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THE FOUR-DIMENSIONAL VARIATIONAL DATA ASSIMILATION SYSTEM FOR THE JMA MESOSCALE MODEL

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1. Introduction

The four-dimensional variational data assimilation system for the JMA mesoscale spectral model (MSM) has been developed since 1997. The MSM is a hydrostatic model with a horizontal resolution of 10km. The system is planned to run operationally from March 2002.

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 but its physical processes are simpler ones.

The background error covariance matrix is formulated in grid space and simplified by assuming homogeneity and Gaussian type.

In this report, the results which has been got since the previous report (Ishikawa, 2001) is presented, that is, observation error setting for precipitation, speed-up of background-term calculation and forecast-analysis cycle experiment. Impacts of observational data from the JMA wind profiler network will be also demonstrated at the conference.

2. Observation error of precipitation

In this system, precipitation amount observed with the radar-AMeDAS system is assimilated so that precipitation forecast is improved especially in the first several hours of the forecast.

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).

$$p(y|x) = \frac{1}{x}\exp(-\frac{y}{x}) \qquad (1)$$

here, x denotes true value and y observation.

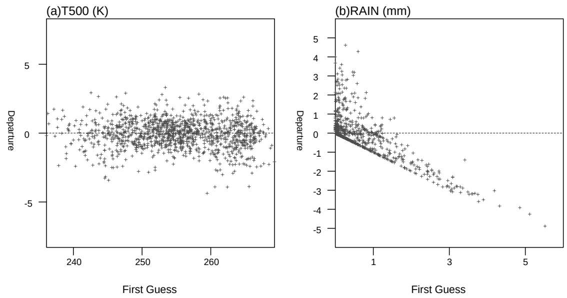

Fig. 1 scatter diagram of first-guess value and departure of observation from first-guess. (a) temperature at 500hPa, (b) one-hour precipitation amount.

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

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

Since it is preferable that the cost function has a quadratic form for the stability of optimizing process, the above function is expanded around its minimum point (x=y)

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

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 asymmetricity is seen from Fig. 1(b).

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

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

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where

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

When y<1mm/h, r1 has a constant value which is the forecast error of precipitation for observed precipitation less than 1mm/h. Otherwise r1 is proportional to observed precipitation amount.

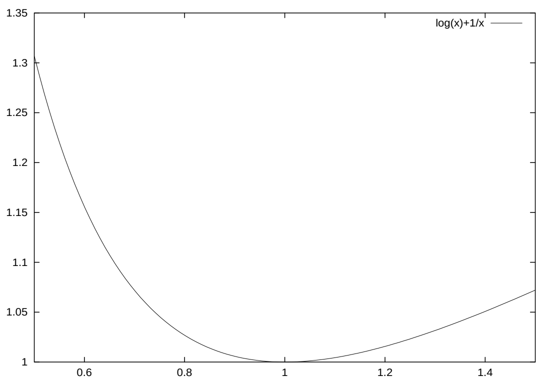

Fig. 2 Function (2) around its minimum point in the case of y=1

3. Reducing computational time for the background term calculation

The background term calculation is one of the time-consuming processes in 4D-Var system even though the background error covariance matrix is simplified with an assumption of homogeneity and Gaussian type. Reducing the computational time for matrix calculation of the background term is indispensable for the system to be used operationally.

For this purpose, the grid distance beyond which the background error covariance value becomes negligible is searched in advance. The calculation is skipped when the distance between two grid points is larger than a threshold value, which is set for each vertical mode of each control variable.

In this system, the covariance is regarded as negligible when the correlation value is smaller than 0.0001. With the method, the background term calculation becomes five times faster(table 1).

Table 1 Elapse time for one iteration (sec.)

	Total	Background term calc.
Full matrix calc.	**86**	**39.0**
Trivial term skipping	**53**	**6.8**

4. Forecast-analysis cycle experiment

In order to evaluate the impact of the 4D-Var system on precipitation forecast, an experimental forecast-analysis cycle has been operated since January 2001.

The forecast model used in this experiment is of 20km horizontal resolution, that is, the incremental method is not implemented. Its performance is compared with the 20km resolution routine model (RSM) whose assimilation method is the optimum interpolation and physical initialization.

Fig. 3 shows an example. A band of heavy rain in the southwest of Japan is well reproduced in the forecast starting from the 4D-Var analysis. The threat score of precipitation over 10mm/3h for 9-12 hour forecast is 0.28 for the 4D-Var forecast and 0.12 for the routine forecast.

Though there are several cases where the 4D-Var improves forecasts up to 15 hours as shown above, usually clear positive impacts are not seen after 9 hours (fig.4). However, the results are only from a few months' experiment and further researches, especially for other seasons, are necessary.

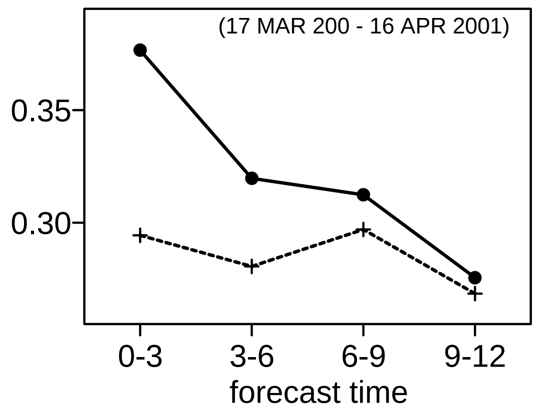

Fig. 4 Threat scores of precipitation over 1mm/3hour from 17 Mar 2001 through 16 Apr 2001. Solid line is for the forecast from 4D-Var analysis and dashed line is for the routine forecast.

5. Impact of wind-profiler network observation

JMA is planning to deploy a 25 station wind-profiler network (fig. 5) which covers all over Japan with approximately 100km intervals for the purpose of precise observation of lower atmosphere (approximately up to 5km).

The impact of the assimilation of these wind-profiler data on prediction of heavy rainfall events will be demonstrated at the conference.

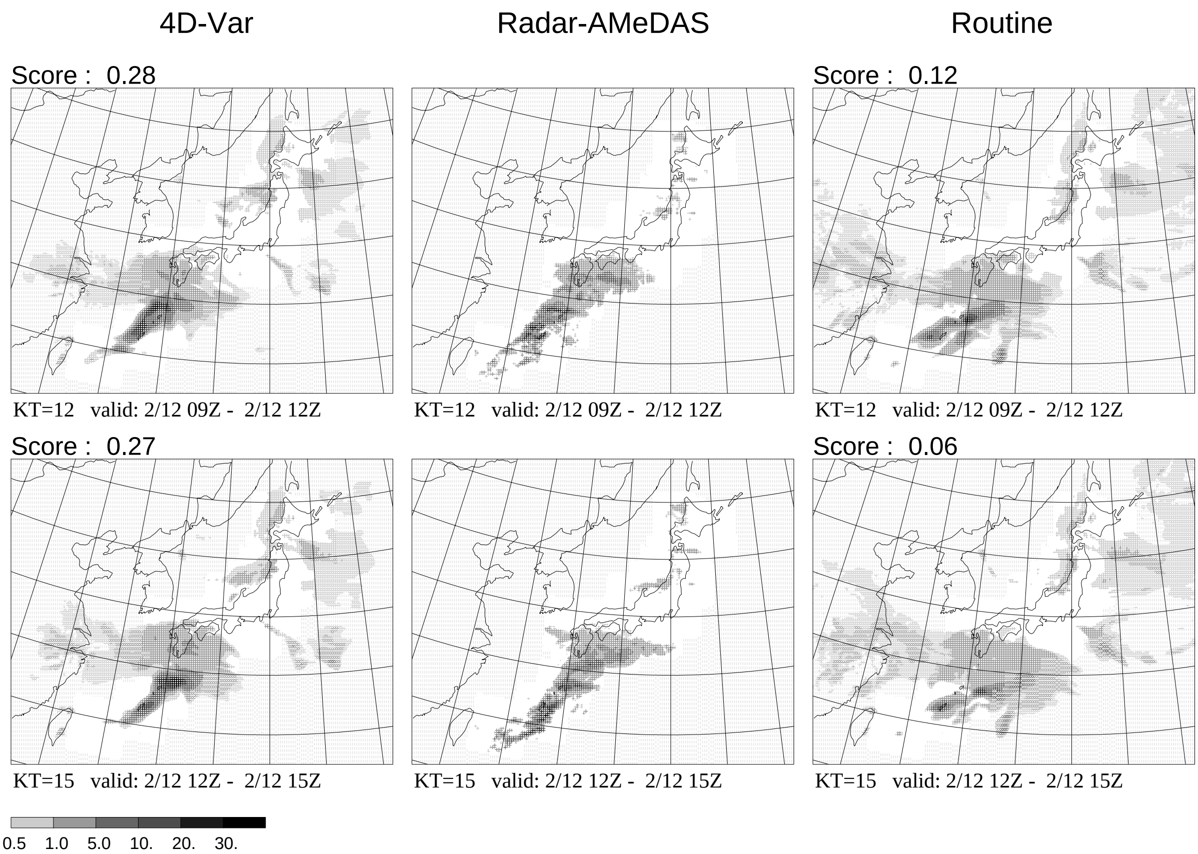

Fig. 3 Forecasts and observations of 3-hour precipitation amount. Left column shows forecasts starting from the 4D-Var analysis, center column the radar-AMeDAS observations and right column the forecasts of routine NWP. Initial time of forecasts is 00Z 12 Feb 2001. Upper row is for 09-12Z 12 Feb 2001 (forecast time is 9-12 hour) and lower is of 12-15Z 12 Feb 2001 (forecast time is 12-15 hour). Radar-AMeDAS observation is not available in the region shaded with light gray. Score values at the left top of panels are threat scores of rainfall amount over 10mm/3hour.

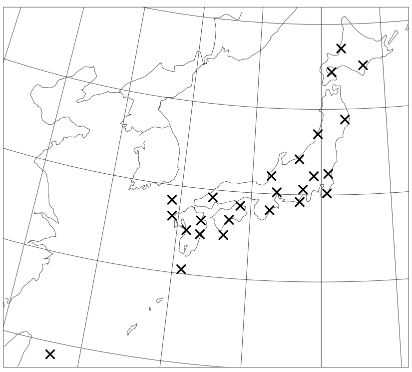

Fig. 5 Locations of wind-profiler stations.