

# PRECIPITATION ASSIMILATION TO JMA MESOSCALE MODEL USING A FOUR-DIMENSIONAL VARIATIONAL METHOD

Ko KOIZUMI (JMA/NPD), Yoshihiro ISHIKAWA (NSSL),  
Tadashi TSUYUKI, Shigenori MURAKAMI (JMA/MRI), Yoshiaki SATO (JMA/MSM)

## 1. INTRODUCTION

In March 2001 the Japan Meteorological Agency (JMA) started the operation of the mesoscale model (MSM) to produce 18 hour forecasts four times a day (00, 06, 12 and 18 UTC initial) to assist forecasters in issuing warnings (JMA, 2002). MSM is a hydrostatic spectral model with a horizontal resolution of 10 km and 40 vertical levels up to 10 hPa.

The initial condition of MSM was at first prepared by a 1-hour cycle analysis system with optimum interpolation and physical initialization to assimilate 1-hour accumulated precipitation data. This analysis system was executed for the 3-hour period just before the initial time with the first guess at the beginning of the period taken from the latest forecast of RSM. This analysis system is hereafter referred to as the pre-run system. The pre-run system was successfully replaced in March 2002 by a full forecast-analysis cycle with a 4-dimensional variational (4D-Var) method with 3-hour assimilation windows.

This paper describes the precipitation data assimilation to MSM by the mesoscale 4D-Var system and reports on the impacts of precipitation assimilation on the MSM precipitation forecasts.

## 2. PRECIPITATION NOWCASTING IN JMA

JMA has 20 operational C-band radars and about 1,300 automatic surface weather stations called AMeDAS. Using those observations, a precipitation nowcasting product is made as follows.

First, radar echo intensity is converted to precipitation rate using the relationship  $Z = 200R^{1.6}$ . Then, the estimated precipitation rate is averaged over eight observations during one hour to produce an estimate of one-hour precipitation amount. Finally, the estimated amounts are calibrated using rain gauges to provide one-hour precipitation amount distribution all over Japan and surrounding are with 2.5 km resolution (cf. Makihara, 2000).

This nowcasting product is called "radar-AMeDAS precipitation analysis" which is

up-scaled to model grids and assimilated to MSM.

## 3. MESOSCALE 4D-VAR SYSTEM

The cost function of mesoscale 4D-Var system consists of a background term, observation terms, and a penalty term for reducing gravity wave noise. The control variables are the initial and boundary conditions of unbalanced wind, temperature, surface pressure, and specific humidity. The background error statistics are obtained by using the NMC method. The horizontal background error correlations are assumed to be homogeneous and Gaussian type to significantly reduce memory requirement.

An incremental method is taken for reducing computational time. The forward model in this system has the same architecture as the forecast model (viz. MSM) except that its horizontal resolution is reduced to 20km. The adjoint model has the same dynamical process as the forward model while its physical processes include moist processes, boundary layer processes, long-wave radiation and horizontal diffusion only.

Assimilated data are radiosonde, synop, ship, buoy, aircraft, wind-profiler and radar-AMeDAS precipitation data.

It is to be noted that most of precipitation in MSM comes from the grid-scale condensation although MSM contains a prognostic Arakawa-Schubert scheme to parameterize deep cumulus convection. Therefore, the absence of deep cumulus convection in the adjoint model may not cause a serious problem in the 4D-Var system.

## 4. OBSERVATIONAL COST FOR PRECIPITATION

Since the precipitation amount has quite different error probability distribution from other elements such as temperature or wind speed, the Gaussian type cost-function is not appropriate for precipitation. Fig.1(b) shows scatter diagram of first-guess values of precipitation and departures of observation from first-guess. It is not symmetrically distributed around zero departure as in the case of temperature at 500hPa (Fig.1 (a)).

Then we assume probability density distribution

of precipitation as the exponential distribution which is suggested from Fig. 1(b).

According to the maximum likelihood method the cost function of precipitation becomes

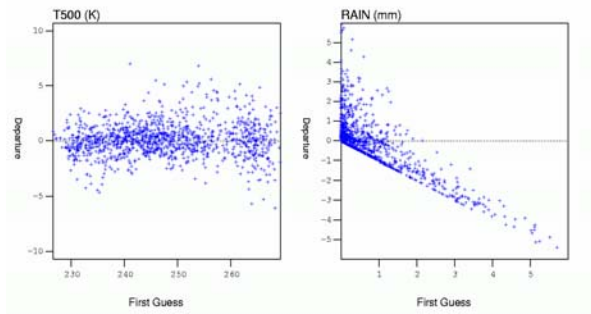
$$J_{rain} = -\log(p(y|x)) = \log(x) + \frac{y}{x} \quad (2)$$

However, this formulation is not appropriate to be used in minimization algorithms as it becomes singular around  $x=0$ . Moreover, it is more preferable that the cost function has a quadratic form for the stability of optimizing process. Therefore, the above function is expanded around its minimum point ( $x=y$ )

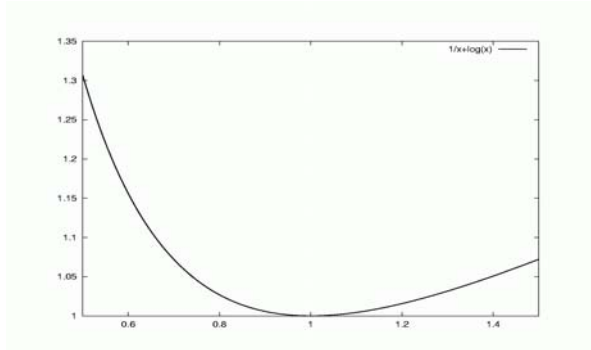
$$J_{rain} = 1 + \log(y) + \frac{1}{2y^2} (x-y)^2 + O((x-y)^3) \quad (3)$$

If truncated at the second order of  $(x-y)$ , the function becomes Gaussian type with the observation error equal to  $y$ .

On the other hand, the function (2) is not symmetric around its minimum point (fig. 2) which means that the observation error is assumed smaller in the case of  $x < y$  than in the case of  $x > y$ . This asymmetry is seen from Fig. 1(b).



**Fig. 1** scatter diagram of first-guess value and departure of observation from first-guess. (a) temperature at 500hPa, (b) one-hour precipitation amount.



**Fig. 2** Function (2) around its minimum point in the case of  $y=1$

Considering these properties, we practically define the cost function as follows:

$$J_{rain}(x) = \frac{1}{2r^2} (x-y)^2, \quad (4)$$

where

$$r = \begin{cases} r_1 & (x \leq y) \\ r_2 = 3r_1 & (x > y) \end{cases}$$

When  $y < 1\text{mm/h}$ ,  $r_1$  has a constant value which is the forecast error,  $r$  of precipitation for observed precipitation less than  $1\text{mm/h}$ . Otherwise  $r_1$  is proportional to observed precipitation amount.

## 5. ASSIMILATION TEST

Figure 3 shows an example of precipitation assimilation. By assimilating one hour precipitation amounts during three hour assimilation window, precipitation distribution is well reproduced. The forecast starting from the initial condition to which precipitation data were assimilated also shows good agreement with observation (fig. 4).

## 6. IMPACTS ON FORECASTS

In order to evaluate the performance of 4D-Var and the impact of precipitation assimilation, several analysis-forecast cycle experiments were performed.

First, two sets of one-month experiments during June and September 2001 were made to compare the 4D-Var and pre-run systems. The result shows that the precipitation forecasts starting from 4D-Var are much better than those from the pre-run (figures not shown).

Second, an observation system experiment (OSE) for precipitation data was performed for June 2001 using the 4D-Var system. Threat scores (fig.5 left) show that the precipitation forecasts were improved by assimilating precipitation data especially for first few hours and bias scores (fig. 5 right) show that the spin-up problem of MSM is alleviated by precipitation assimilation.

However, the 4D-Var system sometimes failed to assimilate the precipitation data when the first guess was in a dry condition in spite of the fact that the full-physics nonlinear model is used as the inner-loop forward model. This is an inherent problem with 4D-Var assimilation of precipitation data using model physics that contain “on-off” switches. That problem may be ameliorated by assimilating moisture data.

Then the third experiment is an OSE for TMI (TRMM Microwave Imager) precipitable water data and combined use of TMI-PW and precipitable

water data from ground-based GPS observation.

Figure 6 shows an example of first three hour forecasts. A spurious heavy rain area (“A” in fig. 6) produced by precipitation assimilation was reduced by using TMI-PW data though it was a little bit too much suppressed (“B”). Complementary use of TMI-PW (moisture information over sea) and GPS-PW (moisture information over land) gave the best result among them. Threat scores of 1mm per 3 hour precipitation (fig. 7) show that the combined use of TMI and GPS improves the precipitation forecasts all through the 18-hour forecast time.

### 7. CONCLUDING REMARKS

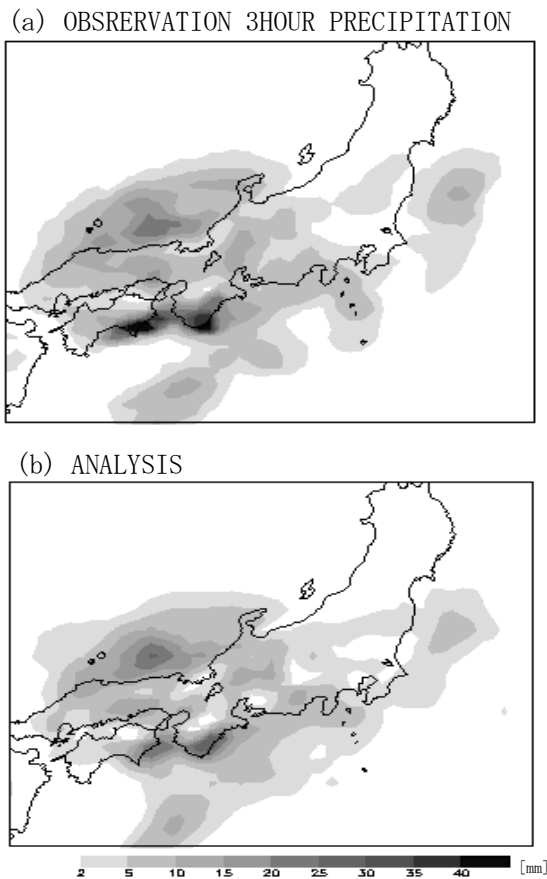
Precipitation forecasts of JMA mesoscale model are improved by assimilating precipitation data especially for first few hours of forecast time, that means that the NWP precipitation of first few hours may become more reliable by assimilating precipitation data. However, the 4D-Var is not always successful in assimilating precipitation as

stated in the previous section, hence the assimilation of moisture data from GPS, satellite microwave observation and others is indispensable.

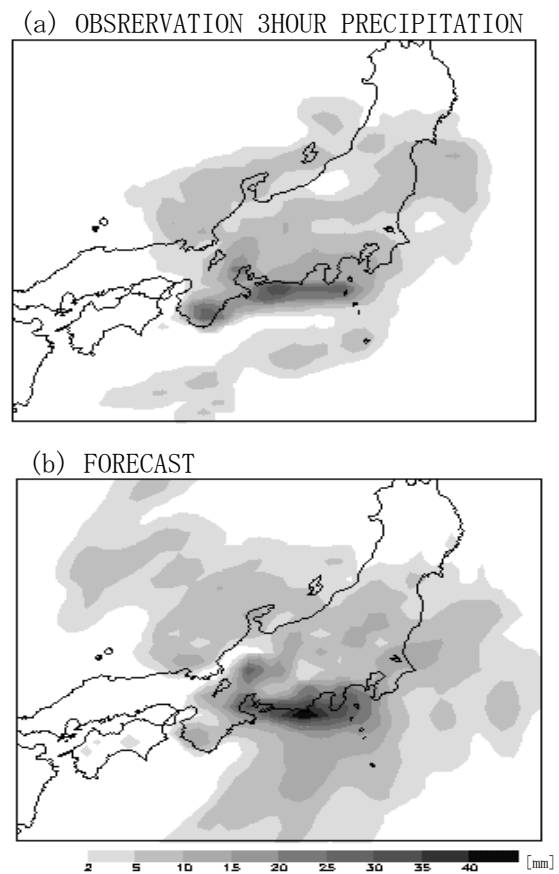
A negative aspect of the NWP precipitation is that it has considerable errors even for short forecast time and its probability density distribution is sometimes different from the nature (see fig. 1). Whether spatial or temporal averaging can alleviate the problem requires further investigation.

### REFERENCES

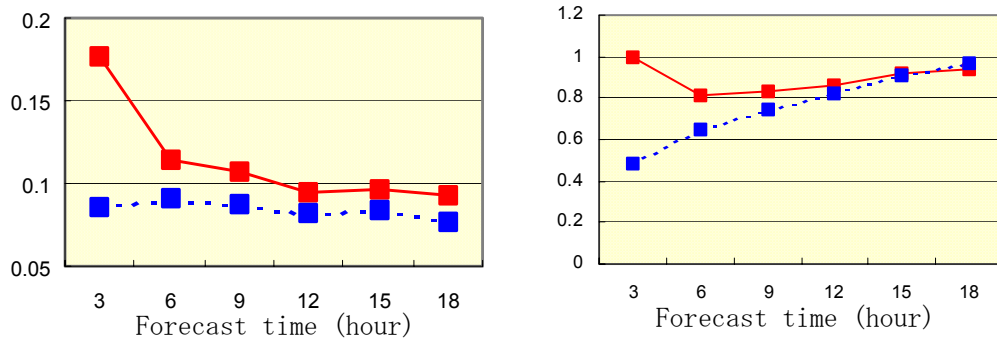
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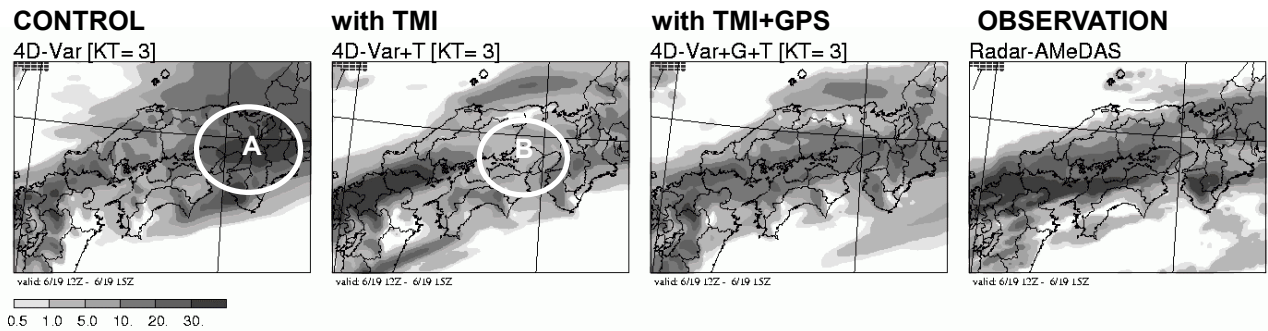
**Fig.3** The 3-h precipitation accumulated over the assimilation window for (a)observation and (d)4D-Var analysis. The target analysis time is 00UTC 16 March 2000. The operational forecast with JMA regional spectral model from initial condition of 12UTC 15 March 2000 is used as the first guess.



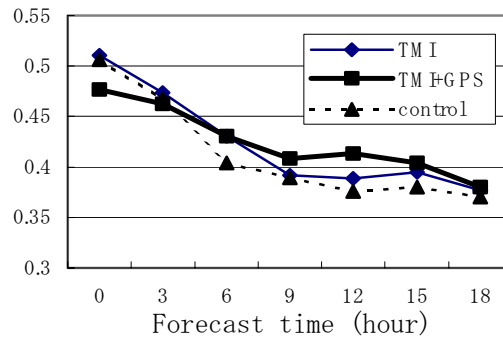
**Fig.4** The 3-hour precipitation accumulated over 0-3hours for (a)observation and (d) forecast starting from the initial condition produced by precipitation assimilating 4D-Var.



**Fig. 5** Threat score (left) and bias score (right) of 3-hour accumulated precipitation over Japan plotted against forecast time for one month period of June 2001. Threshold value is 10 mm with a horizontal resolution of 10 km. Red (solid) and blue (dashed) lines are with and without assimilating the precipitation data, respectively.



**Fig.6** Three hour precipitation amount during 12 – 15 UTC 19<sup>th</sup> June 2001 of control run, TMI run, TMI+GPS run and observation from left to right respectively. Initial time of forecasts is 12 UTC 19<sup>th</sup> June 2001.



**Fig. 7** Threat scores of forecast precipitation over 1 mm/ 3 hour. Forecast time is -3-0 (within assimilation window), 0-3, 3-6, 6-9, 9-12, 12-15 and 15-18 hour from left to right respectively. Solid bold line shows those of TMI+GPS run, solid thin line TMI run and dashed line control run. Scores are calculated for 15 cases during 18 UTC 18<sup>th</sup> June 2001 to 12 UTC 21<sup>st</sup> June 2001 against radar- AMeDAS precipitation analysis data which are interpolated to model grid.