Development of Land-surface Processes in the JMA Nonhydrostatic Model

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1 Introduction

At the Japan Meteorological Agency, mesoscale model (MSM) output is used as input data for applications such as maximum/minimum temperature forecasts and weather classifications. Land surface processes of NWP models play roles of lower boundary conditions and influence atmospheric conditions near the surface. Accordingly, surface process improvement is an important task in the development of the MSM.

The operational MSM employs a simple slab model as a land surface scheme, in which the effects of vegetation are expressed only as the influence of stomatal resistance on the computation of latent heat flux. The initial conditions of soil moisture are set to climatological values. Snow is expressed as a kind of land use, and the conditions of land use are constant during the time integration of the model. Because of this simplification, the MSM sometimes fails to forecast surface air temperature accurately, underestimating the maximum temperature on hot days and the minimum temperature on snow melting days.

The JMA nonhydrostatic model, the forecast model of the MSM, includes a more detailed land surface model called the MJ-SiB (MRI/JMA Simple Biosphere model) as an option. We are developing the MJ-SiB for implementation into the operational MSM, and this report focuses on recent improvements to the MJ-SiB.

2 Specifications of the MJ-SiB

The MJ-SiB is based on the New-SiB (Hirai et al. 2007) implemented into JMA's Global Spectral Model. The MJ-SiB includes three models, a vegetation canopy model, a soil model and a snow model. The vegetation canopy model (hereafter, canopy model) is based on Sellers et al.(1986), and considers evaporation and transpiration from canopy and grass cover. The canopy model is directly coupled with the atmospheric model. The soil model has three and four layers for soil moisture and temperature, respectively. Diffusive equations are solved to forecast soil temperature and the saturation rate of soil moisture and phase changes in soil moisture are considered in the model. The snow model employs a multiple layer structure (four layers at maximum) with the number of layers depending on the amount of snow water equivalent amount.

3 Categories of vegetation types

For the original MJ-SiB, distribution of vegetation is divided into 13 categories (Dorman and Sellers, 1989). To allow the use of data with higher resolution and accuracy for the Japan Area, We add 12 further categories of vegetation based on land use data produced by the country's Geographical Survey Institute. The new categories are forest, farmland, urban area, each of which is subdivided into four smaller categories according to the coverage rates of forest or buildings in indivisual grids. Parameters such as the Leaf Area Index and coverage rate of the vegetation are set in each new category.

4 Improvement of computational stability

Figure 1 shows a time series of temperature forecasted/diagnosed by the canopy model. The curves of temperature oscillate with a frequency of $2\Delta t$. In particular, T_1 (the temperature at the lowest level of the atmospheric model) and Tc (the temperature at the canopy) reach $270K$ because of this oscillation. The oscillation is due to the computational instability.

To solve the problem, we refined the prognostic equations of the canopy model. First, an implicit scheme is employed for the eddy diffusive term of the equation for T_1. Then, we evaluate the eddy diffusive term for heat based on the vertical gradient of dry static energy replacing vertical gradient of temperature. Finally, the future values of Ta and Qa (canopy air temperature and water vapor) are returned to the atmospheric model. All of these modifications reduce the magnitude of surface and turbulent fluxes, and stabilize the time integration. Figure 2 shows a time series of temperature in a case with the modified MJ-SiB. The modifications remove almost all the oscillation and make the time integration stable. Due to the reduction of turbulent fluxes to the upper atmosphere, the temperature in the canopy model becomes higher than that shown in Figure 1.

5 Performance of the MSM coupled with the MJ-SiB in summer

To assess the performance of the MSM coupled with the MJ-SiB, a number of experiments were carried out for summer conditions. In this section, we ontline an experiment for a period of heavy rain (3 to 7 August 2008). Hereafter, we refer to the experiments using the MJ-SiB and operational surface scheme as SiB and Rtn, respectively. Figure 3 shows the mean errors (ME) for surface air temperature of each experiment in the period of heavy rain days. Compared to Rtn, SiB expands the negative and positive biases during the daytime at nighttime, respectively. The positive biases expand rapidly in the evening (6 to 9 UTC in Figure 3).This means that SiB damps the diurnal cycle of temperature near the surface. The amplitude of the diurnal cycle strongly depends on the heat capacity of the ground skin. Using an analogy of the force restore method (Deardorff, 1978), the heat capacity of the ground skin can be estimated as follows;

$$c_g = \sqrt{\frac{c_s \rho_s k_s}{2\omega}} \quad W/\left(m^2 \cdot K\right)$$

$c_s\rho_s$ and k_s represent the heat capacity per unit volume and the thermal conductivity of the soil. ω is equal to the angular frequency for a day. According to the values of $c_s\rho_s$ and k_s in Pielke(2002), c_g varies from $O(10^4) \sim O(10^5) W/\left(m^2 \cdot K\right)$. In the MJ-SiB, c_g is set to $2.5 \times 10^5 W/\left(m^2 \cdot K\right)$, at the high end of the range. When the heat capacity of the ground skin was reduced to one thirds of its original value, the ground skin temperature tended to fall in the evening. Positive biases in the evening were reduced (see the curve of SiBcap in Figure 3).

6 Summary and future plans

We have been developing the MJ-SiB for implementation into the operational MSM. Preparation of landuse data and the improvement of computational stability have been carried out over the last few years. Numerical experiments for the summer season showed that the performance of the MSM coupled with the MJ-SiB depended on the heat capacity of the ground skin in the evening. Reducing the heat capacity to within a realistic range, made the mean error of surface temperature comparable to that of the operational MSM.

It is important in short range forecasting to estimate the initial conditions of temperature, water and snow depth at the land surface. We are also developing a land-surface analysis system using the offline version of MJ-SiB. In this system, the land-surface model is driven by atmospheric forcing data such as analyzed temperature, wind, observation based precipitation, and sunlight. The land surface analysis is expected to impact on forecasts of the MSM when the surface is too dry/wet or covered with snow.

References

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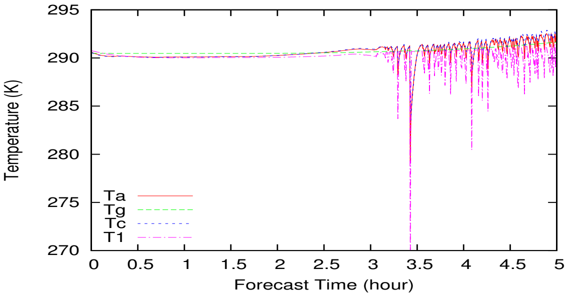

Figure 1: Time series of temperature of the canopy model. Ta:Air temperature in the canopy, Tg:Ground skin temperature Tc:Canopy Temperature T1:Air temperature at the lowest level of the atmospheric model.

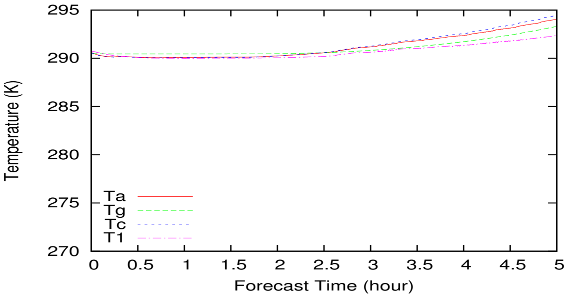

Figure 2: Same as Figure 1 but for the computationally stabilized MJ-SiB

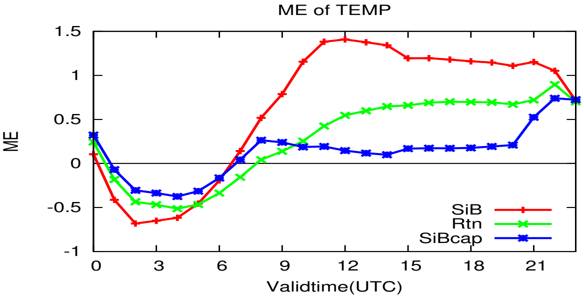

Figure 3: Time series of mean error of surface temperature.