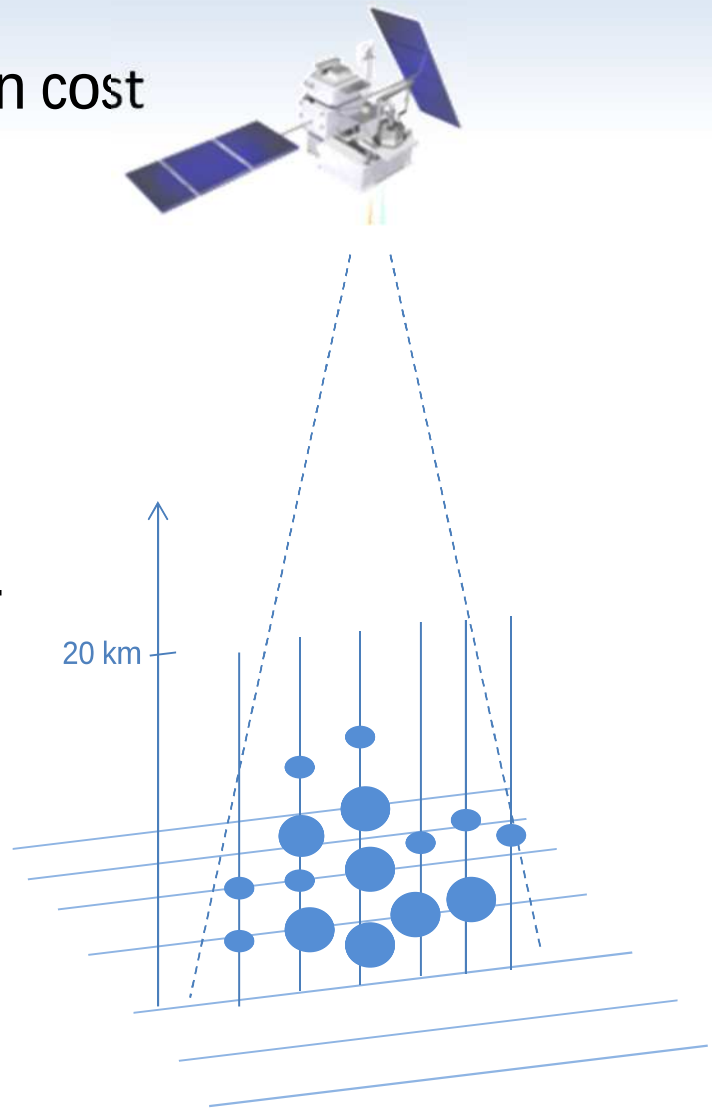




☐ Beam blockage by topography

Space-borne radar simulator

- Simplification for reducing computation cost
  - Slant beam path, beam width and beam bending
    - Horizontal resolution of MSM is 5km, it is coarse-grid about beam simulation.
    - Small Impact for DA
  - Attenuation
    - Corrected Z factor products has been used.



- For computing efficiency
  - Z factor Table is prepared at offline.
  - In online, Z factor is given by Look up table method

Space-borne radar simulator

- Reflectivity calculation
  - Effective particle: Rain, snow and graupel
    - Cloud water and cloud ice are ignored.
  - Size distribution: Negative exponential dist.
    - Intercept parameter is fixed
  - Particle shape: sphere
  - Scattering calculation: Lorenz-Mie theory
    - Single scattering

$$\eta_x = \int_{D_{\min}}^{D_{\max}} \sigma_{bx}(D) N_x(D) dD$$

  - Dielectric constant
    - Water: Debye
    - Snow: Boren and Batton (1982)

- Size distribution:

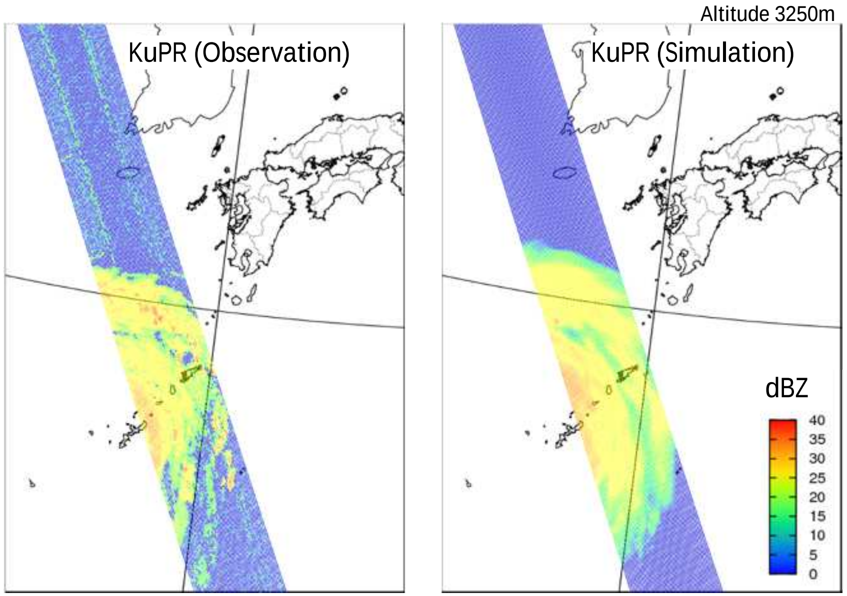
$$N_X(D) = N_{X0} \exp(-\lambda_X D_X)$$

- Slope parameter:

$$\lambda_X = \left(\pi \frac{\rho_X}{\rho_a} \frac{N_X}{Q_X} \right)^{\frac{1}{3}}$$

- Intercept parameter:

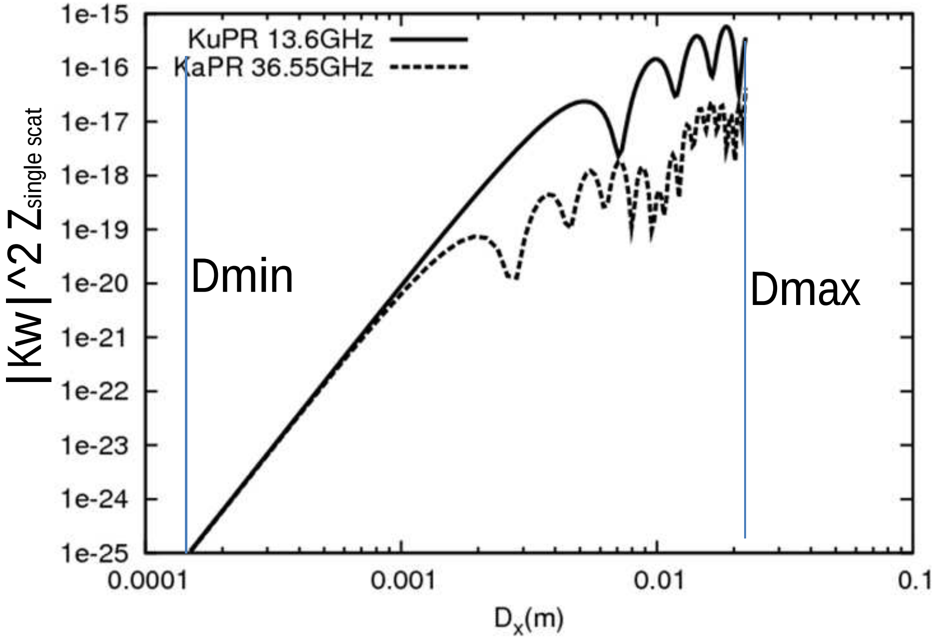
$$N_{X0} = N_X \lambda_X$$



Space-borne radar simulator

- Bias of simulated Z factor exists in ice phase (Eito and Aonashi 2009)
  - Case of fixed intercept parameter in 1-moment scheme
    - Insufficient to describe size distribution
    - Especially, error becomes large at large diameter.
  - Case of unfixed intercept parameter in 2-moment scheme
    - Better scheme to describe size distribution than 1-moment scheme
- Operational model
  - 1-moment scheme
    -> Large bias caused by error of large size particle

Minimum diameter to maximum diameter



Comparing the KuPR and KaPR

KuPR > KaPR from large size particles.
Model bias affects simulated KuPR than KaPR.

GPM/DPR data assimilation

- Assimilation method of KuPR and KaPR
  - 1D+4D-Var method
    - This method is same as ground based radar assimilation at JMA.(Ikuta and Honda, 2011)

1. RH is retrieved from observed reflectivity, simulated reflectivity and first-guess. (Caumont et al., 2010)
2. This retrieved RH is assimilated in the same way as conventional data by 4D-Var.

<u>RH estimation based on Bayesian theory</u>

$$\mathbf{y}_{KuPR}, \mathbf{y}_{KaPR} \rightarrow \left[H_{PR}\left(\mathbf{X}^b\right) \text{ DATABASE(RH,Ze)} \right] \rightarrow \hat{\mathbf{y}}_{RH} \rightarrow \text{4D-Var}$$

Bayesian Theory

- RH estimation is based on Bayesian theory.

Best estimation

$$\hat{x} = \int x \cdot P(x \mid y) dx$$

Conditional probability

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

approximation

Bayes' rule

$$P(x \mid y) = \frac{P(y \mid x) P(x)}{P(y)}$$

Marginal probability

$$P(y) = \int P(y \mid x) P(x) dx$$

Weighted average

$$\hat{x} \equiv \sum_i x_i \frac{w_i}{\sum_j w_j}$$

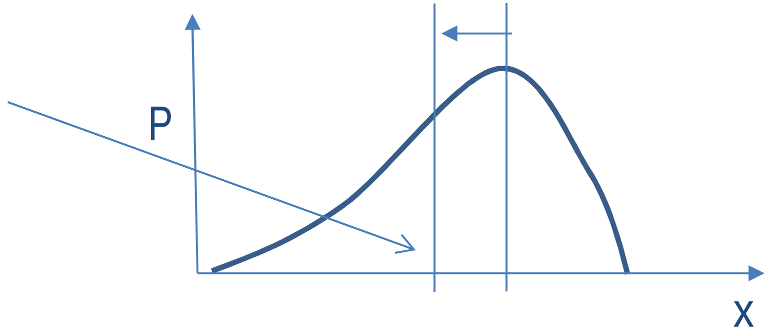
Weight function

$$w_i = \exp\left[-\frac{1}{2}(H(x_i)-y)^T R^{-1}(H(x_i)-y)\right]$$

Bayesian theory with Kernel density estimation

Weighted average ≠ Maximum likelihood
→ Under estimation in case of non-Gaussian

$$\hat{x} = \sum_i x_i \frac{w_i}{\sum_j w_j}$$



Our approach

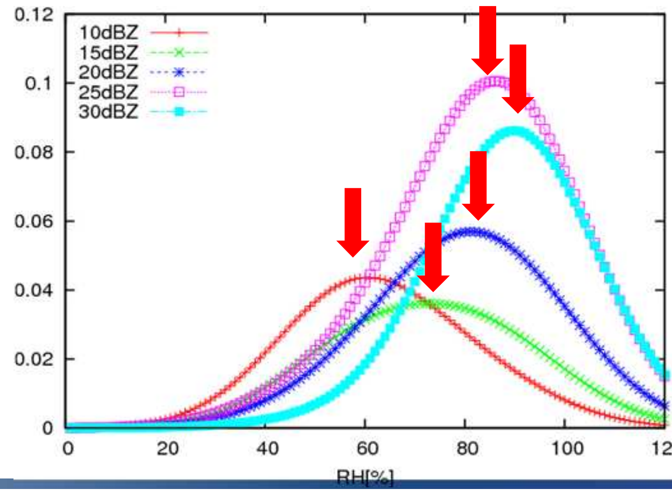
Maximum likelihood using kernel density estimation

$$\hat{x} = \arg\max_x L(x \mid y_{Ku}, y_{Ka})$$

This method describes the likelihood function in a superposition of the Gaussian kernel.

$$L(x \mid y_1, y_2) \propto \frac{1}{n h_1 h_2} \sum_i^n \left[\prod_{j=1}^{2} K\left(\frac{H(x_i) - y_j}{h_j} \right) \right]$$

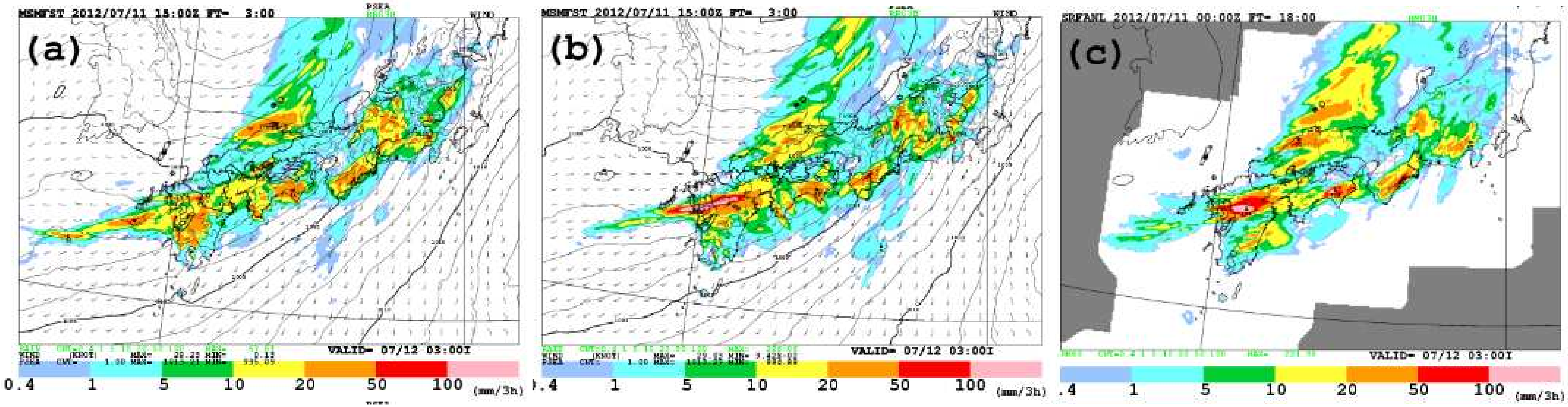
Kernel function: $K(t_i) = w_i \frac{1}{\sqrt{2\pi}} \exp(-t_i^2 / 2)$



Impact of weighted average v.s. kernel density

Assimilation experiment using ground-based weather radar of JMA

EXP: Weighted average　　EXP: Kernel density　　Observation



Precipitation forecast improved using the Kernel density approach than the weighted average approach.

Estimation of relative humidity profiles

The RH profiles are updated using reflectivity observation profiles.

- The set of column in the first-guess are regarded as the pseudo ensemble members.
- Making a database of the relation between RH and Z.
- The RH profiles are estimated by based on Bayes' theorem with kernel density estimation.

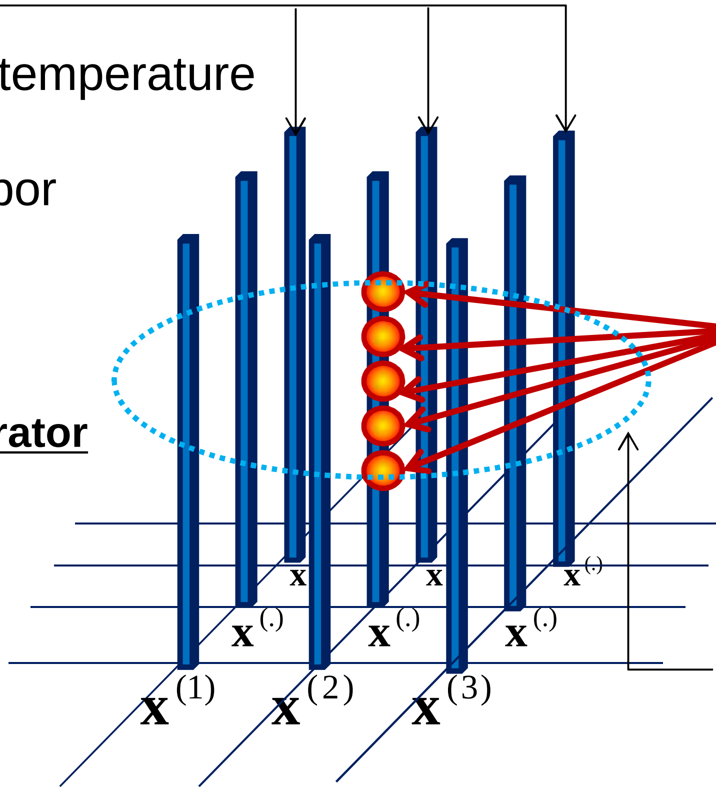
State vector

$$\mathbf{x} = \begin{pmatrix} \theta \\ \mathbf{p} \\ \mathbf{q}_v \\ \mathbf{q}_r \\ \mathbf{q}_s \\ \mathbf{q}_g \end{pmatrix}$$

Potential temperature
Pressure
Water vapor
Rain
Snow
Graupel

Observation operator

$$H_{DPR}(\mathbf{x})$$



Observation vector

$$\mathbf{y} = \mathbf{Z}$$ ⇐ KuPR,KaPR profile

Pseudo ensemble vector

$$\mathbf{X}^b = \left(\mathbf{x}^{(1)} \cdots \mathbf{x}^{(m)}\right)$$

Schur production of the observation localization

$$\mathbf{L}_{d,T}$$

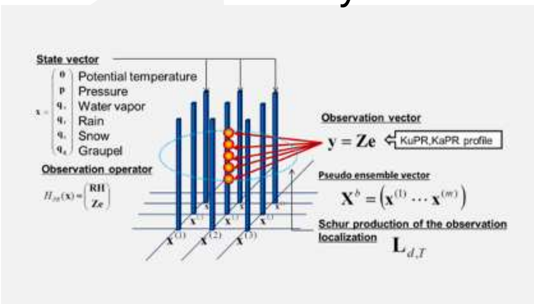
Bayesian theory with Kernel density estimation

$$y_{KuPR}, y_{KaPR}$$

$$H_{DPR}(x)$$

DATABASE

Database is made by model columns.



Adaptive bias correction Bias is recalculated every analysis.

$$\langle d \rangle = \langle H(x) - y \rangle$$

Model probability density P(x|y) is redefined using <d>.

$$P(y\,|\,x) \propto \exp\left[-\frac{1}{2}\left(H(x) - y - \langle d \rangle\right)^T R^{-1}\left(H(x) - y - \langle d \rangle\right)\right]$$

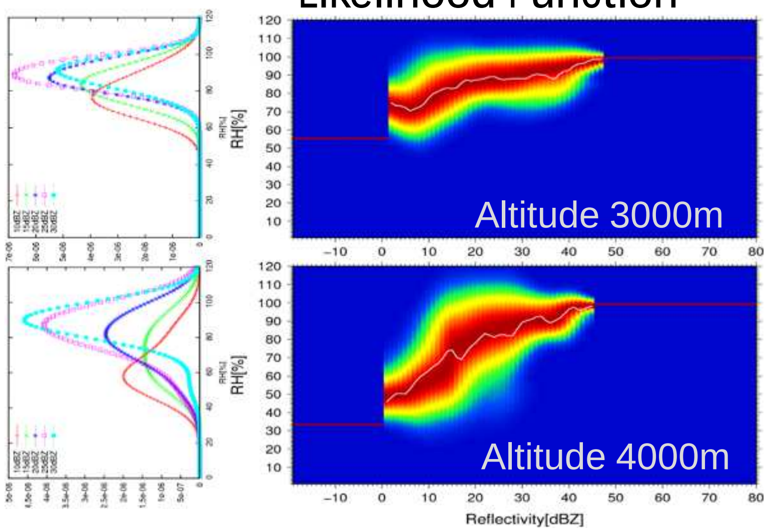
Maximum likelihood using Kernel density estimation

$$RH = \arg\max L(x\,|\,y_{Ku}, y_{Ka})$$

4DVar

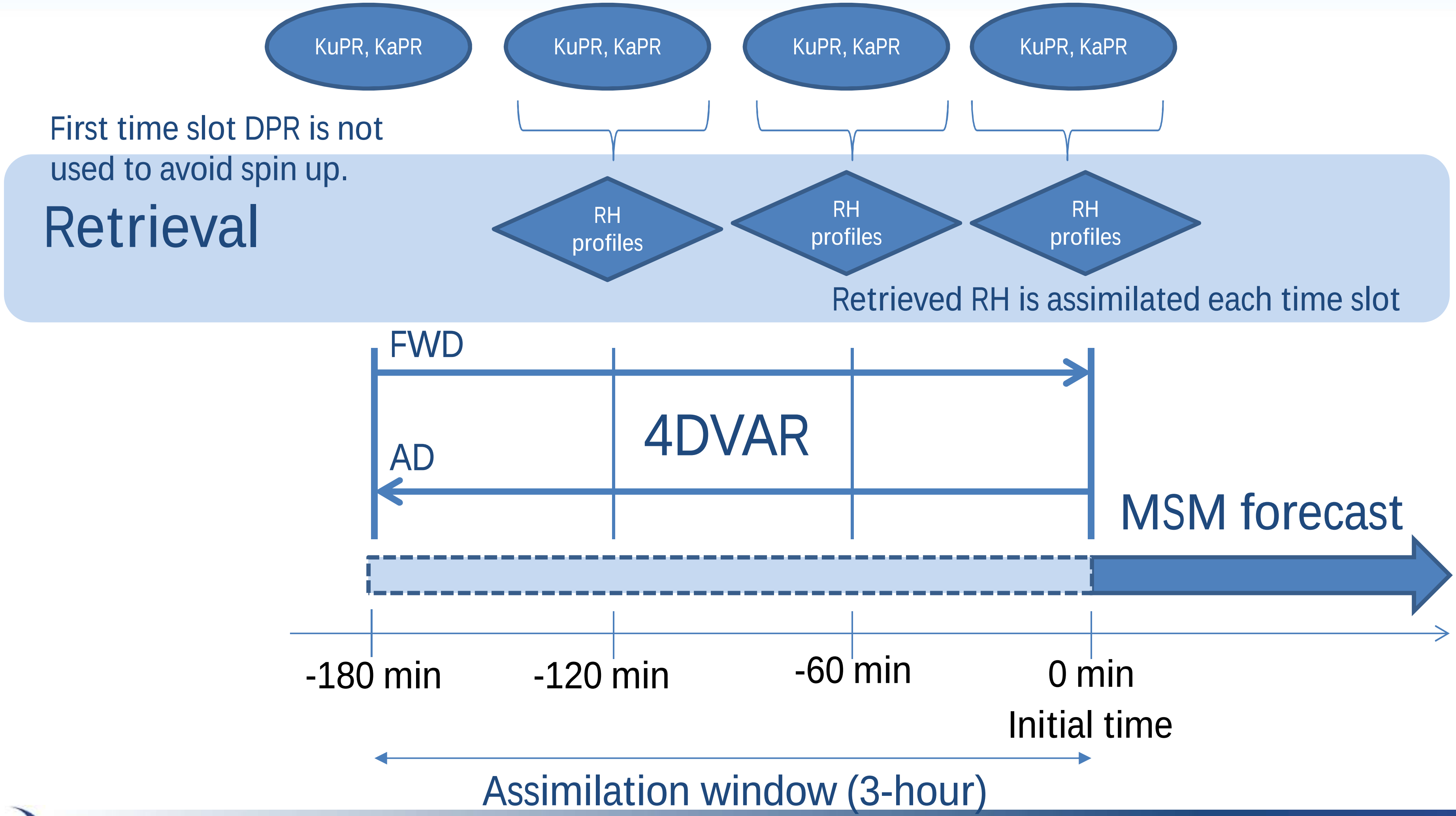
Correlation of between B and R is neglected.

Likelihood Function

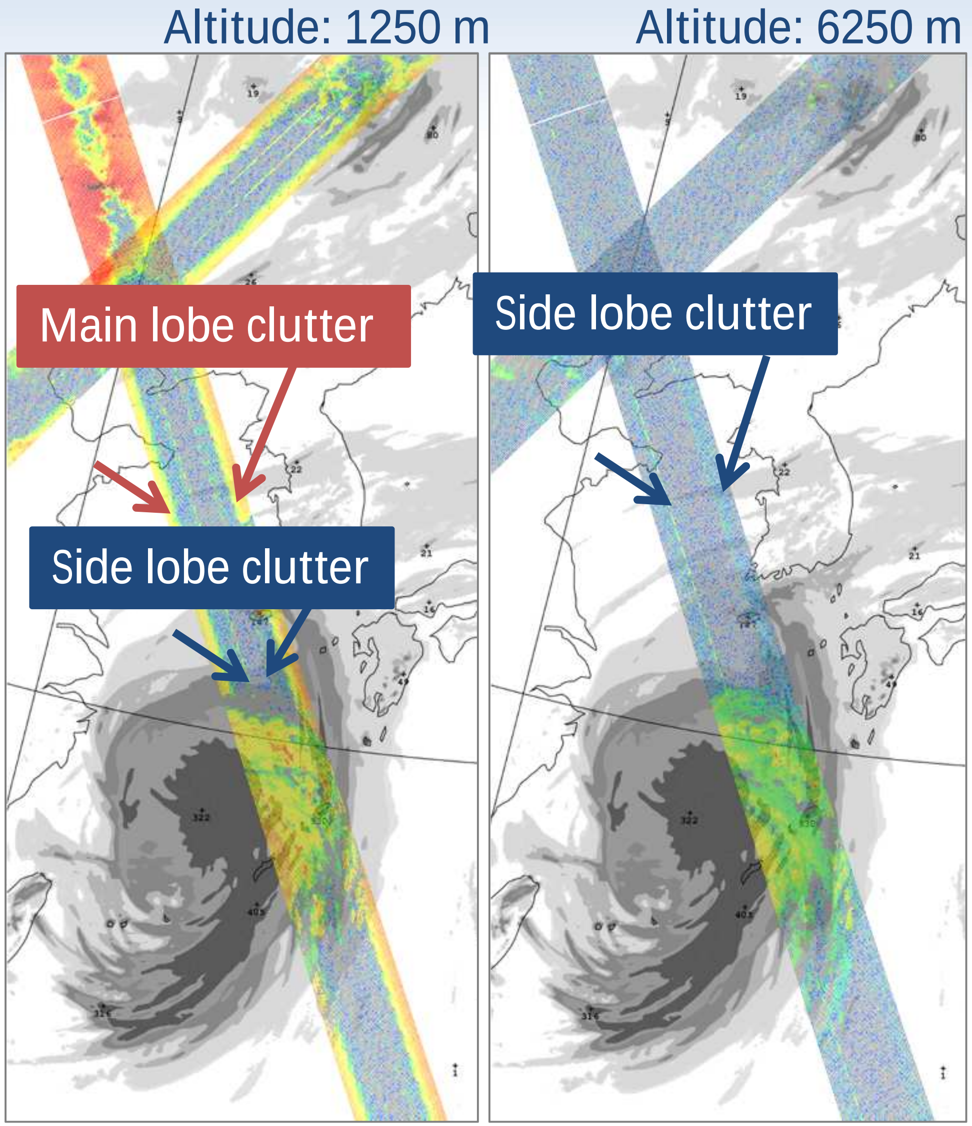


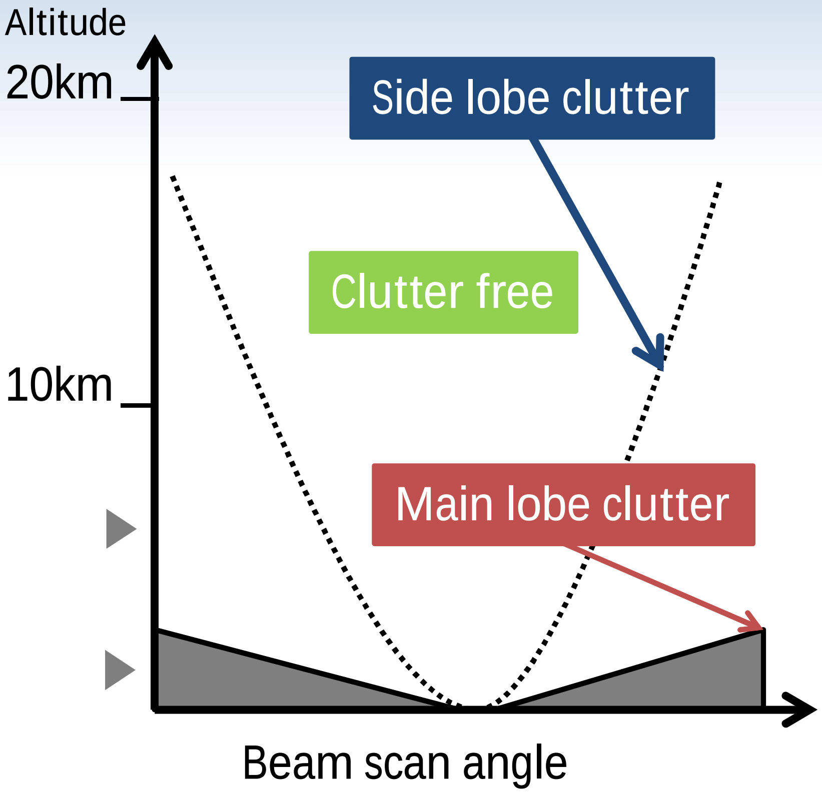
DPR assimilation in Meso Analysis

- The observation are distributed to 4 time-slots by rounding off the observation time to hours.
- The observation within the period from 3.5 h before to 0.5 h after the initial time are assimilated.



Quality Control [Clutter]





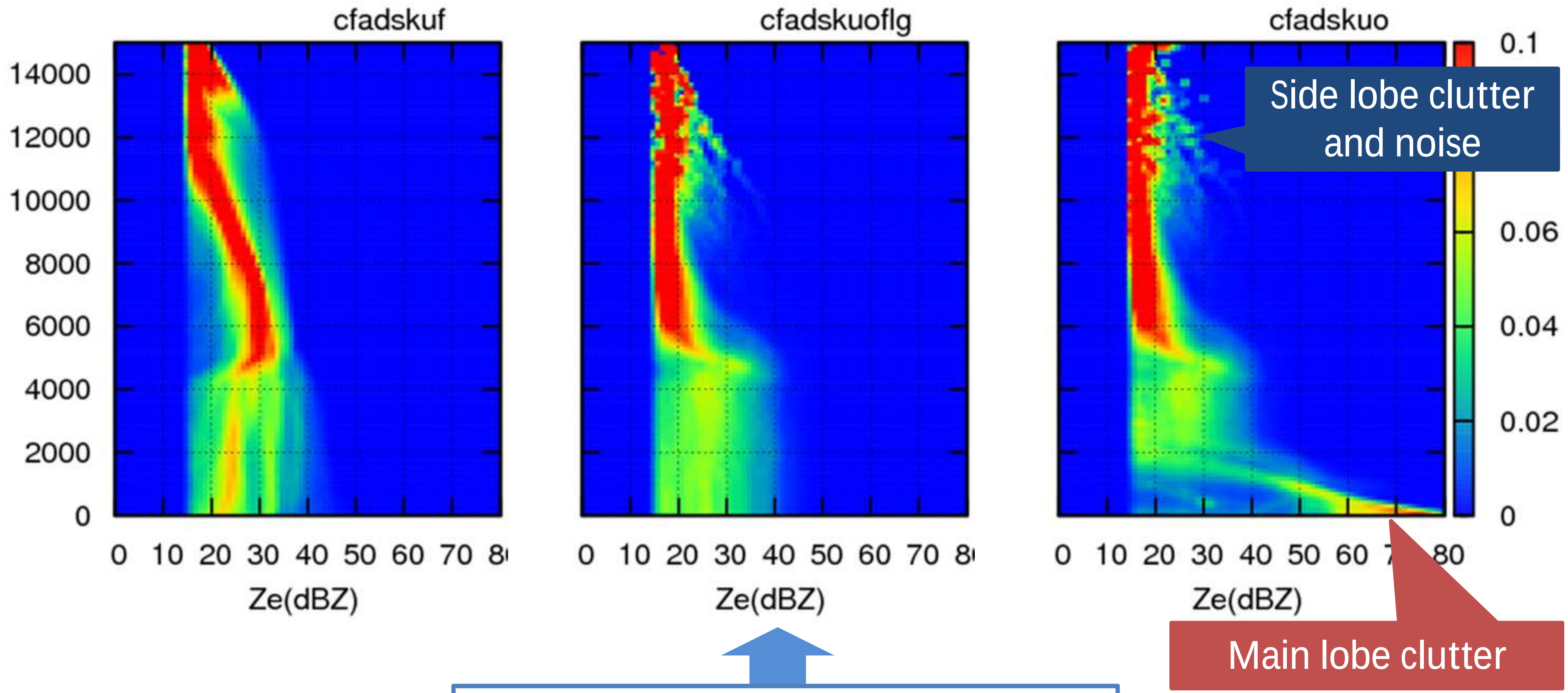
Ref. Tagawa et al. (2007)

- Value of both edge on the path is main lobe clutter.
- Two lines on the path are side lobe clutter.
- For DA, clutter must be removed.

Quality Control [Clutter]

Comparisons between model and DPR using Contoured Frequency with Altitude Diagrams (CFADs)
CFADs: > 15dBZ

KuPR (Simulation) KuPR after QC (Observation) KuPR (Observation)

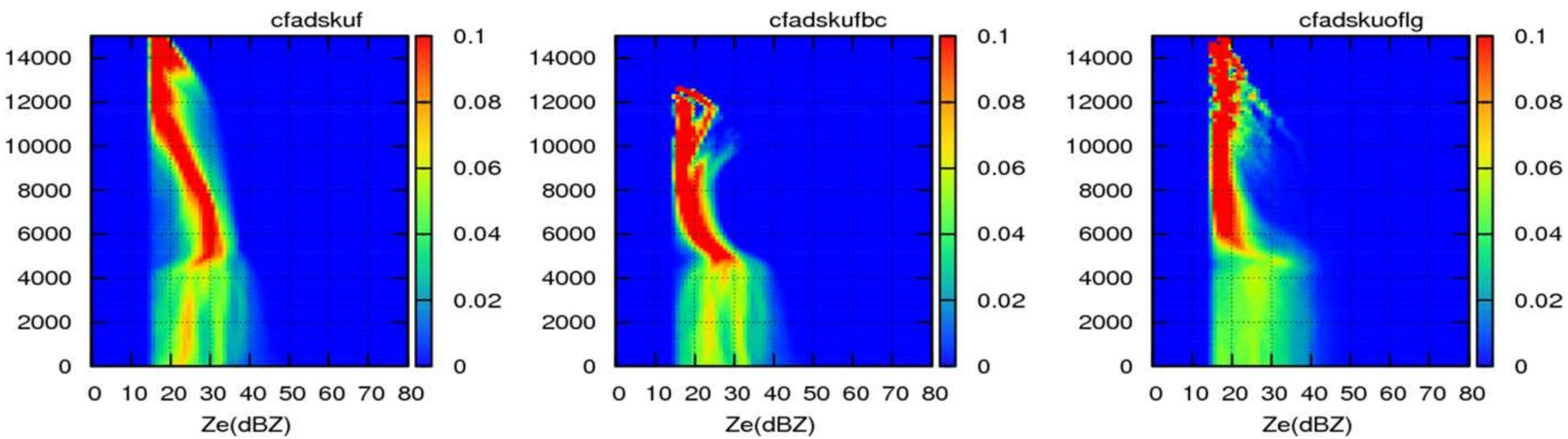


Removed noise using clutter-flag and precipitation-flag

Quality Control and Bias Correction

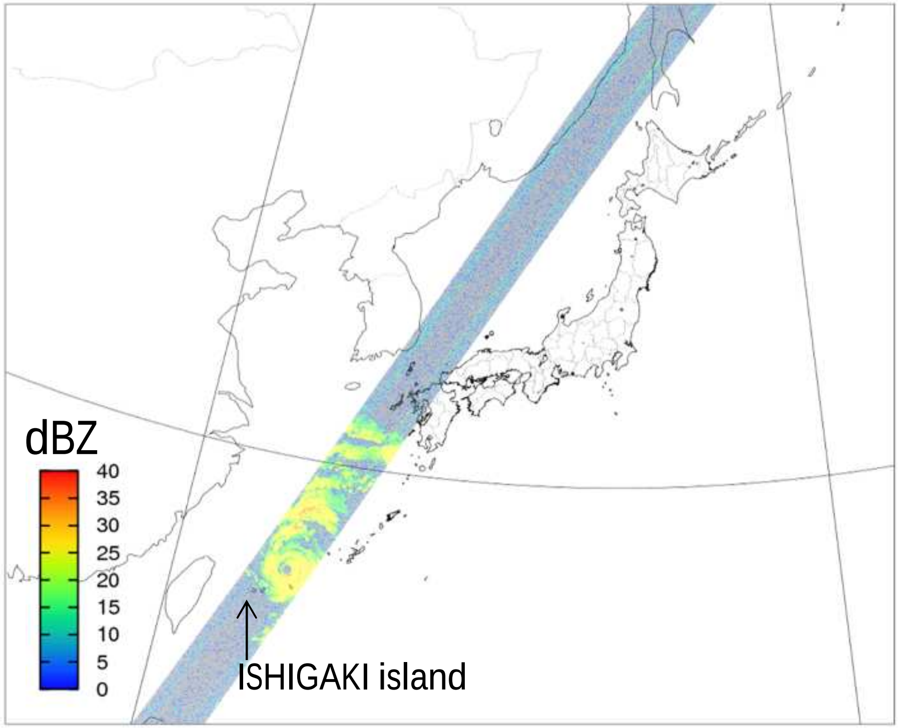
- Removal of clutter is very important.
  - flagEcho (by JAXA) can be removed noise almost of all.
- Small noise handling
  - Threshold is defined 15 dBZ.
- Bias of simulated reflectivity handling
  - Bias is removed little by adaptive bias correction.
  - Ice-phase data cannot be assimilated because weak rain (< 1 mm/3h) forecast become negative bias.

KuPR simulation | KuPR simulation after BC | KuPR observaion after QC

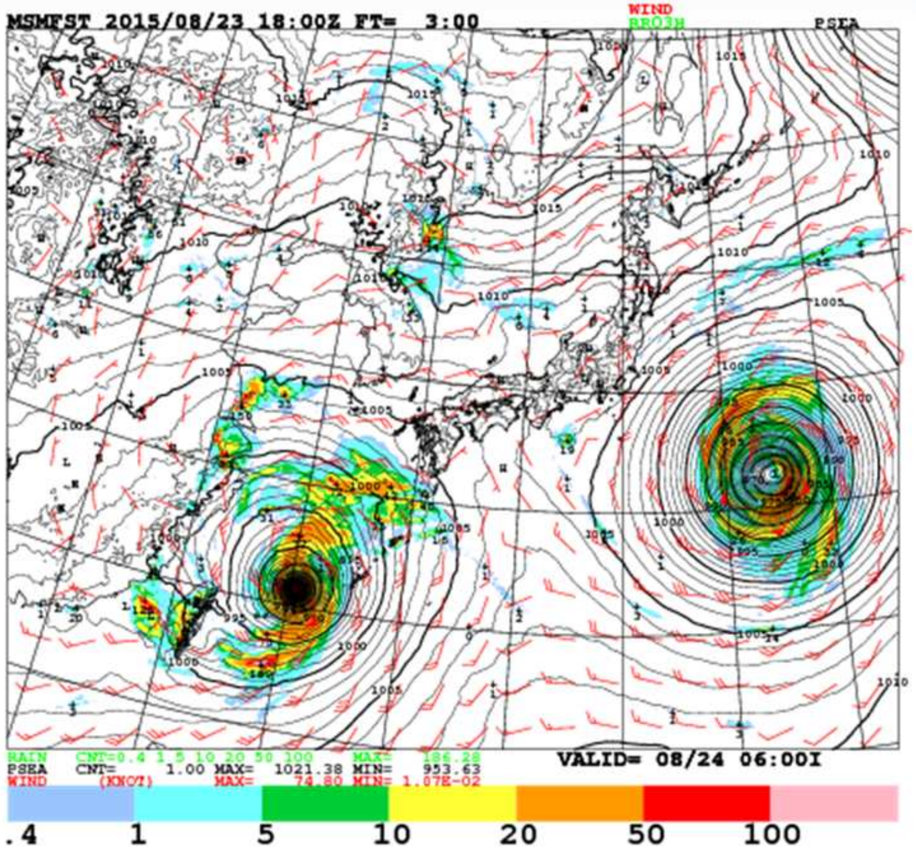


Case study of DPR assimilation

GPM/DPR KuPR



First Guess of MSM



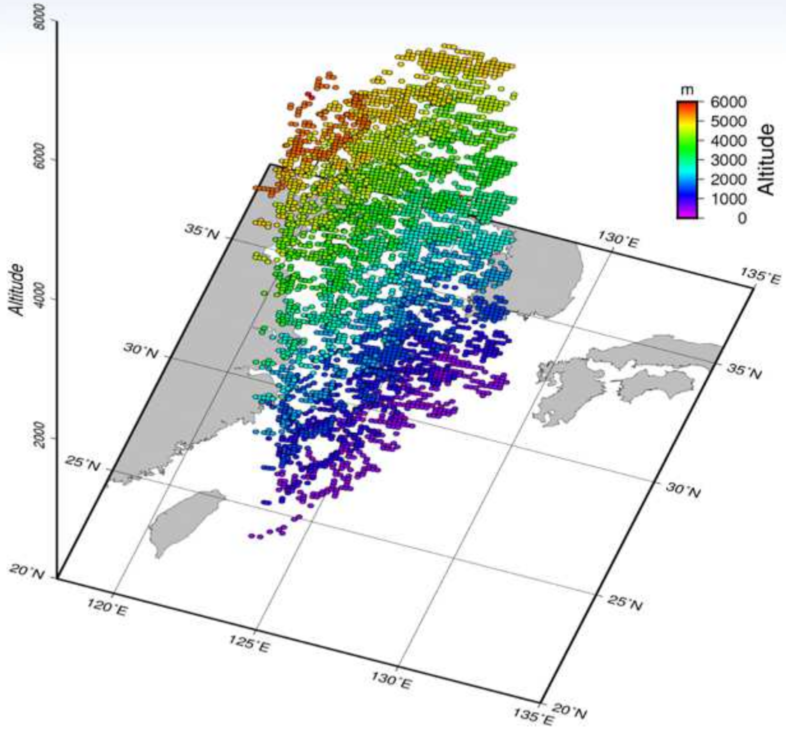
Typhoon No.15 Goni

Lowest central pressure is 930 hPa.

Maximum instantaneous wind speed 71.0 m/s was observed on ISHIGAKI island.

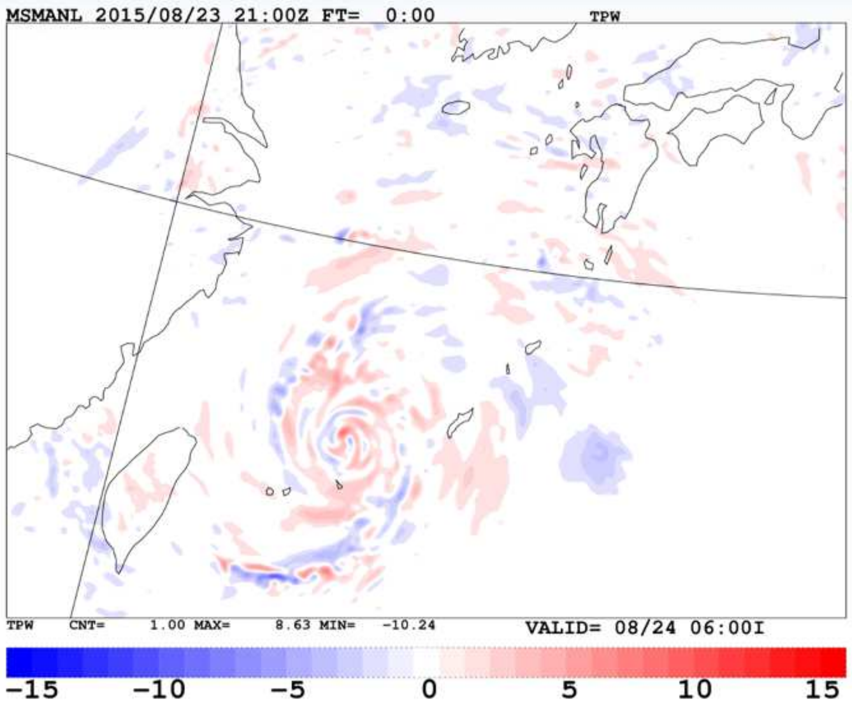
Case study of DPR assimilation

Assimilated retrieved RH



Retrieved RH from KuPR and KaPR.
Only liquid phase data is used, because the ice phase reflectivity has model bias.
We can assimilate 3-dimensional atmospheric information about moisture !

Impact of DPR assimilation on initial time



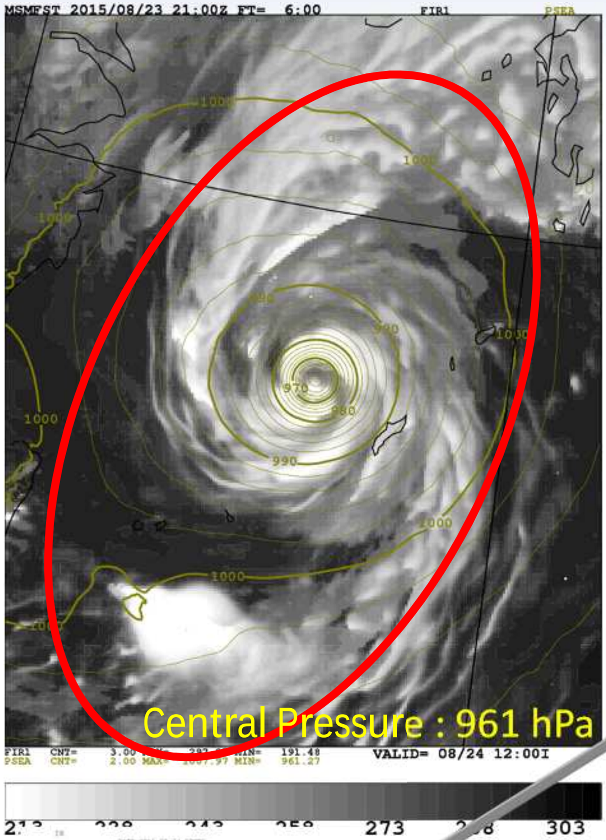
Dry up Humidify

Difference of TPW increment between EXP w/o DPR and EXP w/ DPR.

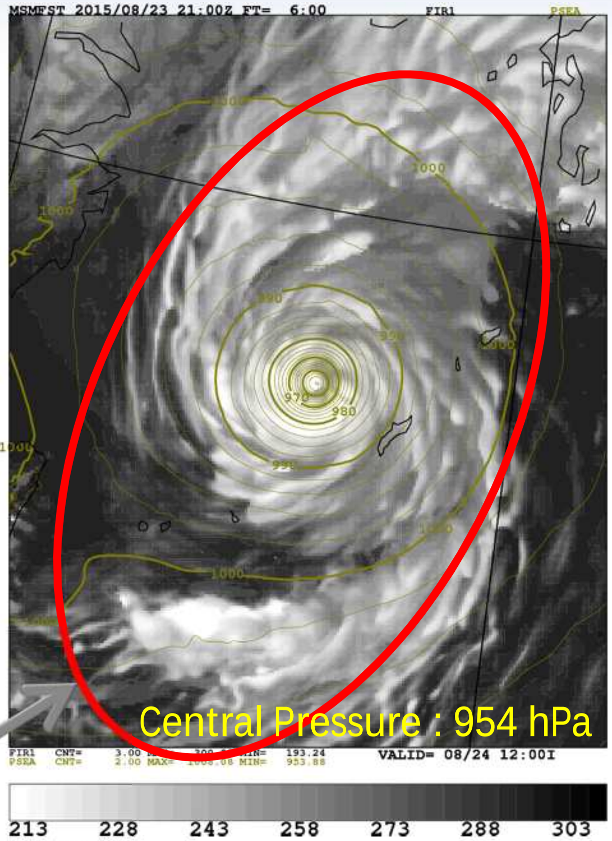
Impact of GPM/DPR assimilation

Forecast time 6-hour

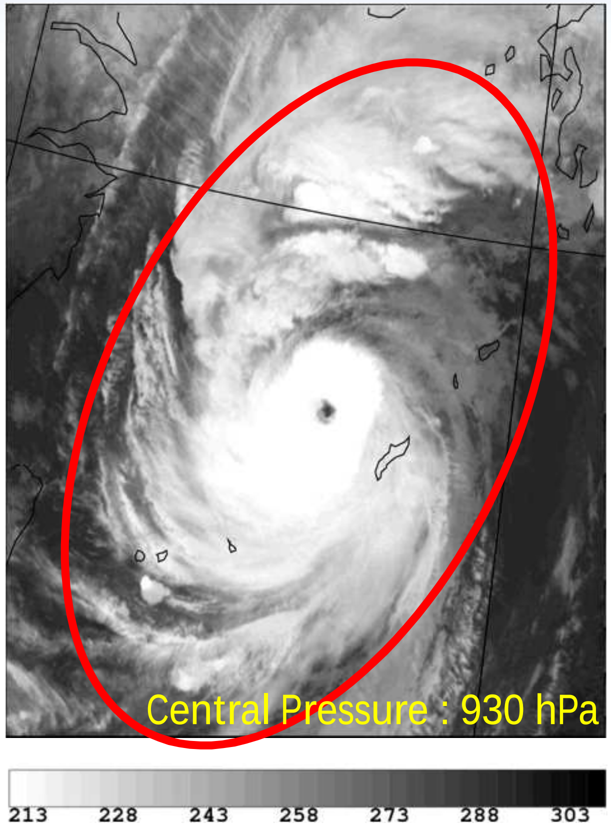
Exp. without GPM/DPR
IR1 Simulation

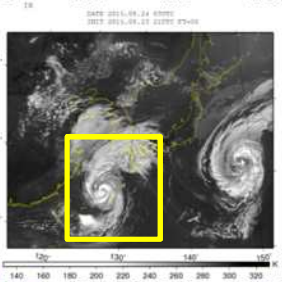


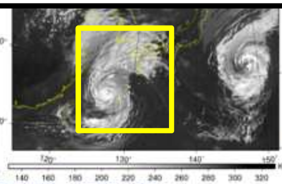
Exp. with GPM/DPR
IR1 Simulation

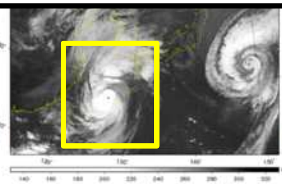


Observation(Himawari-8)









GPM/DPR assimilation reproduce meso-scale convective phenomena.

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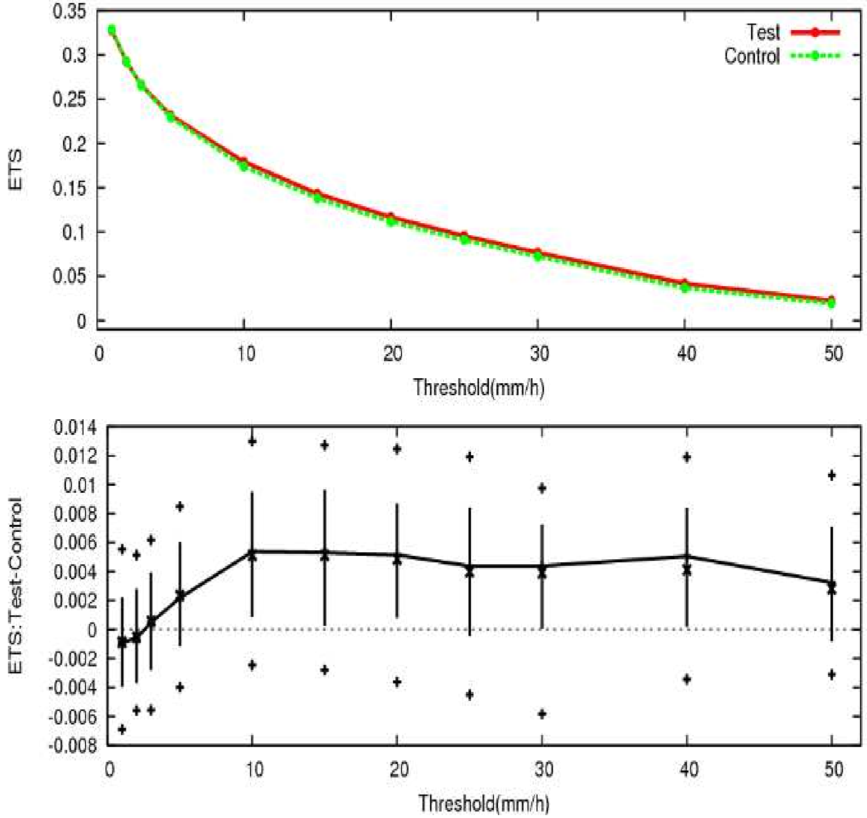
Performance evaluation test

- Meso-scale NWP system
  - Control experiment: with DPR
  - Test experiment: without DPR
    - In both experiments, GMI is not assimilated.

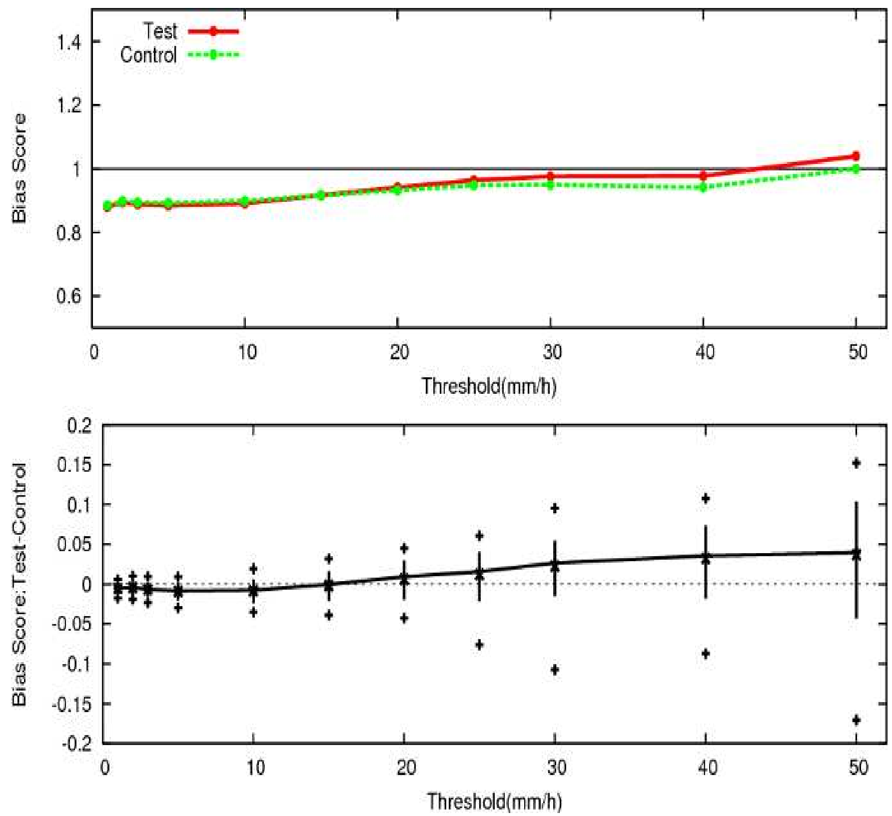
- Experiment periods
  - SUMMER: 7 AUG 2015〜11 Sep 2015
  - WINTER: 10 DEC 2014 〜 14 DEC 2015

Equitable Threat Score and Bias Score

Equitable Threat Score



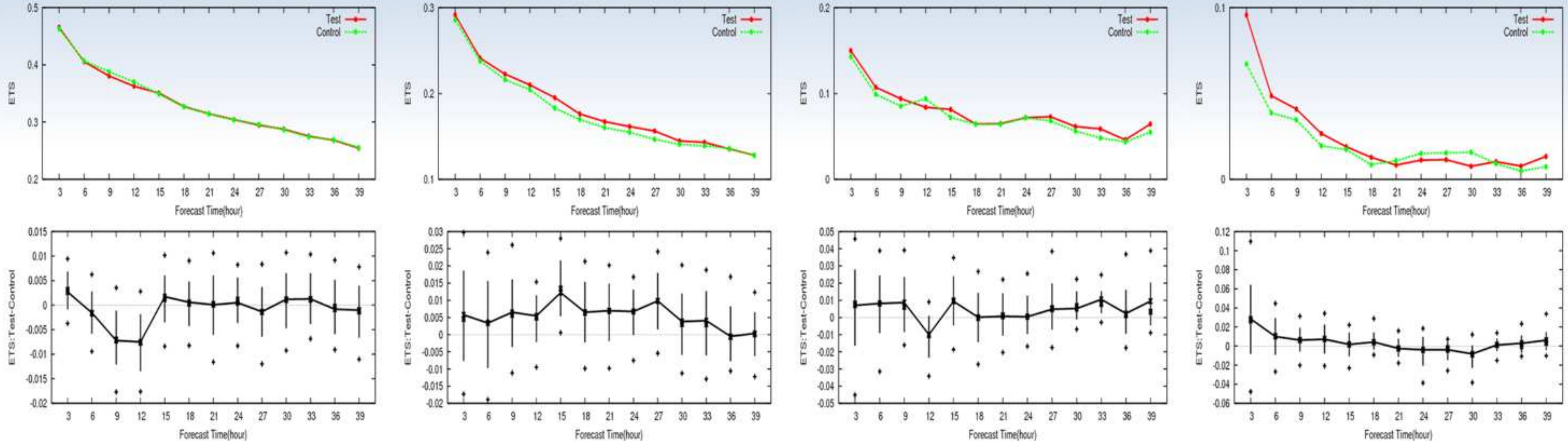
Bias Score



Error bar: 95% confidence interval by block-bootstrap sampling (Wilks 1997)

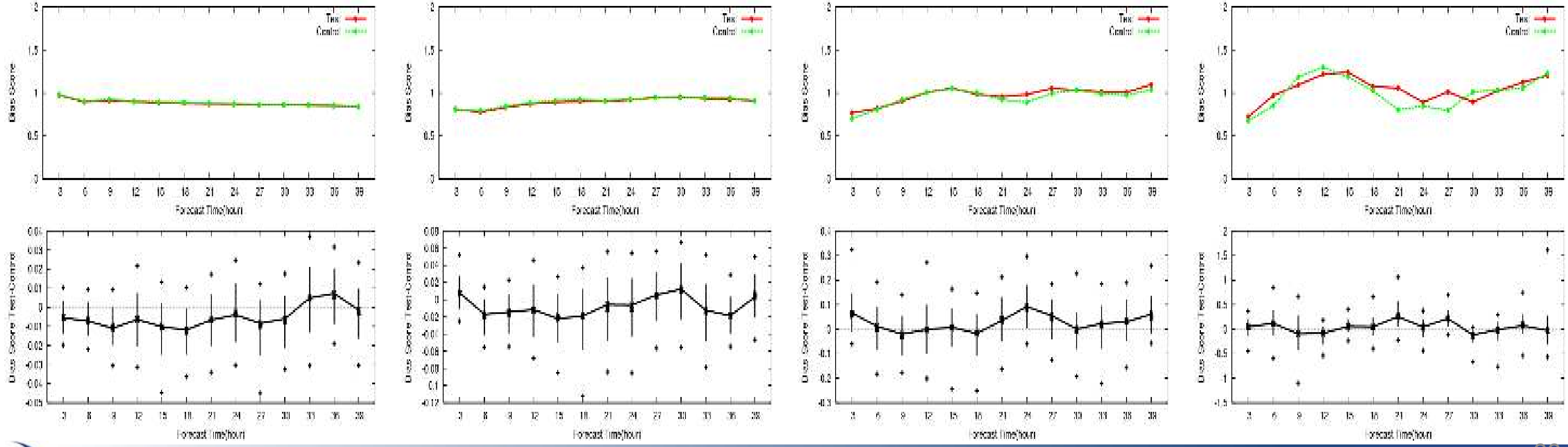
Equitable Threat Score

1mm/3h | 10mm/3h | 30mm/3h | 50mm/3h

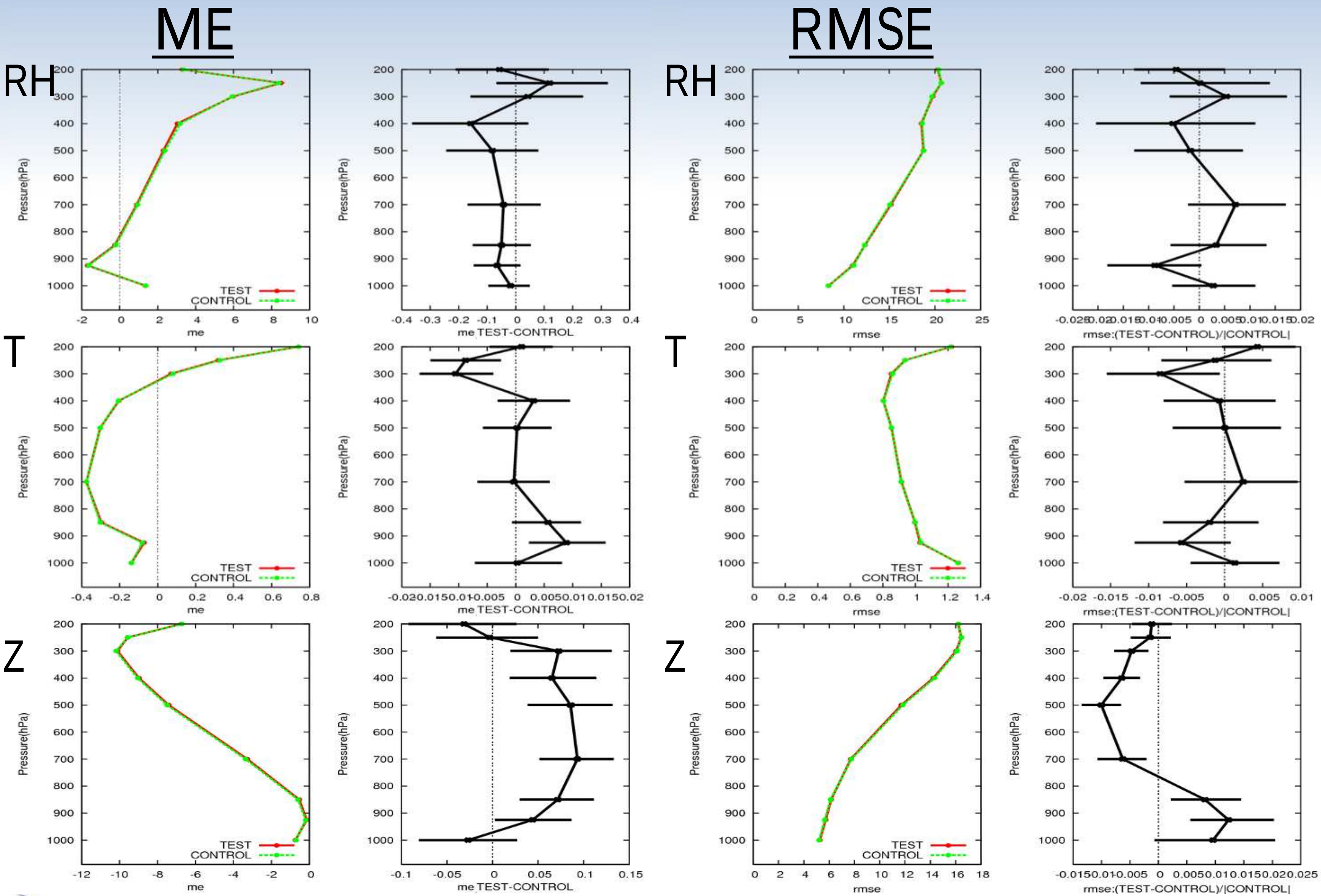


Bias Score

1mm/3h | 10mm/3h | 30mm/3h | 50mm/3h

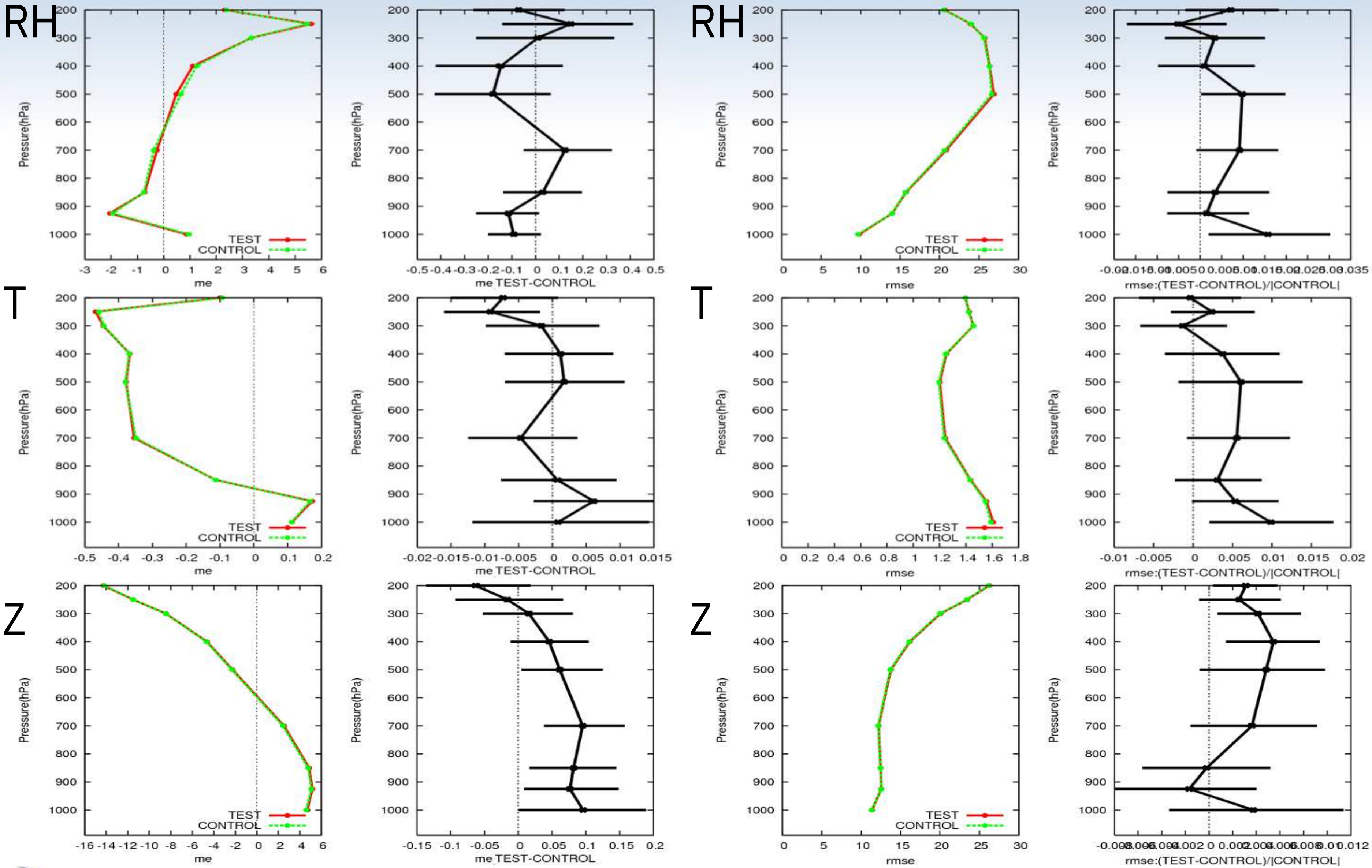


Sonde verification, Lead time: 0-hour



Sonde verification, Lead time: 39-hour

ME RMSE



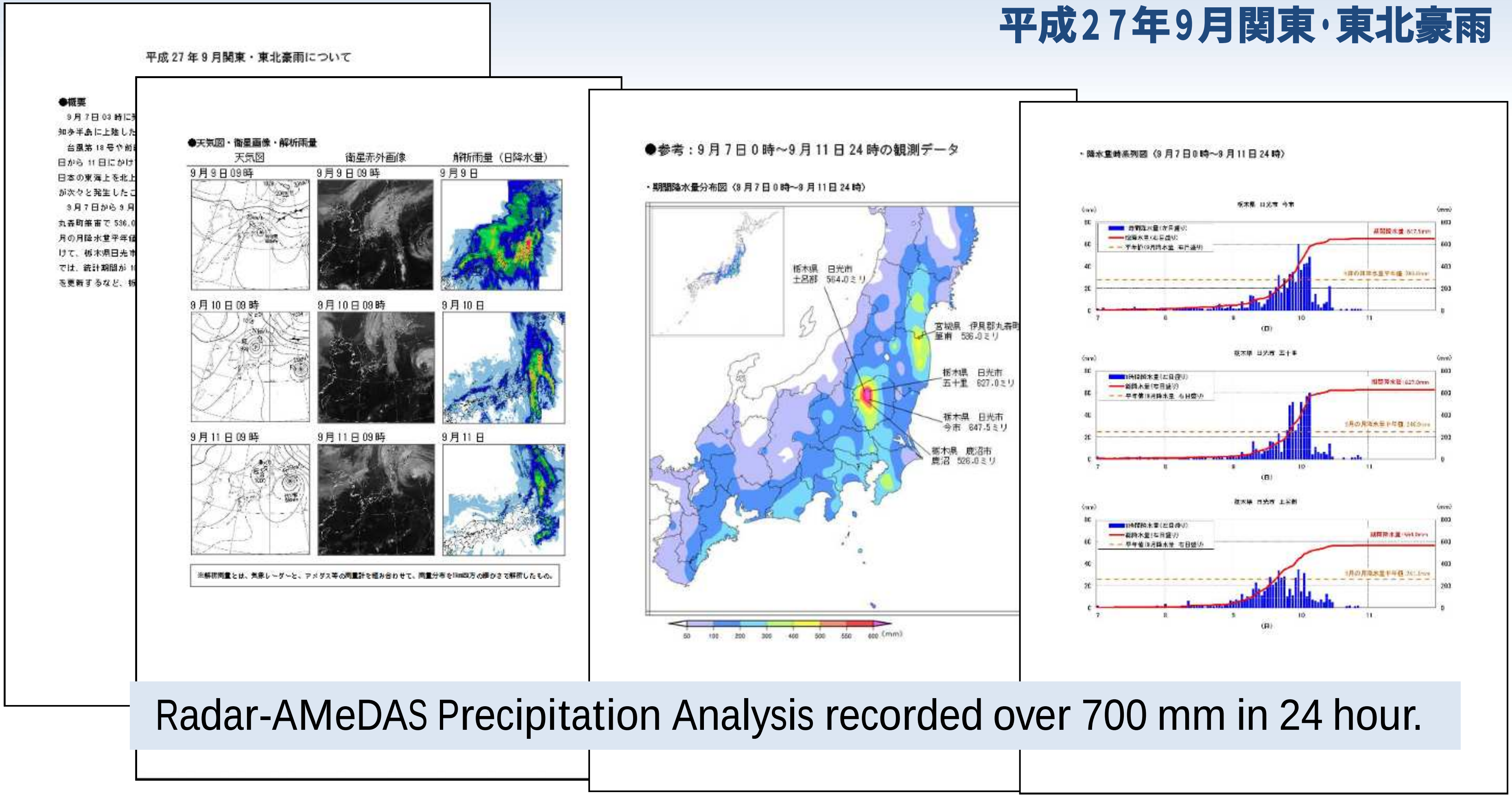
気象庁 Japan Meteorological Agency

Verification results

- Summer experiment
  - Precipitation
    - ETS over the threshold 10mm/3h is significant improved.
  - Sonde
    - ME of T, Z, RH are improved in initial time.
- Winter experiment
  - Very small impact of DPR
    - Ice phase data are not used.

Case of Heavy rainfall

平成27年9月関東･東北豪雨

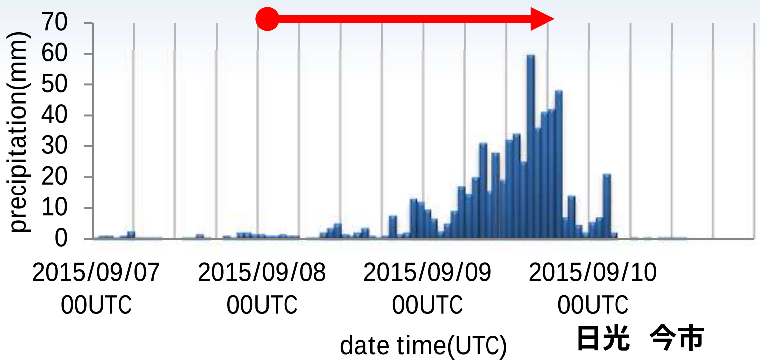


Radar-AMeDAS Precipitation Analysis recorded over 700 mm in 24 hour.

JMA HP: http://www.jma.go.jp/jma/press/1509/18f/20150918_gouumeimei.html

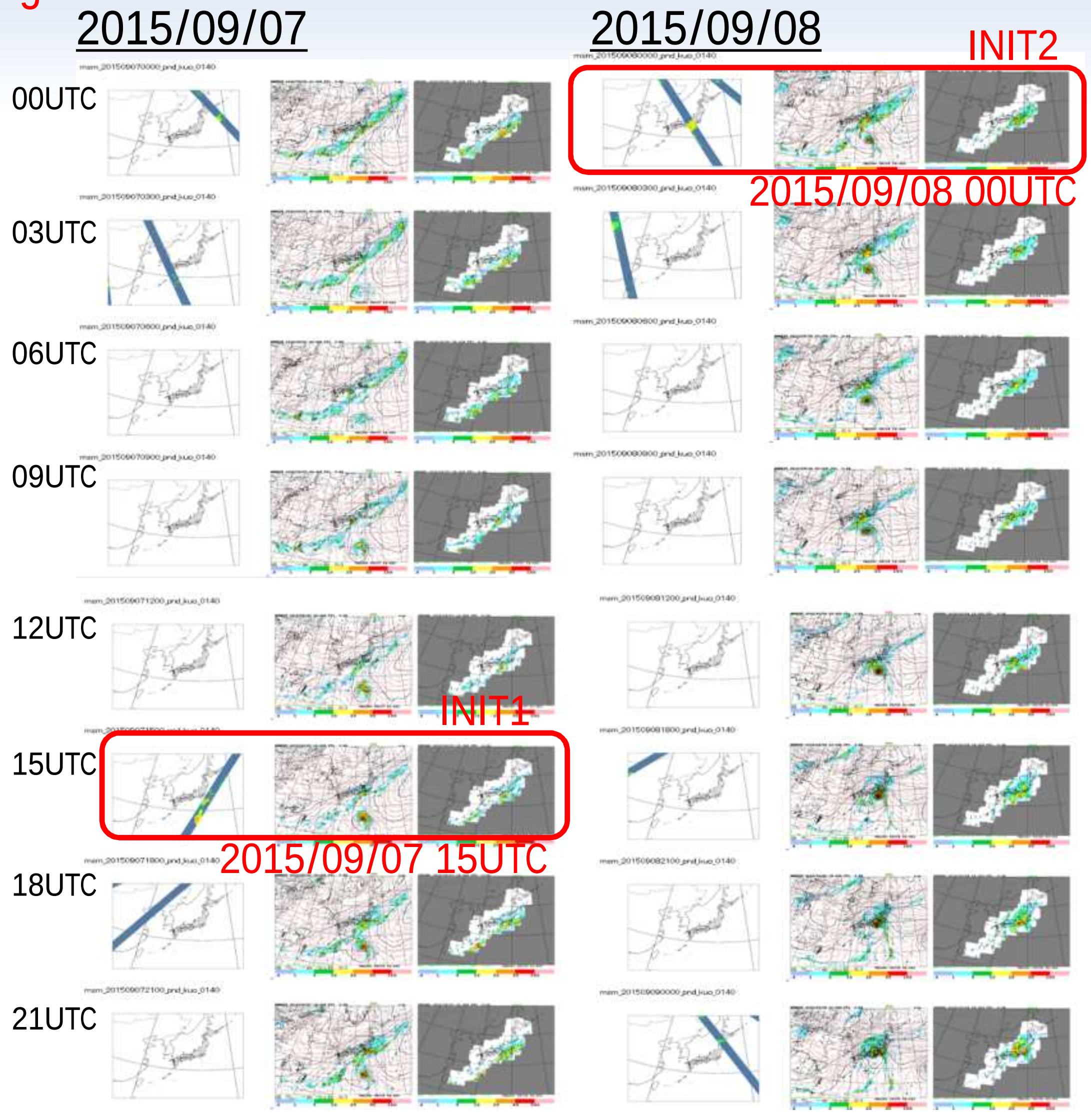
Case of Heavy rainfall

Init:2015/09/08 00UTC MSM forecast range



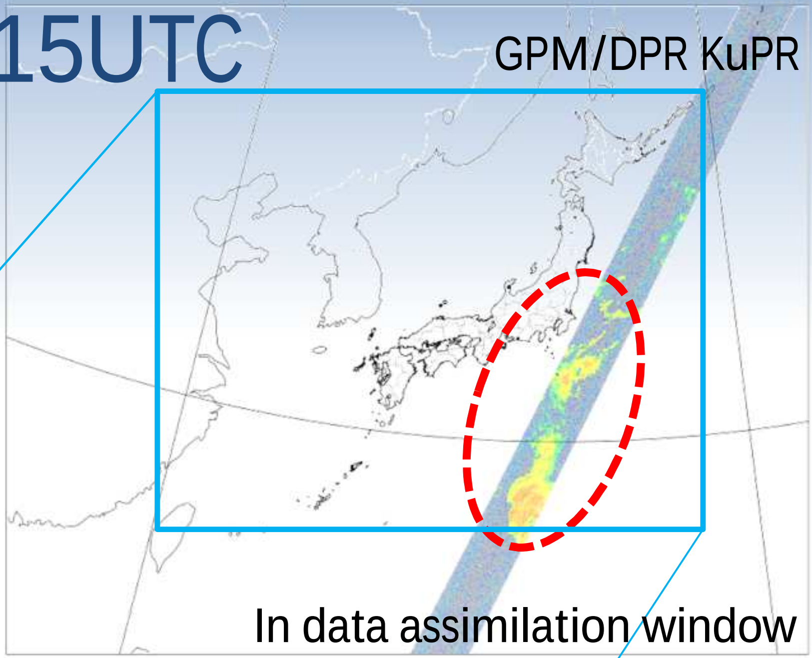
Effect of DPR observation assimilation in to this initial time is carried over by the analysis-forecast cycle.
DPR observation that could contribute to the improvement of heavy rain case, be assimilated in the following initial time.

- INIT1: 2015/09/07 15UTC
- INIT2: 2015/09/08 00UTC

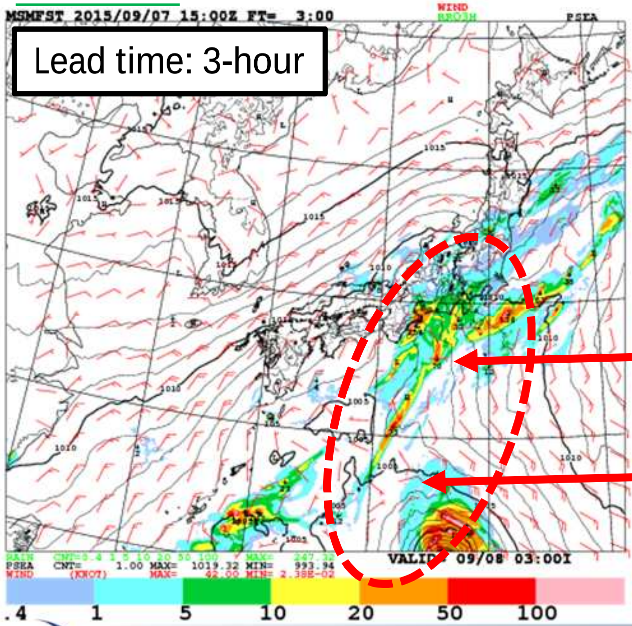


Case 1 INIT1: 2015-09-07 15UTC

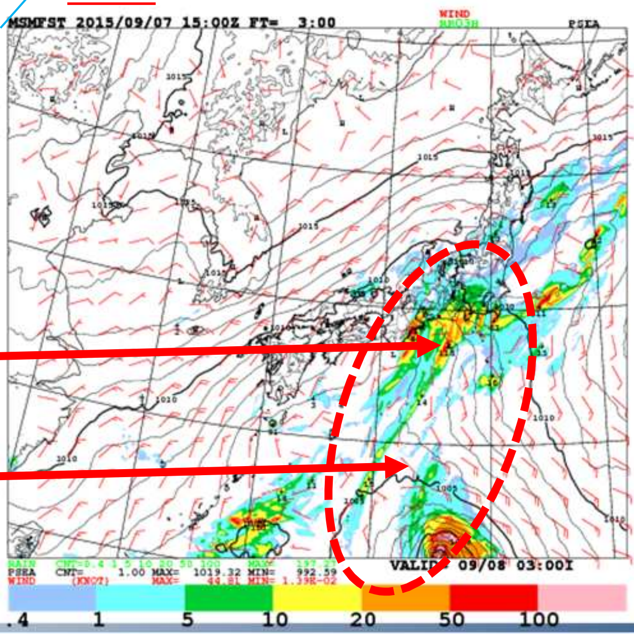
Impact on the rainfall in the south of the sea in the Kanto and Typhoon No. 18. This effect will be taken over to subsequent analysis .



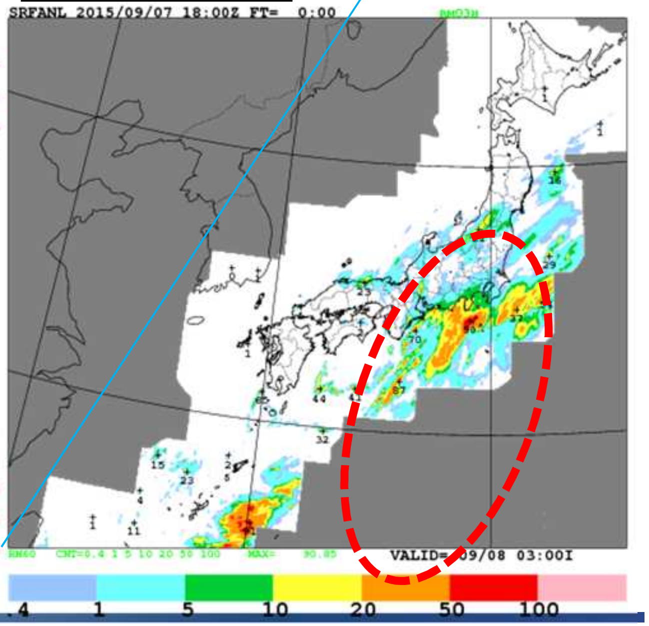
Control



Test

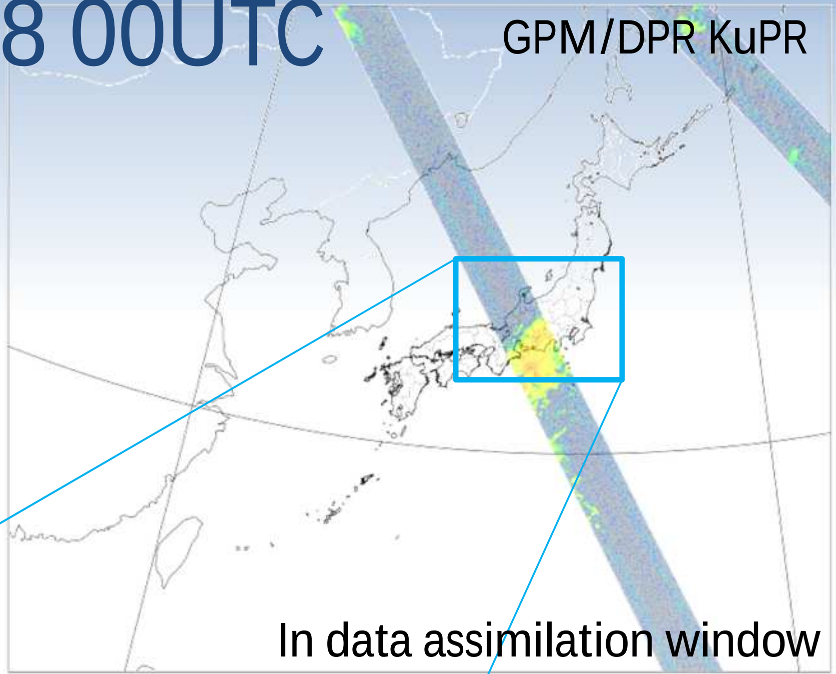


Observation

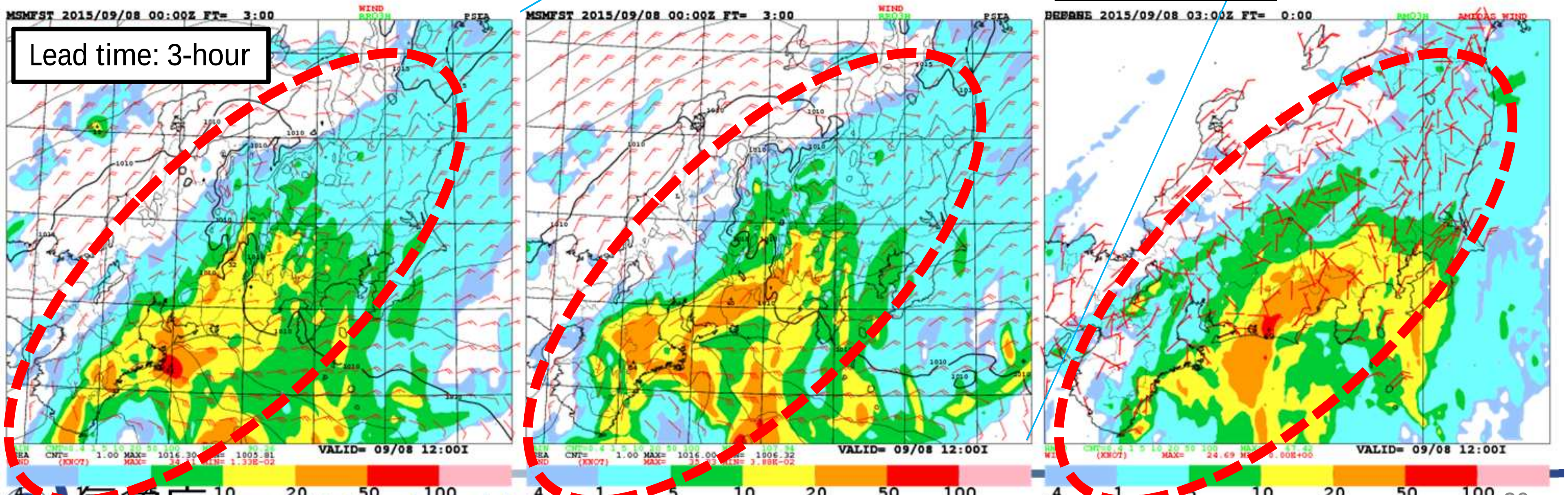


Case 2 INIT2: 2015-09-08 00UTC lead time: 3-hour

Improvement of precipitation forecast on the DPR path.

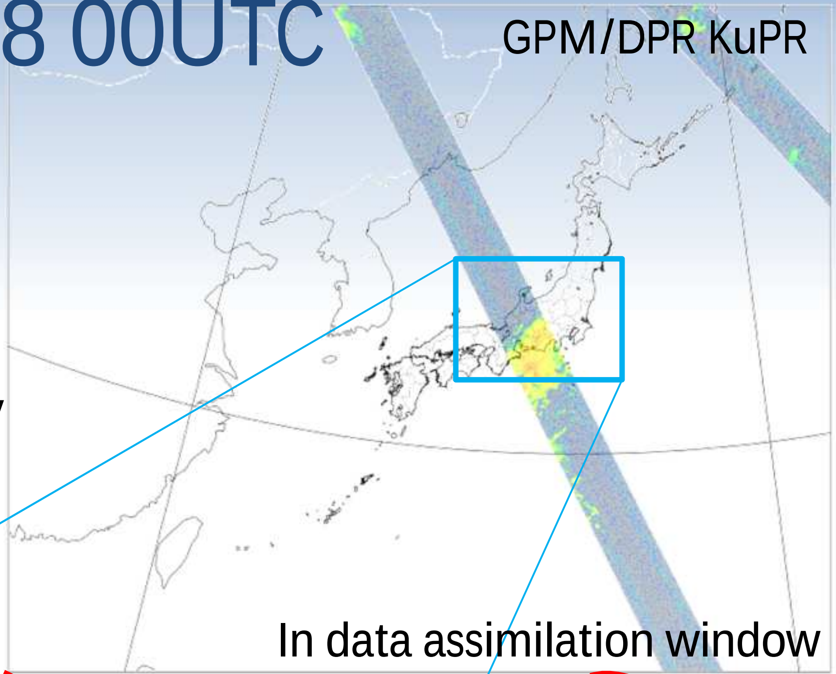


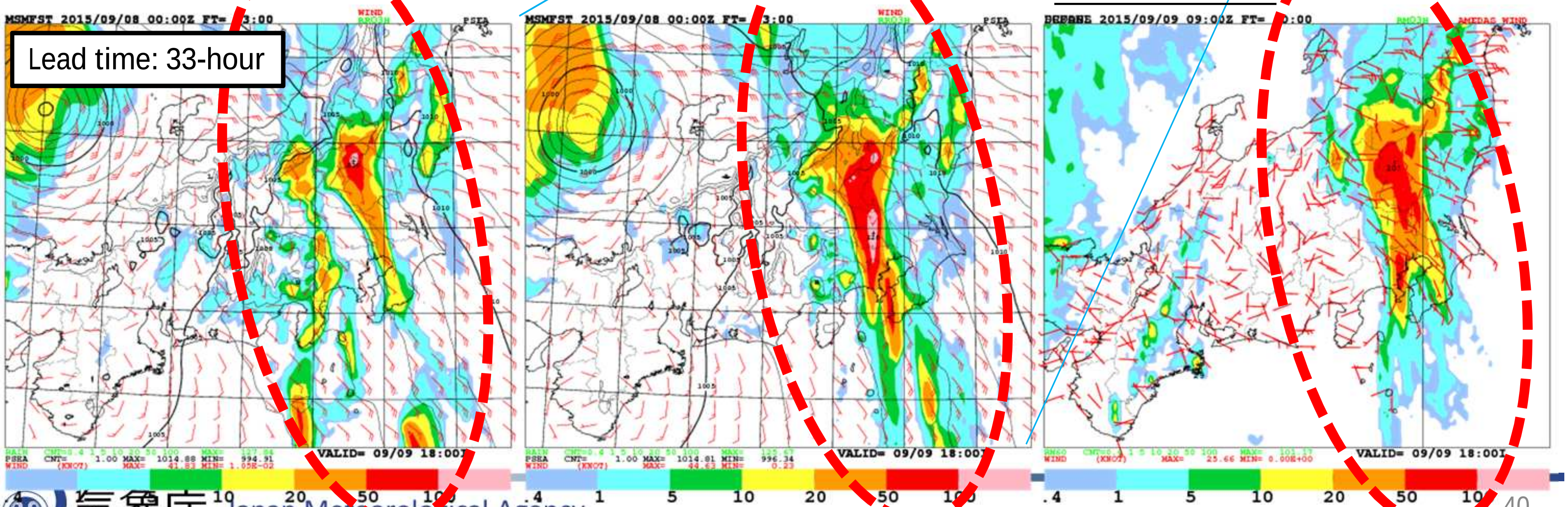
Control　　Test　　Observation



Case 2 INIT2: 2015-09-08 00UTC lead time: 33-hour

The effect of past assimilation has been taken over in the analysis forecast cycle.
→ Water vapor in south of Japan has already improved by past analysis(INIT1). Then, in lead time 33h, reproducibility of precipitation is improved also.





OUTLINE

1. Introduction
2. Operational NWP system at JMA
3. DPR data assimilation
    - Radar simulator
    - 1D+4DVAR
        - Relative humidity estimation
    - Quality control
4. Performance evaluation
5. Summary

Summary

- Operational assimilation of GPM/DPR started in March 2016 at JMA.
- Benefit of GPM/DPR data assimilation
  - 3-D information of GPM/DPR is valuable and important data to make initial condition of the meso-scale model.
  - GPM/DPR assimilation improved the forecast of meso-scale convection around Typhoon.
- GPM data will be indispensable data in JMA NWP system.

Next step of DPR assimilation

Indirect assimilation

using retrieved RH profiles
in traditional 4DVAR

Direct assimilation

using reflectivity (KuPR, KaPR) profiles
in new Hybrid-4DVAR


THANK YOU FOR YOUR ATTENTION