Implementation of improved Mellor-Yamada Level 3 scheme and partial condensation scheme to JMANHM and their performance

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1 Introduction

JMANHM is a non-hydrostatic model which is being developed in the Japan Meteorological Agency(JMA). It is employed as an operational mesoscale model (MSM) for 15-hour forecast 8 times a day to provide information for preventing disaster such as severe rain, wind and so on[1].

The horizontal resolution of MSM was enhanced from 10 km to 5km in March 2006, and we plan to expand forecast time of MSM from 15 hours to 33 hours in May 2007. At the same time, the model of which many physical processes are improved will be in operational[2]. One of the improvements is the turbulence scheme which is a main topic of this report.

It has been pointed out that diurnal changes of surface temperature and wind speed predicted by the current MSM are small, that is, it has the negative bias in the daytime and the positive bias in the nighttime. It is possibly caused by the inappropriate representation for transportation of momentum and heat by turbulence in the boundary layer and the insufficiency of short wave radiation flux to surface due to excessive cloud fraction diagnosed by relative humidity.

To get improved for the problem, the improved Mellor-Yamada Level 3 scheme (MY3)[3][4][5] is introduced to JMANHM. Furthermore, cloud fraction and cloud water content used in the radiation process are calculated by the partial condensation scheme[6] with outputs from MY3.

It is confirmed that the model with the improved MY3 and the partial condensation scheme is better on diurnal changes of surface temperature and wind speed and vertical profiles of temperature and wind through our experiments. They will be adopted in the next operational model scheduled in May 2007.

In this report, we will introduce the implementation of MY3 and partial condensation schemes to JMANHM and their performances.

2 Turbulence scheme and cloud in the radiation process of the current MSM

The turbulence scheme of the current MSM is based on Klemp and Wilhelmson[7], in which the coefficients of diffusion which determine the physical quantities of transportation depends on turbulence kinematic energy (TKE) and mixing length. The algebraic equation to get TKE is derived by forecast equation for TKE by neglecting terms of time differential, advection and diffusion of itself assuming the balance between local producing and dissipation of TKE, and TKE is calculated diagnostically by solving the algebraic equation. To consider non-local effect, mixing length is estimated dependently on the height of boundary layer according to Sun and Chang[8]. Because of diagnostic scheme to calculate TKE, the variation of TKE at each time step is considerably large and it possibly disturbs the atmospheric field in the model. Moreover, the mixing length seems not to be suitable in many cases. In some cases it is excessively long and boundary layer is destroyed as a result.

On the other hand, short wave radiation flux in the current model is much less than that of observation because of too much cloud fraction by diagnosis with relative humidity[9]. It is tried to use the quantities of the cloud microphysics in the radiation process, but the coverage of cloud is too small and consequently too large short wave radiation flux pours on surface. It is because cloud water and cloud ice in the cloud microphysics are produced only at saturated grid, and it suggests necessity to introduce the scheme in which cloud water can be produced even if it is not saturated.

3 Introduction of the improved Mellor-Yamada Level 3 scheme and the partial condensation schemes

Mellor-Yamada scheme is the second-order turbulent closure model. In its Level 3 scheme, the variables to be forecasted are TKE, $\theta_l'^2$, $q_w'^2$, $\theta_l' q_w'$, where θ_l', q_w' are the fluctuations from the average values of liquid water potential temperature and total water content respectively. The counter-gradient terms which are considered as non-local effect are naturally appeared as correction of the coefficients of diffusion.

In the improved Mellor-Yamada Level 3 scheme, closure constants and mixing length are corrected based on large-eddy simulation (LES). Stabilization for integrating forecast variables is also taken.

The partial condensation scheme gives cloud fractions and cloud water content through a probability density function (PDF) on θ_l', q_w', which we assume bi-normal distribution. The attributes of PDF determine how much vapor partially condensates at an unsaturated grid. The width σ of distribution function depends on θ'^2, $q_w'^2$, $\theta_l' q_w'$. The evaluated cloud fraction and cloud water content are applied in the radiation process and the turbulence process.

We are provided source code of the main part of the improved MY3 and the partial condensation scheme by Dr. Nakanishi who is the developer of the improved MY3, and we implemented it to JMANHM with some changes.

We add the further improvement as following:

- While total water content q_w consists of mixing ratio of vapor q_v and cloud water q_c in the original code, mixing ratio of cloud ice q_i is additionally considered. Condensed water q_l is assigned to q_c more than 0°C, q_i under -36°C, and q_c and q_i linearly on a temperature between 0°C and -36°C.
- Not only turbulence contributes to produce subgrid cloud, but also cumulus convection and so on. The width of PDF σ is limited to a minimum value which depends on saturated vapor amount to consider the effect. It means that production

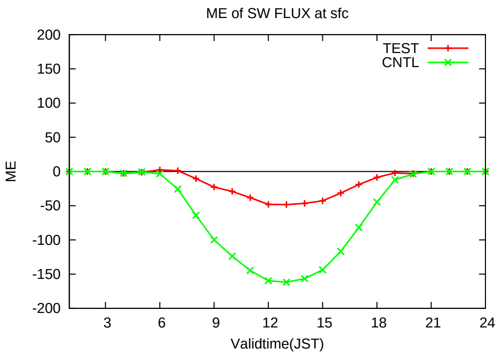

Fig. 1: Mean error of short wave radiation flux in models compared with observations for each local time. Unit: W/m^2. Green line: the current MSM. Red line: the new MSM which includes the improved MY3 and the partial condensation schemes.

of cloud water becomes easier than without this limitation.

4 Performance

The statistical verifications for the new MSM including the improved MY3 and the partial condensation scheme are displayed on [2]. 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 through our experiments for impact of each improved physical process that the other improvements do not contribute to these improvements very much.)

Fig.1 shows the comparison of short wave radiation flux to surface between model and observation. While the flux of the current model (green line) has large negative bias, that of the model with those new schemes (red line) is well reduced.

Fig.2 shows the impact of introducing the improved MY3 and the partial condensation scheme for precipitation forecasts. Although the position of rainband differs from the corresponding observation, the rainband is forecasted clearer by the model with those schemes. In this case, because the transportation of momentum from upper to lower is larger than the original model, wind velocity becomes faster and convergence at lower layer seems to be strengthened.

5 Conclusion and Remarks

The improved Mellor-Yamada Level 3 and the partial condensation scheme works much better on diurnal changes of surface temperature and wind, vertical profiles of temperature and wind. And it gives remarkable impact for a heavy rain case. They are included in the new MSM which will operationally run in 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 on unsaturated grid 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.

References

[1] K.Aranami and T.Segawa. Verification of mesoscale forecasts by a high resolution non-hydrostatic model at jma. *CAS/JSC WGNE Res. Activ. Atmos. Oceanic Modell.*, 36, 66–67, 2006.

[2] T.Hara, K.Aranami, R.Nagasawa, M.Narita, T.Segawa, D.Miura, Y.Honda, H.Nakayama, and K.Takenouchi. Upgrade of non-hydrostatic operational mesoscale model at jma. *CAS/JSC WGNE Res. Activ. Atmos. Oceanic Modell.*, 37, 2007.

[3] M.Nakanishi. Improvement of the mellor-yamada turbulence closure model based on large-eddy simulation data. *Bound.-Layer Meteor.*, 99, 349–378, 2001.

[4] M. Nakanishi and H. Niino. An improved mellor-yamada level 3 model with condensation physics : Its design and verification. *Bound.-Layer Meteor.*, 112, 1–31, 2004.

[5] M. Nakanishi and H. Niino. An improved mellor-yamada level-3 model: Its numerical stability and application to a regional prediction of advection fog. *Bound.-Layer Meteor.*, 119, 397–407, 2006.

[6] G. Sommeria and J.W. Deardorff. Subgrid-scale condensation in models of nonprecipitating clouds. *J. Atmos. Sci*, 34, 344–355, 1976.

[7] J.B. Klemp and R.B. Wilhelmson. The simulation of three-dimensional convective storm dynamics. *J.Atmos.Sci.*, 35, 1070–1096, 1978.

[8] W. Y. Sun and C. Z. Chang. Diffusion model for a convective layer. part i: Numerical simulation of convective boundary layer. *J. Climate Appl. Meteor.*, 25, 1445–1453, 1986.

[9] R.Nagasawa. Improvement of a radiation process for the non-hydrostatic model. In *12th Conference on Atmospheric Radiation*, pages P2–10. American Meteorological Society, 2006.

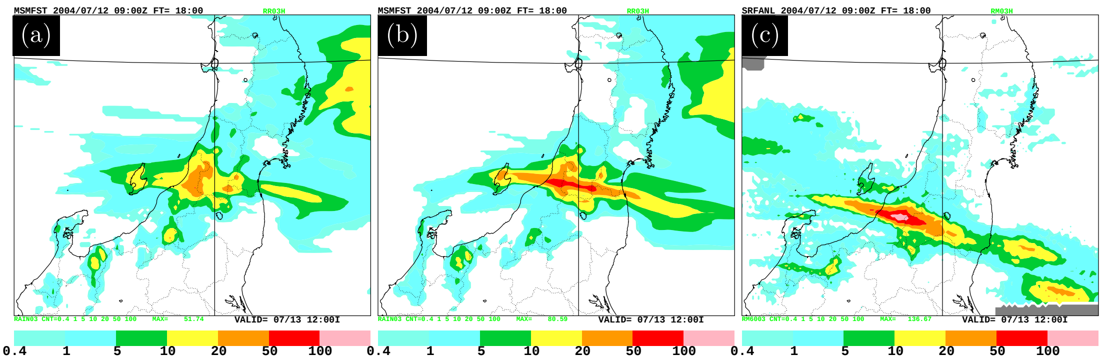

Fig. 2: Forecasted 3-h precipitation (unit: mm) at forecast time 18 hours with the initial time of 09UTC 12 July 2004. (a) the current MSM. (b) MSM with the improved MY3 and the partial condensation scheme. (c) corresponding observation.