Operational status and recent developments on cloud and precipitation assimilation at JMA

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Outline

- JMA NWP models and DA system
- Precipitation assimilation in MSM
- Radiance assimilation in GSM

- Development of all-sky MW radiance assimilation for the global DA system
- Early study for cloudy IR radiance assimilation with 1D-Var method

- Summary and Recommendations

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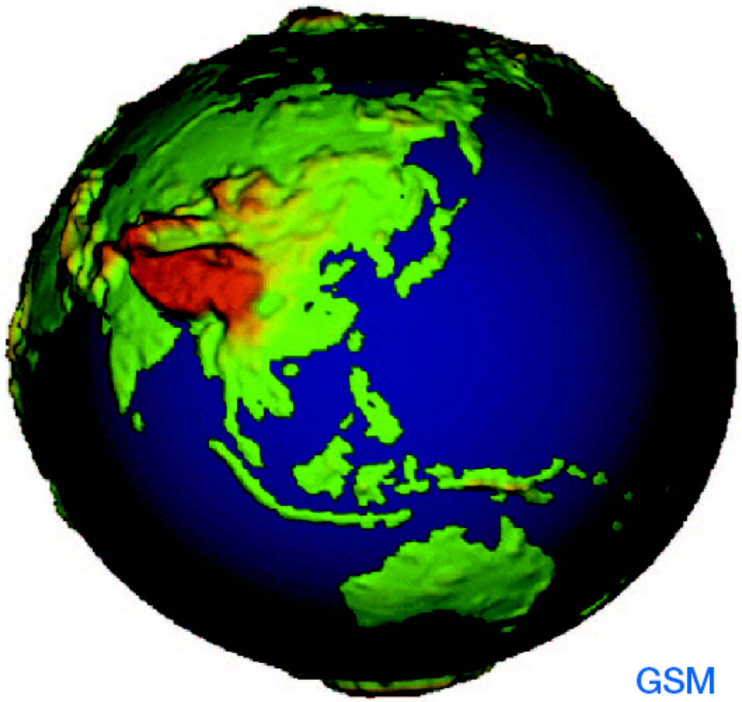
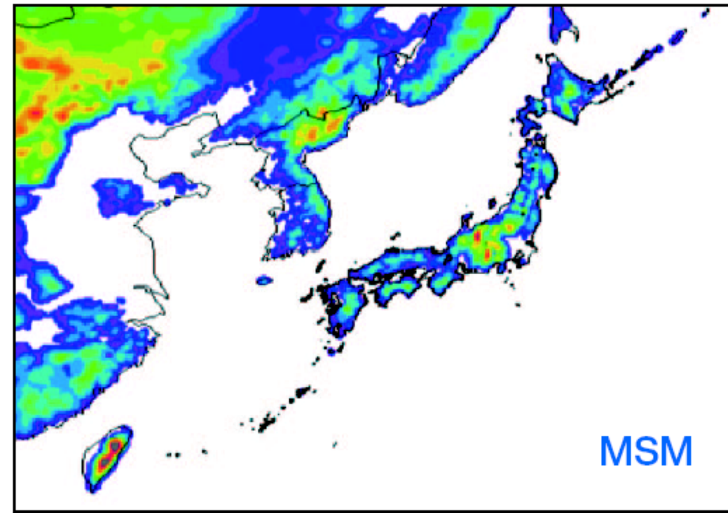
JMA NWP models



GSM



	Global Model (GSM)	Meso Scale Model (MSM)
Purposes	Short- and medium-range forecast	Very-short-range forecast
Forecast domain	Globe	Japan and its surrounding areas
Grid size and/or number of grids	0.1875 deg. (TL959)	5 km / 721 x 577
Vertical levels / Top	60 / 0.1 hPa	50 / 21,800 m
Forecast hours (Initial time)	84 hours (00, 06, 18 UTC) 216 hours (12 UTC)	15 hours (00, 06, 12, 18 UTC) 33 hours (03, 09, 15, 21 UTC)
Analysis	4D-Var	4D-Var

DA system

- Incremental 4D-Var for GSM and MSM
  - G: Outer TL959L60, Inner T159L60
  - M: Outer horizontal reso. 5km, Inner 15km, non-hydrostatic model based 4D-Var
  - Assimilation time window (G: 6-hour, M: 3-hour)
- Clouds and large-scale precipitation
  - G: Prognostic cloud water content, Smith (1990), Sommeria and Deardorff(1977), Sundqvist (1978)
  - M: 6categories bulk cloud microphysics (Inner: large scale condensation only)
- Cumulus convection
  - G: Prognostic Arakawa-Schubert scheme(1974)
  - M: Kain-Fritsch Scheme (N/A for adjoint model)

Observation type	Instrument	Global DA system	Meso Scale DA system
Conventional data	Surface Observations	Surface Pressure	Surface Pressure
	AMeDAS(Automated Meteorological Data Acquisition System)		Rain (Analyzed Rain)
	Ship, Buoy	Surface Pressure	Surface Pressure
	RAOB	Wind,Pressure,Temperature,Relative Humidity	Wind,Pressure,Temperature,Relative Humidity
	Aircraft	Wind, Temperature	Wind, Temperature
Groud based remote sensing	Wind profiler	Wind	Wind
	Radar		Radar reflectivity (Analyzed Rain), Doppler velocity
	GPS		Total Precipitable Water
Satellite	VIS IR radiometer	AMV, Radiance (clear sky)	AMV
	IR MW Sounder	Radiance (clear sky)	Radiance(Temperature)
	MW Imager	Radiance (clear sky)	Radiance(TPW and Rain Rate)
	Scattrometer	Surface Wind	Surface Wind
	GPS-RO	Refractivity	

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Operational Precipitation assimilation in MSM

Fig. 1. The forecast domain of JMA Meso-Scale Model. The radar-AMeDAS precipitation analysis data are available within the gray area.

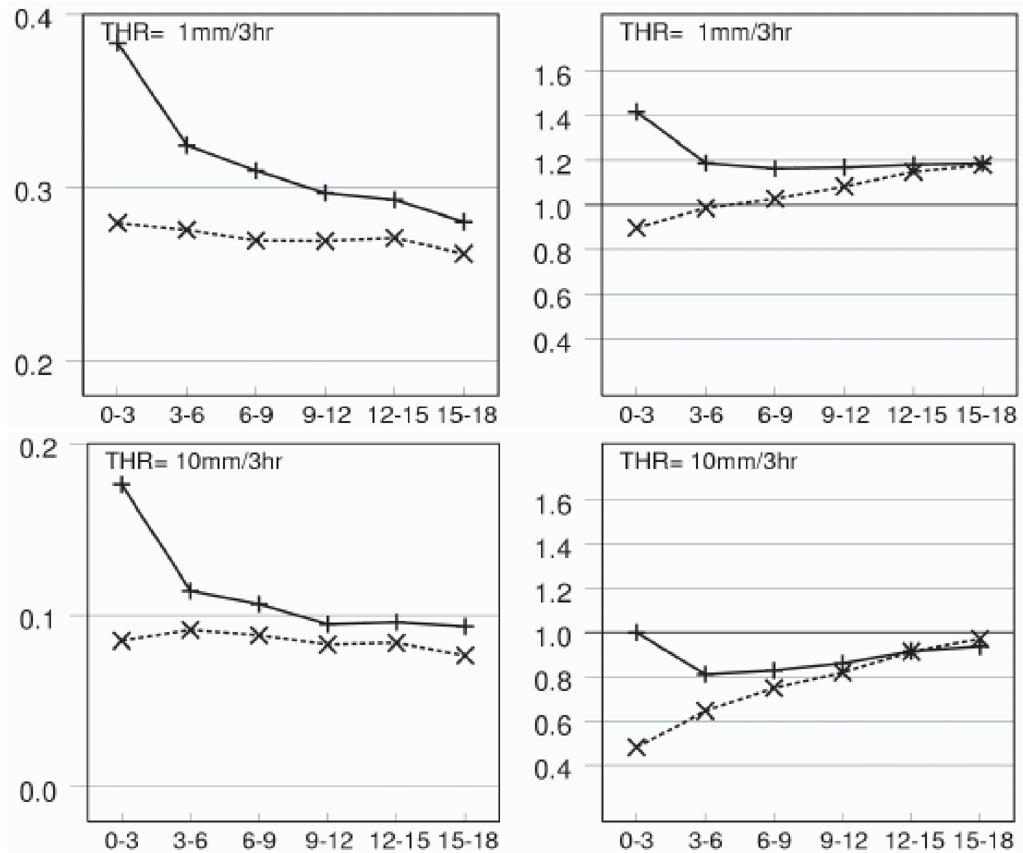
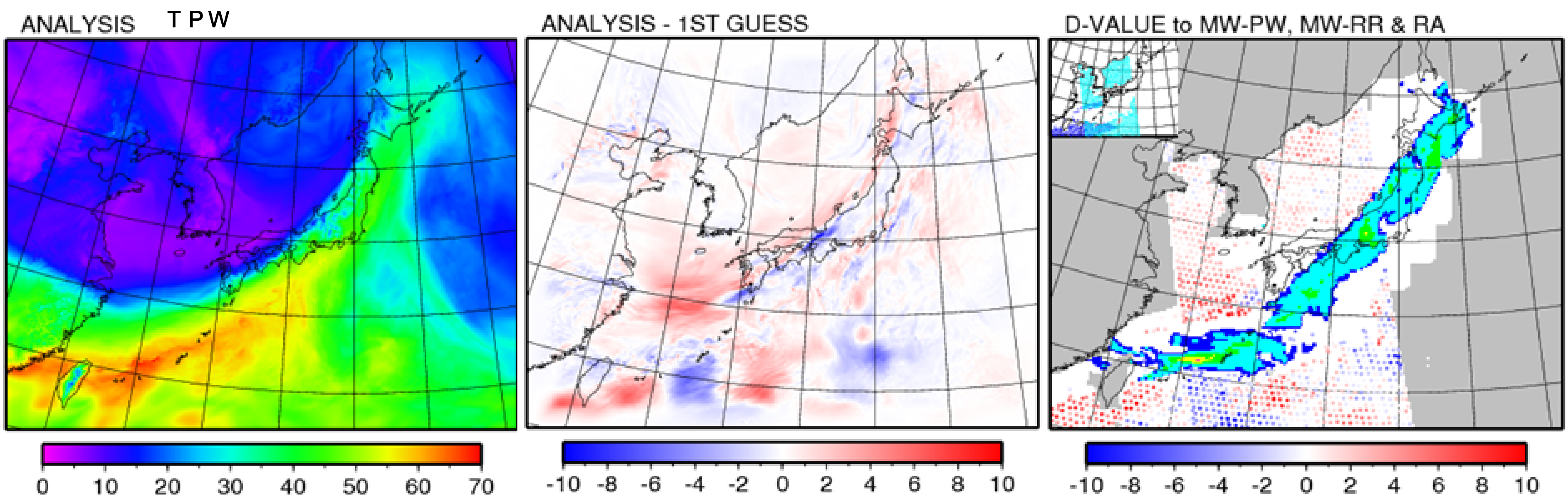


Fig. 4. Threat scores (left) and bias scores (right) for 3-hour precipitation forecast starting from analysis with precipitation assimilation (solid line) and without one (dashed line). The threshold value is 1 mm per 3 hour (top) and 10 mm per 3 hour (bottom).

In 2002, JMA started direct assimilation of precipitation in Meso-scale 4D-Var data assimilation system operationally.

Operational Precipitation assimilation in MSM

- Total Precipitable Water (TPW) derived from MW-Imager, Rain Rate(RR) derived from ground based Radar and MW imager have been assimilated in MSM 4D-Var.
- Conventional data (such as surface observation, RAOB, aircraft, AMVs and GPS-TPW) around Japan are assimilated.
- Assimilation of TPW and RR produces better rain precipitation. RR assimilation reduces the model spin-up in precipitation.



Impacts of TPW and RR assimilation

Analysis (TPW)

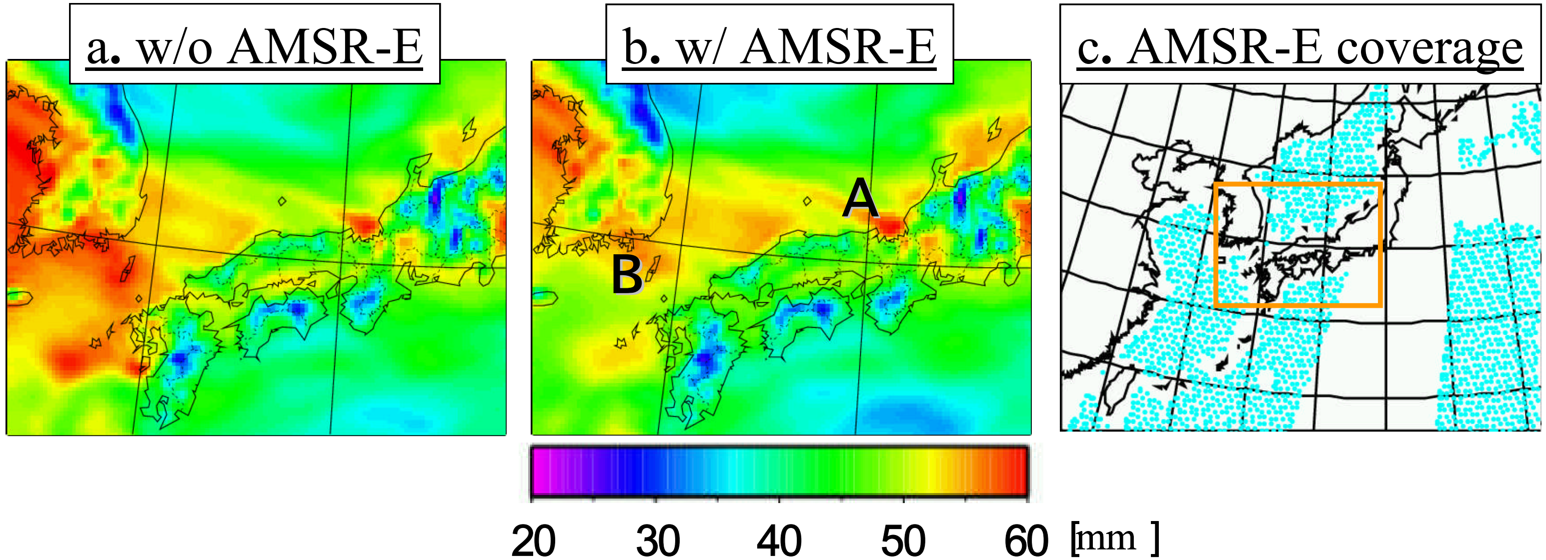


Fig. 1 (a) Analyzed TCPW field without the AMSR assimilation at 18UTC 17 July 2004. (b) Same as in (a) but with the AMSR-E assimilation. (c) The AMSR-E data coverage at the same time.

Forecast (Rainfall)

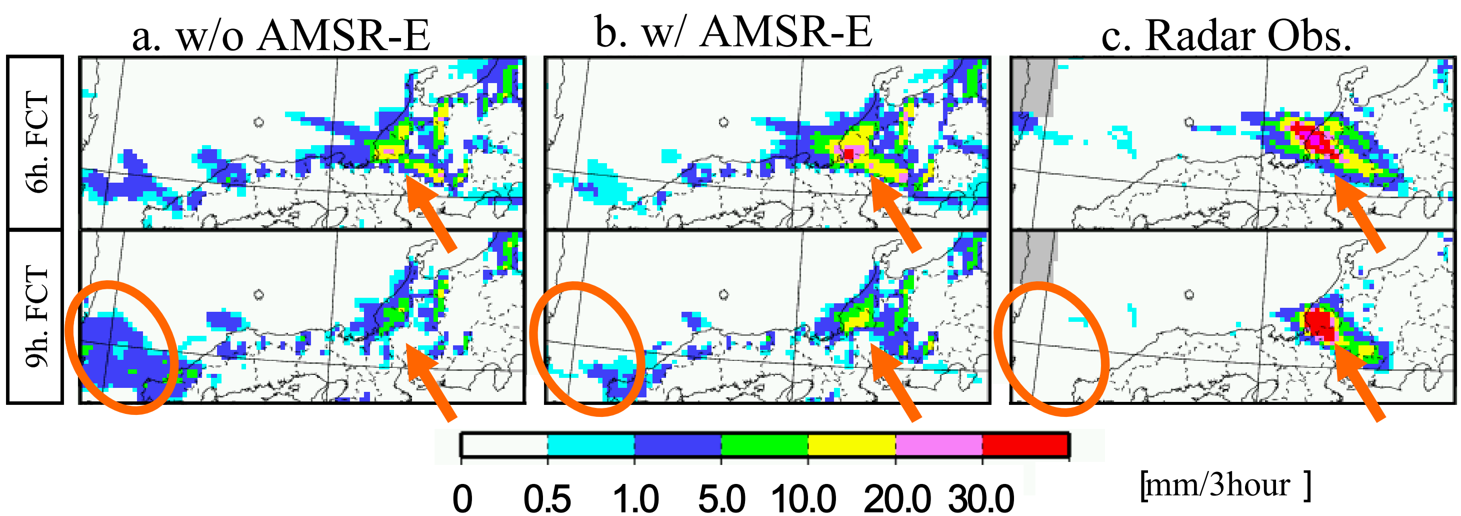
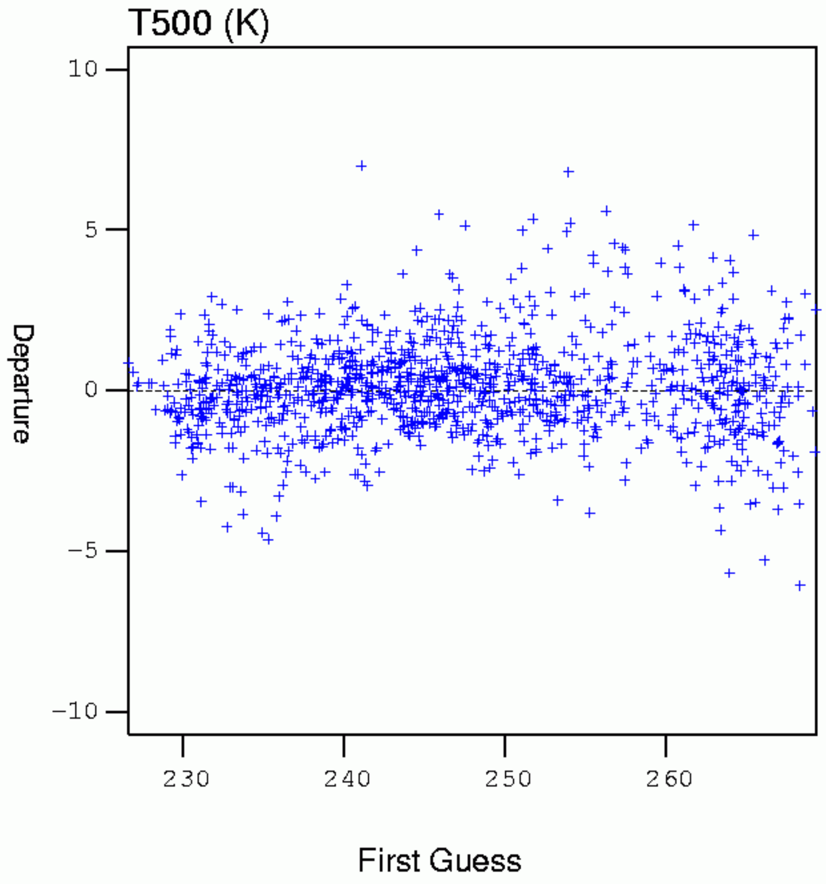


Fig. 2 (a) 3-hour rain forecasts after 6 hours (upper) and 9 hours (lower) from the initial condition of Fig.1 (a). (b). Same as in (a) but from the initial condition of Fig.1 (b). (c) 3-hour rain at 00UTC 18 July 2004 (upper) and 03UTC (lower) estimated by radar observation.

Precipitation assimilation in MSM

Scatter diagram of first-guess value and O-B departure



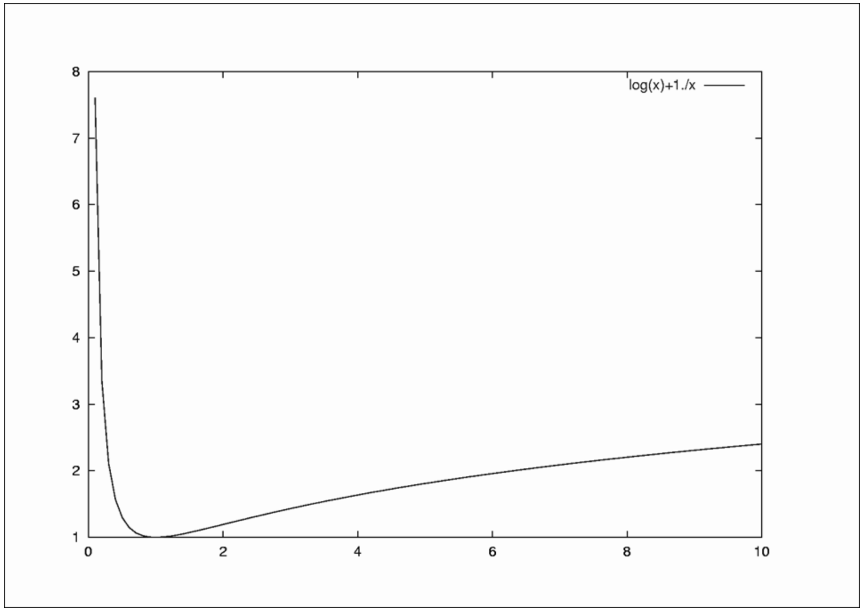
Precipitation departure is not Gaussian distribution and not symmetrically distributed around zero.

PDF of Precipitation

- PDF is assumed to follow the exponential distribution

$$P(y \mid x) = \frac{1}{\alpha}\exp(-\frac{y}{\alpha})$$

$$E(y) = \alpha \approx x$$



In this case,

$$J_{rain} = -\log P(y \mid x) = \log(x) + \frac{y}{x}$$

Taylor expansion

A devised cost function of precipitation observation

Quadratic form representation

$$J_{rain} \approx 1 + \log(y) + \frac{1}{2y^2}(x-y)^2 + O((x-y)^3)$$

That is, Obs. error $\approx y$ in Gaussian distribution approximation

Considering the asymmetricity around minimum point, following cost function is employed for precipitation amount

$$J_{rain} = \frac{1}{2\sigma^2}(x-y)^2 \qquad \sigma = \begin{cases} y & (x \le y) \\ 3y & (x > y) \end{cases}$$

Empirically determined the factor “3”

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Radiance assimilation in JMA Global DA system

(a) Departure is calculated by using High-reso. NL model.

(b),(c) High-res. NL field is interpolated to low-reso., and low-reso. NL model is performed to make trajectory.

(d) Low-reso. TL and AD model are used in minimization. No updates of background due to a computational limit.

(e) Obtained increment is added to high resolution background field.

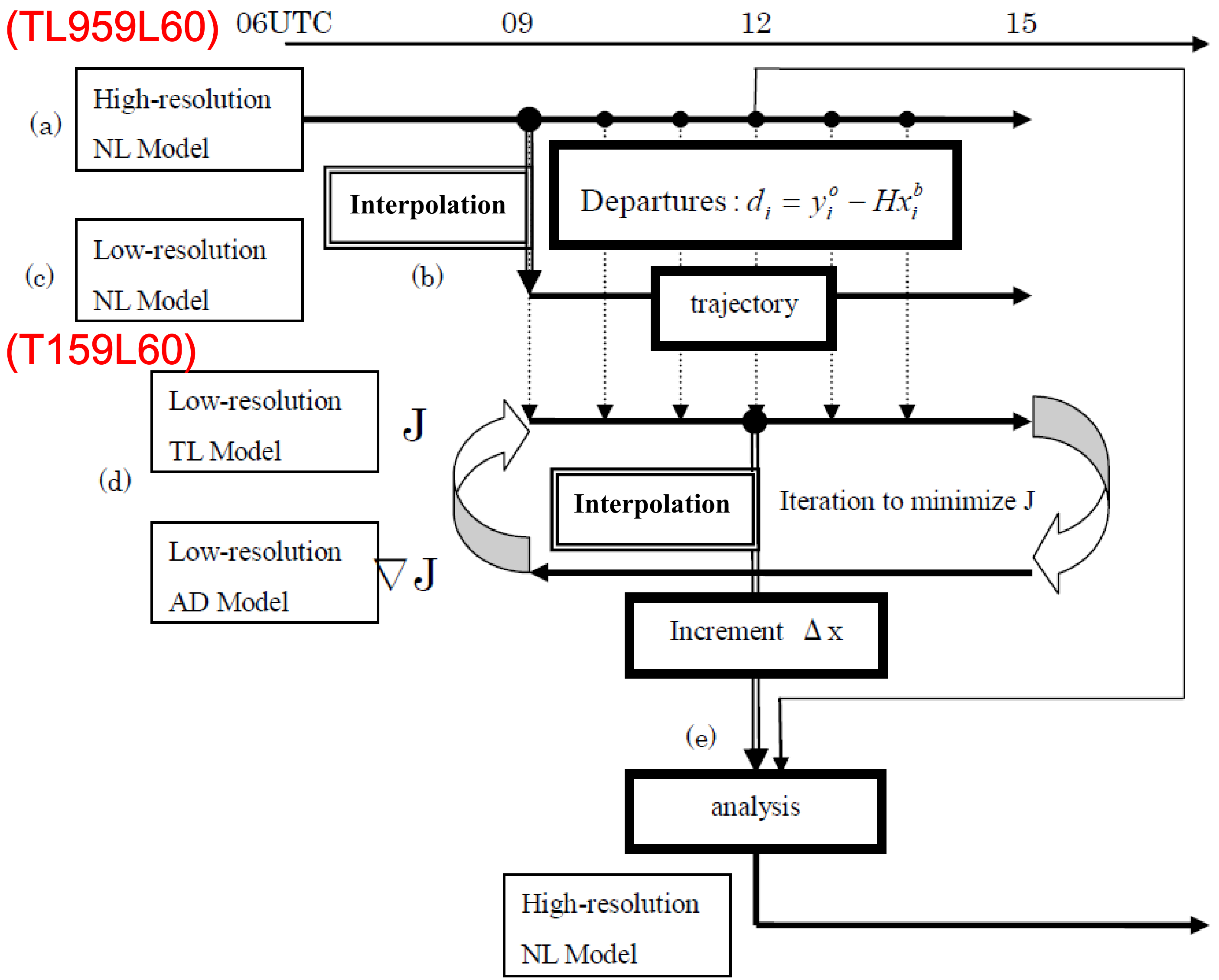


Fig. 3.5.2 Flow of 4D-Var procedure for the case of 12UTC analysis time

Radiance assimilation in JMA Global DA system

RTM: RTTOV-9.3 (rttov_k)

Data thinning: Equal distance thinning with grid box (200km for MW-Imagers)

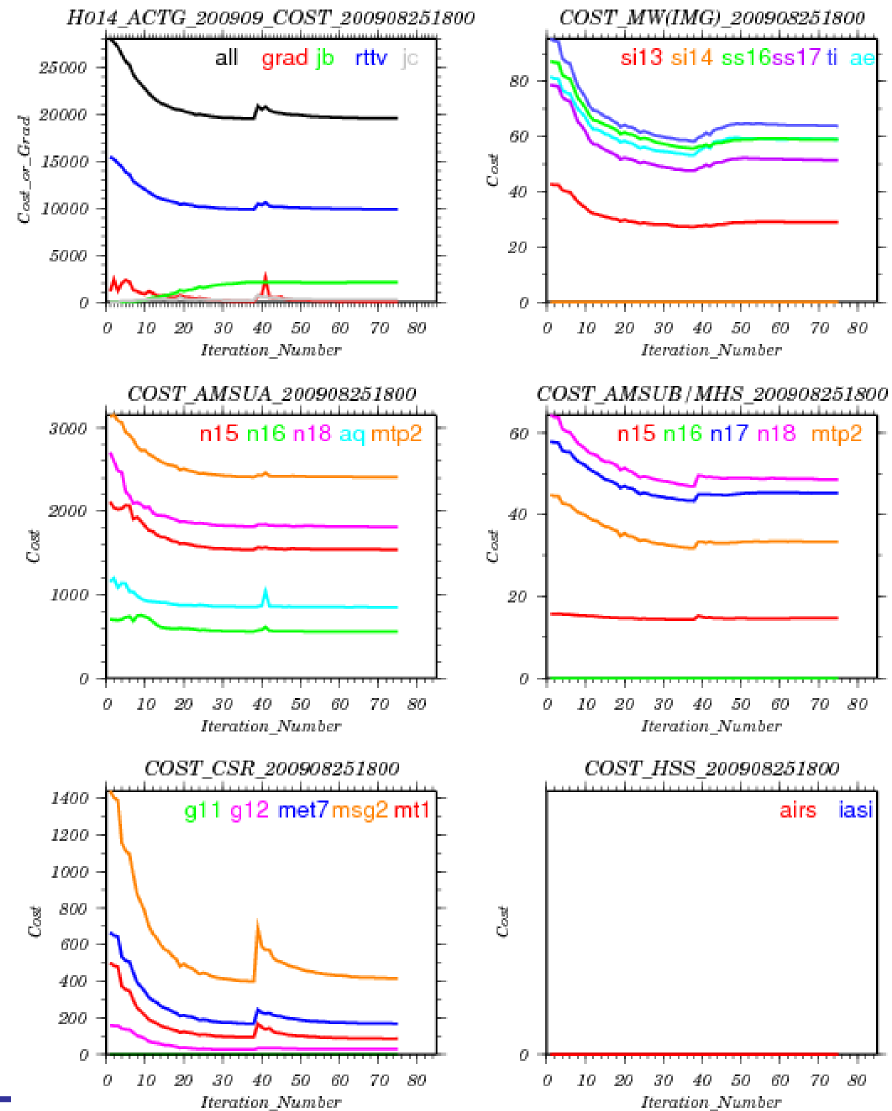
QC: Cloud screening based on CLW and gross error check

Bias Correction : VarBC

Two step minimization process:
First 35 times: Dry model,
Last 35 times: Included moist physics.

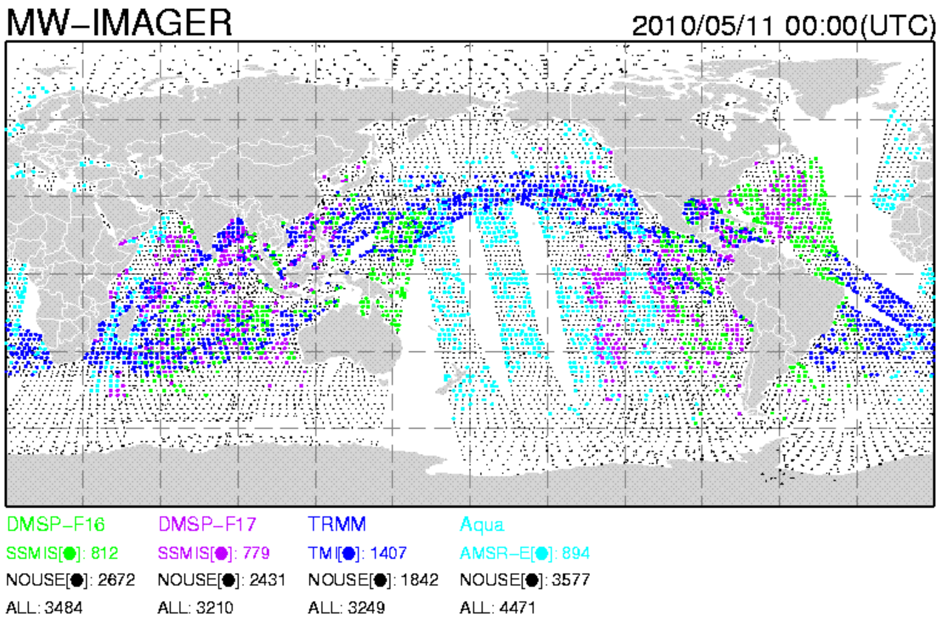
Observational error inflation was pre-determined in the preprocess of 4D-Var.

Relatively large obs. error was assigned for MW-Imager to avoid excessive rainfall in short range (6-hr) forecast.



Cloud screening and Bias correction

Coverage of MW-Imager Data



Colored point data are actually assimilated.

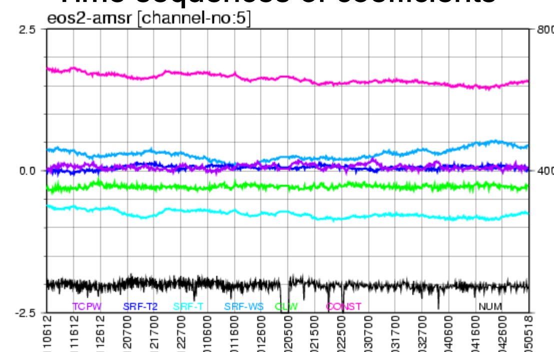
Variational Bias Correction: Linear function with some predictors is used, and the coefficients are optimized in previous 4D-Var analysis and updated every analysis.

$$y = \tilde{\mathrm{h}}(\mathbf{z}) \equiv \mathrm{h}(\mathbf{x}) + \sum \boldsymbol{\beta}\, \mathrm{p}(\mathbf{x}_\mathrm{b}(\cong \mathbf{x}))$$

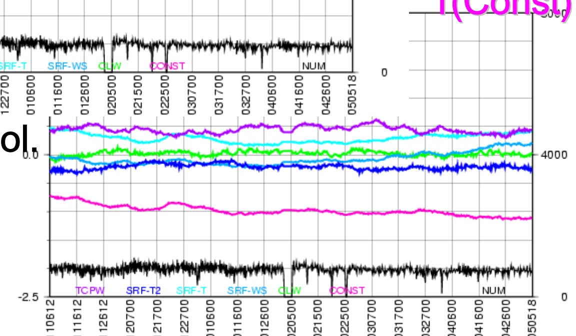
Predictors: p

TCPW,
T_{SRF},
T_{SRF}^2,
WS_{SRF},
CLW,
1(Const)

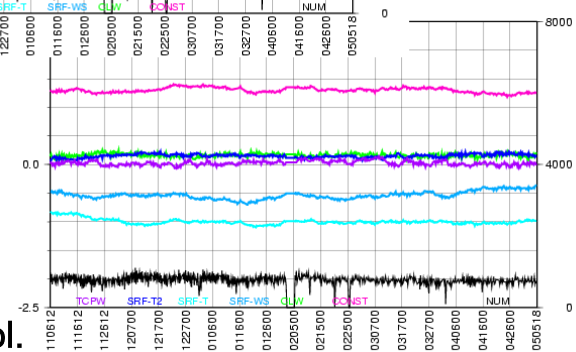
Time sequences of coefficients



19GHz V.pol.



23GHz V.pol.



37GHz V.pol.

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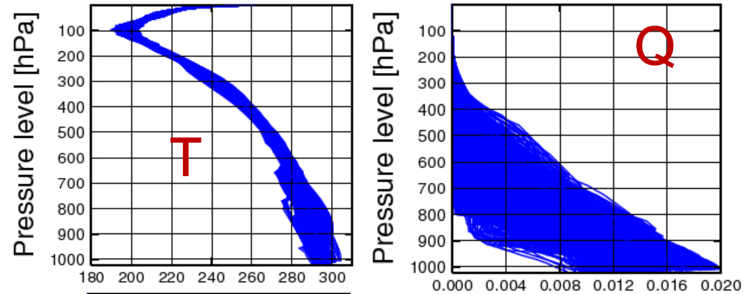
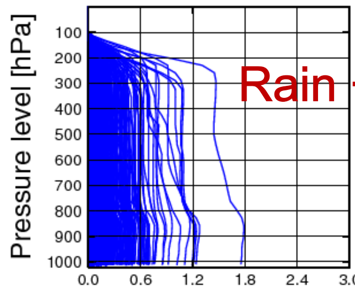
Profile comparisons of JMA and ECMWF (over tropical ocean)

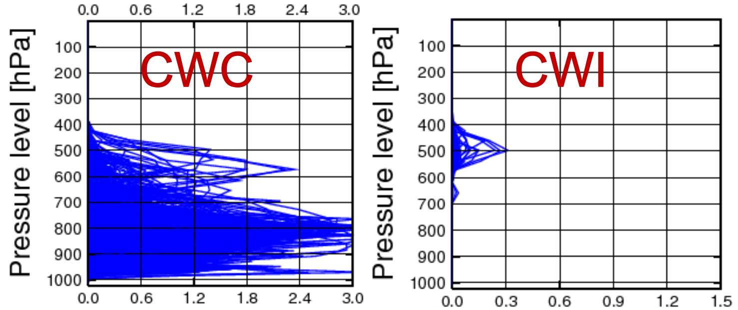


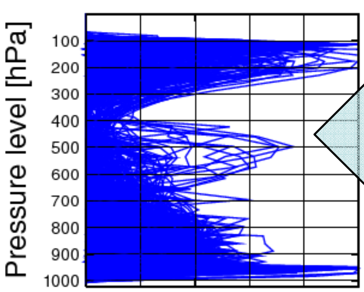


Rain + Snow

JMA

(1124 profiles in 00UTC Jul.20, 2009)

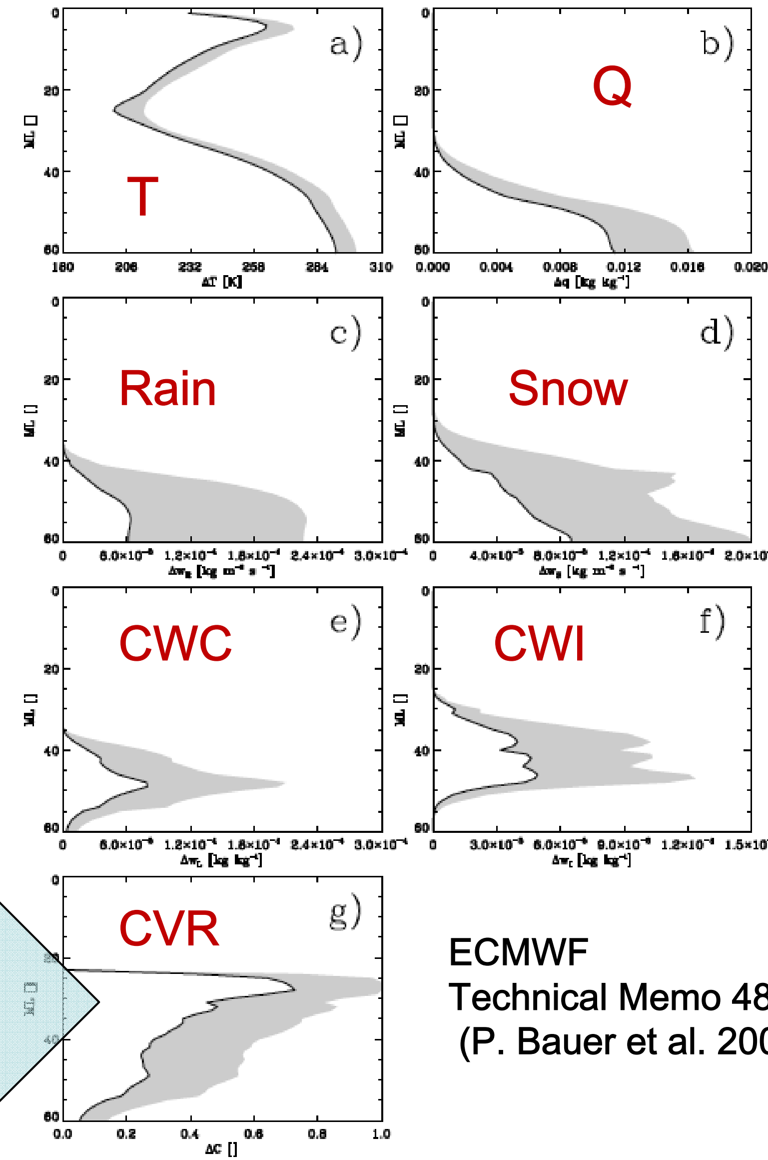




CVR

Quite different characteristic, especially, cloud and rain profiles

The difference of CVR profiles may cause large discrepancy in RTM calculation.

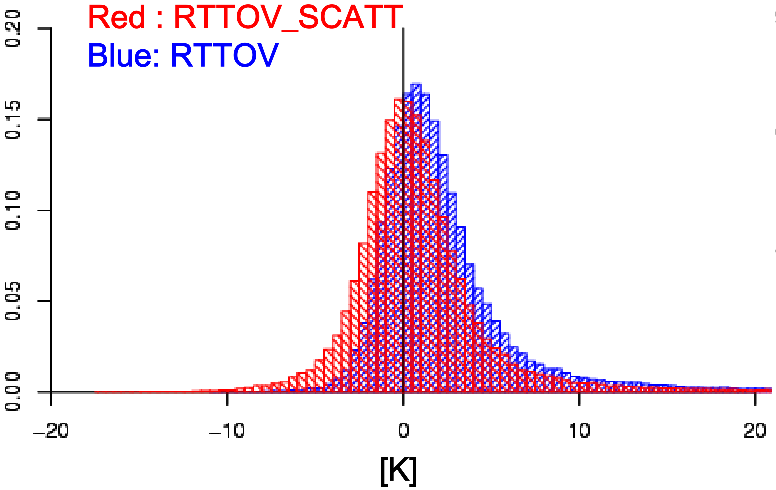


ECMWF Technical Memo 486 (P. Bauer et al. 2006)

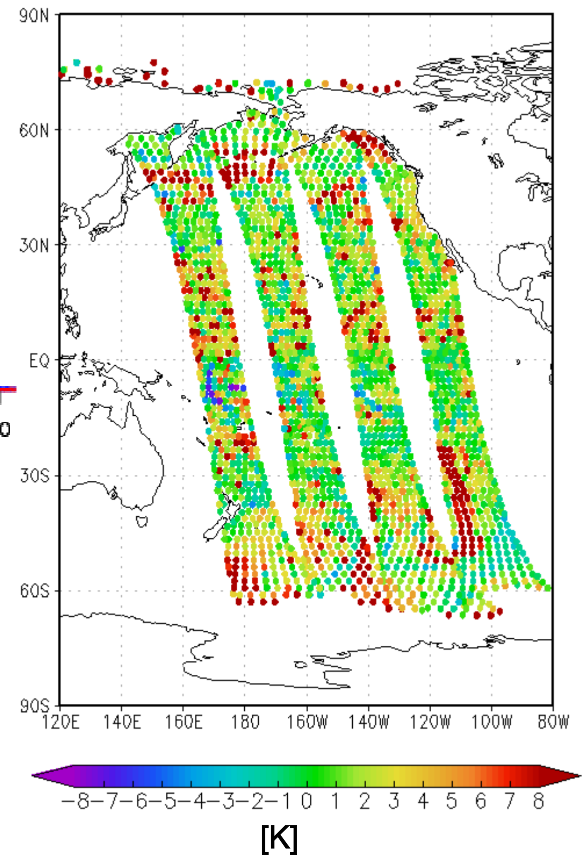
Figure 1: Mean (solid line) and mean +1 standard deviation of T (a), q (b), w_R (c), w_S (d), w_L (e), w_I (f) and C (g) as a function of model level, ML, for test data set.

Comparisons of O-B with RTTOV and RTTOV-SCATT in GSM

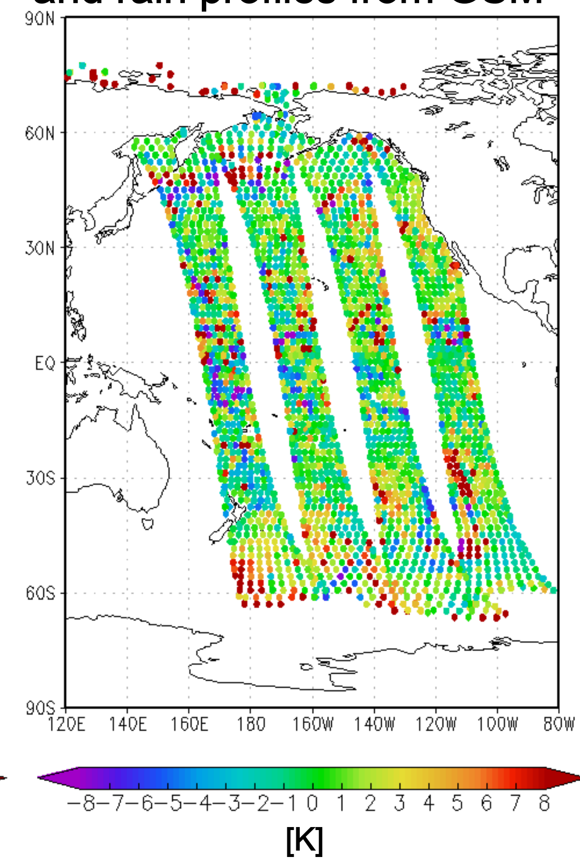
O-B distribution (AMSR-E 19GHz V.pol. over ocean)



RTTOV



RTTOV-SCATT with cloud and rain profiles from GSM



Input: Atmospheric profiles including cloud and rain from JMA GSM

RTM: RTTOV-SCATT

00UTC July 20, 2009

Initial test of MW-Imager radiance assimilation with RTTOV_SCATT

Configuration of the experiment

RTTOV_SCATT for AMSR-E, SSMI(S) and TMI radiance in Test run.

O-B departure was calculated in T, Q, CWC, CC profiles from JMA high reso. model.

In 4D-Var, trajectory from low reso. NL model was used but not updated in the minimization.

CWC and CC were not perturbed.

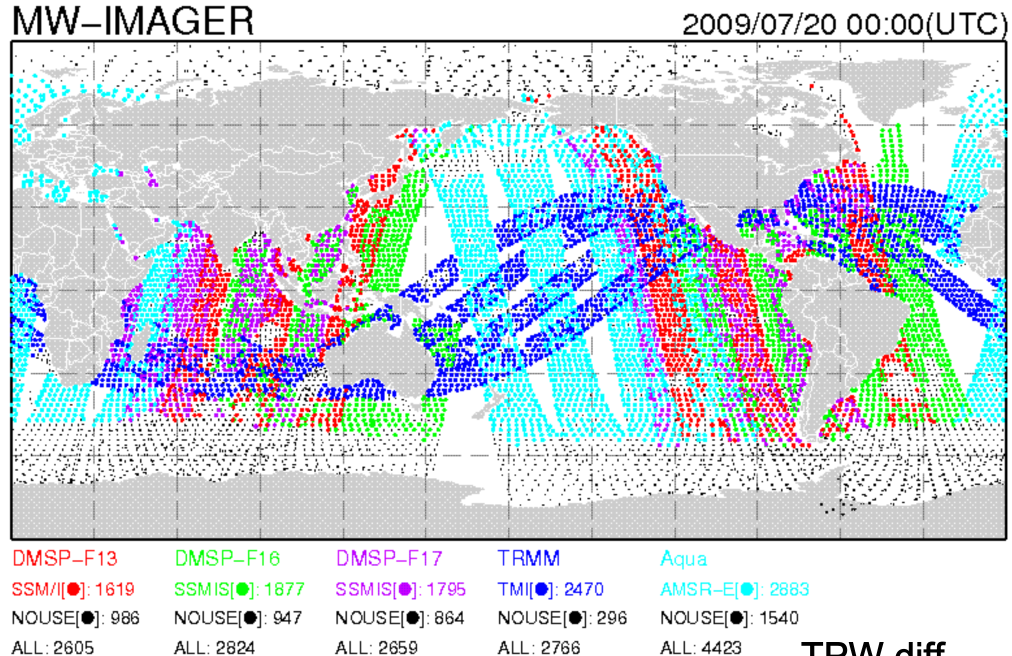
Heavy rain data was screened out in the pre-process to avoid non linearity in 4D-Var.

Result

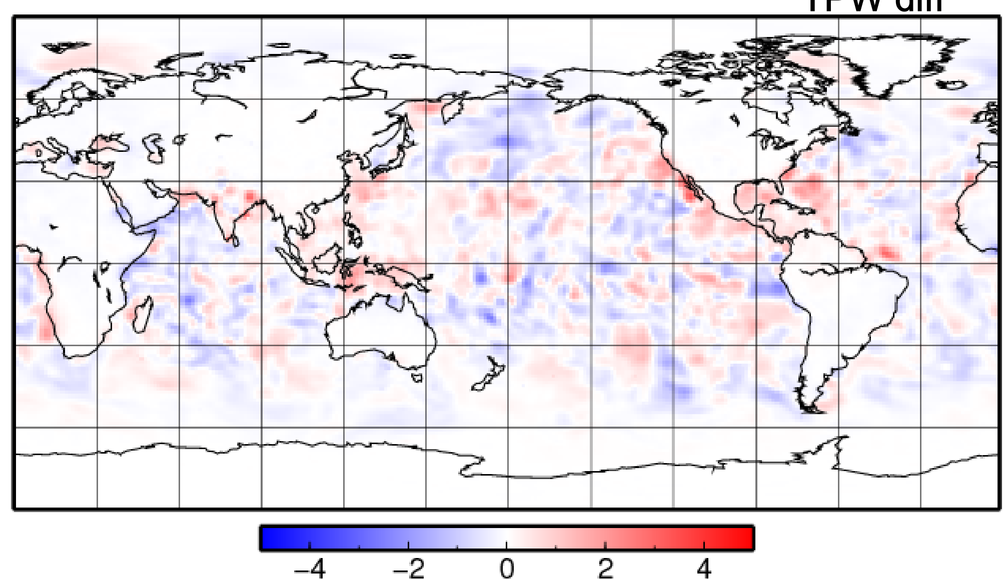
Available data number was increased.

Increased TPW analysis increment over ocean.

It is necessary to investigate the detail on the assimilation result.



TPW diff



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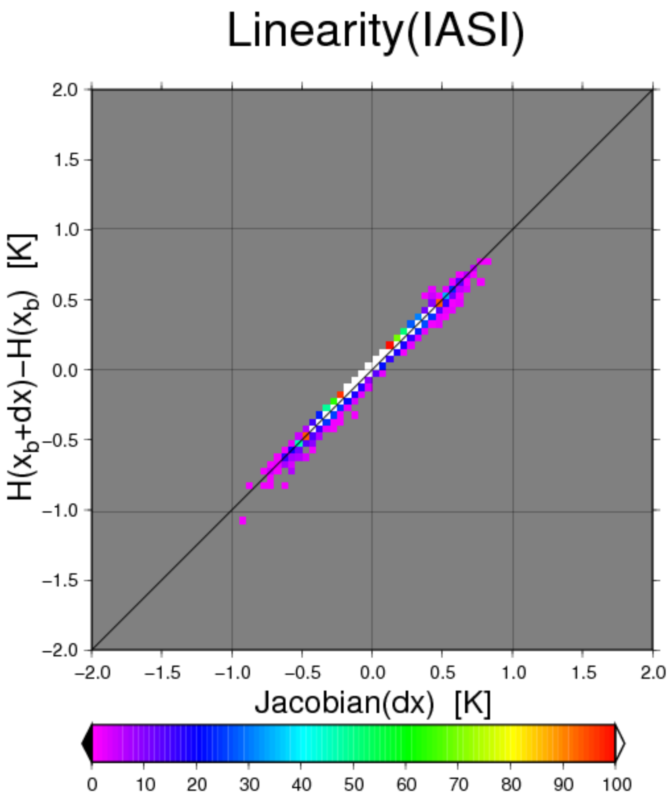
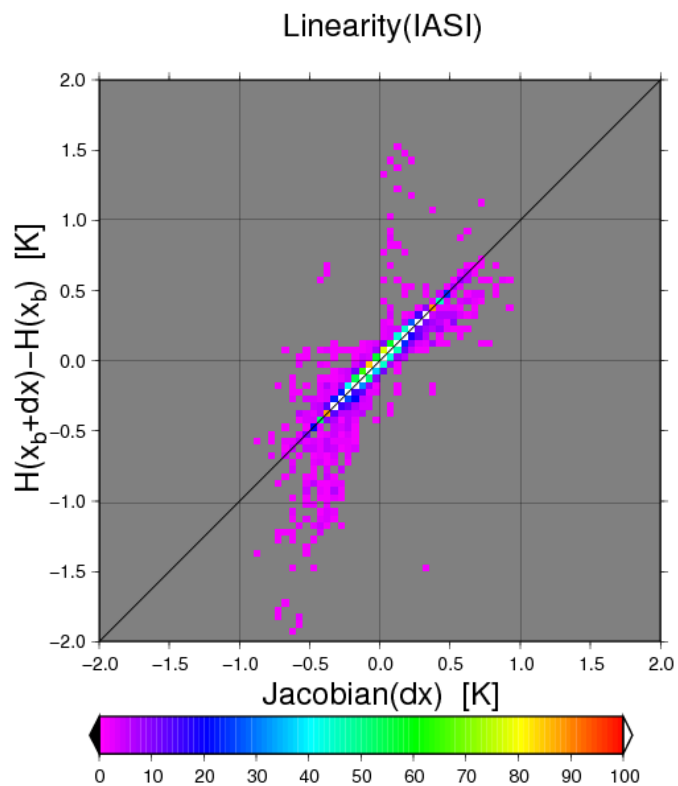
Early study for cloudy IR radiance assimilation with 1D-Var

Cloud profiles (CWC, CC) were diagnosed by ECMWF scheme (Tompkins and Janiskova 2004)

Perturbed variables: T, Q, SST (Fixed CWC, CC)



Perturbed variables: T, Q, SST,CWC (Fixed CC)

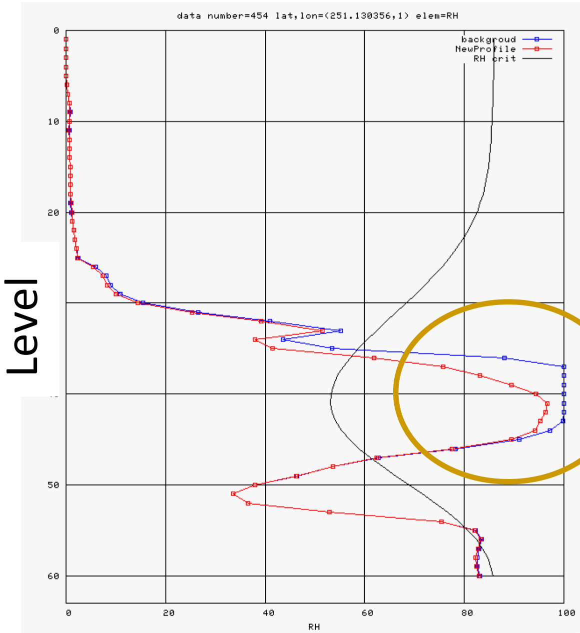


Changes of atmospheric profiles that showed non linearity in 1D-Var

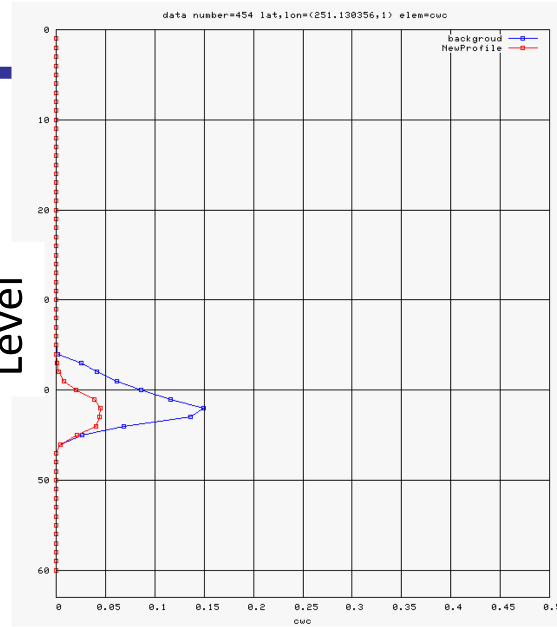
RH

CWC

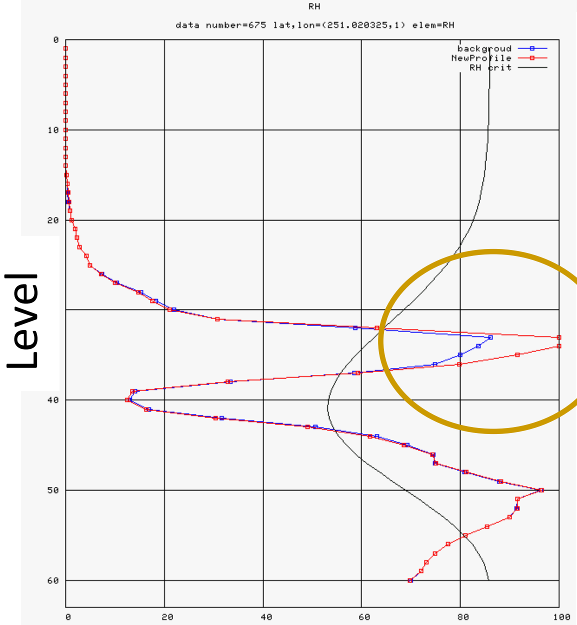
Level



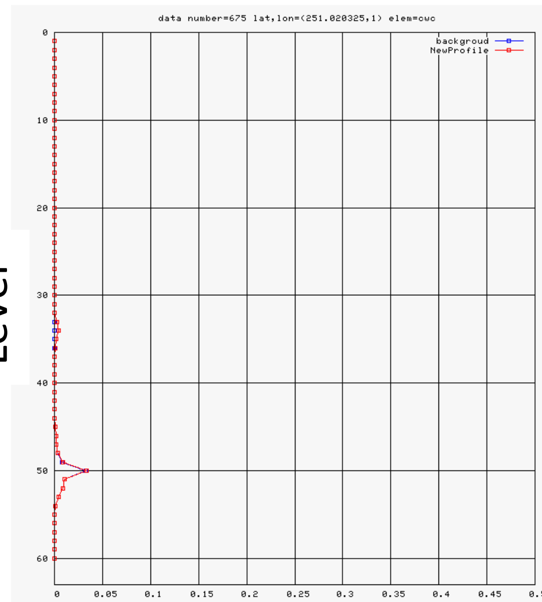
Level



Level



Level



Blue: background profile

Red: Optimized profile

When relative humidity was reached 100 % at any level before or after 1D-Var process,
the non-linearity was found.

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Summary

- JMA operates two deterministic NWP models. Global model (GSM) and Meso Scale Model (MSM). 4D-Var DA is used for both system.
- Microwave Imager data have been assimilated under all weather condition (TPW in clear condition and RR in rainy condition) in the operational MSM 4D-Var DA system. TPW and RR assimilation showed positive impacts on precipitation forecasts.
- In the global DA system, radiance data in clear sky condition are assimilated. All sky microwave radiance DA system is under development. Different characteristic in background profiles (cloud cover) was identified and it is related with forecast model performance differences.
- Early study with 1D-Var method toward assimilation on cloudy IR radiance was started. TL and ADJ model's linearity by using ECMWF cloud scheme was investigated. Better linearity was found when CWC, CC profiles were fixed. However, large non linearity has found when CWC, CC are perturbed in 1D-Var. It suggests difficulty of water vapor saturation or cloud generation in variational DA scheme.

Recommendations

- Improve background atmospheric profiles

  Forecast model performance is an important factor for successful data assimilation in cloudy and rainy condition. Better cloud and rain profiles are necessary. And forecast model spin up issues (e.g. excessive rainfall in early forecast stage) should be reduced. Data assimilation experts and modelers should work together for further improvement in moist physics parameterization.

- Find optimal cloud and rain assimilation scheme in the 4D-Var and forecast model configuration

  Due to computer power and human resource limitation, JMA 4D-Var has some limitations (Low reso. inner model and no update for trajectory. Two step minimization by dry and moist model, and relatively old moist physics parameterization).

- Share the experience and knowledge on cloud and rain assimilation among NWP centers. And learn how to overcome difficulties from advance NWP centers.

  Exchange the information on cloud/rain assimilation will accelerate the development of cloud and rain assimilation scheme.

Thank you for your attention.

Backup Slides

Open Questions

- In JMA Global DA system, larger observation error was assigned for MW Imager radiance data to avoid an excessive rainfall in the short range forecast (6-hr). Unless the model spin down issue is solved, is it difficult to assimilate the radiance data in cloudy and rainy condition? Or are there any advantages of cloud and rain assimilation in this situation?

- To consider spatial and temporal representativeness, is it necessary to make average and/or select nearest neighbor observations in the data thinning ?

- How can we deal with the difference of biases (or observation error) between clear and cloud-rainy condition?

- What kind of observation (BT or TPW) should be used and what kind of variables (T,Q and/or cloud physics parameters) should be analyzed in DA?

Relationship between PDF and J (maximum likelihood estimation)

4D-Var cost function

$$J = J_b + J_o$$

$$= \frac{1}{2}(x_0 - x_{b0})^{\mathrm{T}} \mathbf{B}^{-1}(x_0 - x_{b0}) + \frac{1}{2}(y - \mathbf{HM}\, x_0)^{\mathrm{T}} \mathbf{R}^{-1}(y - \mathbf{HM}\, x_0)$$

Background Term

Observation Term

Maximize

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

Minimize

$$-\log(\mathrm{P}(x \mid x_b, y))$$

$$= -\log(\mathrm{P}(x_b \mid x)) - \log(\mathrm{P}(y \mid x)) - \log(\mathrm{P}(x)) + const.$$

Relationship between PDF and J (maximum likelihood estimation)

$$P(y \mid x) = \frac{1}{\sqrt{2\pi}\sigma_o} \exp\{-\frac{(y - HM(x))^2}{2\sigma_o{}^2}\} \Rightarrow -\log(P(y \mid x)) = \frac{(y - HM(x))^2}{2\sigma_o{}^2} + const.$$

Multidimensional case,

$$P(\mathbf{y} \mid \mathbf{x}) = \frac{1}{(\sqrt{2\pi})^m \sqrt{\mathbf{R}}} \exp\{-\frac{1}{2}(\mathbf{y} - HM\mathbf{x})^{\mathrm{T}} \mathbf{R}^{-1}(\mathbf{y} - HM\mathbf{x})\}$$

$$\Rightarrow -\log(P(\mathbf{y} \mid \mathbf{x})) = \frac{1}{2}(\mathbf{y} - HM\mathbf{x})^{\mathrm{T}} \mathbf{R}^{-1}(\mathbf{y} - HM\mathbf{x}) + const.$$

$$(\mathbf{y} - HM\mathbf{x}_0)^{\mathrm{T}} \mathbf{R}^{-1}(\mathbf{y} - HM\mathbf{x}_0)$$

The cost function in this form assumes Gaussian type probability density function.