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UPGRADE OF THE OPERATIONAL JMA MESOSCALE MODEL AND IMPLEMENTATION OF IMPROVED MELLOR-YAMADA LEVEL 3 SCHEME

Tabito Hara*
Japan Meteorological Agency, Tokyo, Japan

1. INTRODUCTION

The Japan Meteorological Agency (JMA) has been developing a non-hydrostatic model, which is called JMANHM, for operational and research purpose. The model with 5-km horizontal resolution (MSM) is employed for the operational mesoscale numerical prediction which aims at providing the information to prevent disaster (JMA, 2007).

In May 2007, forecast period of MSM was extended from 15 hours to 33 hours 4 times a day out of 8 times, while until then it gave 15-hour forecasts 8 times a day (or every 3 hours). At the same time the new model (MSM0705), in which many physical processes such as radiation, turbulence, cloud physics and cumulus convection are improved, was installed instead of the previous operational model (MSM0603) (Hara et al., 2007).

It has been confirmed that MSM0705 is superior to MSM0603 and the current operational regional spectral model of JMA (RSM) on the accuracy of prediction of precipitation, vertical profiles of temperature and wind velocity, and diurnal changes of surface temperature and wind.

In particular, the introduction of the improved Mellor-Yamada Level 3 scheme and the partial condensation scheme have remarkable impact on the performance of MSM, and they contribute to the considerable part of the improvement of MSM (Hara, 2007a,b). With the schemes, transportation of momentum, heat and water substances in boundary layer can be predicted more suitably and the negative bias of shortwave radiation flux can be much reduced. Consequently reduction of errors in vertical profiles of temperature and wind, and more diurnal changes of surface temperature and wind are realized in MSM0705. In some cases, rainband which caused severe disaster can be predicted more clearly.

In this paper, the specifications of the previous MSM (MSM0603) and the new one (MSM0705) are reviewed in section 2. After that, implementation of the improved Mellor-Yamada Level 3 scheme (MY3) and the partial condensation scheme are mainly focused. In section 3, the turbulence scheme of the previous model and that of the new model, or MY3, are reviewed. The motivations to introduce MY3 and the partial condensation scheme is shown. In section 4, performance of MY3 is displayed comparing with the previous scheme. Section 5 is devoted to the discussion.

2. UPGRADE THE OPERATIONAL MESOSCALE MODEL AT JMA

The specifications of the previous MSM (MSM0603) and the new one (MSM0705) are summarized in Table 1. Although the trigger of this replace of MSM model is to expand forecast time from 15 hours to 33 hours, many processes (mainly physical processes) are improved from the previous one. Refer to Hara et al. (2007) for detail.

3. REVIEW OF THE SCHEMES FOR TURBULENCE AND DIAGNOSING CLOUD FRACTIONS IN RADIATION PROCESS

It is pointed out that diurnal changes of temperature and wind speed near surface predicted by the previous model are too small. One possible reason for it is the insufficiency of vertical transportation of momentum, heat and water substances by turbulence in boundary layer.

The turbulence scheme of the previous model was based on Klemp and Wilhelmson (1978) and Deardorff (1980) with non-local like effect by Sun and Chang (1986).

*Corresponding author address: T.Hara, Numerical Prediction Division, Japan Meteorological Agency, 1–3–4 Otemachi, Chiyoda-ku, Tokyo 100–8122, Japan.
E-mail:tabito.hara@met.kishou.go.jp

	previous MSM (MSM0603)	new MSM (MSM0705)
Number of grids	721 × 577 × 50	
Time step	24sec	
Short time step	6.86 sec	6 sec
Initial Time	00,03,06,09,12,15,18,21UTC	
Forecast period	15 hours	15 hours (00,06,12,18UTC) 33 hours (03,09,15,21UTC)
Initial conditions	Meso 4DVAR with 6-h assimilation window	Meso 4DVAR with 6-h assimilation window (integrating a latter half 3 hours of outer loop with NHM)
Boundary conditions	RSM	
Vertical Coordinates	terrain-following	hybrid terrain-following (Ishida, 2007)
Cloud microphysics	3-ice bulk method	
Falling of cloud ice	not considered	considered
Convective parameterization	modified Kain-Fritsch	modified Kain-Fritsch (with perturbation depending on relative humidity)
Radiation Process cloud radiation clear sky radiation	 Kitagawa (2000) Kitagawa (2000)	 Kitagawa (2000) Yabu et al. (2005)
Cloud in the radiation process	cloud fraction: Ohno and Isa (1984) cloud water content: Hack (1998)	partial condensation scheme
Turbulent process	based on Klemp and Wilhelmson (1978); Deardorff (1980) with non-local effect by Sun and Chang (1986)	improved Mellor-Yamada Level 3 (Nakanishi and Niino)
Surface flux	Sea: Kondo (1975), Land: Louis et al. (1982)	Beljaars and Holtslag (1991)

Table. 1: Specifications of the previous MSM and the new MSM.

The scheme is first-order closure, where

$$\overline{u_i'u_j'} = -K_m\left(\frac{\partial\overline{u_i}}{\partial x_j} + \frac{\partial\overline{u_j}}{\partial x_i}\right) + \frac{2}{3}E\delta_{ij}, \quad (1)$$

$$\overline{u_i'C'} = -K_h\frac{\partial\overline{C}}{\partial x_i} \quad (C = \theta, q_v, \cdots), \quad (2)$$

and the diffusion coefficients are calculated with the turbulent kinetic energy (TKE) E, mixing length ℓ and Prandtl number Pr as following:

$$K_m = C_m\ell E^{\frac{1}{2}}, \quad (3)$$

$$K_h = \mathrm{Pr}^{-1}K_m, \quad (4)$$

$$\mathrm{Pr}^{-1} = \frac{1}{1+2\frac{\ell}{\Delta z}}. \quad (5)$$

C_m is the proportional constant which is set as 0.2 in mixing layer and otherwise 0.1. But the constant C_m in the previous model may be too small because it is confirmed in the experiment by Large Eddy Simulation (LES) that this proportional constant can become about 1 ∼ 2 in unstable layer (Nakanishi and Niino, 2004).

TKE is diagnosed assuming the balance between local producing and dissipation of TKE (Saito et al., 2006). Because of diagnostic scheme to calculate TKE, the variation of TKE at each time step is considerably large and it possibly disturbs the structure of boundary layer in the model. It is also found that the maximum height at which TKE exists seems to be excessively restrained, and momentum, heat and water substances are not enough vertically transported in the previous model. That is one reason for insufficient diurnal changes of surface temperature and wind in the previous model.

In the improved Mellor-Yamada scheme suggested by Nakanishi (2001); Nakanishi and Niino (2004, 2006), closure constants and mixing length in the original Mellor-Yamada model are revised based on the results of LES, and stabilization on time integration of turbulent variables is taken.

Mellor-Yamada model has second-order closure, in which the proportional constant C_m is variable to be determined depending on field structure in the scheme. It is expected more suitable transportation is realized in unstable mixing layer than the previous scheme in which C_m is a constant.

We implemented the improved MY3 into JMANHM with the source code of the main part of the scheme provided by Dr. Nakanishi.

Another possible reason for too small diurnal change of surface temperature and wind speed of the previous model is the shortage of shortwave radiation flux toward surface due to overestimated cloud fraction for radiation process, which is evaluated based on relative humidity.

As one of the trial to resolve the problem, the partial condensation scheme (Sommeria and Deardorff,

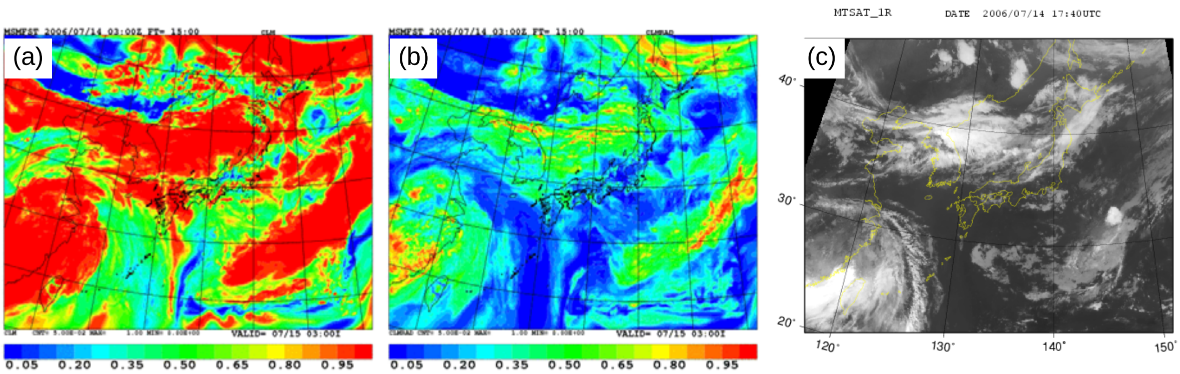

Fig. 1: Example of middle level cloud fraction for the radiation process, 15-hour forecast of which initial time is 0300 UTC 14 Jul. 2006. (a) diagnosed by relative humidity, (b) the same as (a), but by partial condensation scheme, (c) corresponding satellite image by MTSAT-1R IR channel.

1976) with outputs by MY3 is applied to provide cloud fraction and cloud water content for the radiation process. Note that the partial condensation is considered only in diagnosing cloud fraction and cloud water content for the radiation process and evaluating the effect of buoyancy to turbulence, and no feedback is given to cloud micro physics at present.

4. PERFORMANCE OF MY3 AND PARTIAL CONDENSATION SCHEME

4.1 Impact on shortwave radiation flux toward surface

The partial condensation scheme gives drastic impacts on cloud fraction. The example of cloud fraction

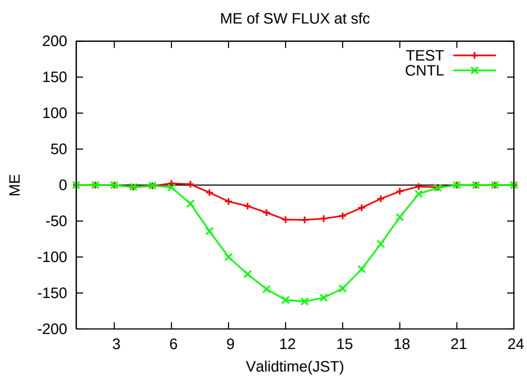

Fig. 2: Mean error of shortwave radiation flux toward surface compared with observation for each validtime. The verification term is from 1 Jul. 2006 to 31 Jul. 2006. The horizontal axis indicates validtime in JST localtime (UTC + 9). Green: with cloud diagnosed by relative humidity, red: with cloud by partial condensation.

in the models is shown in Fig.1. With cloud fraction diagnosed by relative humidity, almost areas are covered with clouds and clear regions can hardly be seen. On the other hand, clear regions with cloud fraction by the partial condensation scheme agree better with its observation.

To validate the cloud fraction by the partial condensation scheme, shortwave radiation flux toward surface was compared with observations as shown in Fig.2. The large negative bias of shortwave radiation flux the previous model had is considerably reduced with cloud fractions by the partial condensation scheme.

4.2 Impact on heavy rain in July 2004 in Niigata and Fukushima

On 13 July 2004, heavy rain hit Niigata and Fukushima Prefecture in central Japan. It brought over 400 mm precipitation from the beginning, and 15 people were killed. The heavy rainband was generated on a stationary front and it stood still for a long time. In this case, the model with MY3 is able to predict the rainband better than the one with the previous turbulent scheme as in Fig. 3, although the position of the rainband differs a little.

4.3 Impact on mixing layer on Japan Sea in winter

In winter, mixing layer is often developed on the Japan Sea because of cold air from the continent advecting on warm sea surface, where cloud streaks along wind direction, from northwest to southeast, are observed. When cold advection is strong enough to cross the Japan island, mixing layer is also seen on

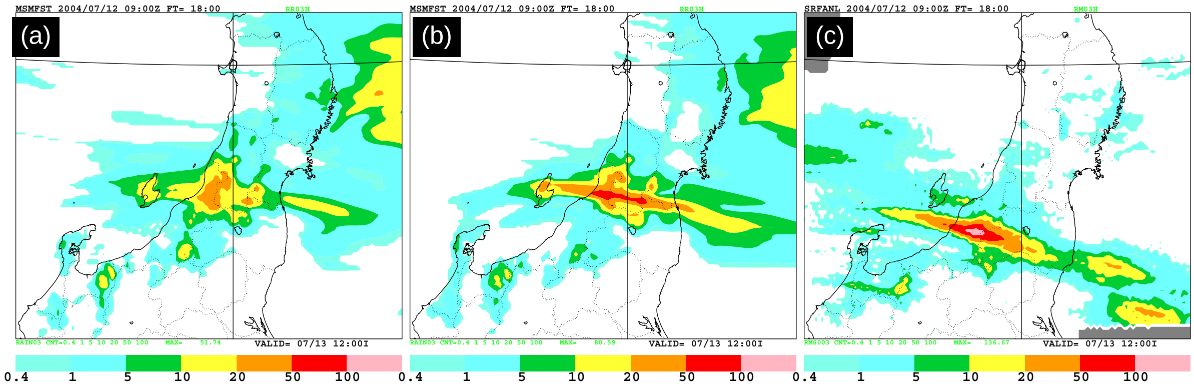

Fig. 3: 3-hour accumulated precipitation at 0300UTC 13 Jul. 2004. (a) 18-hour forecast by the model with the previous turbulent scheme, (b) the same as (a) but with MY3, (c) corresponding observation.

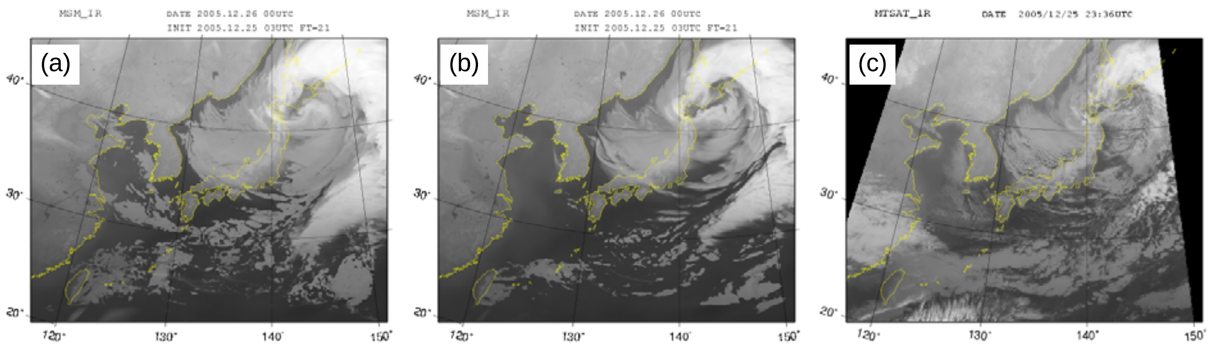

Fig. 4: Simulated IR channel satellite images with predicted quantities and observed image on 0000UTC Dec. 26 2005. (a) simulated image by 21-hour forecasts with the previous scheme, (b) the same as (a) but with MY3, (c) corresponding observed image.

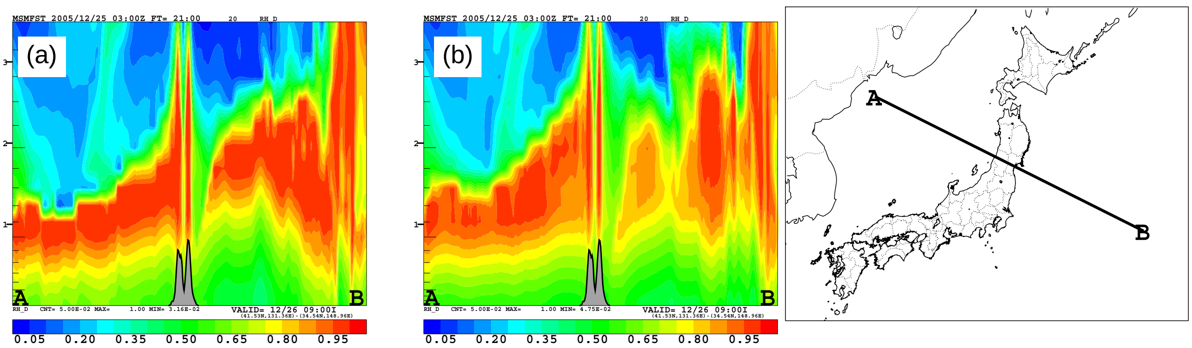

Fig. 5: Cross section of predicted relative humidity along line AB on the right figure on 0000UTC Dec. 26 2005. Its initial time is 0300 UTC Dec. 25 2005. (a) with the previous scheme, (b) the same as (a) but with MY3.

the Pacific Ocean. The typical case is shown in Fig. 4, which includes observation by MTSAT-1R satellite and simulated satellite images with the predicted quantities of the model with MY3 and the one with the previous turbulent scheme. The representation of cloud on the Japan Sea and the Pacific Ocean should be attracted. Detail structures of cloud can be observed in the image simulated by the model with MY3. With the previous scheme, cloud spreads excessively wider. It is because vapor is concentrated as the result of the suppression of vertical diffusion of vapor, and then more cloud is generated due to condensation, which is sup-

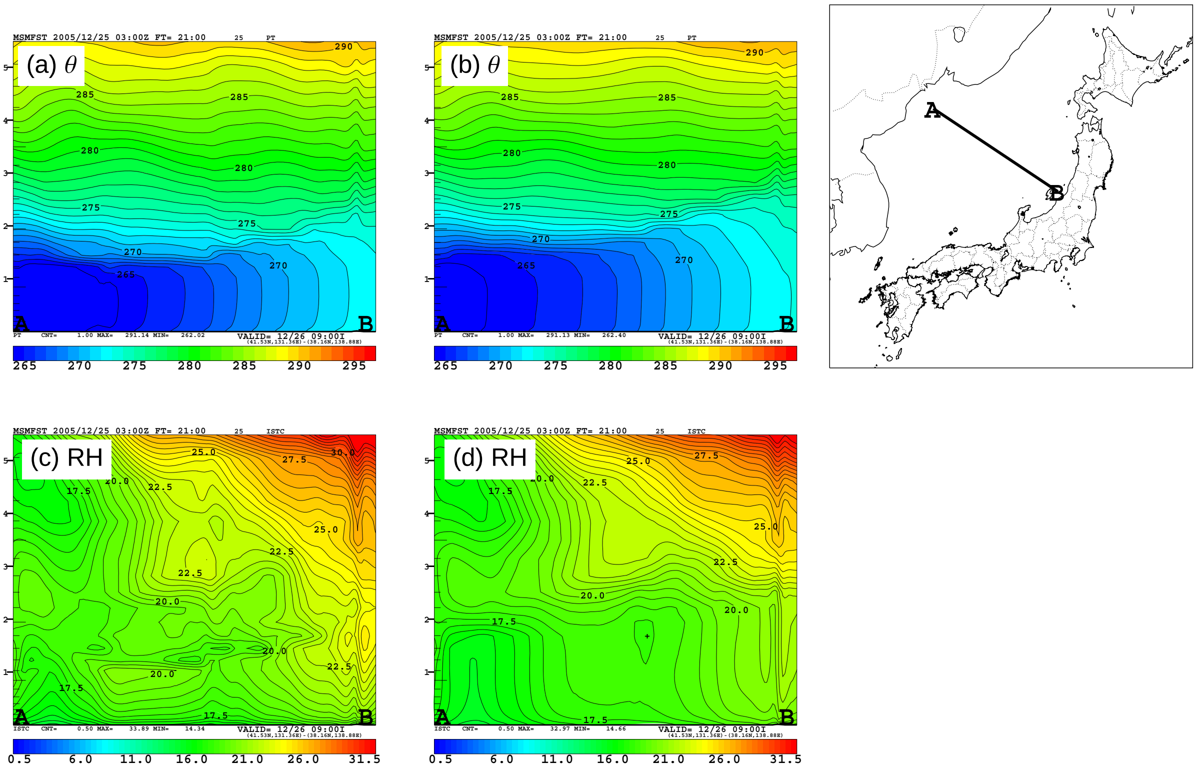

Fig. 6: Cross section of predicted potential temperature and wind speed along line AB on the upper-right figure on 0000 UTC Dec. 26 2005. Its initial time is 0300 UTC Dec. 25 2005. (a) potential temperature with the previous scheme, (b) the same as (a) but with MY3, (c) wind speed with the previous, (d) the same as (c) but with MY3.

ported by Fig 5, or cross section of relative humidity.

The remarkable difference between the results of the model with MY3 and the one with the previous can be seen in the vertical profile of wind speed. Fig 6 shows cross section of potential temperature and wind speed along the line crossing the Japan Sea. The uniformly diffused distribution, which characterizes mixing layer, is realized for potential temperature by both of schemes, but as for wind speed, horizontal contours come into sight with the previous scheme while uniformed one can be seen with MY3. It means that vertical transportation of momentum with the previous scheme is not large enough to generate uniform mixing layer which should be generated under this environment.

4.4 Statistical Verification

The statistical verifications for the new MSM including the improved MY3 and the partial condensation scheme are displayed on Hara et al. (2007). The more realistic diurnal changes of surface temperature and wind velocity and more accurate vertical profiles of temperature and wind are brought mainly by the adoption of these schemes. (It is found that the other improvements do not contribute to these improvements very much through our experiments for impact of each improved physical process.)

5. CONCLUSION AND REMARKS

The improved Mellor-Yamada Level 3 and the partial condensation scheme work much better on vertical profiles of temperature and wind, diurnal changes of surface temperature and wind. Especially, the vertical structure of wind speed in mixing layer is drastically improved. And it gives remarkable impact for a heavy rain case. They are included in the new MSM which has been operational since 16 May 2007.

In the partial condensation scheme, condensed water is used only in the radiation process and the turbulence process, in which buoyancy flux is evaluated, and does not affect the variables in the cloud microphysics. Because cloud water should not exist in unsaturated grid box in the current cloud microphysics scheme, inconsistency occurs if the partial condensation is allowed. (For example, partially condensed water evaporates soon.) It is our future work that how the cloud microphysics and the partial condensation scheme can be consistently combined.

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