Adaptation of the land surface scheme SiBUC to cold regions, with inclusion of freezing/melting processes

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Abstract

Attention has gathered around problems regarding climate change such as global warming. Focus has been given to land surface schemes (LSSs), as they mainly aim to be used for numerical weather prediction (NWP) models and general circulation models (GCMs), which can be used for prediction of such problems. Precise predictions of climate processes and climate changes require accurate predictions by LSSs. Tibet and Siberia are selected as important areas for the investigation of the climate behavior and climate changes. The characteristics of energy and water cycle there differ from those in other areas. Energy transfer due to phase change of soil moisture can greatly influence the energy and water cycle. To incorporate freezing/melting processes to the Simple biosphere including urban canopy (SiBUC) model, some modifications have to be considered. SiBUC showed good results after the inclusion of the new modifications. The prediction of melting process of soil moisture was successfully obtained at Tiksi in Siberia. This indicates that for accurate estimations of the energy and water cycle, the modifications implemented on phase change of soil moisture are necessary.

1 Introduction SVATs have played an important role in giving fluxes as boundary conditions to NWP models and GCMs or as amount of evapotranspiration to runoff models. Moreover, not only giving boundary conditions to them but also prognostic variables themselves are contributing to resolution of global energy and water cycle behavior recently. The Project for Intercomparison of Land-surface Parameterization Schemes (PILPS) operates off-line inter-comparisons of LSSs. It was underscored that there were lack of validation in cold regions.

The soil schemes of SVATs can be broken into two broad categories in terms of the method of soil temperature forecasts: A force-restore model and multi-layer model. Boone et al. (2000) [2] compared ISBA Force-restore model (ISBA-FR) and ISBA Explicit multi-layer model (ISBA-DF) and obtained improved estimates by not only ISBA-DF and but also ISBA-FR which both had the soil ice schemes.

This study aims to enhance the applicability of the land surface scheme SiBUC in cold region by characterizing the vegetation parameters in summer season and by inclusion of soil freezing/melting processes with a minimum complexity.

2 Incorporation of freezing/melting processes of soil moisture into SiBUC The Simple Biosphere including Urban Canopy (SiBUC) model was presented by Tanaka (2005) [1]. SiBUC has three sub-models which are called as the green area, urban area and water body. **Fig. 1** shows the schematic image of this model. To adapt this model to cold regions, Soil freezing processes were introduced to the green area sub-model.

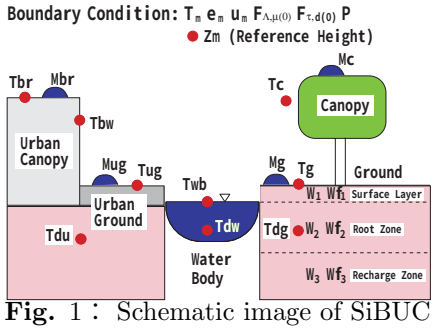


Fig. 1 : Schematic image of SiBUC

2.1 Outline of the green area model Vegetation scheme is based largely on the SiB model (Sellers et al. (1986)[3]). Some modification (simplification) from original SiB was done. The morphological and physiological characteristics of the vegetation community at a grid point are used to derive coefficients and resistances which govern the fluxes between the surface and the atmosphere. All of these fluxes depend upon the state of the vegetated surface and the atmospheric boundary conditions.

In SiB, the world's vegetation is divided into two morphological groups : trees or shrubs which constitute the upper story or canopy vegetation, and the ground cover which consists of grasses and other herbaceous plants. There is an upper, thin soil layer (soil layer 1), from which there can be a significant rate of withdrawal of water by direct evaporation into the air when the pores of the soil are at or near saturation. Beneath the root

zone (soil layer 2), there is an underlying recharge layer (soil layer 3) where the transfer of water is governed only by gravitational drainage and hydraulic diffusion.

2.2 Prognostic equations In **Eq(1)-Eq(7)**, there are two sets of the simultaneous equations. Both of them are based on the force-restore method. When snow covers surface, an explicit snow layer is defined. In **Eq(8)-Eq(11)**, there are three equations for soil wetness. Three frozen soil wetness values (W_{f1}, W_{f2}, W_{f3}) are newly defined for freezing/melting processes of soil moisture.

Canopy, ground surface, deep soil and snow temperatures

Snow-free

$$C_c \frac{\partial T_c}{\partial t} = Rn_c - H_c - \lambda E_c - \xi_{cs} \quad (1)$$

$$C_g \frac{\partial T_g}{\partial t} = Rn_g - H_g - \lambda E_g - \xi_{gs} - \zeta_{gs} - \omega C_g (T_g - T_d) \quad (2)$$

$$C_d \frac{\partial T_d}{\partial t} = Rn_g - H_g - \lambda E_g - \xi_{gs} - \zeta_{gs} \quad (3)$$

Snow

$$C_c \frac{\partial T_c}{\partial t} = Rn_c - H_c - \lambda E_c - \xi_{cs} \quad (4)$$

$$C_s \frac{\partial T_s}{\partial t} = Rn_g - H_g - \lambda E_g - K_s \frac{T_s - T_g}{D_s} - \xi_{gs} \quad (5)$$

$$C_g \frac{\partial T_g}{\partial t} = K_s \frac{T_s - T_g}{D_s} - \zeta_{gs} - \omega C_g (T_g - T_d) \quad (6)$$

$$C_d \frac{\partial T_d}{\partial t} = K_s \frac{T_s - T_g}{D_s} - \zeta_{gs} \quad (7)$$

where

C_c, C_g, C_d, C_s = effective heat capacities	(J m^{-2}K^{-1})
T_c, T_g, T_d, T_s = temperatures	(K)
Rn_c, Rn_g = absorbed net radiation	(W m^{-2})
H_c, H_g = sensible heat flux	(W m^{-2})
$\lambda E_c, \lambda E_g$ = latent heat flux	(W m^{-2})
ξ_{cs}, ξ_{gs} = energy transfer due to phase change in $M_{c,cs}$ and $M_{g,gs}$, respectively	(W m^{-2})
ζ_{gs} = energy transfer due to phase change in $W_{1,2,3}$	(W m^{-2})
D_s = snow depth	(m)
K_s = snoe thermal conductivity	(W m^{-1}K^{-1})

Soil moisture stores

$$\frac{\partial W_1}{\partial t} = \frac{1}{\theta_s D_1} \left[P_1 - Q_{1,2} - \frac{1}{\rho_w}(E_s + E_{dc,1}) + F_1 \right] \quad (8)$$

$$\frac{\partial W_2}{\partial t} = \frac{1}{\theta_s D_2} \left[Q_{1,2} - Q_{2,3} - \frac{E_{dc,2}}{\rho_w} + F_2 \right] \quad (9)$$

$$\frac{\partial W_3}{\partial t} = \frac{1}{\theta_s D_3} \left[Q_{2,3} - Q_3 + F_3 \right] \quad (10)$$

$$\frac{\partial W_{fn}}{\partial t} = \frac{1}{\theta_s D_n} \left[-F_n \right] \qquad (n = 1, 2, 3) \quad (11)$$

where

W_1, W_2, W_3 = soil water wetness in the three soil layers	
W_{f1}, W_{f2}, W_{f3} = soil ice wetness in the three soil layers	
θ_s = saturated volumetric soil moisture	
D_1, D_2, D_3 = thickness of the soil layers	(m)
P_1 = rate of infiltrating into the surface soil layer	(m s^{-1})
$Q_{i,i+1}$ = water flow between i and $i+1$ layer	(m s^{-1})
Q_3 = gravitational drainage from recharge layer	(m s^{-1})
E_s = evaporation from the surface soil layer	(m s^{-1})
$E_{dc,i}$ = abstraction rate of soil moisture by transpiration	(m s^{-1})
F_1, F_2, F_3 = rate of phase change of soil moisture	(m s^{-1})

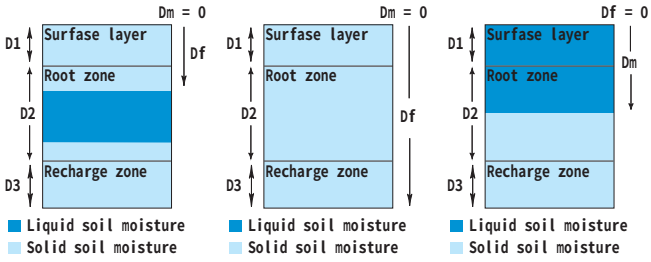
2.3 Energy due to freezing/melting of soil moisture Prognostic variables of a force-restore method are the surface soil temperature T_g, and restore temperature (deep soil temperature) T_d of which meaning is daily average temperature. T_g represents an actual surface soil temperature, however, T_d does not represent a soil temperature of a certain actual depth. It's difficult for a force-restore model to associate temperature with an existence ratio of frozen soil moisture at each layer. When soil freezing/melting processes are incorporated into the model, two options have been taken to escape this problem: adoption of multiple-soil-layer model which can estimate profile of soil temperature, modification of estimating energy used in phase change processes of soil moisture from net energy at surface.

In this study, soil freezing/melting processes are incorporated into the green area model without change of fundamental model structure. This means the three soil layers for soil moisture and the force-restore method for temperatures. Especially, using the force-restore method requires only much less computational intensity.

2.4 Effective frost/thaw depth To estimate ratio of net energy at surface is used for phase change processes of soil moisture from net energy at surface, the effective frost/thaw depth was introduced. The soil moisture of the shallower layer is start to freeze early and freezing faster than that of the deeper. The energy for phase change of soil moisture at surface looks dependent on where phase change occurs through this phenomenon.

In fact, there are coexistences of liquid and frozen soil moisture at a certain depth in freezing/melting processes. The effective frost/thaw depth was defined as all soil moisture was freezing/melting above a certain depth.

Fig. 2 is the schematic image of seasonal change of soil moisture on permafrost. The frozen soil moisture dominates in deep soil layer even in summer at Tiksi, one of the study areas in this study. The thickness of root layer, D_2 is from 0.9-1.4 m in 15 vegetation categories. This range is too wide to determine the effective frost/thaw depth by using only W_{f2}, especially where permafrost exists. W_{f2} will indicate sum of frozen soil moisture of permafrost and newly freezing in this layer. Thus, ${W^*}_{f(n)}$ $(n = 1, 2, 3)$ was defined as upper frozen soil water wetness of each layer which is coming newly in the freezing season. ${W^*}_{f(n)max}$ $(n = 1, 2, 3)$ are also introduced to describe the effective thaw depth, D_m when ${W^*}_{f(n)}$ $(n = 1, 2, 3)$ are exist and melting process occurs.



(a) freezing process (fall) (d) all ice (winter) (e) melting process (spring)

Fig. 2： Seasonal change of soil moisture at Tiksi

Through these treatments of liquid or frozen soil moisture, the effective frost/thaw depth, D_f/D_m are described as

Freezing process

$$D_f = \sum_{k=1}^{j-1} D_k + \frac{W^*{}_{fj}}{W_{fj}+W_j} D_j \quad (12)$$

if $W_1 > W_{min},\ j=1$

if $W_1 = W_{min},\ W_2 > W_{min},\ j=2$

if $W_1 = W_2 = W_{min},\ W_3 > W_{min},\ j=3$

Melting process

$$D_m = \sum_{k=1}^{j-1} D_k + \frac{W^*{}_{fjmax} - W^*{}_{fj}}{W_{fj}+W_j} D_j \quad (13)$$

if $W^*{}_{f1} > 0,\ j=1$

if $W_{f1} = 0,\ W^*{}_{f2} > 0,\ j=2$

if $W_{f1} = W_{f2} = 0,\ W^*{}_{f3} > 0,\ j=3$

$$= \sum_{k=1}^{j-1} D_k + \frac{W_j}{W_{fj}+W_j} D_j$$

if $W^*{}_{f1} = 0, W_{f1} > 0,\ j=1$

if $W_{f1} = W^*{}_{f2} = 0,\ W_{f2} > 0,\ j=2$

if $W_{f1} = W_{f2} = W^*{}_{f3} = 0,\ W_{f3} > 0,\ j=3$

2.5 Parameterization of phase change energy

Total incoming energy into the soil, E_{in}, is sum of terms in right side of prognostic equations of deep soil temperature T_d (see **eq.(3)**, **(7)**), that is:

Snow-free

$$E_{in} = Rn_g - H_g - \lambda E_g - \xi_{gs} \quad (14)$$

Snow

$$E_{in} = K_s \frac{T_s - T_g}{D_s} \quad (15)$$

E_{in} becomes one of the limitation of energy which is available for phase change of soil moisture. E_{gs} also is the limitation of its energy defined by the distance between where phase change occurs versus the surface, D_f/D_m. E_{gs} is described by the following equations:

Freezing process

$$E_{gs} = -\alpha \times 10^{-\beta \times D_f} \quad (16)$$

Melting process

$$E_{gs} = \alpha \times 10^{-\beta \times D_m} \quad (17)$$

where, α, β are the coefficients which were determined as 100 W m^{-2}, 2 m^{-1} in this study, respectively. ζ_{gs} is defined after satisfying these two condition and making the best of its energy.

Freezing process

$$\zeta_{gs} = \mathrm{Max}[E_{in}, E_{gs}] \quad (18)$$

Melting process

$$\zeta_{gs} = \mathrm{Min}[E_{in}, E_{gs}] \quad (19)$$

The phase change rate of soil wetness in each layer is divided as,

Freezing process

$$F_1, F_2, F_3 = \begin{cases} \frac{\zeta_{gs}}{\lambda_s \rho_w}, 0, 0 \quad (if\ W_1 > W_{min}) \\ 0, \frac{\zeta_{gs}}{\lambda_s \rho_w}, 0 \\ \quad (if\ W_1 = W_{min}, W_2 > W_{min}) \\ 0, 0, \frac{\zeta_{gs}}{\lambda_s \rho_w} \\ \quad (if\ W_1 = W_2 = W_{min}, W_3 > W_{min}) \end{cases} \quad (20)$$

Melting process

$$F_1, F_2, F_3 = \begin{cases} \frac{\zeta_{gs}}{\lambda_s \rho_w}, 0, 0 \\ \quad (if\ W_{f1} > 0) \\ 0, \frac{\zeta_{gs}}{\lambda_s \rho_w}, 0 \\ \quad (if\ W_{f1} = 0, W_{f2} > 0) \\ 0, 0, \frac{\zeta_{gs}}{\lambda_s \rho_w} \\ \quad (if\ W_{f1} = 0, W_{f2} = 0, W_{f3} > 0) \end{cases} \quad (21)$$

3 Study regions and data

Various experiments have been implemented to understand the climate and climate variability. The GEWEX Asian Monsoon Experiment (GAME) is one of the continental-scale experiments in the Global Energy and Water cycle EXperiment (GEWEX). GAME is being implemented to understand the role of the Asian monsoon in the global energy and water cycle and to improve the simulation and seasonal prediction of Asian monsoon patterns and regional water resources. GAME has the four regional experimental studies: GAME-Siberia, GAME/HUBEX, GAME-Tibet

and GAME-Tropics. In this study, characterization of the vegetation parameters in cold regions is tested and estimated at Amdo in Tibetan Plateau and Tiksi in Siberia during summer. Moreover, soil temperatures are below freezing point in winter, which causes freezing/melting processes of soil moisture. Therefore, simulations are conducted for the periods when soil moisture is freezing and melting at Tiksi.

4 Numerical experiments for characterization of the vegetation parameters Two numerical experiments for characterization of the vegetation parameters have been conducted in this study. Firstly, the simulation at Amdo of Tibetan Plateau is carried out to understand the adaptabilities of the green area sub-model to the characteristic vegetation at such an important area for Asian summer monsoon. Secondly, the simulation is carried out for the verification of the behavior of the vegetation under wetland conditions influenced by permafrost. Estimation of water and energy cycle may change due to inclusion of soil phase change processes, as permafrost exists below the surface in Tiksi.

4.1 Grassland at Amdo The longest continuous period was selected after lack of the forcing data within 8 hours was linear-interpolated. Its period was defined between 4:00 (UTC) 25, July, 1998 and 15:00, 31, August, 1998 and contains 900 hours. **Fig. 3** to **Fig. 9** show the results of this simulation. The blue plots and red solid lines represent observed and simulated values in time series figures, respectively. X and Y axises represent observed and simulated values in scatter figures, respectively. First of all, the very accurate estimations of radiation budget are obtained [see **Fig. 3** and **Fig. 4**]. Upward short wave radiation depends on albedos of soil and vegetation, and upward long wave radiation represents averaged temperature. Therefore, the parameters for albedos are believed to be properly defined. Surface temperature is also believed to be accurately predicted, as upward long wave radiation represents surface temperature. Note that the model defined surface temperature T_{sfc} as $T_{sfc} = V_c T_c + (1-V_c)((1-A_{snow})T_g + A_{snow}T_{snow})$ where, A_{snow} is fraction of snow cover. As for turbulent fluxes, **Fig. 5** and **Fig. 6** indicate that the sensible and latent heat flux are well estimated. The surface temperatures are shown in **Fig. 7** . Surface temperature is well simulated. The soil wetness in surface and root layers are shown in **Fig. 8** and **Fig. 9** . The variation and trend during the whole simulation is properly predicted in both of the soil wetness, while the peaks in surface layer immediately after rainfalls are overestimated. The statistics of the results are shown in **Tab. 1** . There is no bias in estimates, however there is little difference between observed and calculated values. SiBUC generally estimates the water and energy budget in this important area, Tibetan Plateau.

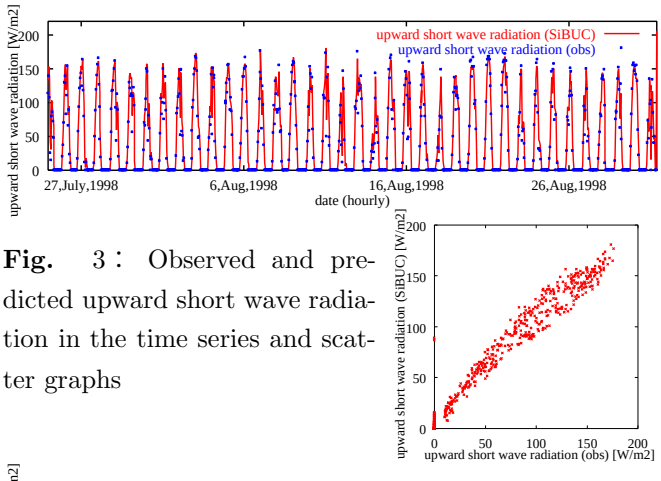


Fig. 3: Observed and predicted upward short wave radiation in the time series and scatter graphs

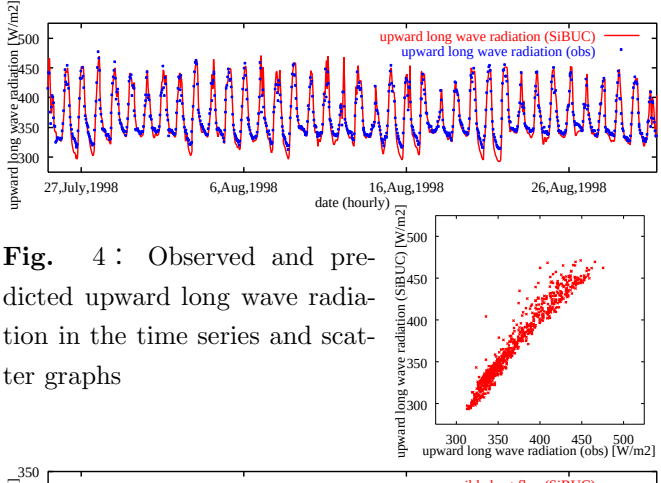


Fig. 4: Observed and predicted upward long wave radiation in the time series and scatter graphs

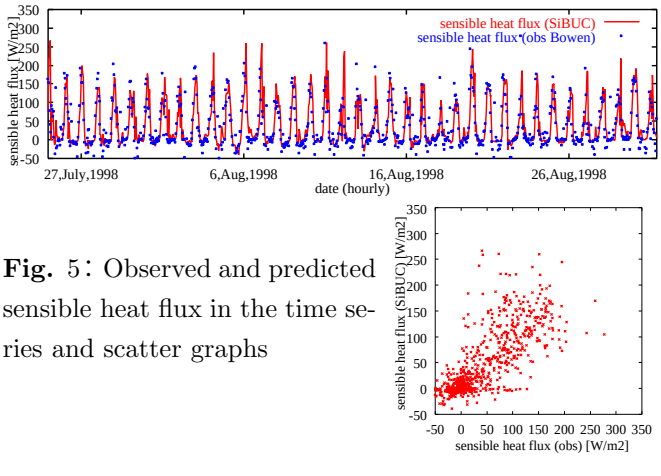
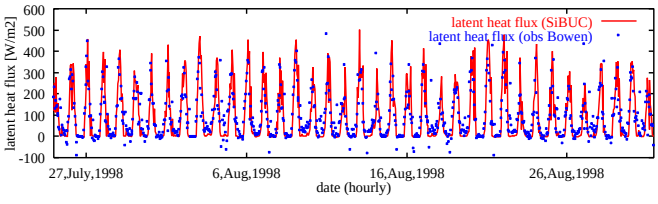


Fig. 5: Observed and predicted sensible heat flux in the time series and scatter graphs



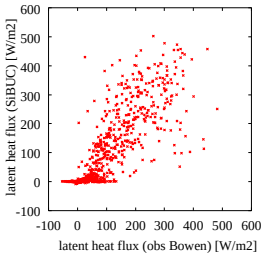
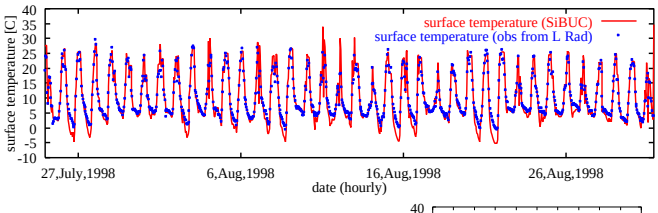


Fig. 6 : Observed and predicted latent heat flux in the time series and scatter graphs



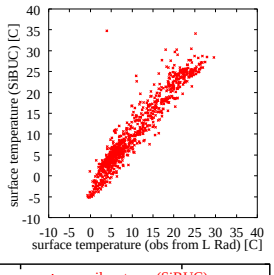
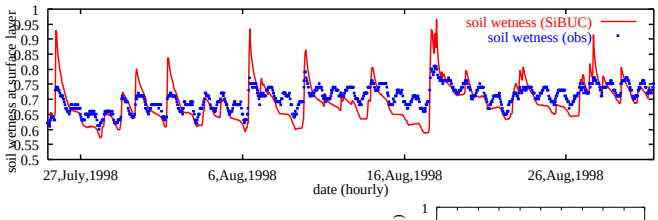


Fig. 7 : Observed and predicted surface temperature in the time series and scatter graphs



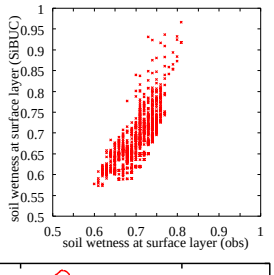
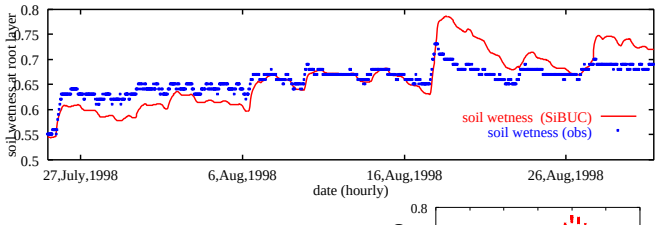


Fig. 8 : Observed and predicted soil wetness at surface layer in the time series and scatter graphs



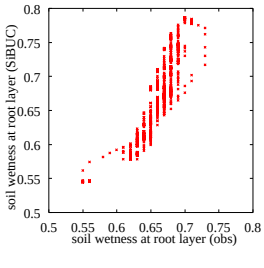


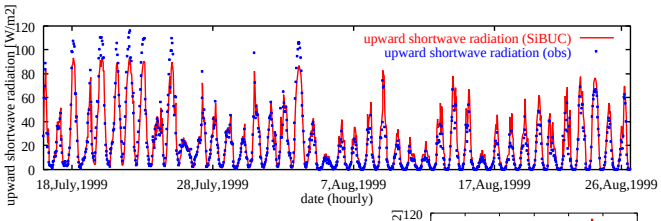
Fig. 9 : Observed and predicted soil wetness at root layer in the time series and scatter graphs

Tab. 1 : Statistics calculated by hourly data for 4:00 (UTC) 25, July, 1998 to 15:00, 31, August, 1998 at Amdo

Symbol	Mean observation	Mean simulation	Correlation	RMSE
S_u	43.06	47.53	0.98	12.25
L_u	369.03	367.95	0.97	11.84
H	38.25	42.00	0.78	39.68
λE	93.33	96.45	0.84	66.15
t_{sfc}	10.50	10.27	0.95	2.86
W_1	0.70	0.69	0.77	0.043
W_2	0.66	0.66	0.88	0.033

4.2 Tundra at Tiksi In this experiment, the continuous period of 1000 hours was selected after the gaps within 8 hours on the forcing data were liner-interpolated. The chosen period is defined between 1:00 (UTC) 16, July, 1999 and 16:00, 26, August, 1999. The simulation period apparently differs from the weather condition during the first half of the simulation period to that of the second half. There was no rainfall from the beginning to the middle midpoint of the simulation period whereas there were continual rainfalls in the second half. As for the radiation budget, **Fig. 10** and **Fig. 11** show very accurate estimations of upward short and long wave radiations, respectively. The parameters of the soil and vegetation albedos are believed to be given to the model correctly. Surface temperature is also believed to be predicted accurately as upward long wave radiation is estimated with good accuracy. As there are no direct observations of the turbulent fluxes, the Bowen ratios are used for comparison of the sensible and latent heat fluxes. The change of the energy characteristics balance is shown in **Fig. 12** . The high Bowen ratios are predicted in the dry period and the low ones are done in the wet period. **Fig. 13** shows the predicted and observed surface temperatures. The surface temperature is better simulated in the both periods. The predicted and observed soil wetness in surface layer are show in **Fig. 14** . The increase of the predicted soil wetness is less than that of the observed value. The predicted wetness does not reach saturation under condition of no evapotranspiration and no base flow in the model. The observation site is surrounded by hills. Surface runoff or water flow through soil gathers near the site after rainfalls, which leads to heighten the water level of the waterbodies near the site. It is known that the groundwater level is related to the water level of the waterbodies. Rainfalls cause raise of groundwater level and sometimes may cause that the surface is covered with water. Two-dimensional water flow, which cannot be treated in this model, causes the saturation of soil wetness during the second half period. However, there is no significant change of predictions due to in-

clusion of phase change of soil moisture processes. The sum of the base flow, Q_3 during this simulation period is dramatically reduced from 1.74 kg m^{-2} to 1.46×10^{-9} kg m^{-2}. This is thought to indicate the real condition in which permafrost prevents base flow. The statistics of the results are shown in **Tab. 2** . However, there is no direct comparison of sensible and latent fluxes, SiBUC generally estimates water and energy budget at Tiksi of Siberia.



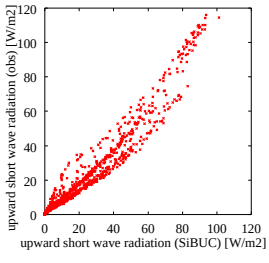
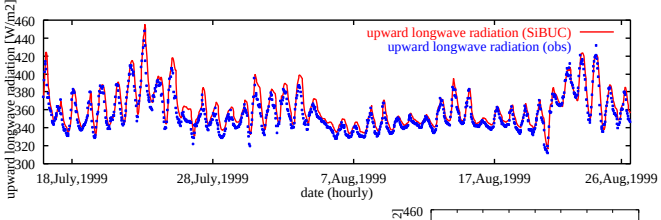


Fig. 10 : Observed and predicted upward short wave radiation in the time series and scatter graphs



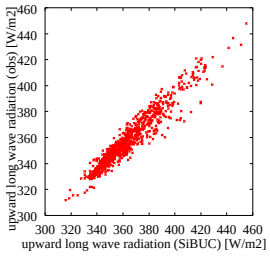
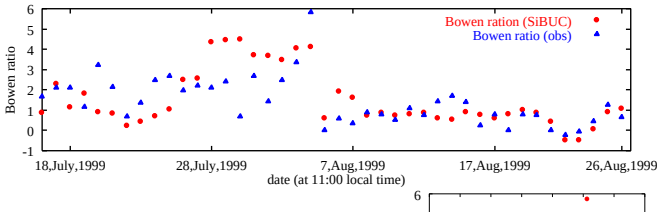


Fig. 11 : Observed and predicted upward long wave radiation in the time series and scatter graphs



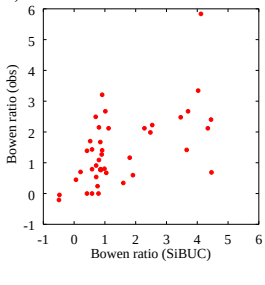
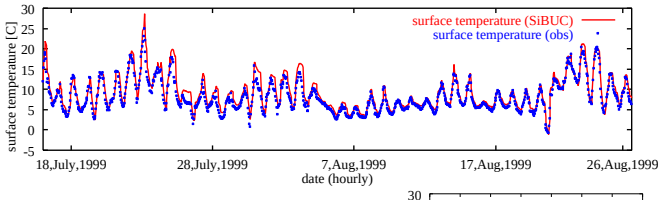


Fig. 12 : Observed and predicted Bowen ratio at 11:00 (local time) in the time series and scatter graphs



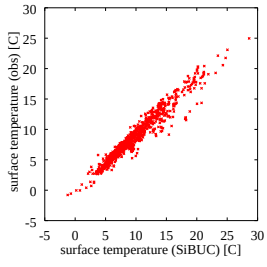
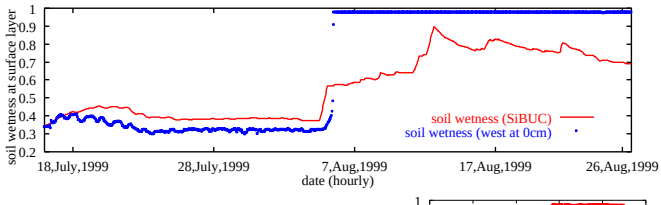


Fig. 13 : Observed and predicted surface temperature in the time series and scatter graphs



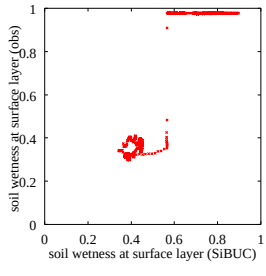


Fig. 14 : Observed and predicted soil wetness at surface layer in the time series and scatter graphs

Tab. 2 : Statistics calculated by hourly data for 1:00 (UTC) 16, July, 1999 to 16:00, 26, August, 1999 at Tiksi

Symbol	Mean observation	Mean simulation	Correlation	RMSE
S_u	22.28	23.49	0.97	6.47
L_u	355.78	351.82	0.96	8.31
t_{sfc}	8.20	9.22	0.97	1.34
W_1	0.66	0.57	0.93	0.19

5 Numerical experiments for freezing and melting processes

Accurate prediction of various surface conditions in cold regions requires consideration of freezing/melting processes of soil moisture. These processes affect not only energy and water cycle but also release of green house gasses dissolved in the permafrost. In this section, freezing and melting processes are discussed.

5.1 Freezing process

The numerical experiment for validation of freezing process has also been conducted. The beginning and end of simulation were defined between 14:00 (UTC) 18, September 1999 and 2:00 1, October 1999 for validation of freezing process of soil moisture. Three criteria have to be satisfied for occurrence of freezing process in the model: tentatively calculated ground surface temperature, T_g is under freezing point, energy for phase change of soil moisture, ζ_{gs} is less than zero, and there is soil moisture available for phase change. In this experiment, the beginning of the simulation period

is set to two days before 20, September, 1999 when these above criteria were all satisfied first in this year. But in fact freezing of soil moisture started at 28, September [see **Fig. 16**]. There are two conceivable reasons for the time lag of the beginning of freezing. The modifications in the model for the phase change processes of soil moisture may contain problems. Another reason could be that two-dimensional energy flow, which cannot be treated in this model, was predominant. The water flow gathers near the observation site after rainfalls, as this site located at lower altitude surrounded by hills. In addition to this condition, there are several waterbodies and the soil moisture at the site affected by the water level of these waterbodies. The observed soil moisture kept saturated during the simulation period. It is believed that the groundwater level is near the surface or maybe above the surface. The energy from these waterbodies may delay the freezing, or incoming negative energy from atmosphere might be used for cooling the water layer above the surface before cooling the surface soil layer and this might cause delay of the freezing. **Tab. 3** shows the hourly averaged sensible flux, latent flux, energy for phase change of soil moisture and ground surface temperature calculated by the model with and without inclusion of the phase change component. The energy due to the phase change increases the total energy incoming into the soil during freezing periods. The sensible flux, latent flux and ground surface temperature predicted by the new model are higher compared with the case of no consideration of phase change. This result indicates that the energy and water cycle have to be discussed by the inclusion of a component for phase change of soil moisture.

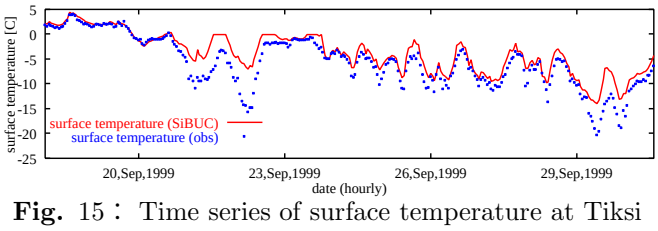


Fig. 15 : Time series of surface temperature at Tiksi

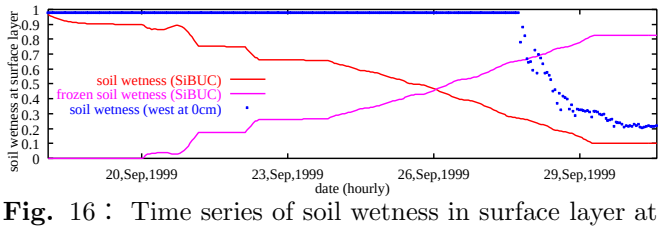


Fig. 16 : Time series of soil wetness in surface layer at Tiksi

Tab. 3 :Averaged sensible, latent heat flux, energy for freezing of soil moisture and surface soil temperature

Phase change	H	λ E	ζ_{gs}	t_g
Yes	2.32	11.26	-16.58	0.52
No	-1.71	9.99	0.0	-1.00

5.2 Melting process The numerical experiment for validation of melting process was implemented. The beginning and end of simulation were defined between 16:00 (UTC) 26, May, 2000 and 4:00 9, June, 2000 for the validation of the melting process of soil moisture. Three criteria have to be satisfied for occurrence of melting process in the model: tentatively calculated ground surface temperature is over freezing point, energy for phase change of soil moisture is greater than zero, and there is frozen soil moisture available for phase change. In this experiment, the soil moisture in surface layer increases in the period between 29, May, 2000 and 1, June, 2000 and decrease after 1, June, 2000. The increase of soil moisture was caused by the melting processes as there were few rainfalls, while the decrease of soil moisture was caused by evapotranspiration as the soil moisture in the deeper layer was still frozen and there were little base flow. These phenomena indicate that the vertical one dimensional water budget was dominant. This condition is believed to be properly reproduced by SiBUC. **Fig. 18** shows the predicted and observed soil wetness in the surface layer. The model newly including freezing/melting processes could properly reproduce melting process of soil moisture. **Tab. 4** shows the hourly averaged sensible flux, latent flux, energy for phase change of soil moisture and ground surface temperature calculated by the model with and without inclusion of phase change. The total energy incoming into the soil is consumed for the melting of soil moisture. The sensible flux, latent flux and ground surface temperature predicted by the new model are lower compared with the case of no consideration of phase change. This result indicates that accurate forecasts of energy and water cycle cannot be achieved without consideration of phase change of soil moisture.

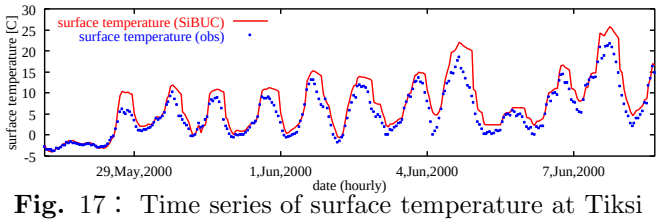


Fig. 17 : Time series of surface temperature at Tiksi

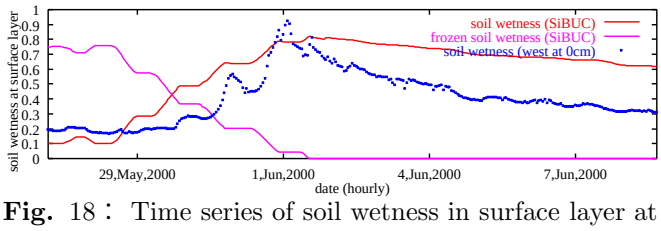


Fig. 18 : Time series of soil wetness in surface layer at Tiksi

Tab. 4 : Averaged sensible, latent heat flux, energy for freezing of soil moisture and surface soil temperature

Phase change	H	λ E	ζ_{gs}	t_g
Yes	72.13	26.02	25.01	6.76
No	84.94	33.65	0.0	8.11

6 Conclusion To apply SiBUC to cold regions, the new prognostic variables, $W_{f(n)}$ were introduced. Note that there were some new modifications for including freezing/melting processes into the soil scheme based on force-restore. The effective frost/thaw depth, D_f/D_m enables to consider the energy transfer due to phase change of soil moisture. The numerical experiments were examined for validation of the characterization of the vegetation parameters in Amdo of Tibet and Tiksi of Siberia. It has been learned that SiBUC can demonstrate good performance in the both areas. Especially, the modifications achieved the decrease of the base flow in summer at Tiksi. The numerical experiments for validation of soil freezing and melting processes were also conducted. The freezing process was not validated enough due to the local geography. It has been identified that the new modifications enable to better predict the melting process of soil moisture. The energy and water cycle is affected by energy transfer due to phase change of soil moisture through both periods. It has been indicated that accurate predictions of energy and water cycle require considerations of phase change of soil moisture. The improved results were obtained after considering the phase change within the SiBUC structure. To ensure to quantify these processes, more numerical experiments and further validations are considered to be necessary.

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