Validation of SSiB Model over Grassland with CHeRES Field Experiment Data in 2001

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ABSTRACT

The Simplified Simple Biosphere model (SSiB) is validated in off-line simulations against field measurements in the summer of 2001 from the China Heavy Rainfall Experiment and Study (CHeRES) over a grassland site located in the lower reaches of the Yangtze River. When initialized and driven by the observed atmospheric forcing, the model reproduced the observed surface heat fluxes and surface skin temperature realistically. The model was also able to well simulate the variation of soil water content. The sensitivity experiments found that the leaf reflectance was the most significant parameter in improving the estimation of surface albedo during both wet and dry periods. This study suggests that the model is capable of simulating the physical processes and of assessing the impact of biophysical parameters that relate to land-atmosphere interactions over the eastern Asian monsoon regions, which is crucial for mesoscale atmospheric models.

Key words: SSiB model, CHeRES, validation, off-line simulation

1. Introduction

Increasingly, much attention has been focused on the realistic simulation of surface fluxes of energy and water exchanges at the land surface. For more than a decade it has been widely accepted that land surface processes have substantial effects on, among other things, the near-surface sensible and latent heat fluxes and the radiation budget, and thus they influence the atmosphere and land characteristics not only in large-scale atmospheric modeling (GCMs) but also in short-range weather predictions (Xue et al., 2001).

More realistic simulations of surface fluxes of moisture and heat are critical for the development of land surface process models and have been a focus of the Project for Intercomparision of Land-surface Parameterization Schemes (PILPS) (Henderson-Sellers et al., 1993, 1995). The Simplified Simple Biosphere Model (SSiB) (Xue et al., 1991) is one of the models participating in PILPS. SSiB's development is based originally upon observational data from the Amazonian rainforest. Since then, it has been validated and calibrated by using observational data from many field experiments over different vegetation types and sites around the world. These field experiments have included Russian hydrological measurements (Robock et al., 1995; Schlosser et al., 1997), the Hydrological Atmospheric Pilot Experiment at Mobilhy (HAPEX-Mobilhy) from a crop site in France (Xue et al., 1996a), the Cabauw experiment on a grassland site in the Netherlands (Chen et al., 1997), the Anglo-Brazilian Amazonian Climate Observation Study (ABRACOS) over an Amazon deforestation site (Xue et al., 1996b), the Sahelian Energy Balance Experiment (SEBEX) and the Hydrological Atmospheric Pilot Experiment in the Sahel (HAPEX-Sahel) over a semi-arid site (Xue et al., 1996c), the First ISLSCP field experiment (FIFE) in Kansas (Chen et al., 1996), measurements in the Red-Arkansas River basin in the southern Great Plains of the United States (Wood et al., 1998), and high latitude hydrological measurements in the Torne_Kalix basin near the North Pole (Nijssen et al., 2003; Xue et al., 2003). The last two experiments focused on river runoff and snow simulations. Some of the aforementioned studies were part of the PILPS. Recently, this model has been validated in its simulations of carbon flux over the Amazon basin (Zhan et al., 2003). But,

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despite the importance of the East Asian monsoon in climate studies, the model has never been validated using data from the East Asian monsoon region due to lack of observational data.

Summer rainfall over the East Asian continent is mainly dominated by the monsoon, which brings monsoon-related flood events frequently, especially over the middle and lower reaches of the Yangtze River. A recent study shows that vegetation processes may contribute to the northward abrupt jump of the East Asian summer monsoon. The vegetation-induced sensible heat flux may also influence the turning of large-scale atmospheric motion during the early monsoon stage through geostrophic balance (Xue et al., 2004). However, the impact and mechanisms of land surface processes on the East Asian monsoon features are still not well understood due to, in part, the lack of field experiments. The primary objective of the China Heavy Rainfall Experiment and Study (labeled as CHeRES), sponsored by China, is to understand the atmospheric and land surface, hydrological and energy cycles over the middle and lower reaches of the Yangtze River. For this purpose, the CHeRES field experiment was carried out in 2001. Two of the CHeRES initiatives are (1) to upgrade the land surface physics, and (2) to implement the land surface model in mesoscale models. Primarily, direct comparisons between field experiment data and model simulations have proved very helpful in identifying systematic errors in the model's physical parameterizations and in developing improved model parameterizations. In this paper, the observational data from the CHeRES site are used to validate and calibrate the SSiB model simulation for aiding the development of the model in the near future. The validation data used and the model are described in sections 2 and 3, respectively. The simulation results are presented in section 4. The conclusions are given in section 5.

2. Forcing and validation data

Extensive surface data were collected from 6 June to 20 July 2001 over a grassland meadow during the CHeRES field experiment. The site is approximately 0.36 km^2 in areal extent and is located at Feixi station (31°41′N, 117°08′E), 20 km south of Hefei, Anhui Province. The in situ flat terrain is almost homogeneously covered with grass so that the coverage of vegetation is nearly equal to 1. The set of observational data used in this study includes the meteorological variables that are used as atmospheric forcing to drive the land surface model, namely, solar and thermal downward radiation, precipitation, surface pressure, horizontal wind, air temperature, and humidity at a height of 10 m. Measurements of sensible, latent, and ground heat fluxes, ground surface temperature, soil temperature at 10, 20, and 40 cm, and mean soil moisture at 15 and 30 cm below the surface are available for validation.

Two measurement systems were used to estimate fluxes of water vapor and sensible heat. The eddy covariance instruments were located 4 m above the ground and were comprised of a three-dimensional ultrasonic anemometer (Model DA 600-3T, Kajio Inc., Japan) and an infrared absorption hygrometer (Model E009B, Advanet Inc., Japan). Analog signals were recorded at a sampling rate of 10 Hz and were generated every 20 minutes. A 10-m tower was installed at the site, and sensors for temperature and humidity (Model HUMP35D, Vaisala) and wind speed (Model CMF3CP, China) were placed at heights of 1 m, 4 m, and 10 m. A wind direction sensor (Model 05106 Monitor-MA, Young, USA) was placed at the top of the tower. Upward and downward shortwave and longwave radiation were measured with radiometers (Model PSP, Eppley Inc., Newport, RI) mounted at a height of 1.5 m. The data were recorded by a Datataker (Model DT-600, DEC Inc., Australia) with a Personal Computer Memory Card International Association (PCMCIA) memory card. The data were sampled each minute and the records were averaged every ten minutes. The results from these two measurement systems were generally in agreement. These raw observational data were combined to form a complete hourly time series for the model. The vegetation and soil parameters in our simulations were the same as those used in Xue et al. (1991) and Sellers and Dorman (1987). The initial temperature (300 K) and soil wetness for SSiB soil layers (0.6) were specified according to observations.

3. Brief model description

Vegetation-soil layers affect the surface radiative transfer and the partitioning of surface energy into sensible heat flux, latent heat flux, and momentum flux. The SSiB model is intended to realistically describe the biophysical controls on these exchanges by modeling the vegetation itself so that the exchange processes are mutually consistent. SSiB has one canopy layer, three soil layers, and eight prognostic variables: temperature at the canopy, ground, surface, and deep soil layers; soil wetness in the three soil layers; water stored on the canopy; and snow stored on the ground. The vegetation type is categorized into 12 different biomes in SSiB, comprising tall vegetation, short vegetation, arable crops, and desert. It has three hydrological soil

Table 1. Vegetation parameters.

Vegetation parameters	Values
Leaf area index (LAI)	4.304
Creenness	0.813
Vegetation cover fraction	0.90
Soil layer thickness (m)	0.02, 0.47, 1
Soil hydraulic conductivity at saturation (m s^{-1})	2.0×10^{-5}
Sorption parameter, B	7.12
Soil water potential at saturation (m)	–0.086
Porosity	0.42
Minimum stomatal resistance (s m^{-1})	117
Environmental adjustment factor for temperature	313, 283, 328
Wilting point	0.31
Rooting depth (m)	0.5
Surface roughness length (m)	0.076
Displacememt height (m)	0.325

layers, including thin, deep root zone, and gravitational drainage layer. There are 23 parameters in SSiB describing the physical and physiological properties of the vegetation and soil, including optical, morphological, and physiological properties of the vegetation, as well as thermal and hydraulic properties of the soil. Many of these parameters are given in Dorman and Sellers (1989) and Willmott and Klink (1986), some seasonally varying monthly values of leaf index and green leaf fraction in Klink and Willmott (1985), and some from field observations. The values of vegetation parameters used for this off-line validation are listed in Table 1. Based on these vegetation and soil parameters, the model predicts atmosphere and land surface variables. Meanwhile, the model also calculates the radiation, transfer of water vapor and sensible heat flux, the interception and re-evaporation of precipitation from plant canopies, the infiltration in the soil layers, drainage, and the storage of the residual precipitation in the soil. These parameterizations are intended to capture quantitatively the complex moisture cycle between the atmosphere and land, especially for biophysical controls of the vegetation on the water cycle.

4. Results and discussions

4.1 *Off-line validation*

In this section, we compare the observed surface data from the 2001 CHeRES field experiment and the off-line SSiB simulations. The root-mean-square (RMS) errors and correlation coefficients of the hourly latent heat flux (LH), sensible heat flux (SH), ground heat flux (G), friction velocity (u_*), surface soil temperature ($T_{\rm s}$), and volumetric soil moisture (θ_1) at the first layer for the integration periods are listed in Table 2. The SSiB model produces very good simulations for the surface fluxes, friction velocity, surface soil temperature, and the first layer volumetric soil moisture.

Figure 1 displays the time series of hourly net radiation, latent heat flux, sensible heat flux, ground heat flux, and friction velocity between the observation and the simulation, which shows that the simulated net radiation and heat fluxes all follow closely the variations of the observations. The observed latent heat flux dropped sharply several times on rainfall events at the beginning of the first month. The model produced well the sudden decrease of latent heat flux during 9–13 June and 17–18 June as well as at 22 June and recovered well. Both the RMS errors for latent and sensible heat fluxes were very small, less than 5 W m^{-2}. The ground heat flux was very small and was also well simulated (Fig. 1d). The simulated friction velocity almost precisely agreed with observations (Fig. 1e), which indicates that the morphological parameters specified in the model and aerodynamic resistances produced by the model were able to produce quite good momentum flux transfer simulations.

Table 2. The RMS errors, correlation coefficients, and mean values in the off-line simulations.

	LH (W m^{-2})	SH (W m^{-2})	G (W m^{-2})	u_* (m s^{-1})	$T_{\rm s}$ (K)	θ_1
RMS	4.7	4.3	17.0	0.1	1.2	0.24
Correlation coefficient	0.96	0.95	0.65	0.93	0.93	0.90

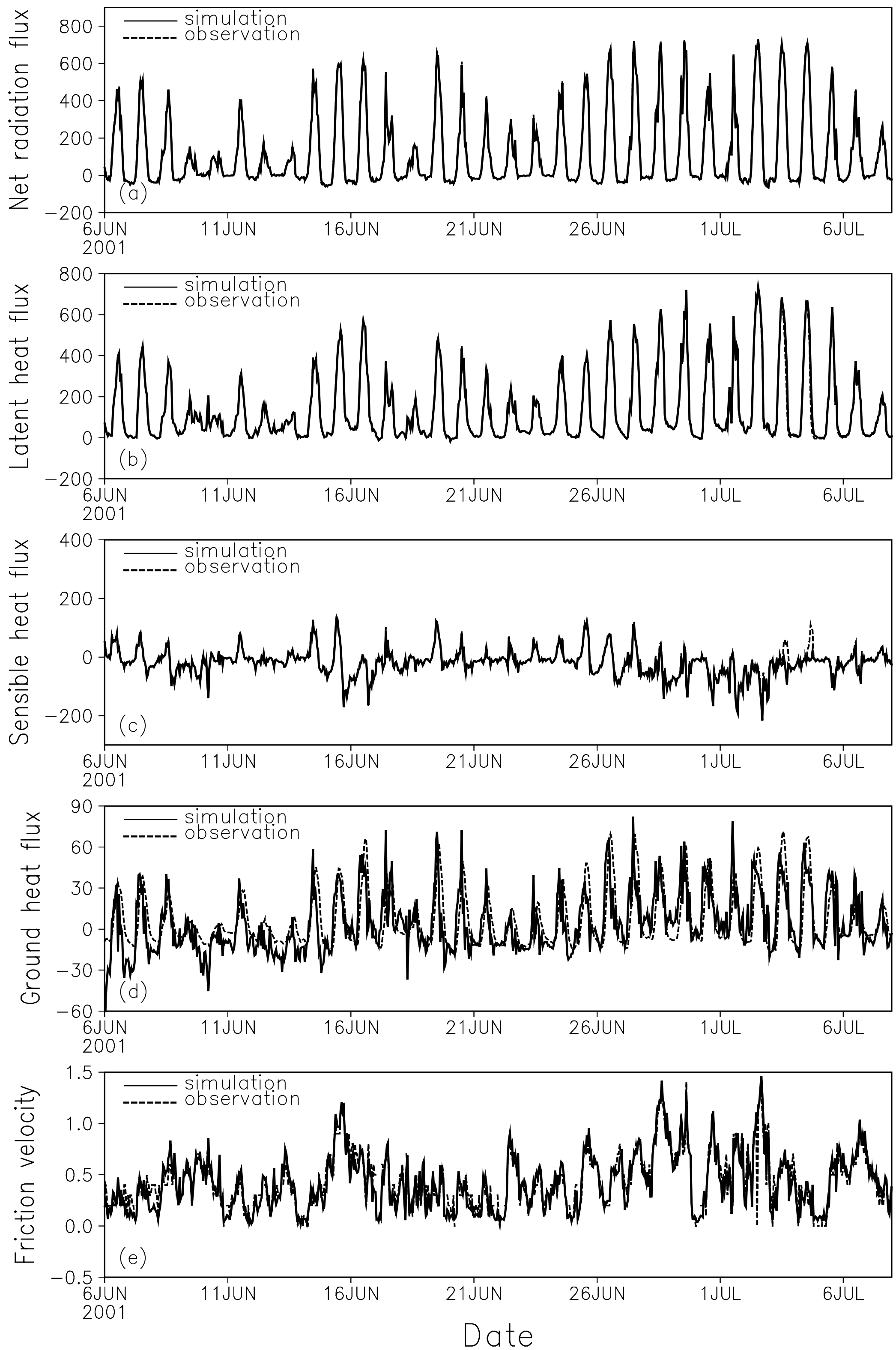

Fig. 1. Comparison of daily variation between simulations and observations for 6 June–7 July 2001: (a) net radiation flux ($W\,m^{-2}$), (b) latent heat flux ($W\,m^{-2}$), (c) sensible heat flux ($W\,m^{-2}$), (d) ground heat flux ($W\,m^{-2}$), and (e) friction velocity ($m\,s^{-1}$).

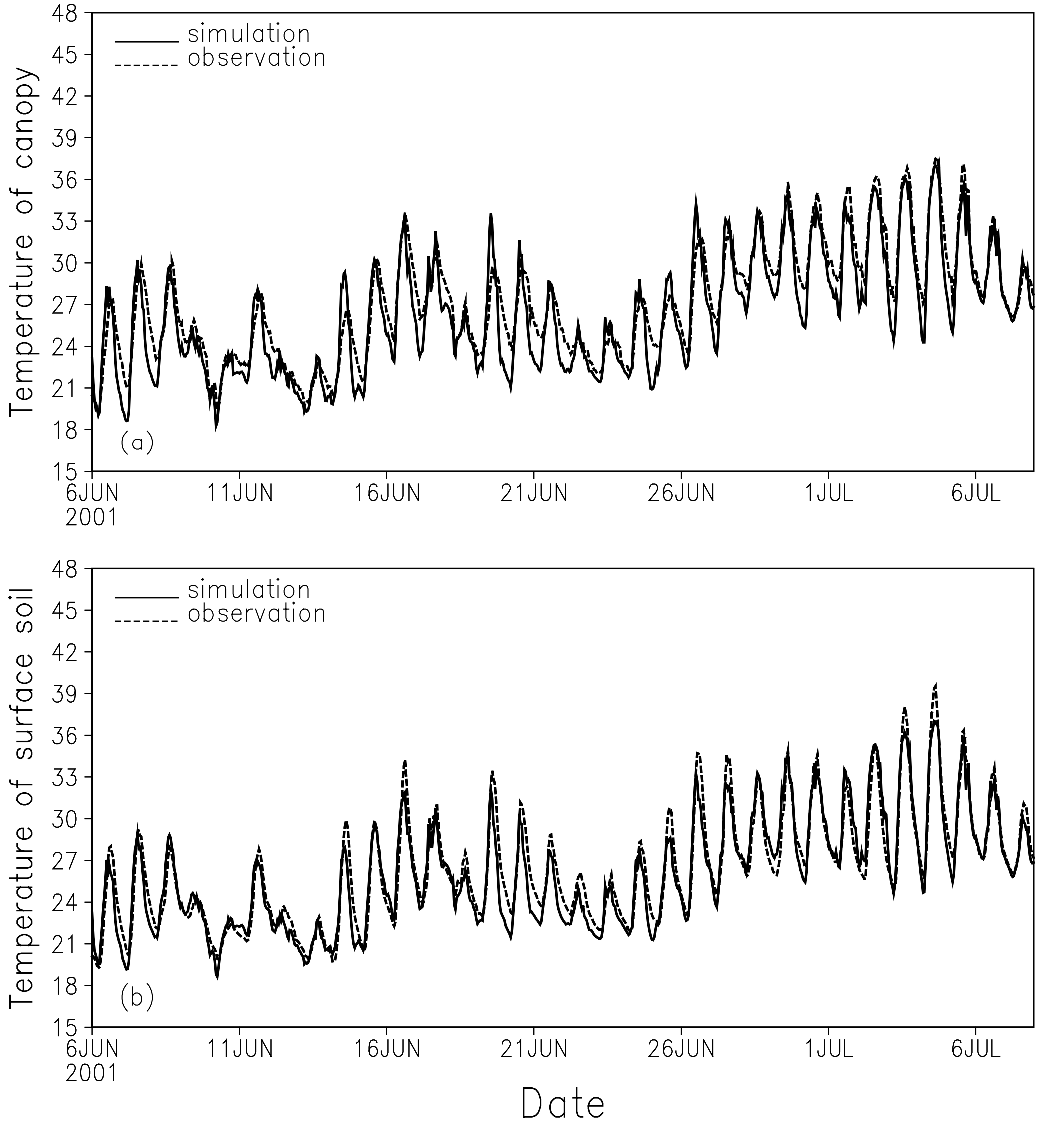

Fig. 2. Daily variation in temperature between simulations and observations for 6 June–7 July 2001: (a) canopy, and (b) surface soil.

The surface fluxes affect the surface energy balance and then the surface temperatures. Figure 2 shows the observed and simulated canopy temperature and surface soil temperature. The simulated canopy temperature generally agrees well with the observation at the reference height (Fig. 2a). Additionally, the simulated surface soil temperature compares well with the observation on most days, too, with the spike of soil temperature being simulated quite well. Both the observed and simulated surface soil temperatures undergo large variations during the daytime, with maximum values in the early afternoon and minimum values during the early morning.

The observed and simulated hourly volumetric soil moisture of the first soil layer is shown in Fig. 3a, and the observed precipitation is shown in Fig. 3b. The first soil layer is set equal to the observed soil depth in order to use the observed volumetric soil moisture. The model and the observation showed a close daily pattern of soil moisture with a drying during clear days and a replenishing during rainy days, especially the sudden increases on 9 June and 11 July immediately following periods of heavy rain on those days. Overall, the model well simulated the variations in the soil moisture and its response to the precipitation forcing. The volumetric soil moisture at the second layer has a positive bias of about 0.1. This discrepancy needs to be further investigated and the model may need furth-

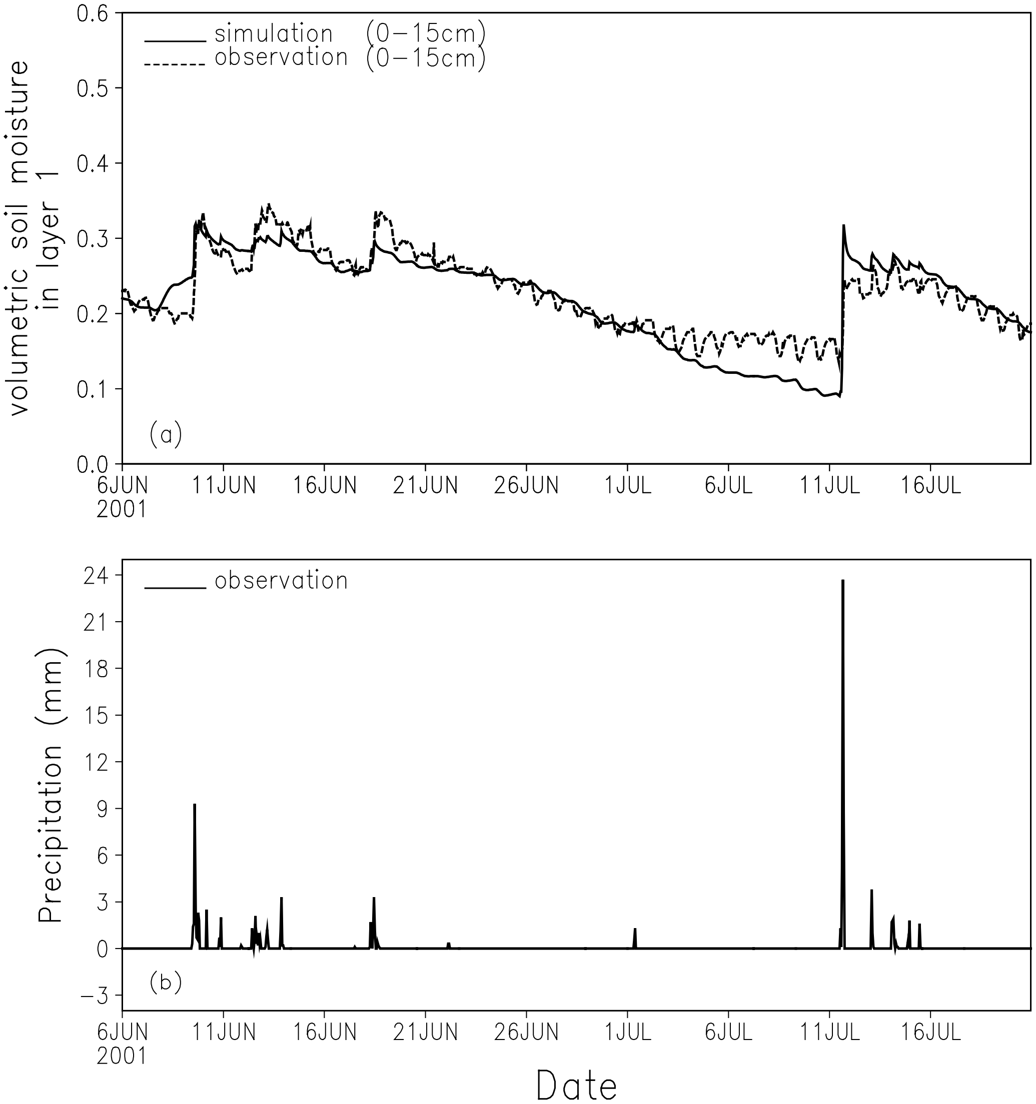

Fig. 3. Daily variation in the volumetric soil moisture of the first layer simulations as compared to observations and precipitation for 6 June–20 July 2001: (a) volumetric soil moisture simulated and observed in the top 15 cm below the surface, and (b) observed precipitation.

er improvement.

Figure 4 shows the diurnal surface flux variations averaged over the entire period of days from 6 June through 20 July. The simulated net radiation and latent and sensible heat fluxes are close to the observations. Although the model produced good simulations of hourly ground heat flux, there is a temporal phase shift of about 1–2 h in the diurnal cycle largely due to the force-restore method, as has been discussed by Xue et al. (1996a).

4.2 *Sensitivity to the vegetation parameters*

Studies have shown that vegetation properties can have a substantial impact on the SSiB's simulations (Xue et al., 1996a, b). There were no vegetation and soil parameter measurements made in the CHeRES field campaign. The typical values for grassland from Table 3 were used for simulations. In this section, we examine the response of the model to individual vegetation parameter changes.

The validation results presented in the previous section show that SSiB is able to simulate the surface fluxes well for the CHeRES site. But the simulated surface albedo was systematically higher than observed throughout the integration period (Fig. 5). To test the causes for such discrepancy, we conducted

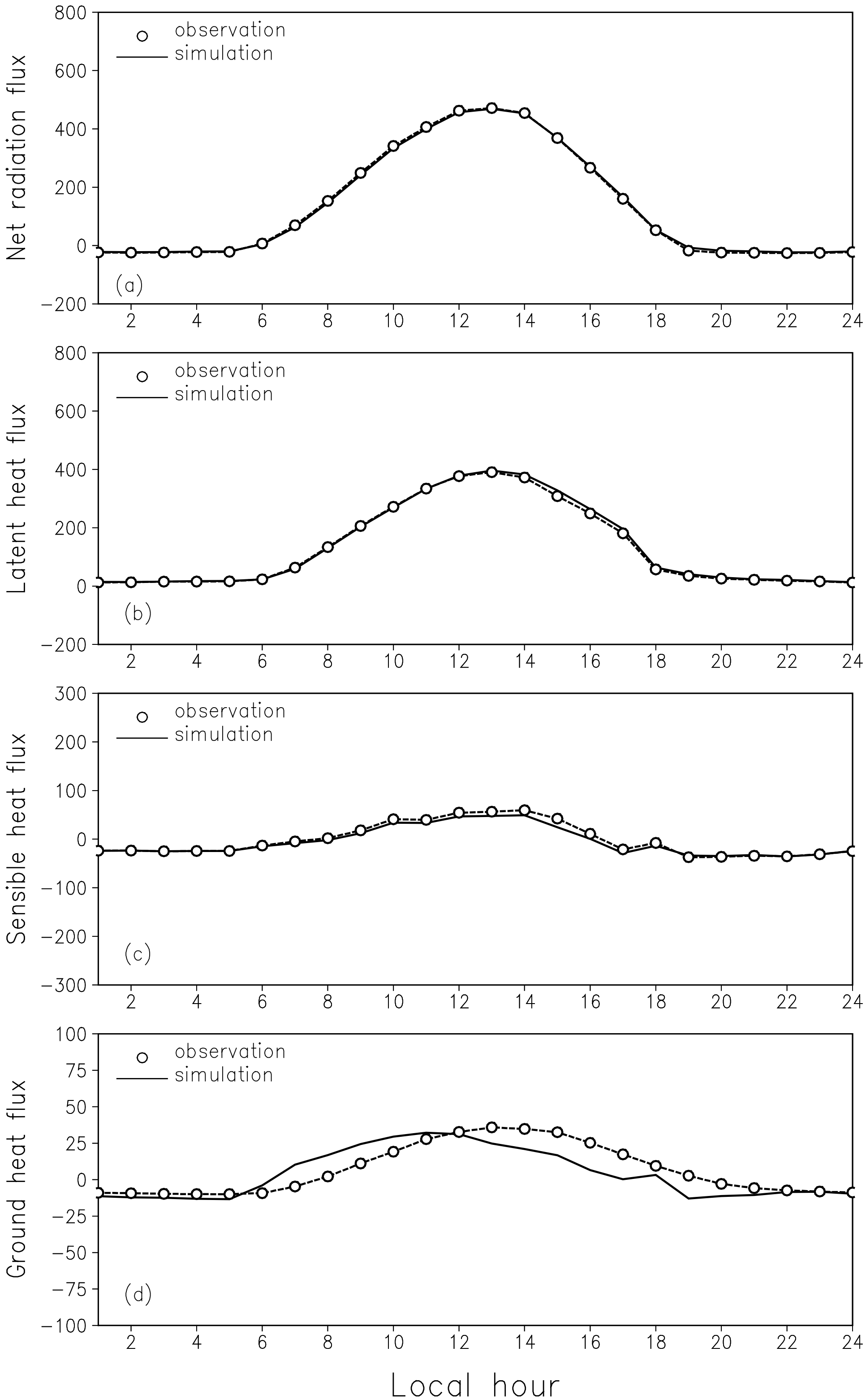

Fig. 4. Diurnal variations of surface heat fluxes (W m^{-2}) between simulations and observation averaged for 6 June–20 July 2001: (a) net radiation, (b) latent heat, (c) sensible heat, and (d) ground heat.

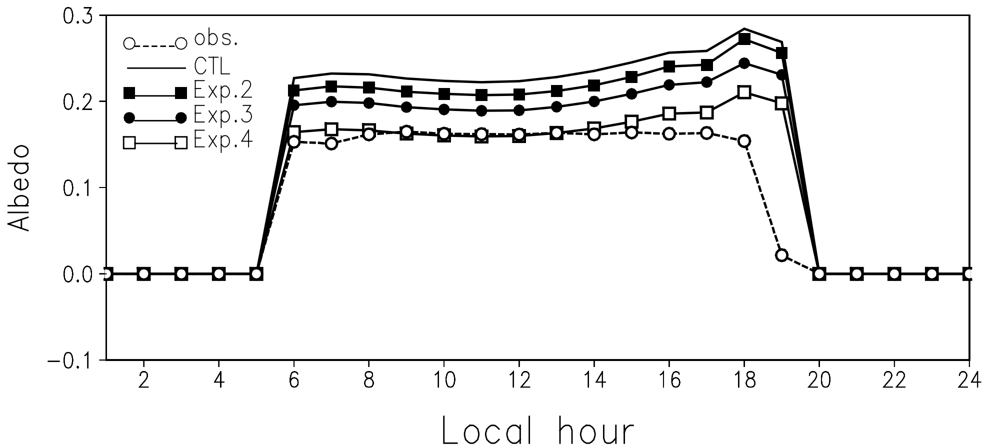

Fig. 5. Mean diurnal variation of surface albedo between simulations and observation averaged from 6 June to 7 July 2001.

several sensitivity experiments with different vegetation parameters to investigate whether such bias was due to the choice of the relevant parameter values. Table 3 lists the leaf area index (LAI) and the leaf reflectance and transmittance of visible, near infrared, and infrared radiation used for Experiments 1–4. Experiment 1 (referred to as CTL) used the parameter value for typical grassland, and in Experiments 2, 3, and 4, part of the grassland parameters used in CTL were replaced by the parameter values from typical shrub lands (Table 3). The results from all the experiments are shown in Fig. 5. The same forcing data were used to drive the off-line model in these experiments.

Table 3 shows that the four RMS errors of daily mean surface albedo are greatly reduced in Experiments 2, 3, and 4. The reduction of the RMS errors is about 16%–74% for all experiments. The simulated albedo in the CTL is quite different from the observations, which shows that some of the vegetation parameters in CTL are inappropriate for the surface albedo over the CHeRES site. The experiments also show that the model's sensitivity to leaf reflectance is greater than its sensitivity to leaf transmissivity. The albedo in Experiment 4 was reduced to about 74%, which is very consistent with observation. We also found a slight response of the surface albedo to the leaf angle distributions of the shrub biomes (figure not shown). Among vegetation parameters in this study, the leaf reflectance plays the most important role in the improvement of albedo. The leaf reflectance is a major component in determining the canopy albedo and then the surface energy budget. Because the model used the downward shortwave and longwave radiation to drive the model, the improvement of the surface albedo decreased the RMS errors of the model's flux and temperature simulations (figure also not shown).

Table 3. Vegetation parameters and simulated RMS errors from sensitivity tests.

No.	LAI	$\delta(\Lambda)^*$	$\alpha(\Lambda)^{**}$	RMS
Expt. 1	4.304	(0.0700, 0.2425, 0.000)	(0.1050, 0.5775, 0.000)	0.049
(CTL)		(0.2200, 0.3750, 0.000)	(0.3600, 0.5775, 0.000)	
Expt. 2	1.804	As in Expt. 1	As in Expt. 1	0.041
Expt. 3	4.304	(0.0500, 0.2500, 0.000)	As in Expt. 1	0.030
		(0.0010, 0.0010, 0.000)		
Expt. 4	4.304	As in Expt. 1	(0.1000, 0.4500, 0.000)	0.013
			(0.1600, 0.3900, 0.000)	

* $\delta(\Lambda)$ is the transmissivity of leaves for wavelength interval Λ. In each pair of lines, the first row is for green leaf and second row is for dead leaf.

** $\alpha(\Lambda)$ is the reflectance of leaves for wavelength interval Λ.

5. Conclusions

Data from the CHeRES study for the summer season of 2001 are used to calibrate and validate the SSiB model over a grassland site. The results show that the model produced the reasonable evolution of latent heat flux, sensible heat flux, momentum flux, and surface skin temperature by using prescribed vegetation parameters. It produced quite good simulations of the variation of soil moisture as well. However, the simulated surface albedo was systematically higher than observed throughout the integration period, and some improper parameters may be responsible for such a bias. The sensitivity tests reveal the important parameters and physical processes involved in the land surface-atmosphere interaction for the CHeRES site, in which the leaf reflectance was found to be the most significant parameter in improving the large overestimation of surface albedo during both wet and dry periods. This study suggests that the model is capable of simulating physical processes and assessing the impact of biophysical parameters that relate to land-atmosphere interactions over the eastern Asian monsoon regions. It would be desirable to use various field observational datasets available for validation, including measurements of the hydrological cycle components like surface runoff and root zone drainage, in the near future.

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