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Comparison of sensible and latent heat fluxes during the transition season over the western Tibetan Plateau from reanalysis datasets

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Abstract

The sensible and latent heat fluxes during the transition season over the western Tibetan Plateau from the NCEP-1 (NCEP/NCAR Reanalysis 1), AR-II (NCEP-DOE Reanalysis 2) and ERA40 reanalysis datasets were compared and analyzed. The results show that the phase change in soil moisture has a significant effect on the sensible and latent heat fluxes over the western Tibetan Plateau (TP) due to the freezing–thawing processes during the transition from the dry to the wet period. The uncertainties in the sensible and latent heat fluxes over the western TP are quite high in the reanalysis data, and depend largely on the success of the soil moisture simulations in the models. Improving the hydrological process simulations in the land-surface models in seasonally frozen ground and in the active frozen soil layer may be an effective way of enhancing the reliability of the surface heat fluxes from the reanalysis data over the Tibetan Plateau.

Keywords: Western Tibetan Plateau; Surface heat fluxes; Reanalysis data; Transition season; Freezing–thawing process

1. Introduction

The thermal effects of the Tibetan Plateau (TP), the world's largest and highest plateau with varied terrains and heterogeneous surface, on the atmosphere has been the subject of extensive scientific investigations since the last several decades. Ye et al. [1] and Flohn [2] studied the thermal effects of the TP on atmospheric circulation, and showed that TP is a source of heat in summer. Flohn [3,4] analyzed the evolution of the South Asia High (SAH) and suggested that the thermal effects of the TP are responsible for the formation of the SAH. Other studies also show that the TP thermal forcing not only plays an important role in producing the East Asia summer general circulation [5–8], but also has significant effects on the development of weather systems in East China [9] and the climate patterns over the Northern Hemisphere [10–13]. However, these results were based on limited observations. Recently, the sensible and latent heat fluxes from improved reanalysis datasets (i.e., NCEP-I, NCEP-II (AR-II) and ERA) have been used widely to study the TP thermal forcing as it relates to global general circulation and climate change [14–18]. The main concerns are the reliability and quality of the reanalysis data over the TP. Su et al. [19] showed that the sensible and latent heat fluxes from the NCEP reanalysis data obviously display a large positive shift over the TP, and Song et al. [20] reported that the reanalysis data are able to reproduce the intensity and inter-annual changes in the ground heat fluxes over the TP. Moreover, the monthly mean temperature from the NCEP reanalysis data is lower than the observations [21,22], while the precipitation is higher [23] than the observations.

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Simulations from the numerical models are largely uncertain over the TP, due to its heterogeneous surface and much more complicated physical processes, especially during the transition season when the interaction between the earth and atmosphere becomes more complicated than usual. Due to snowmelt and thawing–freezing processes, there are also large differences between the sensible and latent heat fluxes in different regions over the TP [24]. Wang and Shi [25] investigated the soil temperature and moisture changes over the TP during the transition season and showed that the latent heat flux contributed more to the process of surface thermal balance after the beginning of the ground thawing-freezing process, which means that the reanalysis data will have larger biases in the transition period. Therefore, spring (the transition season) was chosen as the main study period in their study.

In this study, we focus on a comparison of the sensible and latent heat fluxes of the reanalysis data, including NCEP-I, NCEP-II and ERA, with observations during the transition season over the western TP. Our aim is to find representations of the analysis data during the transition season over the western TP and to try to understand the possible reasons for the large discrepancies observed in the area's reanalysis data.

2. Data and methodology

The daily mean sensible and latent heat flux data of Reanalysis-I, Reanalysis-II (from May 1998 to October 1998) of NCEP/NCAR and ECMWF(ERA) were used in order to compare and analyze the differences between the reanalysis data. Observational data from the intensive period of the Global Energy and Water Cycle Experiment (GEWEX) and the Asian Monsoon Experiment on the Tibetan Plateau (GAME/Tibet) were also used. Two AWS stations over the western TP were chosen, which provide observations 24 times daily: Shiquanhe (80.05°E, 32.30°N, 4378 m) from 1 May to 17 September 1998, Gaize (84.25°E, 32.09°N, 4416 m) from 1 May to 30 July 1998. The main observations included upward/downward long-wave radiation, upward/downward short-wave radiation, ground fluxes (2.5 cm, 7.5 cm), wind speed, wind direction, air temperature and relative humidity at 1.0 m, 2.0 m and 4.0 m, soil temperature (0.0 m, 0.05 m, 0.10 m, 0.20 m, 0.40 m, 0.80 m), precipitation, and pressure. The dataset contains short periods of missing data for the equipment failure.

The daily mean values in the AWS data were calculated using 60 min interval observations. The daily mean sensible and latent heat fluxes were computed using the Bowen scheme (BR) as follows:

$$\begin{cases} Rn = SH + LE + G \\ \beta = \frac{SH}{LE} = \frac{C_p}{L_v(\varepsilon/P)} \frac{\Delta T}{\Delta z} \end{cases} \tag{1}$$

$$\begin{cases} SH = (R_n - G)/(1 + \beta^{-1}) \\ LE = (R_n - G)/(1 + \beta) \end{cases} \tag{2}$$

Here, Rn is the net radiation, G the soil heat flux, C_p the specific heat at constant pressure, β the Bowen ratio, ε the weight ratio of water vapor to the dry air molecule ($\varepsilon = 0.622$), P the pressure, ΔT and Δe are the temperature and vapor pressure difference at different altitude levels, respectively. SH is the sensible heat flux, and LE is the latent heat flux.

The aerodynamic scheme (AD) was also used to calculate the surface heat fluxes in order to obtain more realistic ground heat fluxes over the western TP and to improve the comparison with the reanalysis data. This is given by the following:

$$\begin{cases} SH = -\rho C_p u_* T_* \\ LE = -\rho L u_* q_* \end{cases} \tag{3}$$

$$\begin{cases} \frac{kz}{u_*} \cdot \frac{\partial u}{\partial z} = \phi_m \\ \frac{kz}{T_*} \cdot \frac{\partial T}{\partial z} = \phi_h \\ \frac{kz}{q_*} \cdot \frac{\partial q}{\partial z} = \phi_w \end{cases} \tag{4}$$

Here, u_* is the friction velocity, T_* the turbulent temperature scale, q_* the turbulent humidity scale, κ the Karman constant, z the height, which is a simple function of the wind, temperature and humidity, according to Dyer [26] and Hicks [27].

The reanalysis data from NCEP-I, NCEP-II, ERA40 were interpolated to the observational sites by a bilinear interpolation method to ensure consistent comparisons.

3. Results

The transition season (spring) corresponds to a period of dramatic changes in surface conditions over the plateau. The phases of temperature and humidity change frequently during spring (Fig. 1). This not only corresponds to the early stage of the onset of the East Asian monsoon, but also to the sensitive period of the changing surface hydro-thermal state. Some studies have suggested that the ground freezing–thawing processes of the Tibetan Plateau significantly delayed the onset of the monsoon and the global climate progress [28–30]. Hence, spring was chosen as the study period for our study. Previous studies have shown that the time of the onset of the South China Sea monsoon is 1–23 May 1998, which leads to the onset of the Indian monsoon in early June [31,32]. Therefore, the second pentad of June was used as the date of onset of the Asian monsoon, which also corresponds to the onset of the wet season over the western TP.

3.1. Variability in the ground temperature and moisture

Firstly the BR was used to estimate the sensible and latent heat fluxes. However, when the net radiation remains unchanged, it is mostly dependent on the changes in the surface heat fluxes, so it can indirectly reflect the variations in the soil temperature and moisture. Note that when the soil moisture or temperature change becomes larger, the