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EVALUATION OF THE LAND SURFACE MODEL OF JMA'S OPERATIONAL GLOBAL NWP MODEL - WITH THE CEOP EOP-3 REFERENCE SITE DATASET

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1. Introduction

Land surface conditions affect radiation processes, atmospheric temperature and precipitation through heat and moisture exchanges between land surface and the lower atmosphere. Therefore, in order to evaluate and simulate the energy budget and water cycles properly, a sophisticated land surface model is important for an NWP model.

JMA's operational global NWP model (JMA-GSM) currently adopts a Simple Biosphere (SiB) model. JMA has been developing a new SiB model to upgrade the current SiB model. Major upgrades from the operational SiB model to the new one are described in section 2. JMA is also developing a new clear-sky radiation scheme. Since the new clear-sky radiation scheme is expected to improve heat budget at the surface, this study examines both the operational and the new clear-sky radiation schemes. The main point of the new clear-sky radiation scheme is also shown in section 2.

Long-range forecast experiments with each of the operational and the new SiB models are executed to evaluate the forecasts for snow cover area formations. Results of the experiments are reported in section 3.

In order to understand and model the influence of continental hydro-climate processes on the predictability of global atmospheric circulation and changes in water resources, CEOP (Coordinated Enhanced Observing Period) was launched in 2001, which is striving to achieve an integrated database of common measurements from both in situ and satellite remote sensing measurements, as well as model output. A part of the in situ data for the Enhanced Observing Period 3 (EOP-3), from October 2002 to September 2003, is released from a CEOP data archive center at University Corporation for Atmospheric Research (UCAR). We carry out the assessment of the model forecasts with each SiB model against the CEOP data. The result is reported in section 4.

Finally, discussion and summary are described in section 5 and 6 respectively.

2. The new land surface model and the new clear-sky radiation scheme

2.1 Shortcomings of the operational JMA-GSM for near surface meteorology

The operational JMA-GSM has a systematic error of an overestimation of thaw. Figure 1 shows monthly mean of snow cover area for 72-hours forecast (FT72) and analysis (FT00) in April 2002. Because of an overestimation of thaw, the southern edge of the predicted snow cover

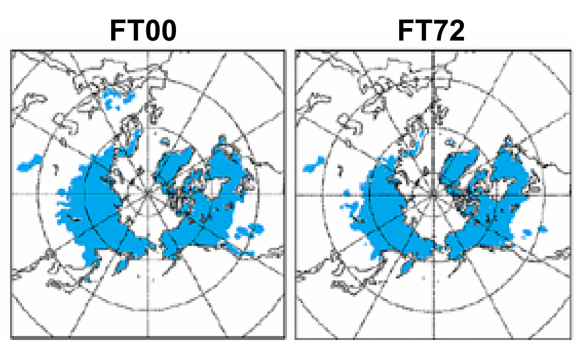

Figure 1. Monthly mean of the snow cover area in April 2002. The left figure shows analysis (FT00), and right one 72-hour forecast (FT72). Shaded area corresponds to snow water equivalent larger than 5 [kg/m^2].

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tends to retreat faster than the analysis. The operational SiB model treats snow and soil processes too simply to simulate a snowpack evolution adequately.

Furthermore, a validation study of JMA-GSM with the CEOP EOP-1 in-situ data reveals an underestimation of incoming long wave radiation (Hirai and Matsumura 2004). It suggests a systematic error in the radiation scheme of JMA-GSM.

2.2 Outline of the new SiB model

The SiB model has been implemented in JMA-GSM as a land surface model since November 1989 (JMA 2002). Figure 2 schematically illustrates the processes related to the energy balance considered in the operational and the new SiB models.

The operational SiB model takes only one soil layer into consideration for an estimation of heat conduction between surface and soil layer. Phase change of soil water and/or ice is not considered, namely soil water is instantaneously changed into ice when soil temperature is lowered to the freezing point. Moreover, the operational SiB model treats snow processes very simply. It considers only upper 5cm snow in the heat budget. Heat capacity of snowpack below 5cm is disregarded

The new SiB model vastly improves soil and snow processes in comparison with the operational one. Major changes from the operational SiB model to the new one are as follows:

* Multiple soil layers are introduced and heat conductions among soil layers are explicitly calculated.

* Phase change of soil water and/or ice is considered.

* The snow submodel is newly designed.

* Multiple snow layers are introduced and the number of layers varies depending on the snow water equivalent.

* A partial snow-covered grid is considered for a little snow.

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

In the new SiB model, snow and soil processes are designed more elaborately than those in the operational SiB model. Therefore, it is expected that the new SiB model can simulate energy and water balances of soil and snow layers more precisely.

2.3 Outline of the new clear-sky radiation scheme

A new clear-sky radiation scheme for JMA-GSM is being developed. Figure 3 illustrates the spectrum of long wave absorptions by each gas considered in the scheme to solve the radiative transfer equations. The long wave spectrum is divided into 9 bands in the new scheme, while 4 bands in the operational one. The absorptions by minor trace gases (CH_4, N_2O and CFC's) are calculated as well as that by major gases (H_2O, CO_2 and O_3). The new scheme takes the Doppler

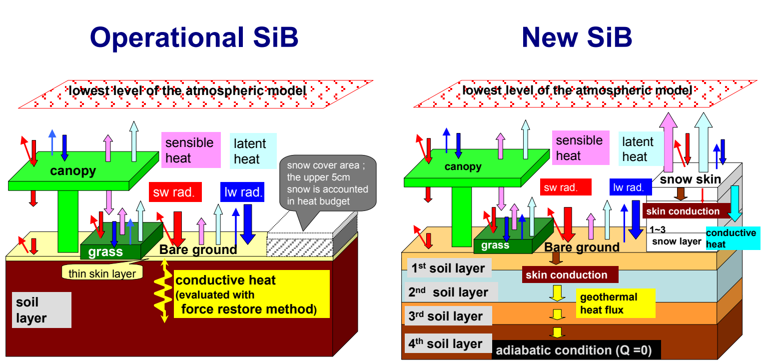

Figure 2. Schematic illustrations of the processes related to energy balance considered in the operational SiB model (left) and the new one (right).

broadening into account. It also includes a water vapor continuum absorption by both e-type (self) and P-type (foreign) line broadening which is newly parameterized over the entire infrared spectrum by referring a recent continuum model. Absorptions by O_3, CO_2 and O_2 for the short-wave radiation are also revised to represent an accurate radiative heating.

3. Snow cover area reproducibility with each SiB model

3.1 Experiment methods

In order to evaluate the reproducibility of snow cover area with each SiB model, long-range forecast experiments are executed. Since the new clear-sky radiation scheme is expected to represent a heat budget at the surface well, the new clear-sky radiation scheme as well as the operational one is examined in the experiment. After all, the following three 4-years forecasts are performed with JMA-GSM (T106L40).

a) The operational SiB model and the operational clear-sky radiation scheme (osib+orad)

b) The new SiB model and the operational clear-sky radiation scheme (nsib+orad)

c) The new SiB model and the new clear-sky radiation scheme (nsib+nrad)

The time integration starts on 1 August 2002, when the most part of the Northern Hemisphere is not covered with snow, so that the predictability of snow cover area is well examined. The period of the time integration is 4 years so that prediction results for 4 winter seasons can be obtained. Daily snow cover forecasts averaged over 4 years are compared with the 4-years averages (1999~2003) of the daily snow cover analysis by NOAA/NESDIS (National Environmental Satellite Data, and Information Service).

3.2 Results

Figure 4 shows the daily snow depth forecasts in every half month of the snow melting

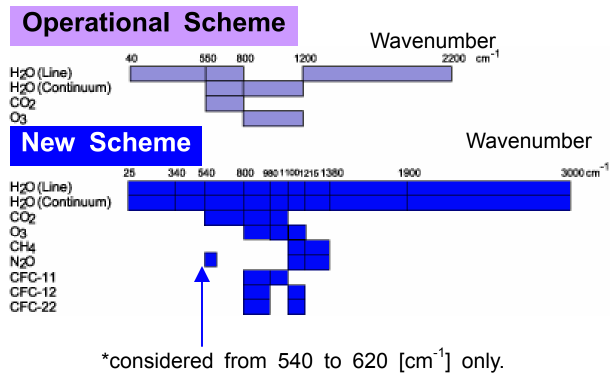

Figure 3. Long wave spectrums by each gas to solve the radiative transfer equations.

season averaged over 4 years. The operational SiB model predicts that the snow melts away from the most part of the Eurasian Continent in the beginning of June, which results in an overestimation of thaw. Especially, a remarkable thaw is seen in North Siberian Plain. On the other hand, the new SiB model reasonably predicts snow cover area in a melting season no matter which clear-sky radiation scheme is adopted.

Figure 5 shows the same as Figure 4 except in the early winter. The new SiB model slightly overestimates a snow cover area in Russia and North America in the early winter with the operational radiation scheme, while the new radiation scheme mitigates the overestimation. It should be noted that the new clear-sky radiation scheme is not tuned well for the new SiB model but that it improves an accuracy of incoming radiation into the surface as described in the next section.

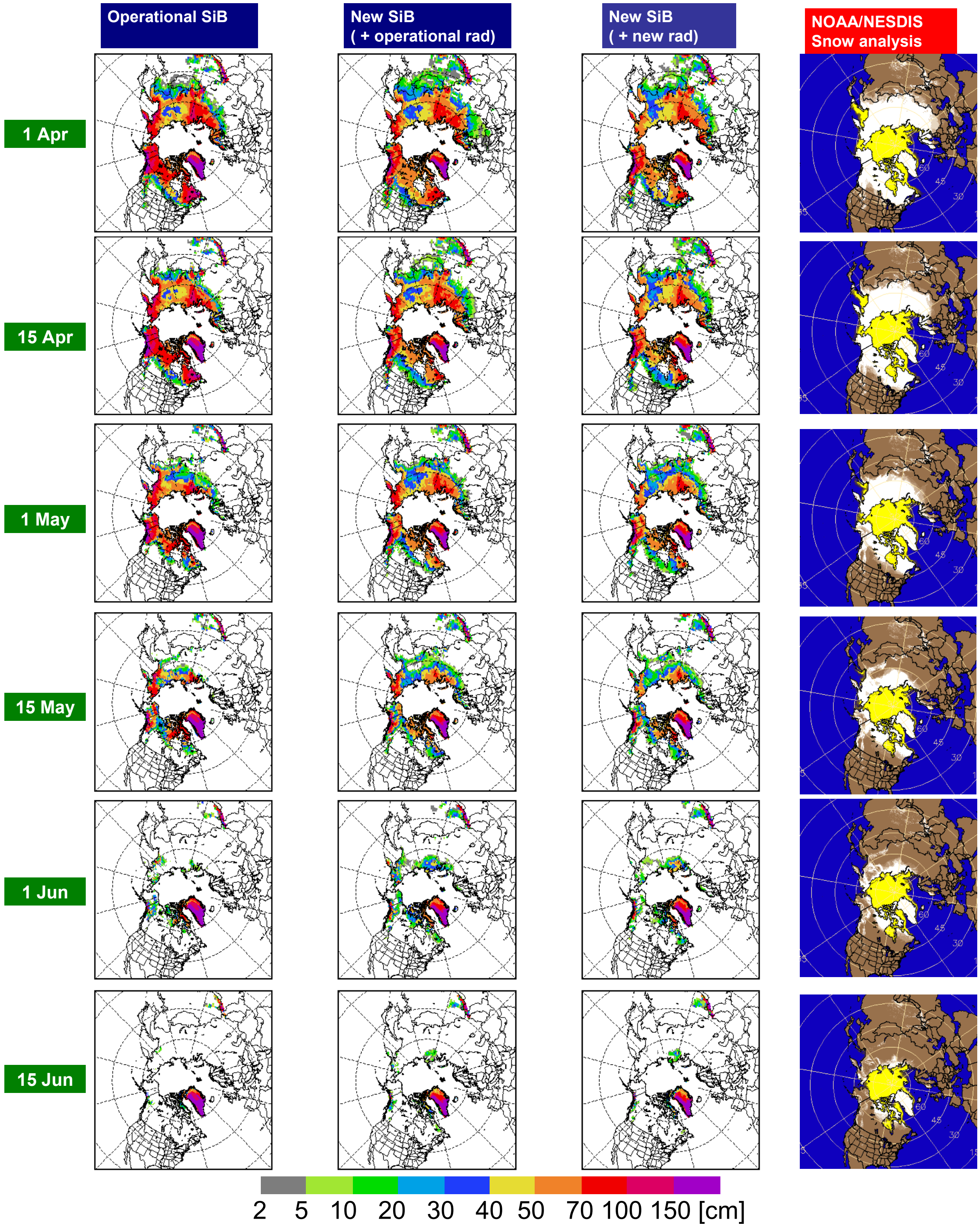

Figure 4. Averages of the snow depth forecasts for the specified dates in the long range forecasts and 5-years averages (1999~2003) of the operational snow cover analysis by NOAA/NESDIS from April to June.

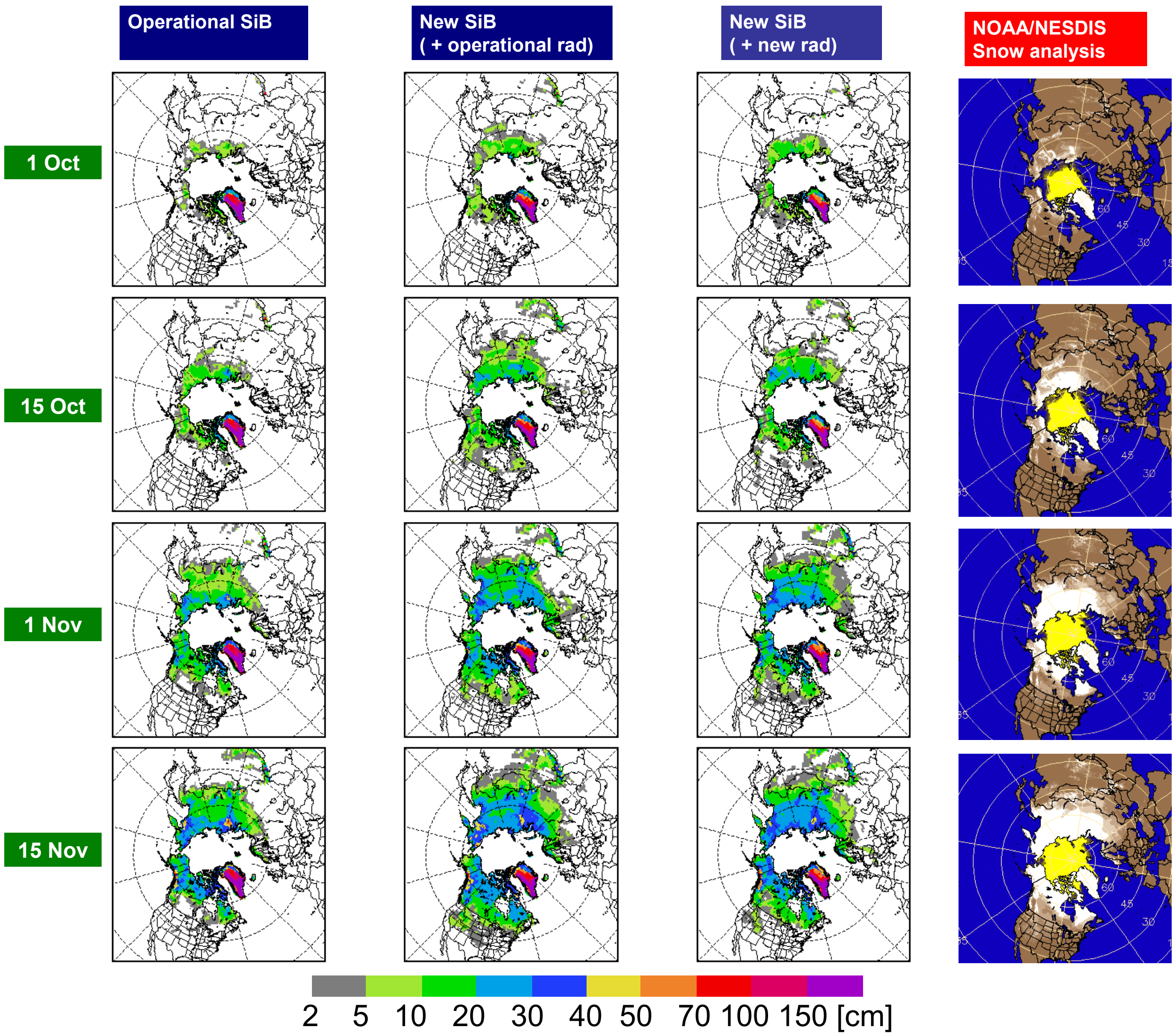

Figure 5. Same as Figure 2, except from October to November.

4 Evaluation of the SiB models using the CEOP EOP-3 datasets

4.1 CEOP EOP-3 datasets

CEOP was launched in 2001 in order to understand and model the influence of continental hydroclimate processes on the predictability of global atmospheric circulation and changes in water resources. CEOP requires a collection of huge dataset from a diversity of in situ and satellite remote sensing measurements and model output. The CEOP integrated database is elaborated and managed with considerable efforts by the CEOP data archive centers, i.e. the University Corporation for Atmospheric Research (UCAR), the Max-Plank Institute (MPI) and the University of Tokyo.

CEOP consists of four Enhanced Observing Periods (EOPs). A part of the in situ data for EOP-3 (from October 2002 to September 2003) has been released from a CEOP data archive center (UCAR).

4.2 Evaluation methods

In order to evaluate both the operational and new SiB models, a validation study using the CEOP EOP-3 reference sites data is carried out. Taking account of an impact on the new clear-sky radiation scheme, the following three formations of constituent schemes are examined again.

a) The operational SiB model and the operational clear-sky radiation scheme (osib+orad)

b) The new SiB model and the operational clear-sky radiation scheme (nsib+orad)

c) The new SiB model and the new clear-sky radiation scheme (nsib+nrad)

Each of them is coupled with JMA-GSM (T213L40) and 120-hours forecasts are executed from the several initial conditions in the first half of EOP-3.

Initial conditions of atmospheric variables are set in the same way as in the operational global analysis, except that the initial soil temperature for the new SiB model is vertically interpolated from

Table 1. Properties of the reference sites and model vegetation characteristics.

Site Name	GEWEX/ CSE	Model Vegetation Type	Elevation (actual/ model)	Model Vegetation Coverage (high vegetation/ low vegetation)	
				October	January
Eastern Siberian Tundra	CAMP	Tundra	38/ 109	0.30/0.40	0.30/0.40
Mongolia	CAMP	Perennial grassland	1368/1357 [*1]	0.59/0.00	0.45/0.00
Korean Haenam	CAMP	High vegetation and ground cover	14/ 49	0.30/0.97	0.30/0.83
Tibet-Gaize	CAMP	Bare soil	4416/4777	0.00/0.00	0.00/0.00
Himalayas	CAMP	Perennial grassland	3888/3538 [*1]	0.59/0.00	0.45/0.00
Chao-Phraya River (Thailand)	CAMP	High vegetation and ground cover	241/ 405	0.30/0.97	0.30/0.83
North-east Thailand	CAMP	High vegetation and ground cover	311/ 225	0.30/0.97	0.30/0.83
Equatorial Island (Sumatra Island)	CAMP	Tropical forest	865/ 388	0.98/0.00	0.98/0.00
Fort Peck	GAPP	Perennial grassland	/ 742 [*2]	0.59/0.00	0.45/0.00
Bondville	GAPP	High vegetation and ground cover	/ 208 [*2]	0.30/0.97	0.30/0.83
ARM Southern Great Plains	GAPP	Mixed forest	425/ 335 [*1]	0.75/0.00	0.75/0.00
Cabauw (The Netherlands)	BALTEX	High vegetation and ground cover	-1/ -10	0.30/0.97	0.30/0.83
Lindenberg (Germany)	BALTEX	High vegetation and ground cover	112/ 75	0.30/0.97	0.30/0.83
ARM Tropical Western Pacific (Darwin)		High vegetation and ground cover	30/ 54	0.30/0.77	0.30/0.83
ARM North Slope of Alaska (Barrow)		Tundra	8/ 1	0.30/0.40	0.30/0.40

[*1] In case the site consists of more than two observing stations, the elevation for actual shows the average of constituents.

[*2] Actual elevation for GAPP/Fort Peck and GAPP/Bondville are unknown.

ARM (Atmospheric Radiation Measurement)
BALTEX (Baltic Sea Experiment)
CAMP (CEOP Asia-Australia Monsoon Project)
CSE (Continental Scale Experiment)
GAPP （GEWEX Americas Prediction Project）
GEWEX (Global Energy and Water Cycle Experiment)

the operational analysis of surface temperature and deep soil temperature.

The predicted variables at the nearest grid point to the reference site are picked up from the model outputs without interpolation and then compared with the observations at a variety of CEOP reference sites.

The reference sites presented here are listed in Table 1. The vegetation characteristics and the elevation in the model for the sites are also shown in the table. If there would be large difference in elevation between the model and the real, this difference could be responsible for some discrepancies between forecasts and observations. Therefore, not only a variation of temperature but also a diurnal range of temperature should be watched.

Some sites consist of more than two observing stations. Such a site has an advantage in taking representativeness or heterogeneity into consideration. The observation data at such sites are used after averaging the data of constituents.

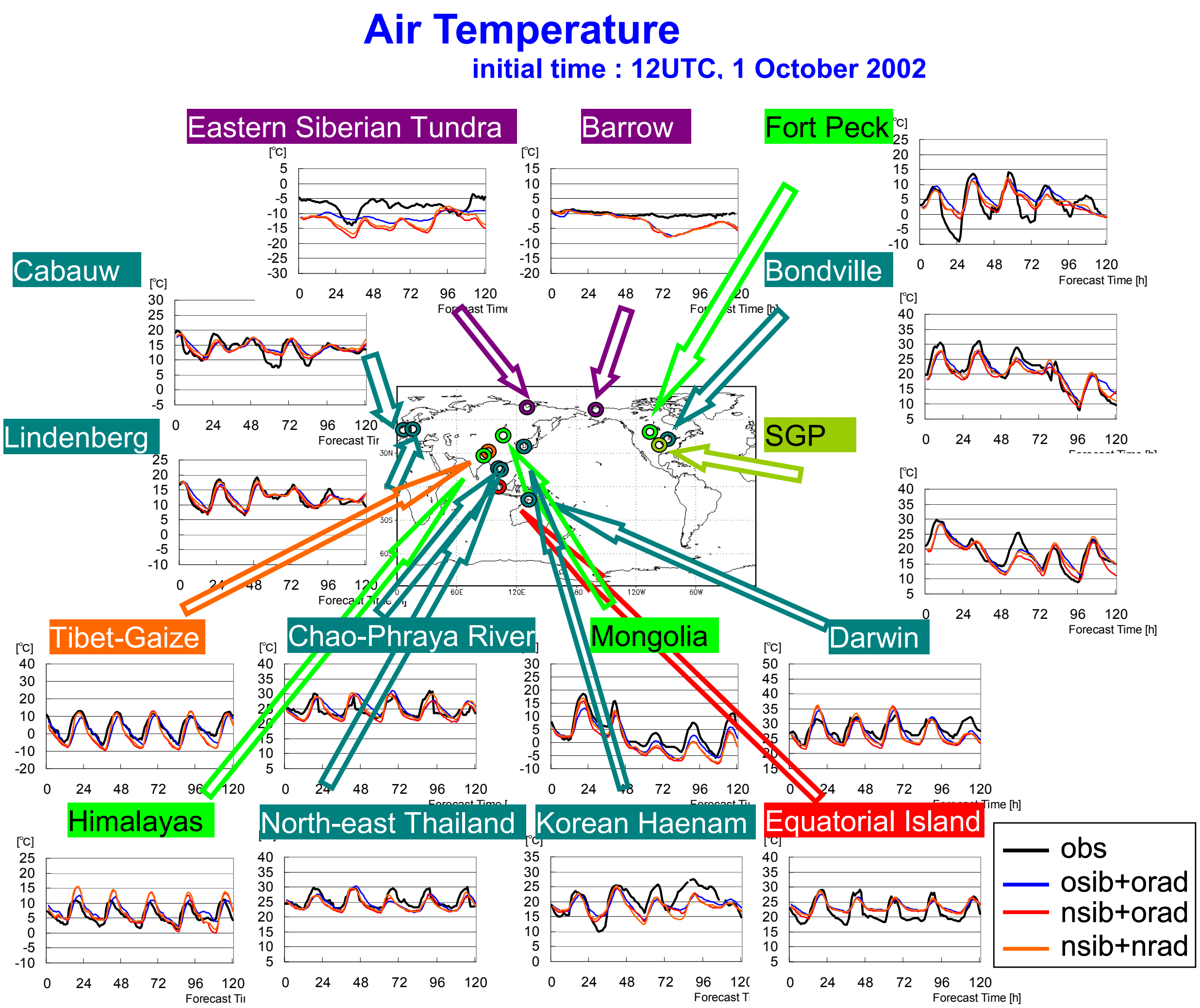

Figure 6. Time series of observations and forecasts for 2m temperature at each site with the initial time of 1 October 2002. The indications, 'obs', 'osib', 'nsib', 'orad' and 'nrad', denote in situ observations, the operational SiB model, the new SiB model, the operational clear-sky radiation scheme and the new clear-sky radiation scheme respectively.

4.3 Results

Comparison results for the forecasts from the initial time of 12UTC 1 October 2002 and 1 January 2003 are illustrated here. Figure 6 and 7 show the observations and forecasts for 2m temperature at each site with the initial time of 1 October 2002 and 1 January 2003 respectively.

Diurnal range of 2m temperature simulated with the new SiB model is generally larger than that with the operational one. Accordingly, the new SiB model predicts a diurnal range of 2m temperature more properly than the operational one for some sites in mid-latitude. Especially, the new SiB model improves the diurnal range for the Mongolia site for January 2003 comparing with the operational one. Similar feature is seen in the results for the Inner Mongolia (not shown). However, it turns out that the new SiB model overestimates the range of a diurnal change for a number of sites.

It is also found that each scheme has a cooling bias for 2m temperature for polar area (Eastern Siberian Tundra and Barrow). In particular, it is revealed that the new SiB model predicts 2m temperature much lower than the actual for some cases.

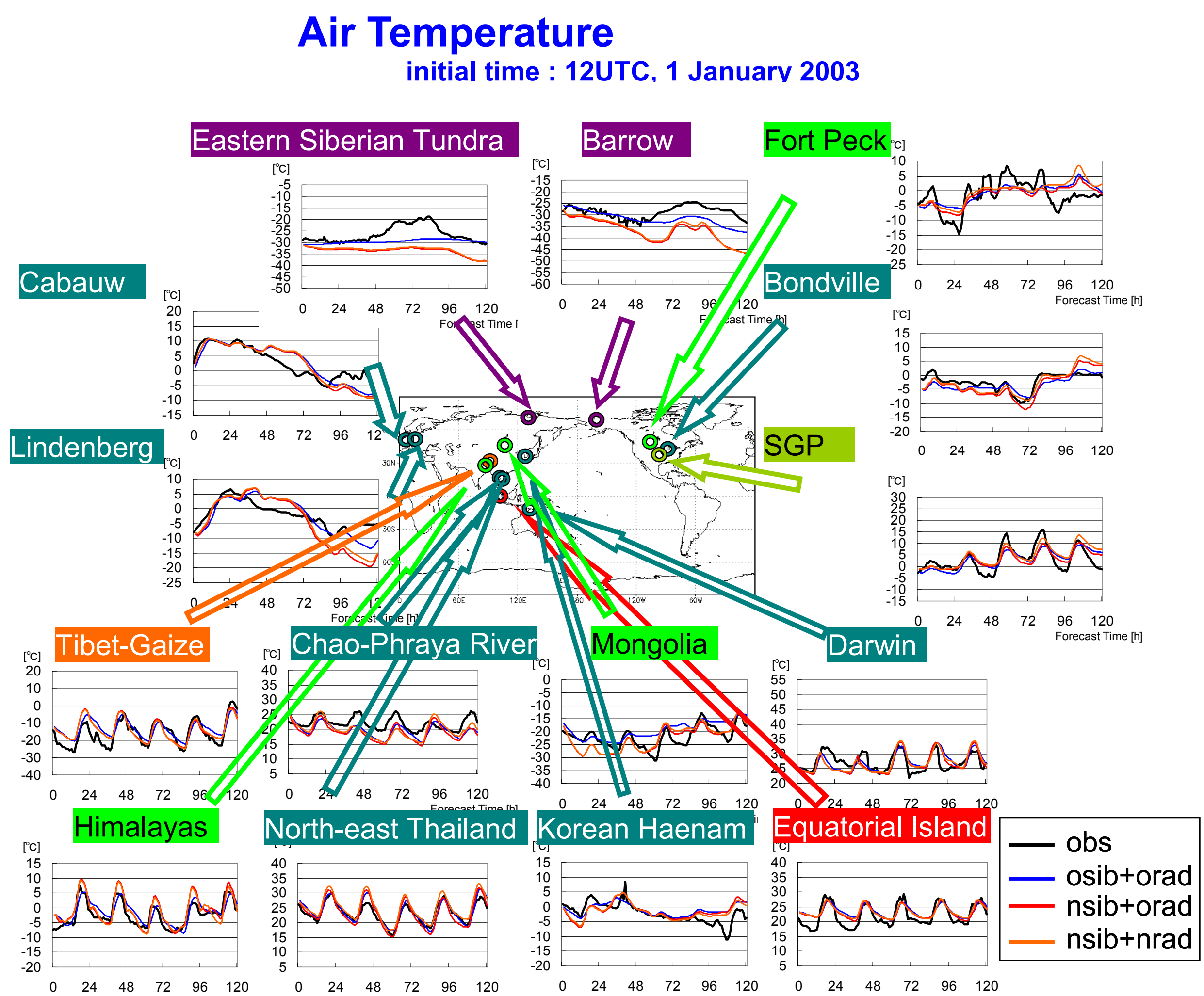

Figure 7. Same as Figure 6, except for the initial time of 1 January 2003.

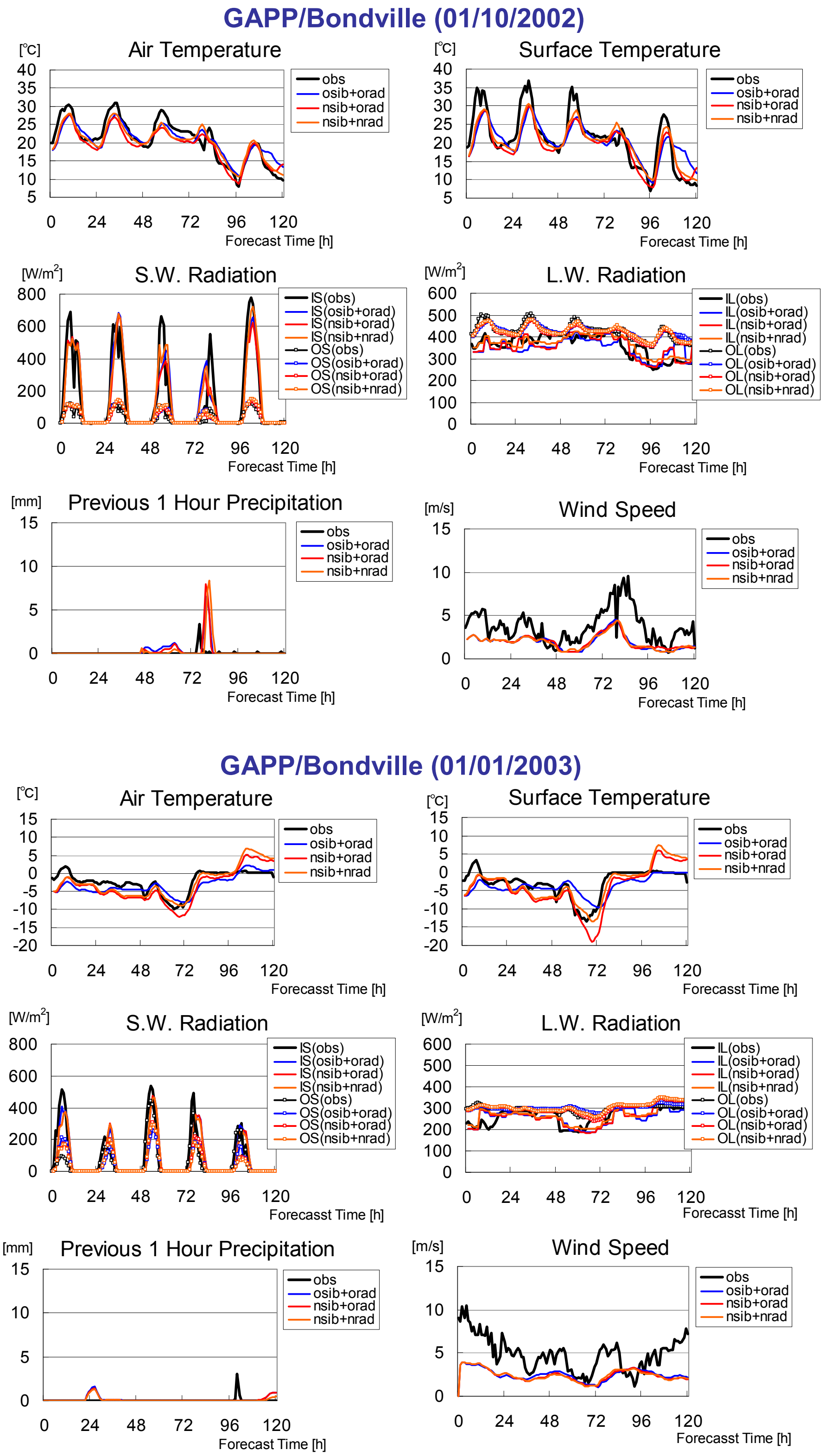

Figure 8. Time series of the GAPP/Bondville site observations and the forecasts with the initial time of 12UTC 1 October 2002 (top) and 1 January 2003 (bottom) for 2m temperature, surface temperature, previous 1 hour precipitation, short wave radiation, long wave radiation and 10m wind speed. The indications, ‘obs’, ‘osib’, ‘nsib’, ‘orad’ and ‘nrad’, are the same as Figure 6.

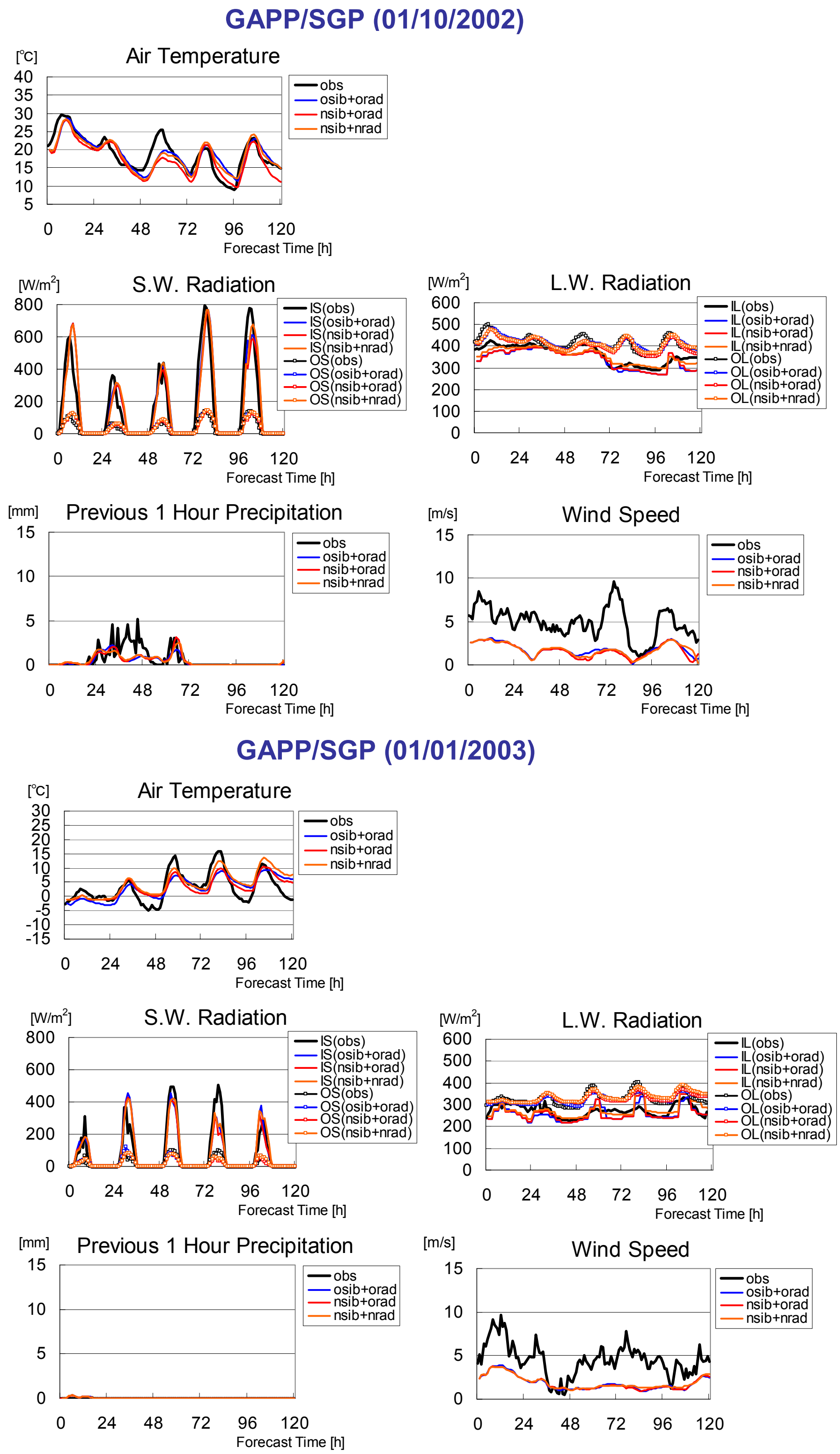

Figure 9. Time series of the GAPP/SGP site observations and the forecasts with the initial time of 12UTC 1 October 2002 (top) and 1 January 2003 (bottom) for 2m temperature, previous 1 hour precipitation, short wave radiation, long wave radiation and 10m wind speed. The indications, ‘obs’, ‘osib’, ‘nsib’, ‘orad’ and ‘nrad’, are the same as Figure 6.

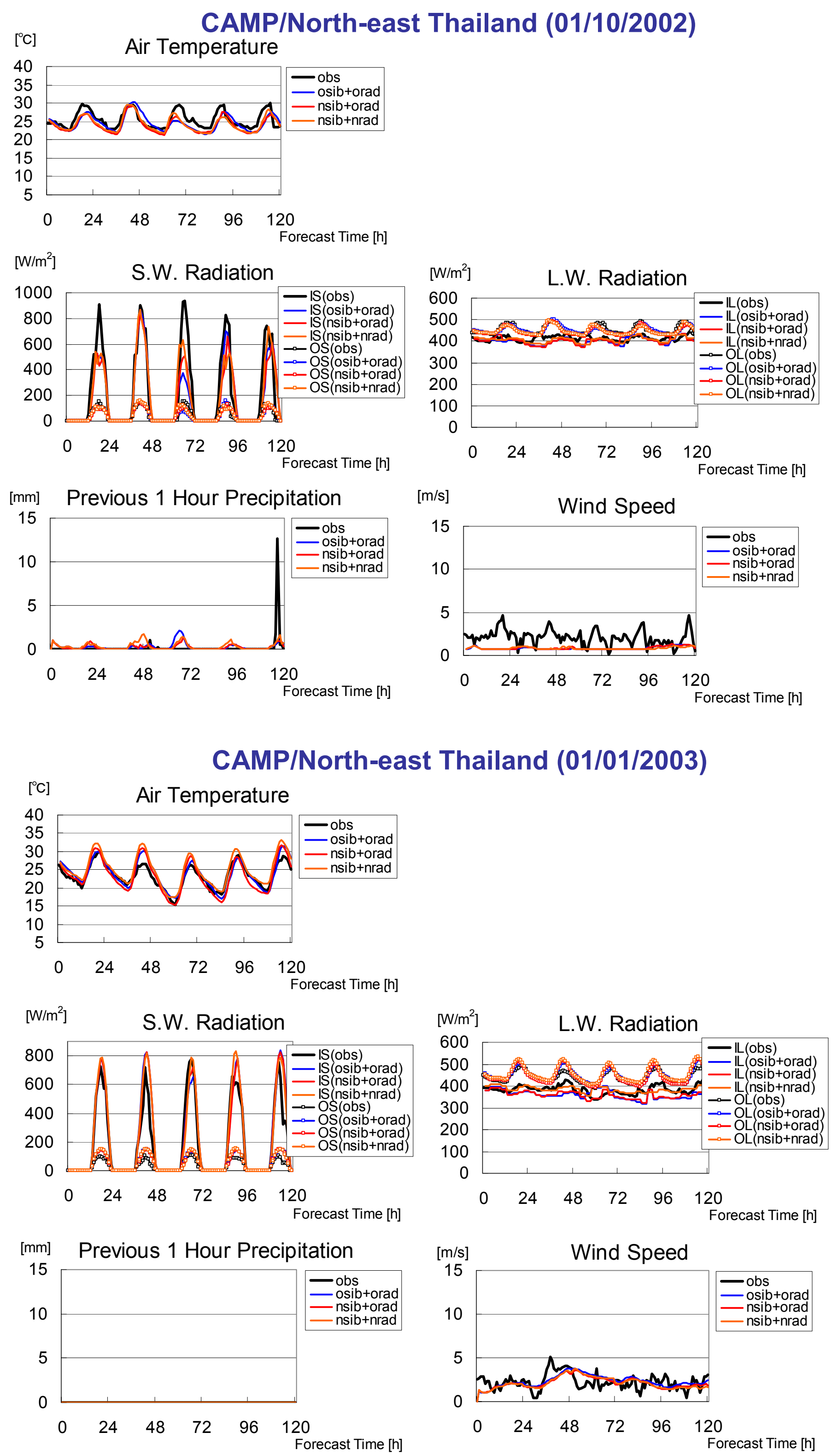

Figure 10. Same as Figure 9, except for the CAMP/North-east Thailand.

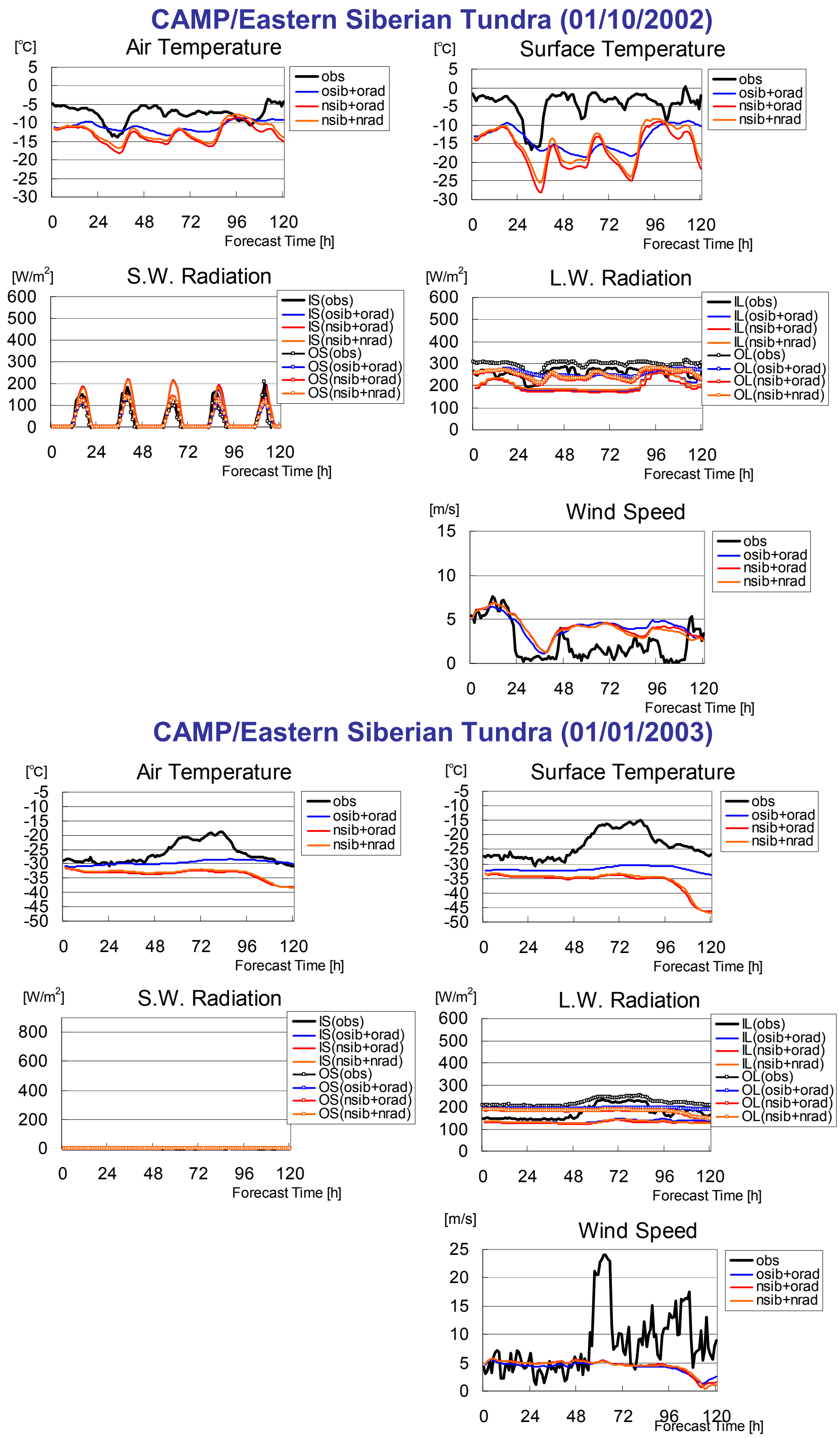

Figure 11. Time series of the CAMP/Eastern Siberian Tundra site observations and the forecasts with the initial time of 12UTC 1 October 2002 (top) and 1 January 2003 (bottom) for 2m temperature, surface temperature, short wave radiation, long wave radiation and 10m wind speed. The indications, ‘obs’, ‘osib’, ‘nsib’, ‘orad’ and ‘nrad’, are the same as Figure 6.

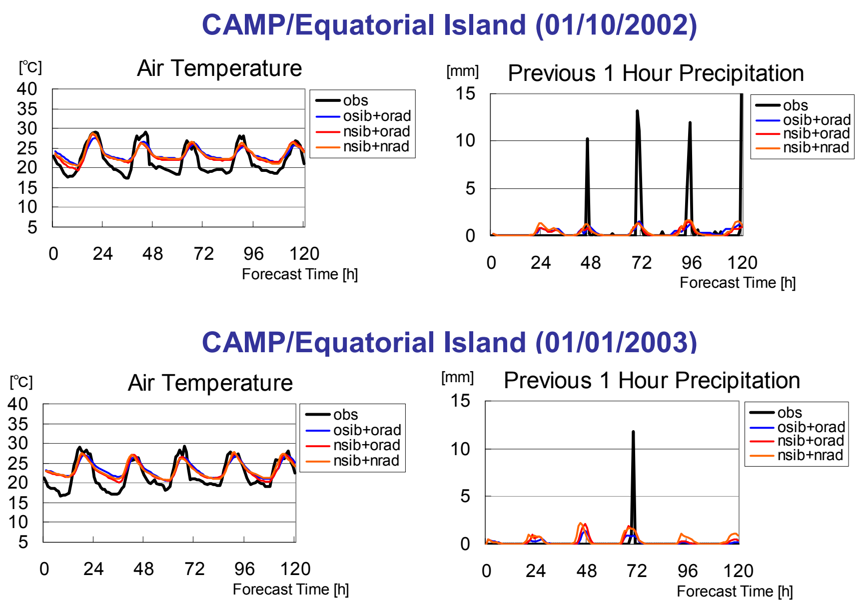

Figure 12. Time series of the CAMP/Equatorial Island site observations and the forecasts with the initial time of 12UTC 1 October 2002 (top) and 1 January 2003 (bottom) for 2m temperature and previous 1 hour precipitation. The indications, 'obs', 'osib', 'nsib', 'orad' and 'nrad', are the sama as Figure 6.

In order to discuss the detailed properties of diurnal change in the model, the time series of forecasts and in situ observations for near surface temperature, previous 1 hour precipitation, short wave radiation, long wave radiation and 10m wind speed at Bondville, Southern Great Plains (SGP), North-east Thailand and Eastern Siberian Tundra are illustrated in Figure 8,9,10 and 11 respectively. Generally speaking, each scheme predicts incoming short radiation well for the clear weather. The new clear-sky radiation scheme mitigates an underestimation of incoming long wave radiation comparing with the operational one.

Each scheme predicts that an incoming long wave radiation at Eastern Siberian Tundra with the initial time for 1 January 2003 is nearly constant over the forecast period, while the observed value is increases on Day 3 and Day 4. Thus the forecasts with each scheme underestimate an incoming long wave radiation on those days. This implies that each model predicts a clear weather over the whole forecast period, though it becomes cloudy on Day 3 and Day 4 in actual. Accordingly, each scheme tends to underestimate a near surface temperature due to an excessive radiation cooling. The similar feature is also found in the case for Eastern Siberian Tundra and Barrow with the other initial conditions.

Figure 12 shows the time series of 2m temperature and 1hour accumulated precipitation for the Equatorial Island in Sumatra Island. Showers are observed 4 times in the period with the initial time of 1 October 2002 and once with 1 January 2003 respectively. Those showers occur within 1 hour and amounts to about 10 mm. However, each scheme estimates the precipitation much weaker and longer than the actual.

5. Discussion

5.1 Snow melting forecasts

The long-range forecast experiments show an overestimation of thaw in the operational SiB model. Short-wave radiation into snow layer is an important factor, which is mainly affected by snow albedo. Sensitivity experiments with JMA-GSM demonstrate that the wet snow albedo has strong impacts on snowpack in the vicinity of the southern edge of the snow cover area (Hirai and Ohizumi 2004). In the operational SiB model, the wet snow albedo is expediently set to 60 % of the dry-snow albedo. According to an observational research on snow properties (Aoki et. al. (2003)), 60 % of the dry-snow albedo is likely underestimated for the wet snow albedo. Since the new SiB model formulates the snow albedo proposed by Aoki et. al. (2003), it improves forecasts of thaw.

5.2 Snowpack formation forecasts

The long-range forecast experiments also find out an overestimation of snowpack formation in the early winter. It probably concerns that the new SiB model tends to predict temperature of the land surface and the upper soil layer lower than the operational one from fall to winter. Thickness of the uppermost soil layer is only 2cm in the model except for an ice sheet area. Thickness of each soil layer is set at the request of the soil water calculations and thus the thickness of 2cm is apparently too small to consider a diurnal change of temperature.

5.3 Properties of diurnal change

It is found that the diurnal range simulated with the new SiB model is generally larger than that with the operational one. Therefore, the accuracy of near surface temperature in Eurasian frozen soil areas is improved by using the new SiB. However, it turns out that the new SiB model tends to excessively underestimate a near surface temperature for some cases comparing with the actual as follows:

* in the beginning of a formation of snow cover.
  (Lindenberg with the initial time of 1 January 2003)
* under a clear weather in polar night. The cooling bias is remarkable when a wind speed becomes light.
  (Eastern Siberian Tundra and Barrow)

The former case probably concerns with an estimation of snow coverage for a little snow in the new SiB model, much as a partial snow cover grid is newly introduced to the new SiB model. The latter suggests a systematic error in an estimation of heat conduction under strong stable stability without solar radiation.

6 Summaries

A verification of the new SiB model coupled with JMA-GSM has carried out. JMA is also developing the new sky-clear radiation scheme, which produces incoming radiation to the surface better than the operational one and the scheme is also examined.

The long-range forecast experiments with each of the operational and the new SiB models shows that the new SiB model predicts a snow cover area reasonably in a melting season while the operational one predicts a snow melting excessively. The refinements of snow processes in the new SiB model bring an improvement of snow melting forecasts. On the other hand, it is found that the new SiB model slightly overestimates a snow cover area in Russia and North America in the early winter.

An evaluation of the SiB models using the CEOP EOP-3 datasets is performed. The diurnal range of near surface temperature is predicted adequately with the new SiB. The accuracy of near surface temperature in Eurasian frozen soil area is also improved with the new SiB model. However, it is revealed that the near surface temperature is predicted much colder than the actual in some cases. Therefore the new SiB model should be refined on heat conduction processes. Meanwhile, it is found that tropical shower is insufficiently simulated in JMA-GSM.

Investigations of diurnal cycle of near surface forecasts, such as temperature, radiations, precipitation and so on, had not been carried out well at JMA until a launch of the CEOP project yet. The CEOP project provides a unique opportunity for an evaluation of model surface processes.

Acknowledgement

The authors gratefully acknowledge the contributions and efforts of the University Corporation for Atmospheric Research (UCAR) in elaborating the CEOP integrated database for in situ observation. We also express sincere appreciations to managers of the following CEOP reference sites.

ARM Tropical Western Pacific
ARM North Slope of Alaska
BALTEX/ Cabauw
BALTEX/ Lindenberg
CAMP/ Eastern Siberian Tundra
CAMP/ Mongolia
CAMP/ Korean Haenam
CAMP/ Tibet-Gaize
CAMP/ Himalayas
CAMP/ Chao-Phraya River
CAMP/ North-east Thailand
CAMP/ Equatorial Island
GAPP/ Fort Peck
GAPP/ Bondville
GAPP/ ARM Southern Great Plains

The reference site data is highly valuable for evaluation of the JMA global model. The operational snow cover analysis by NOAA/NESDIS (National Environmental Satellite Data, and Information Service) is referred in a verification of snow cover forecasts.

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