P2.22 DEVELOPMENT OF A NEW LAND-SURFACE MODEL FOR JMA-GSM

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1. Introduction

The SiB (Simple Biosphere) model (Sellers et al. 1986; Sato et al. (1989a,b)) of JMA has remained unchanged substantially since it was implemented in the operational global NWP model (JMA-GSM) in 1989. Accordingly, following systematic errors, which are considered to be relevant to the operational land-surface scheme (hereafter "Op-SiB"), have come to the surface.

i) Overestimate of thaw.

ii) Warming bias in a lower troposphere on ice sheet area in summer.

In order to mitigate such errors, we have developed a new land-surface model (hereafter "MJ-SiB"), which treats soil and snow processes more accurately. Major upgrades from Op-SiB to MJ-SiB are described in section 2.

Preliminary assimilation and forecast experiments of the SiB models coupled with JMA-GSM (T213L40) are carried out first. The systematic errors, however, scarcely disappears after all. Reports on these experiments are given in section 3.

Next, sensitivity experiments of MJ-SiB to several parameters are carried out in order to find out what factor is a major cause of the systematic errors mentioned above. Findings of these investigations are fruitful. Details are given in section 4.

Finally, summary and future plans are described in section 5.

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2. Shortcomings of Op-SiB and Outline of MJ-SiB

a. Shortcomings of Op-SiB

Fig. 1 shows snow cover area of 72-hour forecast (FT72) and its verifying analysis (FT00) for April 2002. The one-month average of forecast results for operational JMA-GSM is indicated. Because of overestimate of thaw, the southern edge of the snow cover tends to retreat faster comparing with the analysis.

Fig. 2 shows a mean error of temperature at the lowest level of the atmospheric model (about 50 meters in height) for 72-hour forecast against initialized analysis (FT00) in January and July 2003. Warming bias appears in the Antarctic in January 2003 and in Greenland in July 2003.

As mentioned above, the systematic errors, which are considered to be relevant to the land-surface model, are as follows:

i) Overestimate of thaw.

ii) Warming bias in a lower troposphere on ice sheet area in summer.

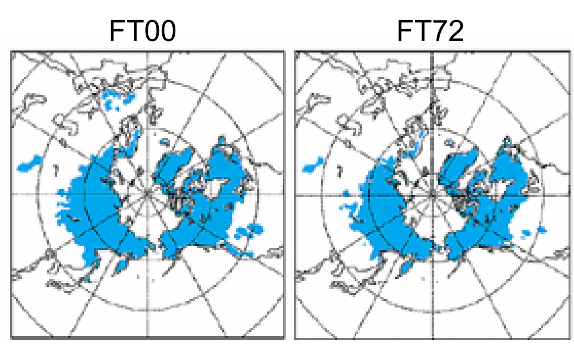

Fig. 1. Monthly mean of the snow cover area in April 2002. The left figure shows analysis (FT00), and right one does72-hour forecast (FT72). Shaded area corresponds to Snow Water Equivalent (SWE) larger than 5[kg/m^2].

b. Outline of MJ-SIB

In order to solve these shortcomings, we have developed a new land surface model (MJ-SIB), which consists of three sub-models, soil, snow and canopy. Major changes from Op-SiB to MJ-SiB are as follows:

* A conventional force restore method for predicting soil temperature is abandoned and heat conductivity among multiplied soil layers is explicitly calculated.

* Phase change of soil water is considered.

* Multiple snow layers are introduced and phase change of snow water is considered.

* Snow cover is classified into two categories, partial snow cover and full snow cover.

* Sophisticated snow processes are introduced such as aging of snow albedo, temporal changes of snow density and heat conductivity, keeping water in snow layers and so on.

Fig. 3 schematically illustrates the processes related to the energy balance considered in Op-SiB and MJ-SiB. In MJ-SiB, the snow and soil processes are designed more elaborately than those in Op-SiB. Therefore, it is expected that MJ-SiB can simulate energy and water balances of snow and soil layer more precisely.

With regard to the canopy process, frameworks of energy and water transfers are kept unchanged in principle. The concept of the canopy process is analogous to an electric circuit as illustrated in Fig. 4.

In the season of snow melting, the snow

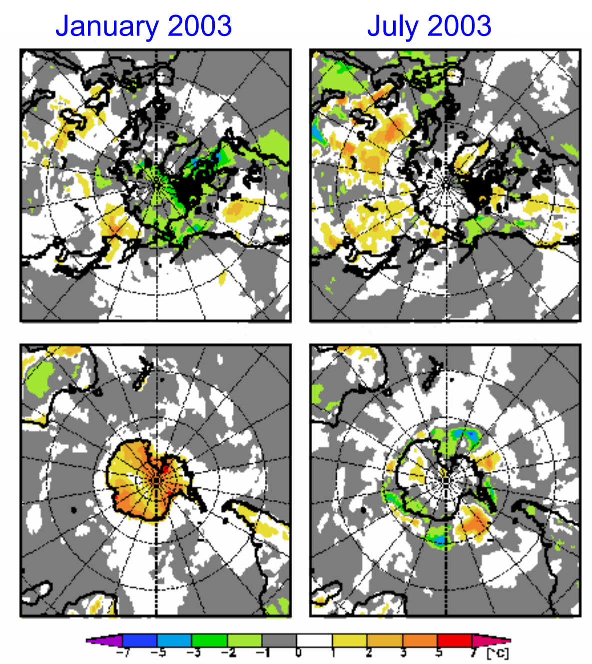

Fig. 2. Mean error of temperature at the lowest level of the atmospheric model (about 50 meters of geopotential height) for 72-hour forecast (FT72) against initialized analysis (FT00). The left is the error for January 2003, and the right is the error for July 2003.

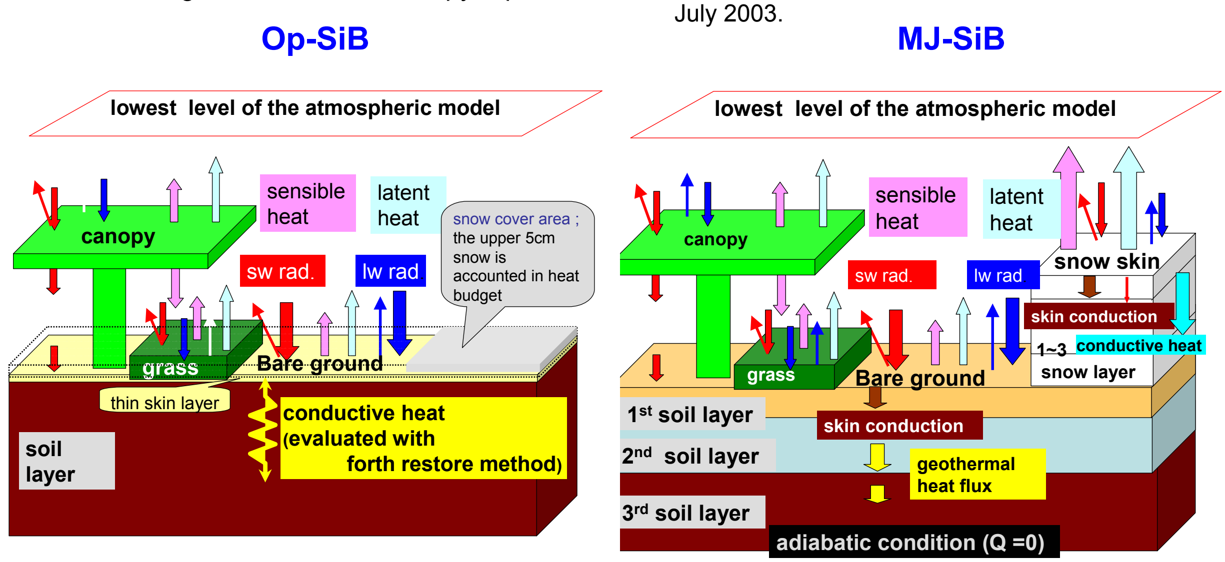

Fig. 3. Schematic illustration of the processes related to energy balance considered in Op-SiB (left) and MJ-SiB (right).

surface tends to be wet, since snow temperature is around at the melting point. Therefore, wet-snow albedo is a very important factor in estimating energy balance. The treatments of snow albedo in both SiB models are presented next for discussions in Section 4.

In Op-SiB, snow albedo is given as in Table 1, where dry snow is defined so that temperature of the snow surface with 5cm of thickness is less than -0.05℃.

To consider aging of snow , dry-snow albedo in MJ-SiB is given as follows:

$$0.6 + (0.8\text{-}0.6)\exp(-t/\tau) \qquad \text{(for VIS)}$$

$$0.5 + (0.6\text{-}0.5)\exp(-t/\tau) \qquad \text{(for NIR)}$$

where τ is a relaxation time (= 4days), and t is a lapse of days from the beginning of covering with snow. In case of wet snow, a coefficient 0.6 is multiplied to the albedo for dry snow in the same way as Op-SiB. In ice sheet (Greenland, the Antarctic and so on) snow albedo for VIS is set to 0.95 (dry snow) or 0.76 (wet snow).

3. Forecast experiments with MJ-SiB

a. Experiment design

Preliminary assimilation and forecast experiments of the SiB models coupled with JMA-GSM (T213L40) are carried out for April 2002. Initial condition of soil water for MJ-SiB is set to a model-climate state obtained from a long-term integration of the model, while Op-SiB uses a climate state by Willmott et al. (1985). The starting date of data assimilation is 11 March 2002. 40 cases of 216-hour forecast are performed for 12UTC from 21 March 2002 to 30 April 2002.

b. Results

Snow depth of 72-hour forecast (FT72) initiated at 12 UTC April 15, 2002 (validtime is 12UTC April 18, 2002) is shown in Fig. 5. The snow cover area in the Tibetan Plateau is well predicted by MJ-SIB, while not by Op-SiB. Comparing with the observation of snow cover

Table 1 Snow albedo.

case	dry snow albedo		wet snow albedo		
	VIS	NIR	VIS	NIR	
Op-SiB	0.8	0.4	0.48	0.24	
MJ-SiB (default)	0.8 ~0.6	0.6 ~0.5	0.48 ~0.36	0.36 ~0.3	
Type a	0.9	0.7	0.9	0.7	*)1
Type b	0.7 ~0.5	0.5 ~0.4	0.42 ~0.3	0.3 ~0.24	
Type c	0.8 ~0.6	0.6 ~0.5	0.8 ~0.6	0.6 ~0.5	*)2

*)1 ; no-aging.
*)2 ; wet-snow albedo is as same as dry-snow albedo.

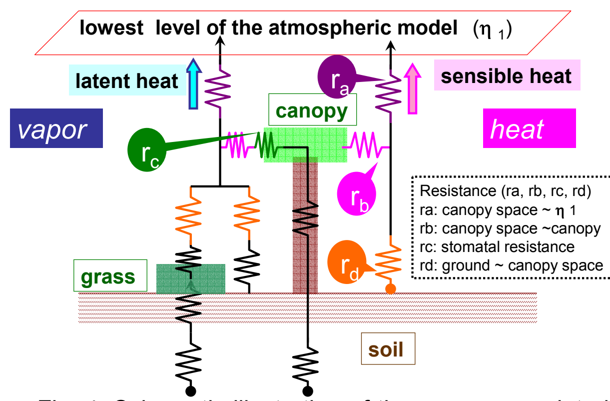

Fig. 4. Schematic illustration of the processes related to energy and water transfer in SiB model.

area estimated from the brightness temperature of SSM/I (Fig. 6), MJ-SiB simulates it better than Op-SiB in this region.

The overestimate of thaw, however, still remains in vast extent of taiga. Moreover, Root Mean Square Error (RMSE) of 850-hPa temperature in the Northern Hemisphere is scarcely improved even by MJ-SiB (Fig. 7). Warming bias of temperature at lower troposphere on ice sheet area in summer is also remained substantially (not shown).

4. Sensitivity experiments of MJ-SiB

a. Experiment design

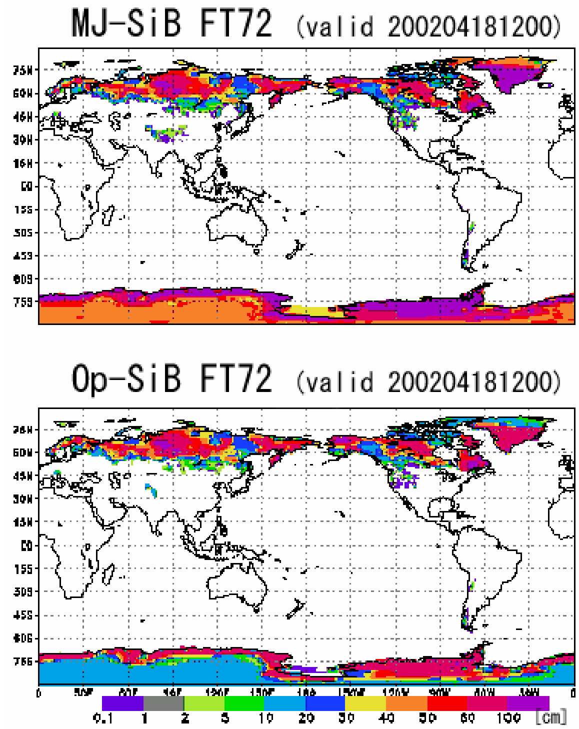

Fig. 5. Snow depth of 72-hour forecast (FT72) with the initial time of 12UTC April 15, 2002 (validtime is 12UTC April 18, 2002). The top is MJ-SIB and the bottom is OP-SiB.

It becomes clear that MJ-SiB scarcely improves prediction of thaw and temperature at lower troposphere on ice sheet area in summer. In order to find out what factor is responsible for these features, sensitivities of each process to various parameters are examined. The initial time is 12UTC 15 April 2002. Among these experiments, several significant cases are explained in this section.

1) Sensitivity to r_d (aerodynamic resistance between snow surface and canopy space)
2) Sensitivity to snow albedo
3) Sensitivity to minimum value of eddy diffusion coefficient for sensible heat in the PBL scheme

b. Results

To start with, the time series of the forecast results at Siberian taiga (55N, 80E) derived from the normal run of MJ-SiB are shown in Fig. 8. Heat flux (>80W/m2) into a snow layer is so large

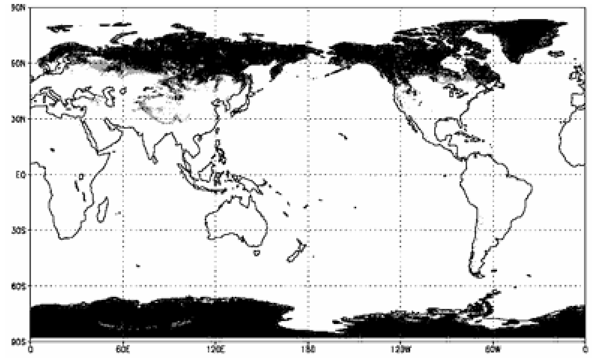

Fig. 6. Snow cover area observation for April 18, 2002 estimated from the brightness temperature of SSM/I.

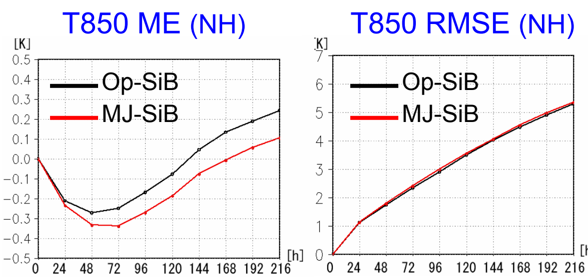

Fig. 7. Mean error (left) and RMSE (right) for 850hPa temperature against initialized analysis (FT00) in Northern Hemisphere extra-tropics (20N~90N). Black line indicates Op-SiB, red line MJ-SiB.

that snow severely thaws in the daytime. Accordingly, we pay attention to thawing in the daytime.

1) Sensitivity to r_d

One of the factors causing thaw is sensible heat flux due to a temperature gradient between snow surface and the atmosphere. In snow-cover area, temperature of canopy tends to be higher than that of snow surface because of absorption of solar radiation in the daytime, as shown in Fig. 8. The impact of enlarging r_d, aerodynamic resistance between snow surface and canopy space, extremely (10,000 times) to thaw is examined. Fig. 9 shows same as Fig. 8 but for the result with an enlarged r_d. While surface temperature (Tg) falls more gradually than

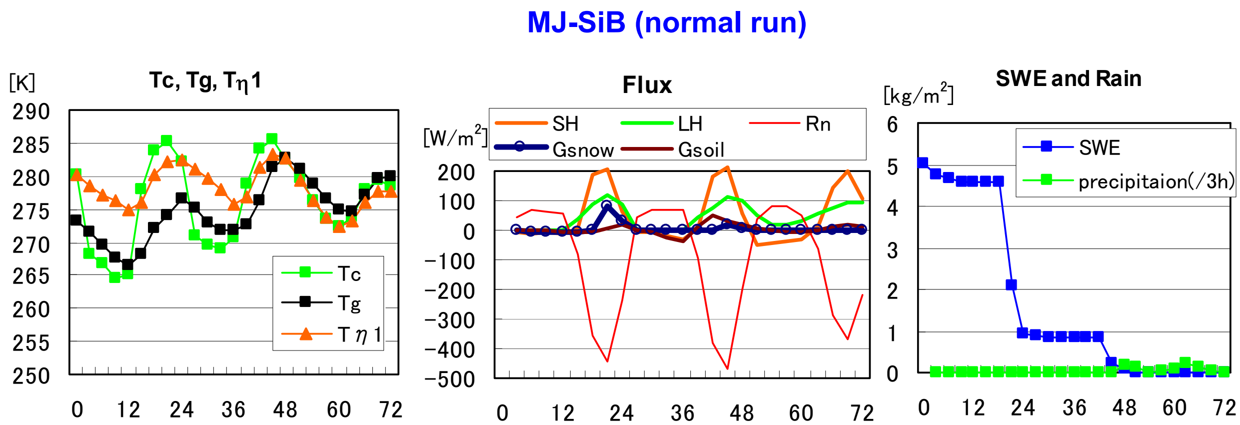

Fig. 8. Time series of the forecast results, which derived from MJ-SiB normal run, of temperature around snow surface (left), energy balance on surface(middle), and SWE (right) at Siberian taiga (55N, 80E).

In left figure Tc denotes canopy temperature, Tg snow (or soil) surface temperature and Tη1 temperature at the lowest level of the atmospheric model.

In middle figure, SH, LH and Rn means sensible heat, latent heat and net radiation (upward) respectively. Gsnow is heat flux into snow layer and Gsoil is that into soil layer.

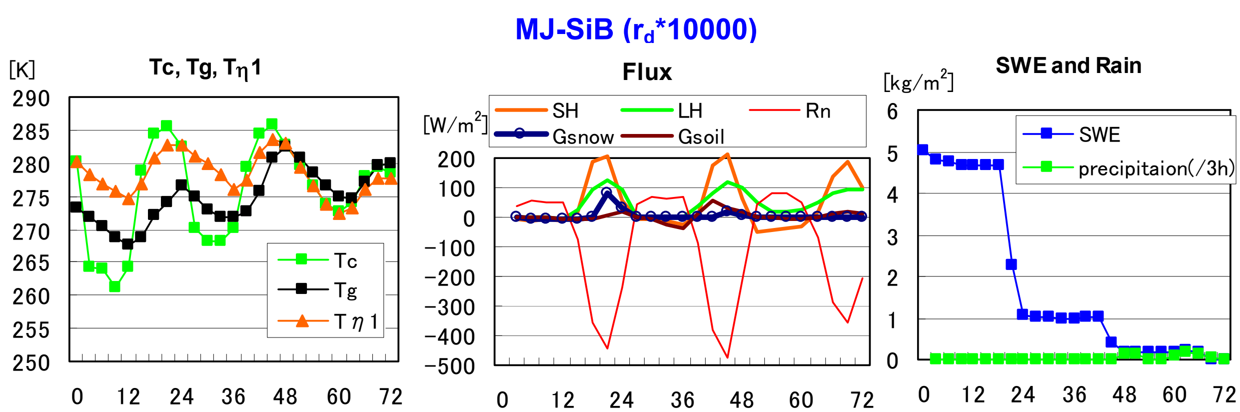

Fig. 9. As in Fig. 8, except for the results for r_d (aerodynamic resistance between snow surface and canopy space) enlarged extremely (10000 times).

the normal run in the first night, Tg rises as well as that of the normal run in the next daytime. The heat flux into the snow layer is also as large as that of the normal run. Consequently, the impacts on snow depth were imperceptible.

2) Sensitivity to snow albedo

An another factor causing thaw is shortwave radiation into snow layer, which is mainly affected by snow albedo. Thereupon, 3 types of albedo as presented in Table1 are examined.

Fig. 10 indicates the impacts of snow albedo on snow water equivalent (SWE) and temperature at the lowest level of the atmospheric model. The larger (smaller) a snow albedo is provided, the more slowly (rapidly) a thaw proceeds (Type a, Type b respectively). Meanwhile, the impact on temperature at lower troposphere in high latitude is large.

When a wet-snow albedo is set to the same value as that for dry snow, thaw becomes much slower. The larger impact on SWE is found in the vicinity of the southern edge of the snow cover. On the other hand, few impacts are seen on

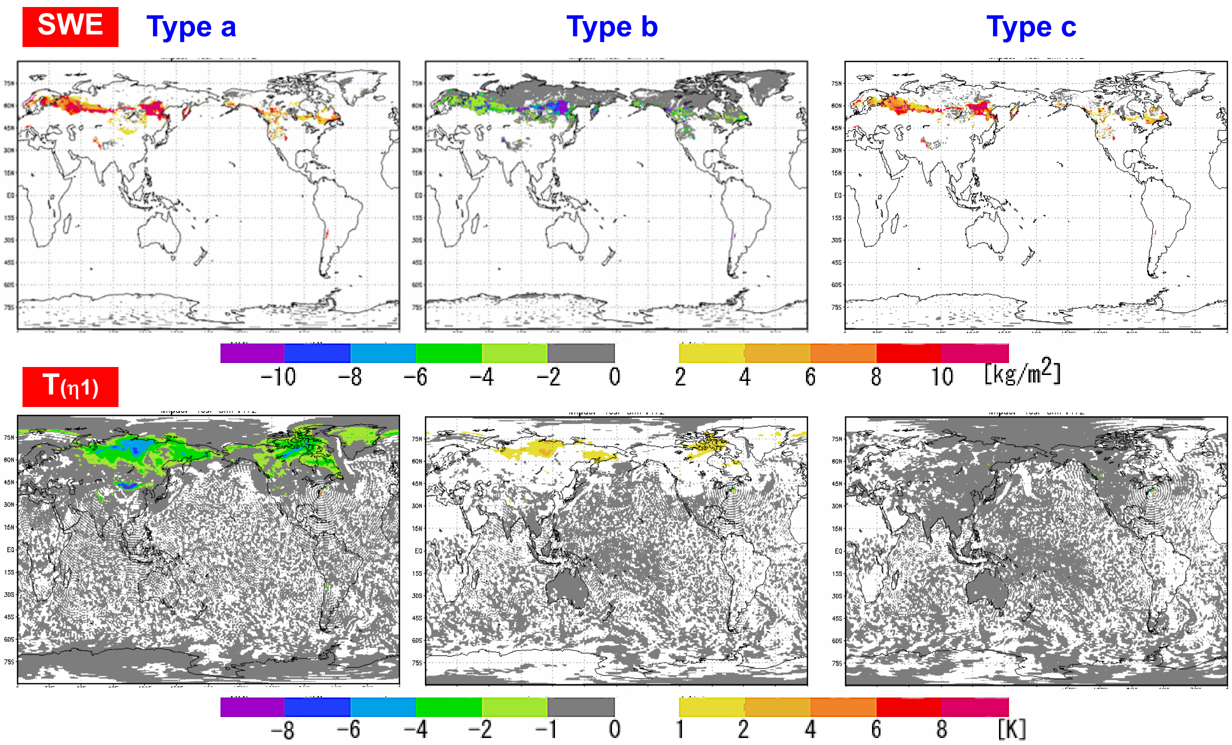

Fig. 10. Impacts on SWE(above) and temperature at the lowest level of the atmospheric model(below) for 72-hour forecast (FT72). Type a, Type b, Type c correspond to the different setting of snow albedo.　See Table 1.

temperature at lower troposphere in high latitude.

3) Sensitivity to minimum value of eddy diffusion coefficient for sensible heat in the PBL scheme

Now let us consider a warming bias in a lower troposphere on ice sheet area in summer in this sub-section.

Generally, an ice sheet surface tends to be colder than the lowest level of the atmospheric model.　Therefore, a strong stable layer is usually formed in such region.

According to the experiments, even though an aerodynamic resistance between canopy space and the lowest level of the atmospheric model (r_a) was nearly neglected (1/10,000 times), the impact on temperature at the lowest level scarcely appears (not shown).　Instead, a temperature of snow layer resulted in rise.

Incidentally, in the PBL scheme of operational JMA-GSM, the minimum of eddy

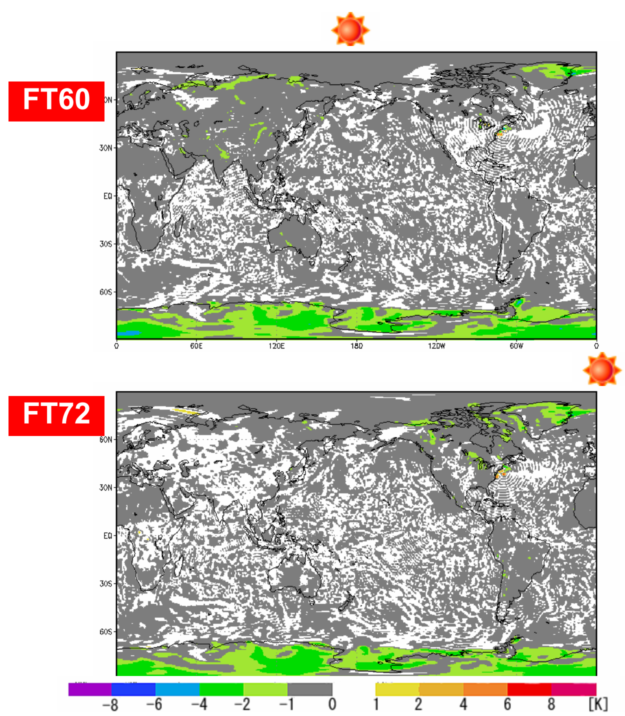

Fig. 11. Impact on temperature at the lowest level of the atmospheric model for 60-hour and 72-hour forecast (FT60 and FT72). As the-Sun-like mark indicates, the central Eurasian Continent is dawn at FT60, and the continents of America is dawn at FT72.

diffusion coefficient for sensible heat at the lowest level is set to 2.0[m^2/s]. The impact of lessening this value in half (=1.0) is examined. While a temperature at lowest level of atmosphere is 2~4 [K] cooler than default (Fig. 11), temperature at the top of boundary layer (about 1,500m height) is 2~4 [K] warmer (not shown). Meanwhile, in middle latitude of the continents, temperature at lowest level of atmospheric model is 1~2 [K] cooler at dawn.

5. Summary and Discussion

The operational JMA-GSM has the following systematic biases, which are considered to be relevant to the land-surface scheme:

i) Overestimate of thaw.

ii) Warming bias in a lower troposphere on ice sheet area in summer.

In order to mitigate such errors, we have developed a new land-surface model (MJ-SiB), which treats soil and snow processes more accurately. Preliminary assimilation and forecast experiments of the SiB models coupled with JMA-GSM (T213L40) are carried out for April 2002. The results of these experiments, however, shows that the overestimate of thaw still remained in vast extent of taiga, though the distribution of snow cover at Tibetan Plateau is well predicted.

Thereupon, sensitivity experiments of MJ-SiB to several parameters are carried out. Consequently, it becomes clear that the overestimate of thaw is closely related to the estimation of wet-snow albedo. Meanwhile, it was found that the warming bias in a lower troposphere on ice sheet in summer was relevant to a vertical diffusion coefficient in the PBL scheme.

In MJ-SiB, wet-snow albedo is provided by multiplying a coefficient 0.6 to dry-snow albedo according to Op-SiB. Note that the coefficient is a constant, though a wet albedo is smaller than dry-snow albedo in actuality. According to an observational research on snow properties (Aoki, Hachikubo and Hori (2003)), the constant value 0.6 is likely underestimated.

As thaw progresses and soil surface appears, an average albedo in the grid box decreases. Multiplying 0.6 is adopted in Op-SiB to represent such situation of partial snow cover implicitly. Therefore such a manner is not necessary in MJ-SiB, since partial snow cover is explicitly treated in MJ-SiB.

We refine on MJ-SiB by making use of the results of the experiments and plan to put it into operation within a next few years.

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