Numerical Simulation of Surface Heat and Water Fluxes in Tibet Plateau

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ABSTRACT

This paper examines the performance of an off-line version of the Community Land Model (CLM3.0) by simulating the soil properties: soil temperature, and soil wetness, in Tibetan Plateau, and the modeled results are validated with direct measurements at three filed sites. The soil properties in the model are initialized with field measurements and are driven by half-hourly observed atmospheric variables (temperature, humidity, wind speed, surface pressure and downward radiation (solar and infrared). The observation (or direct measurements) of the soil properties and atmospheric fields are collected through the Global Energy and Water Cycle Experiment (GEWEX) Asian Monsoon Experiment (GAME)-Tibet project. Results indicate the CLM is able to capture general characteristics of soil in Tibetan Plateau. The model shows sensitivity to initial soil properties, particularly soil moisture. The initial error in the soil moisture contributes largely the simulated bias in soil moisture.

Key words: soil moisture, soil temperature, Tibetan Plateau, Community Land Model

INTRODUCTION

The land component of climate models represents many important processes that control water and energy exchange between the atmosphere and land [1-5]. Thus land surface processes are critical in regional and mesoscale atmospheric modeling [6-7]. Its importance for weather forecasting and climate has been increasingly recognized in the past two decades [8-9]. For this reason, the original bucket-type land surface model [10] has been replaced by more physically based representations of the global soil–vegetation–atmosphere transfer system [11].

Based on NCAR LSM [12-13], IAP94 [14], Bats [15], NCAR Community Land Model is one of the most advanced land surface models. The simulation performance of CLM has been validated for different climate regimes (such as VALDAI [16-17] at Russian, Amazon rainy forest at Brazil). The validations have demonstrated that CLM captures land-atmosphere interaction reasonably well.

Dynamic and thermal impacts of the Tibetan Plateau on regional weather and atmospheric circulation are well-known [18-26]. However the simulation skill of CLM in the region has not yet been examined.

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The objectives of this research are to investigate the simulation performance of CLM in the Tibetan Plateau using the data observed during the intensive observation period (IOP) of GAME in Tibet at Anduo, Shiquanhe and Gaize station in the Tibetan Plateau. Section 2 provides a summary of the CLM model and experimental sites, and in Section 3, we compare observations with the CLM estimates. Finally, the main conclusions are discussed in Section 4.

DESCRIPTION OF THE CLM MODEL AND EXPERIMENTAL SITES

Model

The horizontal land surface heterogeneity of CLM is represented by a nested subgrid hierarchy composed of gridcells, landunits, columns, and plant functional types (PFTs). This hierarchical representation is reflected in the data structures used by the model code. Biophysical processes are simulated for each subgrid unit (landunit, column, and PFT) independently, and prognostic variables are maintained for each subgrid unit. Vertical heterogeneity is represented by a single vegetation layer, 10 layers for soil, and up to five layers for snow, depending on the snow depth.

The bio-geophysical processes related to soil and snow require PFT level properties to be aggregated to the column level. This is generally accomplished in the model by computing a weighted sum of the desired quantity over all PFTs whose weighting depends on the PFT area relative to all PFTs.

The current processes simulated include: vegetation composition, structure, and phenomenology; absorption, reflection, and transmittance of solar radiation; absorption and emission of long wave radiation; momentum, sensible heat (ground and canopy), and latent heat (ground evaporation, canopy evaporation, transpiration) fluxes; heat transfer in soil and snow including phase change; canopy hydrology; snow hydrology (snow accumulation and melt, compaction, water transfer between snow layers); soil hydrology (surface runoff, infiltration, sub-surface drainage, redistribution of water within the column); stomatal physiology and photosynthesis; lake temperatures and fluxes; routing of runoff from rivers to ocean; and volatile organic compounds.

Experimental sites

Several large-scale experiments have been carried out in the Tibetan Plateau , such as the 1st Qinghai-Xizang Tibetan Plateau meteorological experiment in 1979 (QXP-MEX) [35], the 2nd Tibetan Plateau experiment of atmospheric sciences in 1998 (TIPEX) [36-37], and the global energy and water cycle experiment (GEWEX) Asian monsoon experiment in the Tibetan Plateau (GAME/Tibet) in 1998 [38-40].

Here we select Anduo, Shiquanhe and Gaize of the GAME/Tibet) in 1998 as typical site to validate the simulation performance of CLM in the Tibetan Plateau.

The Anduo experimental site is located at 91°63'E , 32°24'N with an elevation of about 4700m above the sea level . A relatively large open area covered by a flat plateau grassy marshland surface (grass height is about 5cm) was chosen for the experiment. Some hills about 100-500m high were standing about 40km to its south and about 10km to its east, west and north.

The ShiQuanhe experimental site stands in the western Qing-Zang Tibetan Plateau (32°30′N，80°05′E), at an elevation of 4278m ASL. GaiZe lies in the center of the western Qing-Zang Tibetan Plateau, with a location of 32°13′N，84°48′E and at an elevation of 4414.9 above ASL. Shiquanhe and Gaize share similar climatic characteristics, with a sandy desert soil layer, several centimeter high needle leaf grasses in the rainy season, and without vegetation cover in other seasons.

SIMULATION ANALYSIS

Anduo

Simulated latent heat, sensible heat, 0.1m soil heat flux, 0.1m soil temperature and 0.05m soil temperature are in good agreement with the observed counterpart. The modeled amplitude and time variances tend to agree with observation. The CLM demonstrates a good performance at the Anduo experimental site.

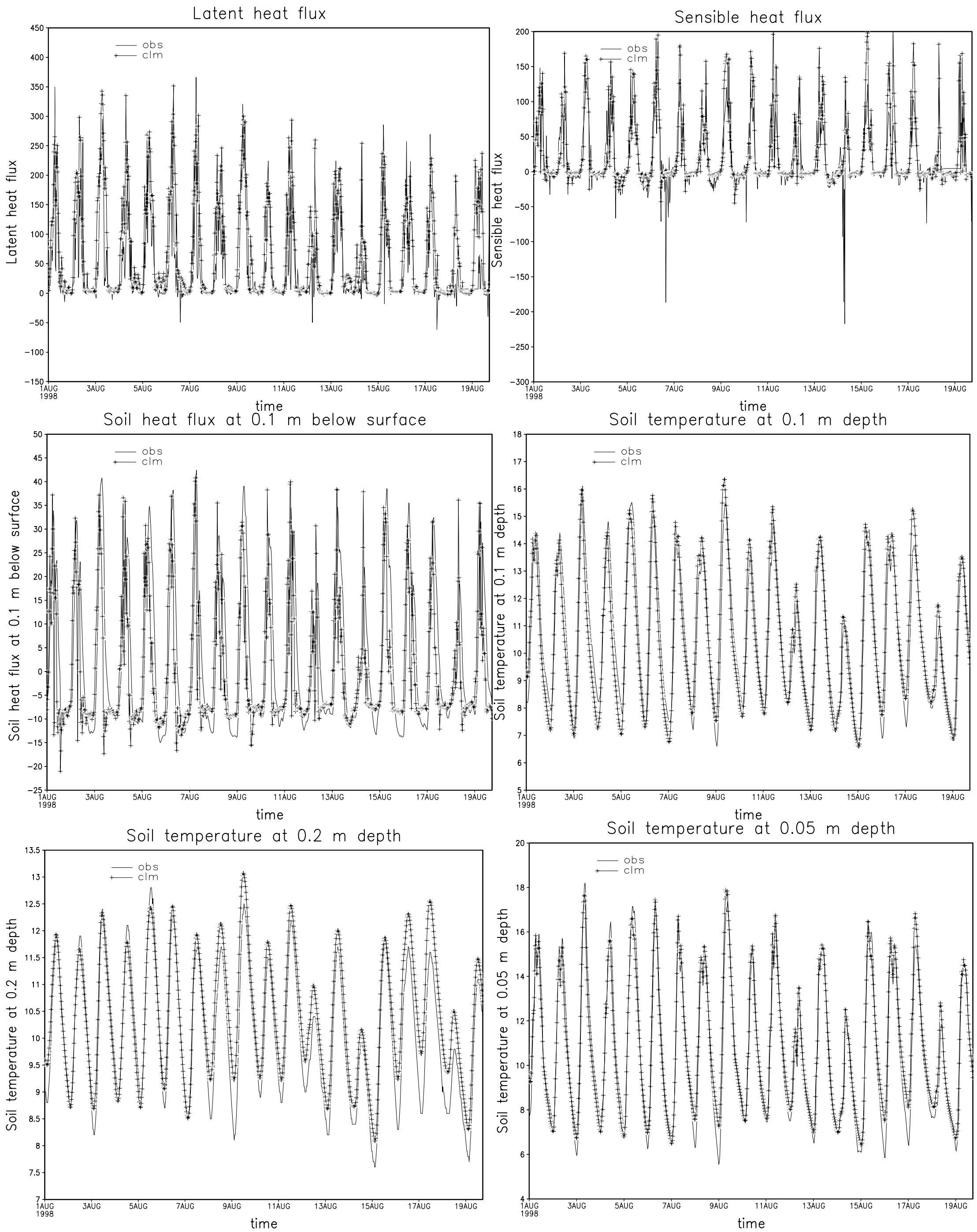

Figure 1 The figure compares the heat-water simulation in August at Anduo. On the left upper part is latent heat flux; on the right upper part is sensible heat flux; on the left middle part is soil heat flux; on the right middle part is 0.1m soil temperature; on the left lower part is 0.2m soil temperature; on the right lower part is 0.05m soil temperature

Shiquanhe

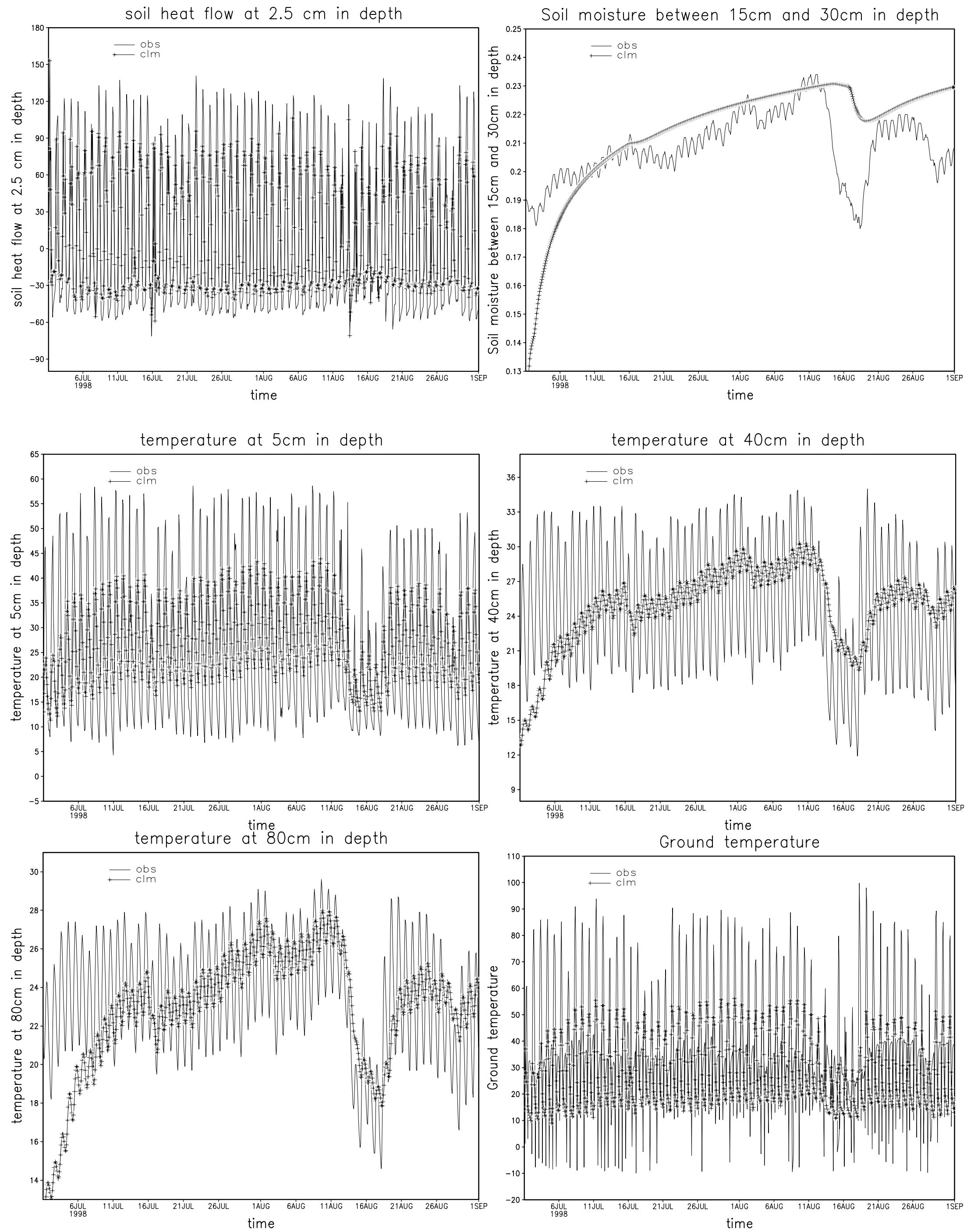

Figure 2 The figure compares the heat-water simulation during July-August at Shiquanhe. On the left upper part is 2.5cm soil heat flux; on the right upper part is 15-30cm soil moisture; on the left middle part is 5cm soil temperature; on the right middle part is 40cm soil temperature; on the left lower part is 80cm soil temperature; on the right lower part is ground temperature

The simulated variance tendency compares well with the observation, but the simulated heat flux jumped across the observed average value and is a little lower than the measurement. The CLM only captures the average value of observed soil moisture in the 0.15-0.30cm depth. The overall tendency agrees well, but the amplitude differs greatly. The error between simulation and observation appears larger at first, smaller in the middle, and larger again at last, which could be attributed to the large error of land surface parameters from CLM initialization. Modeled ground temperature and 0.5cm soil temperature contain more observed average information. The temporal variation of simulated soil moisture in 40cm and 80cm depth is in good agreement with observation, but the simulation is obviously smaller in magnitude than the observation at the first stage, similar to simulated soil moisture in 15-30cm depth, which indicates that the CLM initializes a much smaller value for the soil moisture in the 15-30cm depth and soil temperature in 40 and 80cm depth. From another perspective, in spite of smaller initialization, the generally simulated tendency fit well, which still indicate that the simulation performance of the CLM is good. Thus when running the CLM in this area, better initialization value should be specified because of the unreasonable initialization algorithm in this area.

Gaize

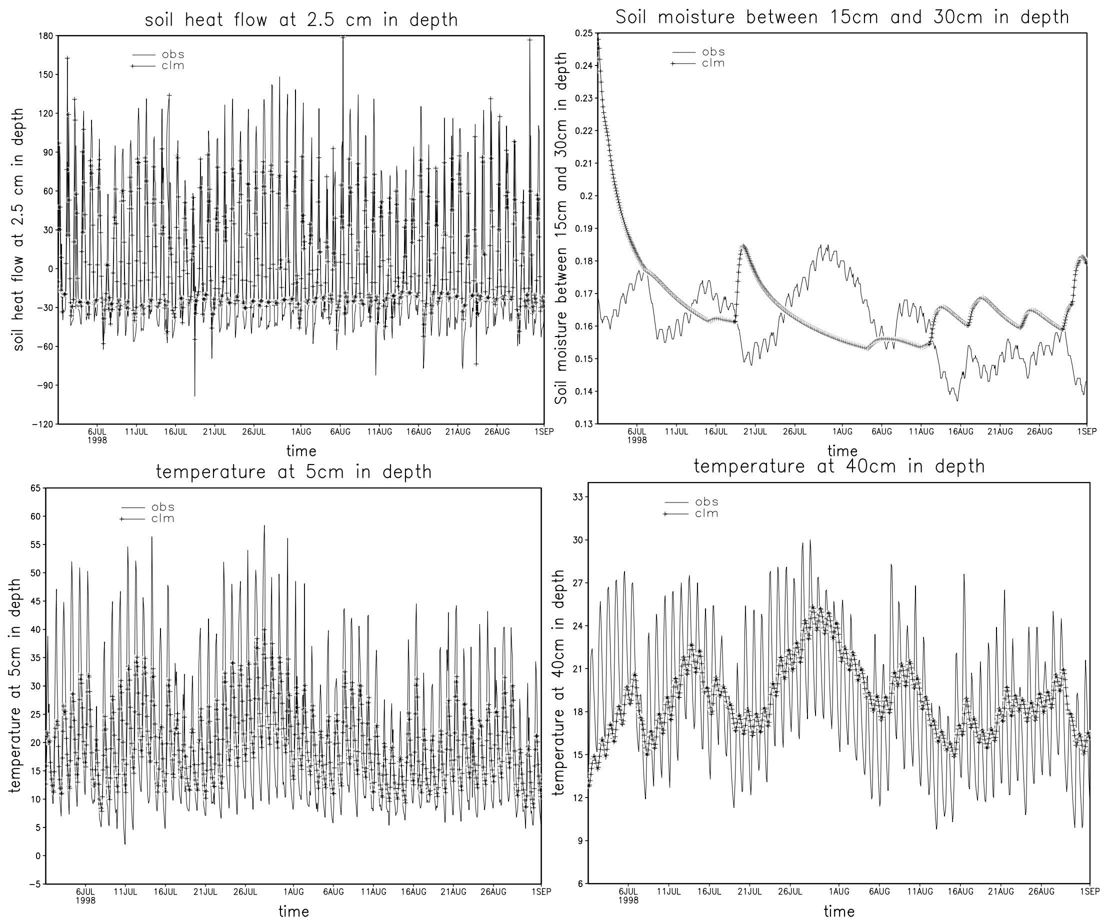

Figure 3 The figure compares the heat-water simulation during July-August at Gaize. On the left upper part is 2.5cm soil heat flux; on the right upper part is 15-30cm soil moisture; on the left lower part is 5cm soil temperature; on the right lower part is 40cm soil temperature

The simulated 2.5cm soil heat flux agrees well with observation in terms of variance tendency and amplitude. Overall, the simulated heat flux is smaller than the observation. For the soil moisture in 15-30cm depth, because of the large initialization error, the simulated amplitude and phase differ significantly from the observations at first, but fit well at last, which also indicates the initialization algorithm of the CLM is poor in this area. Comparing soil heat flux in 2.5cm depth, and the soil temperature in 5cm and 40cm depth, the overall simulation tendency fits well, but with increasing soil depth, the soil heat energy is dispersed quickly, leading to a smaller amplitude wave of soil temperature, which may be related to bad simulation performance of soil moisture.

CONCLUSION

The CLM could delineate the atmosphere-land interaction of these three sites. Variables associated with heat energy appear to be better simulated than those associated with moisture. The CLM appears to perform well at the Anduo experimental site. At the other two sites the CLM simulates the tendency of water-heat variance, with better simulation performance for soil heat variables than for soil moisture variables. Despite the poor initialization of CLM, the overall change tendency still could be captured. The initialized error of soil moisture is larger than that of soil temperature.

This study has examined the data at three experimental sites to validate the CLM simulation performance in the Tibetan Plateau. Further understanding of the simulation skill of the CLM to the Tibetan Plateau will require spatial comparisons with observations.

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