Validation of IAP94 Land Surface Model over the Huaihe River Basin with HUBEX Field Experiment Data①

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ABSTRACT

Off–line experiments have been conducted with IAP94 land surface model on different surface types (cropland, forest and paddy field) in different seasons (spring, summer and autumn) over the Huaihe River basin. The simulated energy fluxes and canopy temperature by IAP94 agree quite well with the observations, simulation results also show that IAP94 can successfully simulate the tendency of total soil water content variation. The comparison results between simulation and observation indicate that strong evaporation at the paddy field in summer should be paid more attention to within the land surface models, and model's performance leads to the conclusion that IAP94 is capable of reproducing the main physical mechanisms governing the land–surface processes in the East Asian semi–humid monsoon region.

Key words: Land surface process, Model validation, Off–line experiments

1. Introduction

Many studies have shown that the land surface process plays an important role in the climate system, especially in the East Asian monsoon region, and the impact of land surface processes on the monsoon system is quite significant (e.g., Charney, 1975; Meehl, 1994; Lin et al., 1996; Li and Yanai, 1996; Yang et al., 1996). When incorporating the complicated land surface processes into the climate model, the model's capability in reproducing the modern climate, including monsoon circulation and its precipitation, can be greatly improved (e.g., Lin and Zeng, 1997; Dai et al., 1998; Ding et al., 1998).

In order to identify the parameterization strengths and inadequacies of the existing land–surface models, and to improve the parameterization of the continental surface, especially hydrology, energy, momentum and carbon exchanges with the atmosphere, the Project for the Intercomparison of Land–surface Parameterization Schemes (PILPS) has been conducted since 1992 (e.g., Henderson–Sellers et al., 1993), which emphasizes sensitivity studies with the existing land surface models, intercomparisons between these models and the development of areally extensive datasets for their testing and validation. All participating Land Surface Models (LSMs), including IAP land surface model (IAP94), have been evaluated and calibrated by intercomparison with many observational datasets over different surface types, such as ARME from Brazil, Cabauw from the Netherlands, HAPEX–MOBILHY from

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France, Valdai from Russia, and Arkansas–Red basin from America (e.g., Henderson–Sellers et al., 1995, 1996; Chen et al., 1997; Liang et al., 1998; Lohmann et al., 1998; Wood et al, 1998; Qu et al., 1998).

China is located in the East Asian monsoon region, where the drought / flood events related to monsoon occur frequently, especially over the arid, semi–arid and semi–humid regions such as the Yangtze River and Haihe River valley, and the anomalies of land surface characteristics can play important roles in these climate anomalies. However, the mechanism of land–air interaction over this region is not clear due to the lack of field observational data. As a component of the GEWEX / GAME project, Huaihe River Basin Experiment (HUBEX) was carried out in 1998, and one of its main goals is to provide a better understanding of mechanism of land–atmosphere interaction over the East Asian monsoon region and then to validate the land surface model by the field observational data. So in this paper, we will use the HUBEX field experimental data to validate and calibrate the IAP94 land surface model, in order for it to be coupled into the regional climate model in the near future.

2. Brief introduction to IAP94 land–surface model

The model used in this study is IAP94 land surface model, which was established at the Institute of Atmospheric Physics, Chinese Academy of Sciences (IAP / CAS) in 1994. Here we give a brief introduction to the structure and the atmospheric boundary conditions of the model, and a full description of the philosophy, design and requirements of the model can be found in Dai and Zeng (1997).

This model is a rather comprehensive one with a detailed description for the processes of vegetation, soil and snow. Canopy in IAP94 is explicitly parameterized as a single layer, and the soil column is divided into three layers: (1) surface layer, in which soil water can be directly evaporated into the atmosphere, and the temperature undergoes a diurnal variation; (2) intermediate layer, it is the vegetation rooting zone, but in which the root may not exceed the bottom; (3) deep layer, where the transfer of water is governed only by gravitational drainage and hydraulic diffusion, and the temperature undergoes a seasonal and annual variation. And twelve classes of land types, twelve classes of soil texture and eight classes of soil color are defined in the IAP94 land surface model.

The atmospheric forcing data needed for IAP94 include precipitation, air temperature, wind speed, surface air pressure, specific humidity, incoming solar radiation and downward long wave radiation. The canopy parameters of IAP94 include leaf area index, fraction cover of vegetation, greenness, roughness length, zero plane displacement height and albedo, and the soil parameters include saturated hydraulic conductivity, saturated matric potential, porosity, soil moisture at field capacity and wilting point.

As one of the participants of the PILPS project, IAP94 has been validated with different field experimental data, such as Red–Arkansas River Basin experiment data, HAPEX data, etc., and the simulation results have shown that IAP94 can capture the main physical mechanisms governing the land–surface process (e.g., Dai and Zeng, 1997, Liang et al., 1998; Lohmann et al., 1998; Wood et al, 1998). However, it has not yet been validated in the East Asian semi–humid subtropics. So in this paper we will try to validate IAP94 land–surface model with the HUBEX field experimental data over different surface types (CROPLAND, FOREST, PADDY FIELD) in different seasons, in order for us to further improve the model's performance in the East Asian semi–humid monsoon region.

3. Data sources

The Huaihe River basin, where the HUBEX field experiment was carried out, is located between the Huanghe River and the Yangtze River. It is a closed basin extending 5 degrees in latitude and 9 degrees in longitude with a total area of 270,000 square kilometers, and belongs to warm temperate semi–humid monsoon climate region, which is the climate transition zone between North and South China. And the observational data used in this paper are the intensive field observational data of land surface processes, which was carried out at the western part of the Shi–Guan River Basin by using the AWS of Kyoto University (KU–AWS), over four characteristic surface types as shown in Table 1. For the year 1998, the observation was conducted during spring, summer and autumn respectively, as for 1999, the observation was conducted only at cropland during summer. The specific crop of 1998 is mulberry and the one of 1999 is bean. The observational terms obtained are: four components of radiation fluxes (upward, downward, long–wave and short–wave radiation), profiles in the lower ABL wind speed, air temperature, turbulent fluxes (momentum, sensible heat, H_2O and CO_2), air pressure, wind direction, precipitation etc. The atmospheric forcing data for off–line experiments are all from the datasets observed by KU–AWS (Table 1).

Table 1. Observational sites and time duration of KU–AWS in HUBEX

Surface type	Forest	Paddy field	Cropland	
Observational Site	Tangquanchi	Yangang	Shuangpu (mulberry)	Wudaoguo (bean)
	(31.700°N, 115.36°E)	(31.99°N, 115.30°E)	(31.91°N, 115.39°E)	(33.20°N, 117.00°E)
Time duration	May 25–29, 1998	May 18–24, 1998		
	Aug. 22–27, 1998	Aug. 08–15, 1998	May 10–18, 1998	
	Oct. 30–Nov. 3, 1998	Nov. 04–08, 1998	Aug. 17–21, 1998	Jun. 24–Aug. 26, 1999

For precipitation, the time interval for the observation is one hour, and then it is linearly interpolated to get the half–hour data suitable for the off–line experiment. As for other observational fields, the time intervals are 2 minutes or 10 minutes respectively, and then they are averaged to obtain the half–hour data for IAP94.

During the off–line experiment, the initial soil temperature and canopy temperature are both taken as the air temperature. For the soil moisture field, the observational data is only available at Wudaoguo, so the observed soil moisture value at the nearby site in the same region is adopted as the initial soil moisture for the sites at Tangquanchi, Yangang and Shuangpu respectively, as described by Peng (1999).

4. Validation of IAP94 over the Huaihe River basin

In this section, nine off–line experiments over three surface types (cropland, paddy field, forest) during different seasons are presented, in order to assess the performance of IAP94 in the East Asian semi–humid monsoon region.

4.1 *Forest*

The FOREST site is located in Tangquanchi (31.7°N, 115.36°E), and the field observation is conducted during the periods of May 25–29, Aug. 22–27 and Oct. 30–Nov. 3, 1998 respectively. The observation and model simulation results during spring, summer and

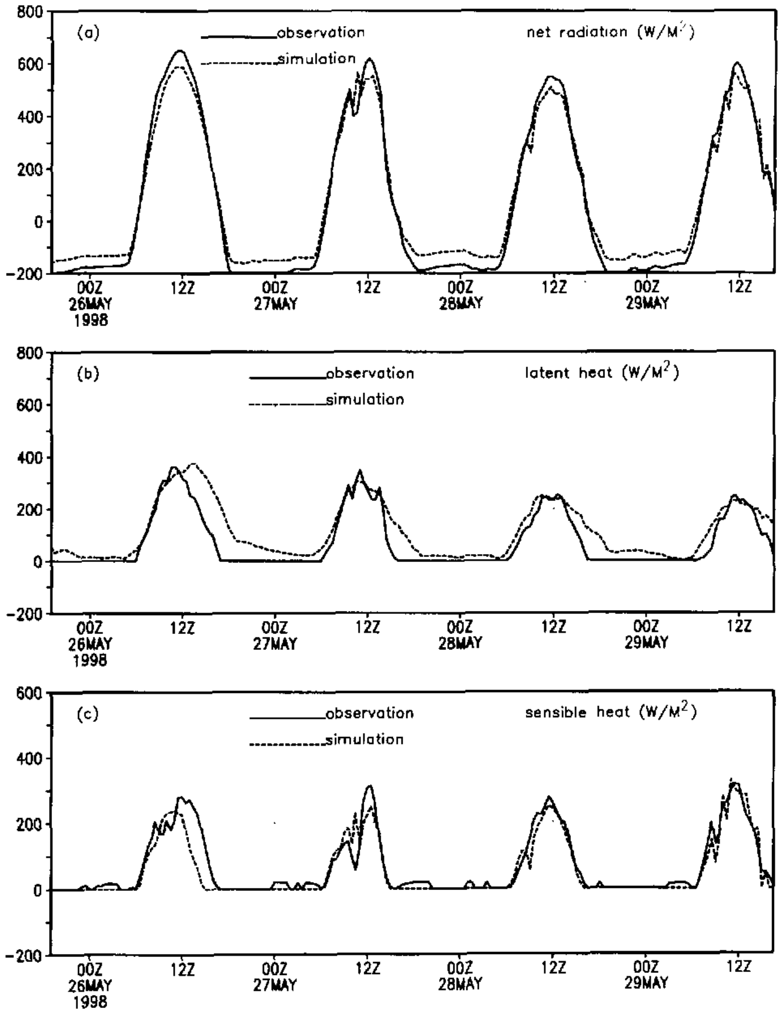

Fig. 1. Daily variation of observed and simulated (a) net radiation, (b) latent heat and (c) sensible heat flux at a forest site (at Tangquanchi, 25–29 May, 1998).

autumn are presented in Fig. 1 to Fig. 3.

Figure 1 shows the time series of the observed net radiation, sensible and latent heat flux in late spring, together with the model results simulated by IAP94. And we can find that the simulated net radiation and heat fluxes all agree reasonably well with the observation, except that the simulated peak values for the sensible heat flux and the net radiation are slightly smaller than the observation.

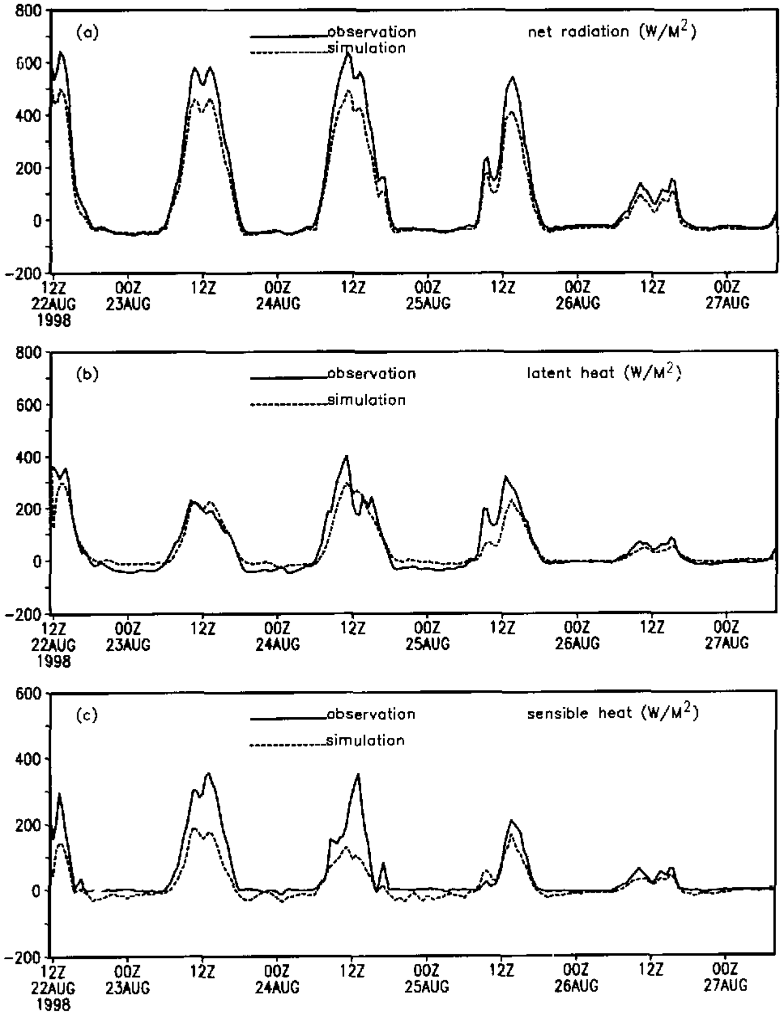

Fig. 2. Daily variation of observed and simulated (a) net radiation, (b) latent heat and (c) sensible heat at a forest site (at Tangquanchi, 22–27 Aug. 1998).

During summer, we can find from Fig. 2 that the model simulated latent heat flux agrees quite well with the observation, both in the magnitude and in the phase of time variation. However, as for the net radiation and the sensible heat flux, although the phases of the daily variations for the observation and model simulation agree quite well, the peak values simulated by IAP94 are generally smaller than the observation, and the difference can even exceed 100 W / m^2 at noon on Aug. 23 and Aug. 24.

Figure 3 shows the comparison results in autumn, and we can find that the simulated results are very close to observational values, except that there exist slight discrepancies in peak

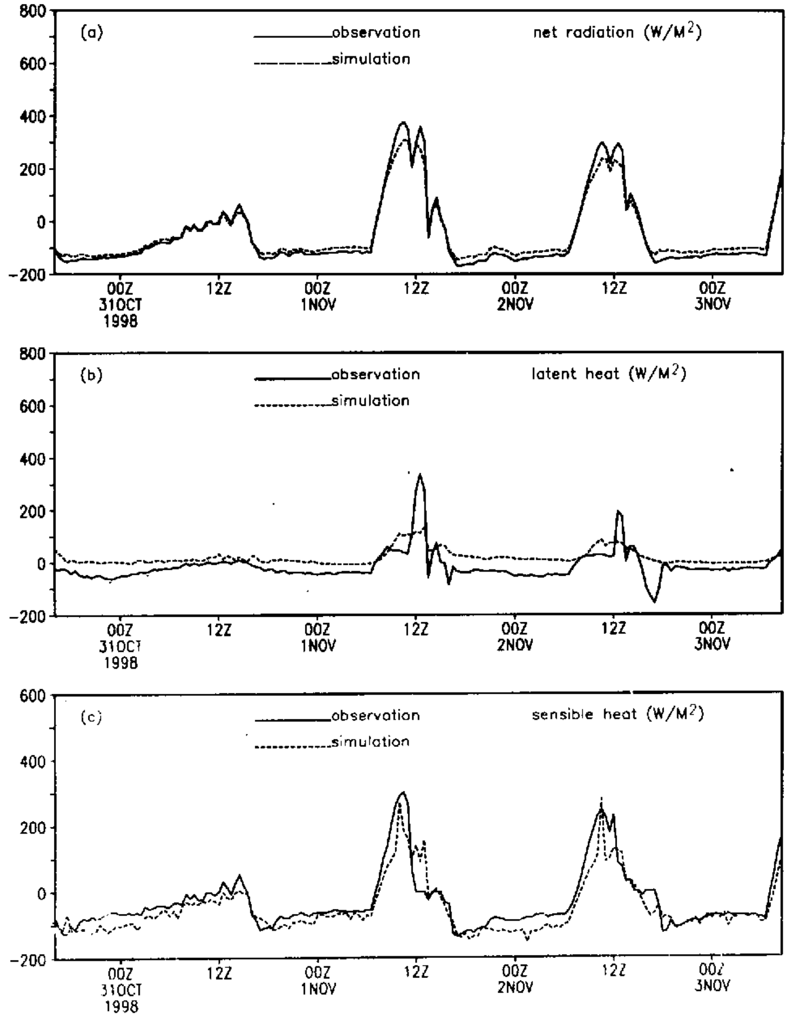

Fig. 3. Daily variation of observed and simulated (a) net radiation, (b) latent heat and (c) sensible heat at a forest site (at Tangquanchi, 30 Oct–3 Nov, 1998).

values for the latent heat flux.

Generally speaking, IAP94 could simulate the energy fluxes quite well at the forest site in different seasons. However, the performance of IAP94 is relatively poor at noon in some days, and this may be ascribed to the fact that the observational site is located in the foothills over the Huaihe River basin, and the heterogeneity of surface conditions can affect the observation and the model simulation.

4.2 *Paddy field*

The PADDY field is located in Yangang (31.99°N, 115.30°E), and the field observation is conducted during the periods of May 18–24, August 8–15 and November 4–8 of Figure 1998, respectively.

Figure . 4 shows the observed and simulated time series for the net radiation, sensible and latent heat flux during spring. Generally, the fluxes simulated by IAP94 are in good agreement with the observations. But for the net radiation, the simulated peak values are

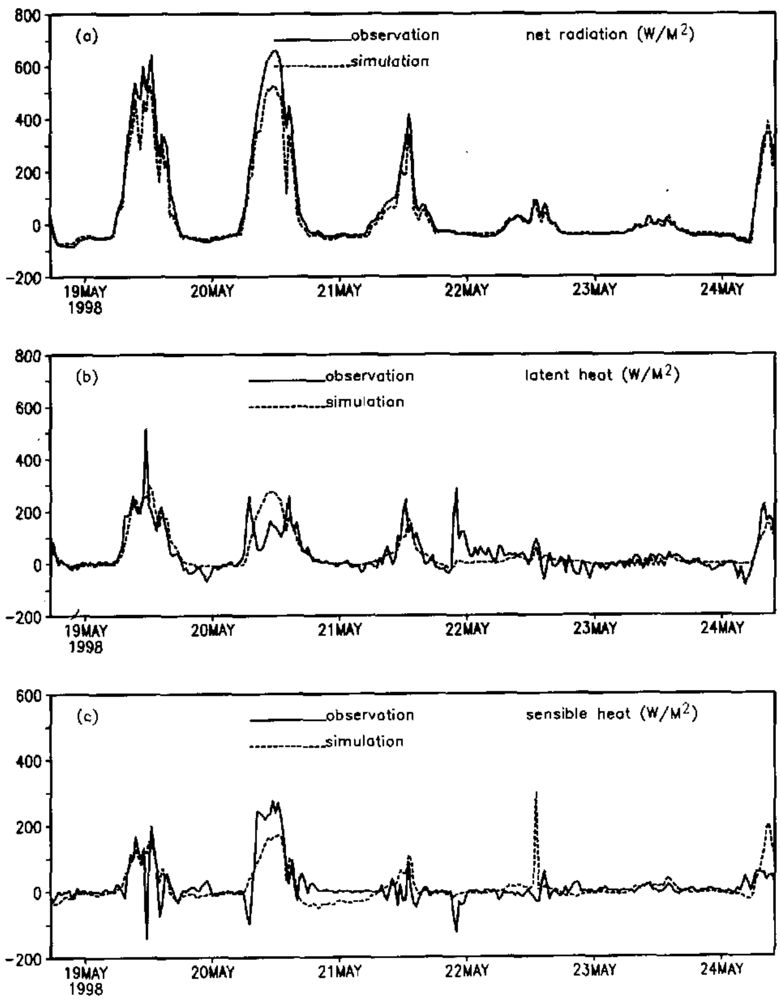

Fig. 4. Daily variation of observed and simulated (a) net radiation, (b) latent heat and (c) sensible heat flux at a paddy field site (at Yangang, May 18–24, 1998).

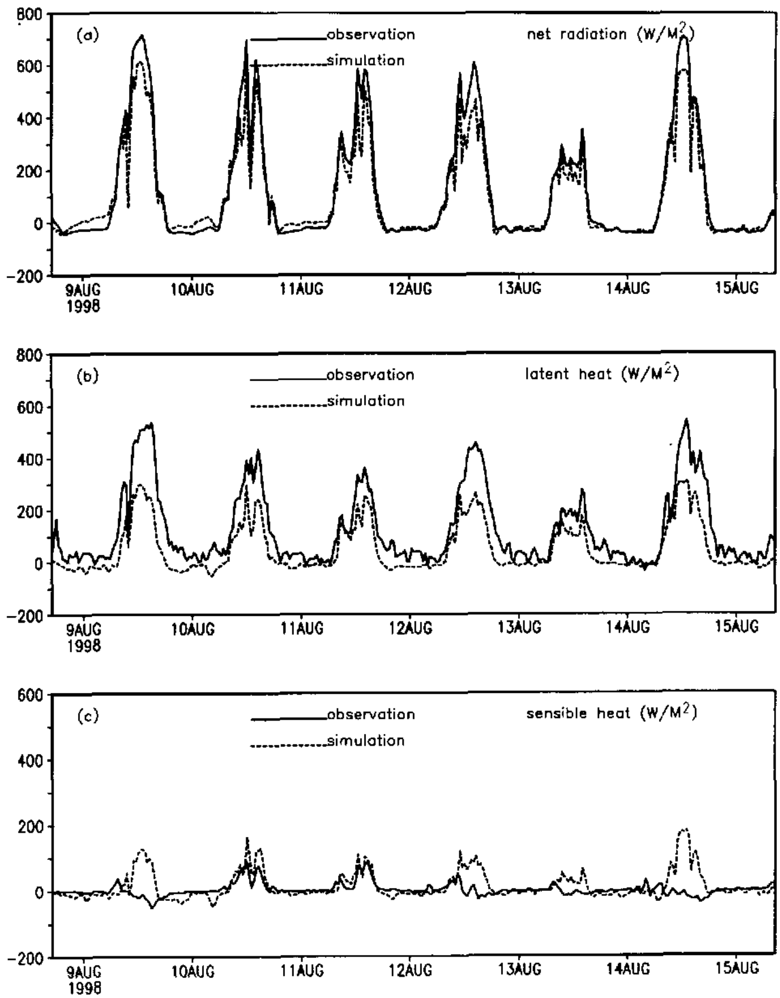

Fig. 5. Daily variation of observed and simulated (a) net radiation, (b) latent heat and (c) sensible heat flux at a paddy field site (at Yangang, May 8–15, 1998).

slightly lower than the observations, as for the simulation of latent heat and sensible heat fluxes, there exists slight phase shift of the peak value compared with the observation.

Figure 5 shows the comparison results between the simulation and observation in summer, and we can find that, although the daily variation of the model simulated net radiation, latent heat and sensible heat fluxes agree quite well with the observation, discrepancies still exist with regard to the magnitude of the simulation results. The peak values for the net radiation simulated by IAP94 are slightly lower than the observed. As for the latent heat, the simulated peak values are remarkably lower than the observation, on the contrary, for the sensible

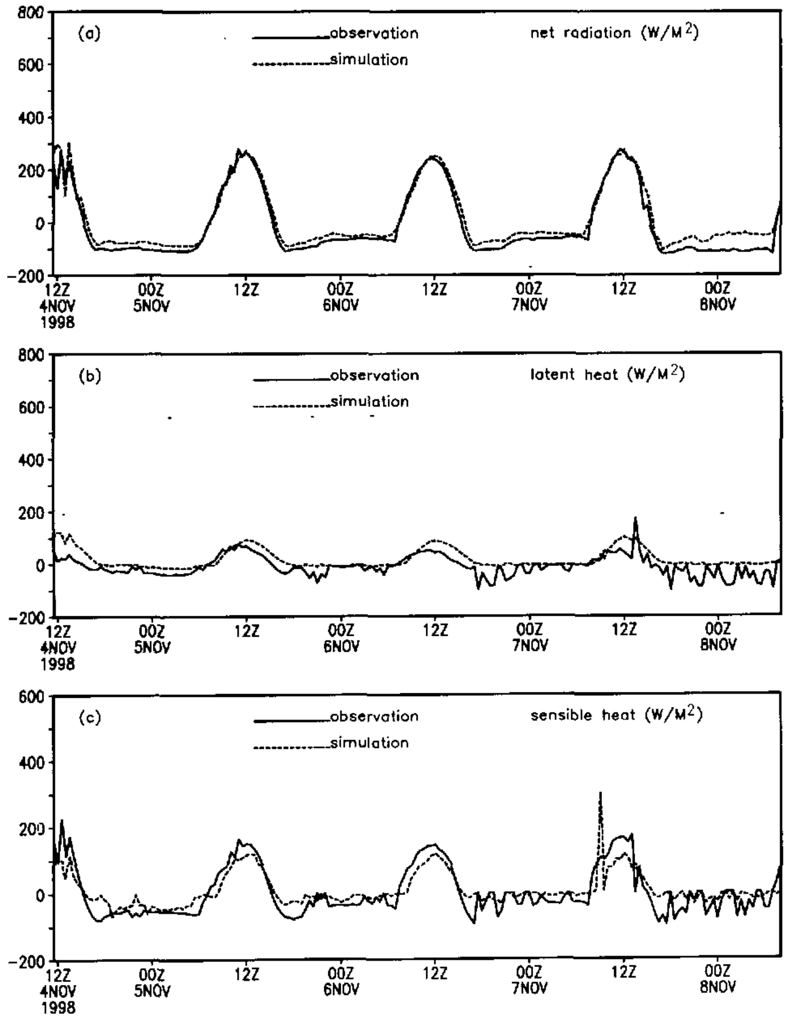

Fig. 6. Daily variation of observed and simulated (a) net radiation, (b) latent heat and (c) sensible heat flux at a paddy field site (at Yangang, 4–8 Nov., 1998).

heat flux, the simulated peak values are obviously higher than the observed.

During autumn, we can find from Fig. 6 that the simulated time series for the energy fluxes (net radiation, latent heat and sensible heat fluxes) agree well with the observation, in both the magnitude and the phase of daily variation.

It must be noted that, there is no surface type of paddy field in the IAP94 land surface model, so it is considered as farmland in this study. During August 8–15, the paddy is stunted and cannot cover the water, so the evaporation over this site is quite strong, however the characteristics of strong evaporation cannot be well simulated by IAP94. As for the situation in May, the paddy is tall and can cover the water, and in November, the paddy field turns dry, so during May and November, IAP94 can simulate the surface evaporation quite correctly. However, the strong evaporation of the paddy field in summer is quite important over this region and needs to be correctly described, and we will consider the paddy field as a new surface type in the IAP94 land surface model in the near future.

4.3 *Cropland*

The CROPLAND field site was located in Shuangpu (31.91°N, 115.39°E) in 1998, and it was moved to Wudaoguo (33.2°N, 117°E) in 1999. The validation data used in this study were

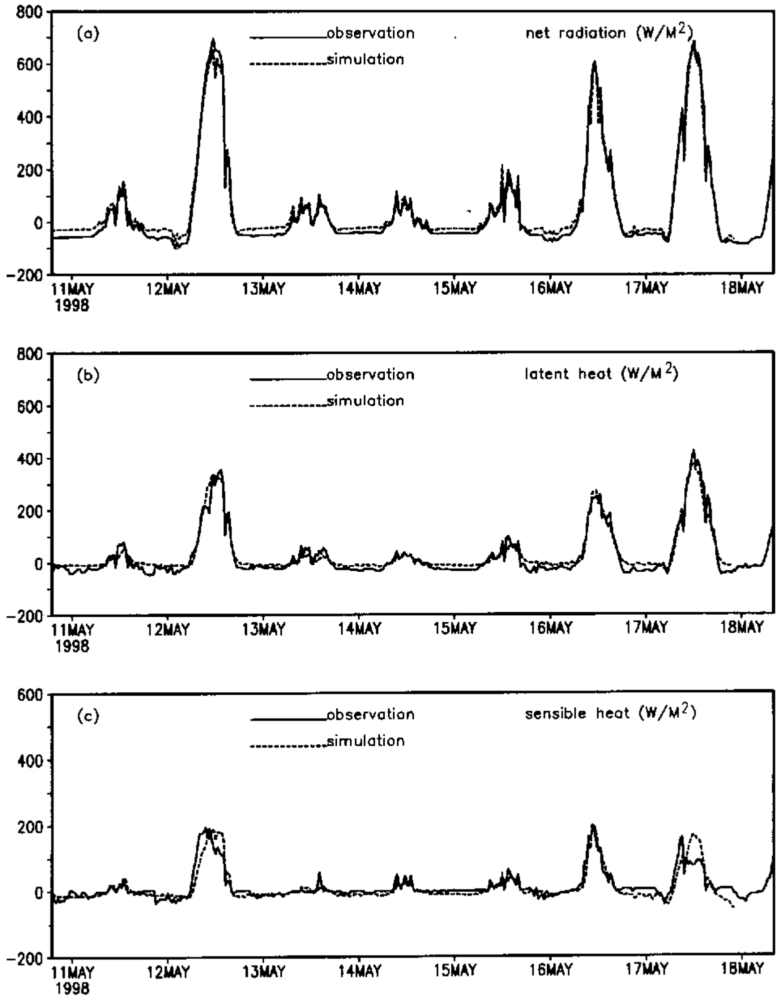

Fig. 7. Daily variation of observed and simulated (a) net radiation, (b) latent heat and (c) sensible heat flux at a cropland site (at Shuangpu, May 10–18, 1998).

taken from the observations covering three periods, i.e., May 10–18, August 17–21 of 1998 and June 22–August 22 of 1999. In the summer of 1999, the observed terms include energy fluxes, soil moisture and soil temperature of different layers, and the observations last for nearly two months, so the data can be used to assess the model's capability in the simulation of soil moisture and soil temperature, except for energy fluxes.

Figures 7 and 8 show the simulated time series by IAP94 and observed ones for energy fluxes in May and August of 1998, respectively, we can find that the simulated fluxes and the observed ones are in good agreement, in both the magnitude and phase of time variation. Compared with the results over other surface types, the performance of IAP94 is the best over cropland.

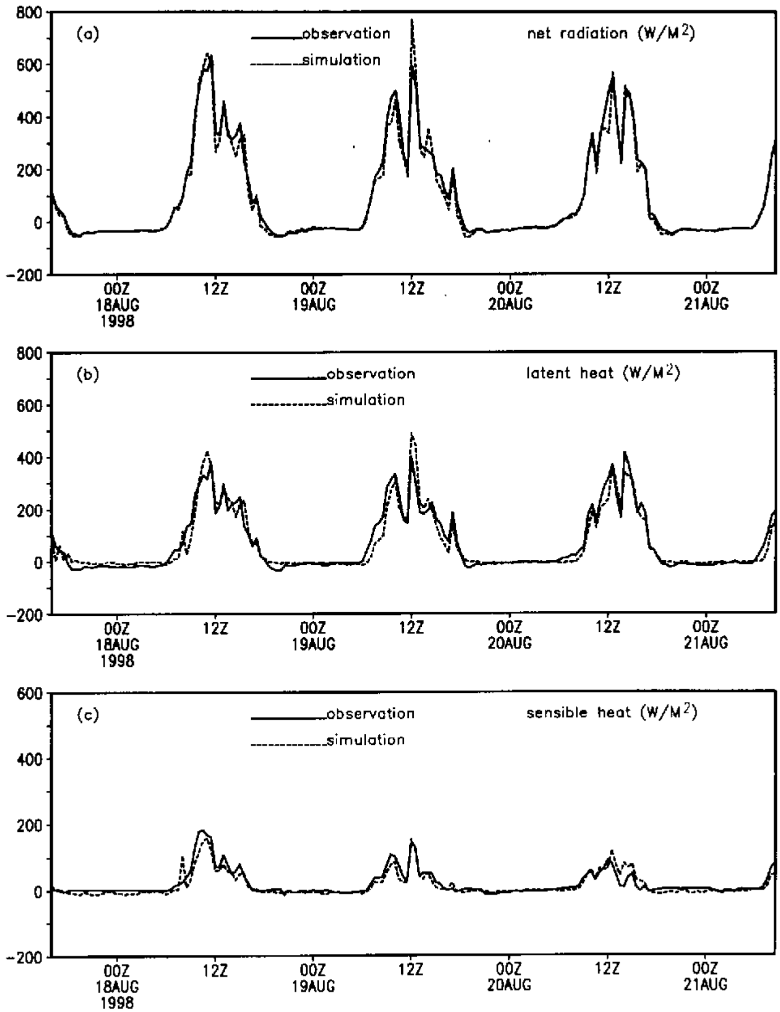

Fig. 8. Daily variation of observed and simulated (a) net radiation, (b) latent heat and (c) sensible heat flux at a cropland site (at Shuangpu, August 17–21, 1998).

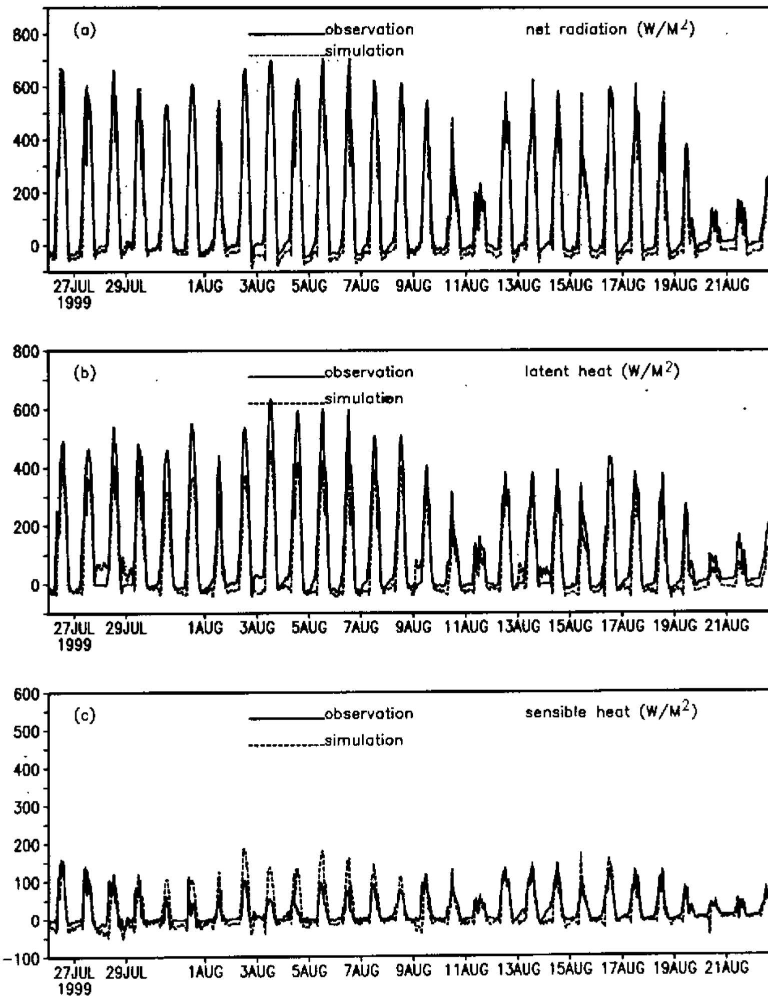

Fig. 9. Daily variation of observed and simulated (a) net radiation, (b) latent heat and (c) sensible heat flux at a cropland site (at Wudaoguo, July 26 —August 22, 1999).

Figure 9 is the case for the summer of 1999. Generally, the model simulation and observation are in good agreement, especially for the net radiation. However, as for the latent heat and sensible heat fluxes, there still exist discrepancies in the peak values in some days.

Figure 10 shows the observed and simulated time series of the total soil water content and the observed daily precipitation. For the observation, only the total soil water content in the top 60 cm layer is available, so we can only compare the tendency of the total soil moisture variation. The comparison result from Fig. 10 indicates that IAP94 is capable of reproducing the tendency of the soil moisture variation, and its response to the forcing of

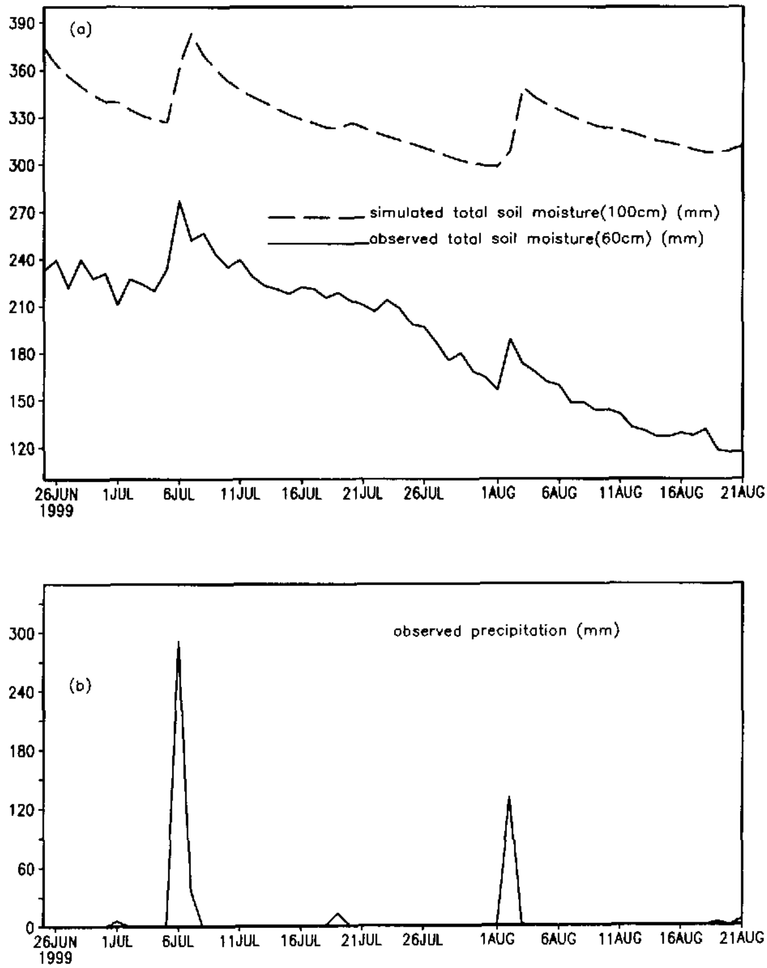

Fig. 10. (a) Time series of observed and simulated total soil water content (b) Observed daily precipitation (at Wudaoguo, June 25—August 21, 1999).

precipitation. When precipitation occurs, the total soil moisture increases quickly in response to this moisture forcing, and then the total soil moisture decreases slowly due to the surface evaporation in clear days.

The time series of observed and simulated canopy temperature are shown in Fig. 11, and from Fig. 11 we can find that the simulated canopy temperature by IAP94 agrees quite well with the observation.

The results from the above nine validation experiments demonstrate that, in general, IAP94 could correctly simulate the energy fluxes over different surfaces and in different seasons in this semi—humid monsoon region, and successfully simulates the tendency of the total

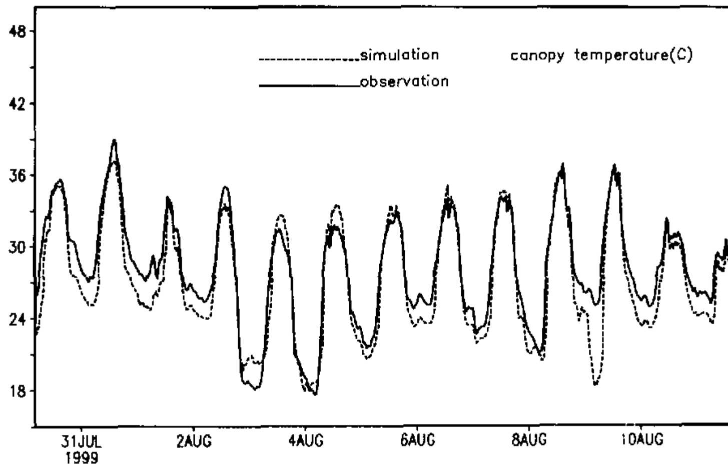

Fig. 11. Daily variations of observed and simulated canopy temperature at a cropland site (at Wudaoguo, July 30–August 12, 1999).

soil water content variation. However, the discrepancies still exist between simulation and observation of energy fluxes, and the differences of the sensible heat flux between the observation and model simulation are opposite in sign to that of the latent heat flux. This may be ascribed to two reasons. Firstly, this maybe results from the observational errors, because the observational values of the sensible and latent heat are calculated by the Bowen–Ratio method, which could make the variations of the sensible heat and latent heat opposite in phase. Secondly, this maybe is ascribed to the fact that the model simulated soil moisture is not quite consistent with the observation, as has been discussed by Liang et al. (1998).

5. Summary and discussions

In this paper, the IAP94 land surface model has been validated against field measurements over the Huaihe River Basin (HUBEX) in three different surface types (i.e., Forest, Paddy field and Cropland) and in different seasons. Generally, the simulated energy fluxes by IAP94 agree reasonably well with the observation, especially over the cropland surface. In this semi–humid monsoon region, the sensible heat and latent heat are comparably important in the air–land energy and water exchange, which is different from the situation in the arid and semi–arid regions, where the sensible heat flux is dominant (Nai and Hu, 1994). This demonstrates that IAP94 is capable of capturing the main physical mechanisms governing the land–atmosphere interaction in the East Asian semi–humid monsoon region. And this gives us the confidence to couple IAP94 into a climate model, in order to increase model's capability in reproducing the East–Asian monsoon climate.

However, IAP94 also shows some discrepancies when comparing with the observation, especially for the model simulated peak values of the net radiation, the latent heat and sensible heat flux. On the other hand, observation and model simulation show that strong evaporation at the paddy field in summer has a great effect on the partition of energy flux and water cycle in this special region. However, this cannot be correctly simulated by IAP94 because the paddy field is not considered as a specific surface type in IAP94 land surface model. All these may suggest that IAP94 still needs to be validated by more field observational data, such as IMGRASS grass land, arid and semi–arid region field observational data, in order for it to be further calibrated and improved.

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IAP94陆面过程模式在淮河流域的验证试验

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摘　要

利用IAP94陆面过程模式对淮河流域不同季节(春、夏、秋)、不同下垫面(旱地、森林、水田)进行了单点数值模拟试验，结果表明IAP94不但能较好地模拟出观测的地气间各种能量通量以及植被的冠层温度，同时还很好地模拟出整层土壤含水量的变化趋势，从而证实了IAP94陆面过程模式具有正确描述东亚半湿润季风区陆气相互作用的能力．另外比较结果还揭示了水田表面强烈蒸发作用的重要性，需要在陆过程模式中予以重视。

关键词: 陆面过程，模式验证，单点试验