Heat and Water Balance Estimates over the Tibetan Plateau in 1997-1998

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Abstract

Xu and Haginoya (2001) used a multi-layer soil model with input data derived from routine meteorological data to estimate heat and water balances over Tibet in 1997. The present paper uses the same method to estimate heat and water balances for 1998. GAME-Tibet intensive observation period (IOP) data are used to verify calculation results. Observed longwave radiation flux agrees well with calculations. Surface air temperatures were higher in 1998 than in 1997. Sensible heat flux dominated the heat balance in the pre-monsoon season, and latent heat flux dominated it in the monsoon season. Peaks of net radiation Rn appear in July of the monsoon season. The rainfall pattern influenced the amount of the drainage. Comparing with 1997, the rainfall events were more concentrated in the monsoon season of 1998. The amount of rainfall available for runoff was larger, and ground soil layers were wetter in 1998.Western Tibet was drier, and eastern Tibet was wetter, in 1998 than in 1997. Evaporation *E* was small (less than 100 mm/year) in western Tibet and large (about 400 mm/year) in eastern Tibet. The wetness index(*WI*) distribution agrees well with the distribution of the normalized difference vegetation index (NDVI). Results were also compared to precipitable water (from the NASA Water Vapor Project, NVAP) in the atmosphere. Calculations were carried out for 14 stations in 1997 and 17 stations in 1998. Datasets of daily and seasonal variations based on 1997-1998 have been established; heat and water balances can be judged from such datasets.

Keyword: sensible heat flux, latent heat flux, heat and water balance, the Tibetan Plateau, IOP dataset.

1. Introduction

Xu and Haginoya (2001) estimated the water and heat balances over the plateau using a multi-layer model initialized with routine meteorological data from 1997. Daily and seasonal variations were shown for 14 sites over Tibet. Subsequently, an intensive observation period (IOP) of the GAME-Tibet Global Energy and Water Cycle Experiment (GEWEX) Asia Monsoon Experiment over Tibet took place in 1998. The present paper will determine the heat and water balances for the Tibetan Plateau during 1997-1998; the results are compared to observations. The relationship between the normalized difference vegetation index (NDVI), as reported by the Center for Environmental Remote Sensing (CEReS), of Chiba University, Japan, and the wetness index (*WI*=Pr/*Ep*) is examined. The relationship between calculated results and precipitable water from the NASA Water Vapor Project (NVAP) dataset will be shown.

2. Method

2.1. Model

The model used in this study was developed by Kondo and Xu(1997a). Sub-surface soil water transport is based on the multi-layer soil model proposed by Kondo and Saigusa, 1994. The soil model has been put to practical use using a simplified calculation scheme (Kondo et al. 1995; Kondo and Xu 1996a, 1996b). Although the vegetation such as grass grows in eastern Tibet seasonally, the surface is assumed to be bare soil surface in the model. We should notice that the assumption might lead to underestimate the amount of evaporation in the monsoon season of eastern Tibet. Soil properties differ greatly from place to place on the earth's surface and also from the top to the bottom of the horizontal layers that constitute a soil profile. The present calculations assume that soil type is constant from the surface to the lowest layer (0.7 m). Water transport within the soil is partitioned into vapor and liquid phases. Xu and Haginoya (2001) applied the model to the Tibetan Plateau to analyze heat and water balances in 1997. Soil parameters in the Tibetan Plateau have been studied and used in the model.

Potential evaporation is also an important climatological index. Kondo and Xu (1997b) and Xu (2001) defined potential evaporation Ep as the evaporation expected from a hypothetical surface with saturated soil and a roughness of 0.005 m; albedo *ref* is 0.06 (water surface), emissivity 0.98, and evaporation efficiency and relative humidity are 1.0. Typical surfaces that satisfy these conditions are fields with a wet, rough, and black surface, or a newly planted paddy field, with dripping wet leaves (Kondo and Xu, 1997b, Xu and Haginoya, 2001).

Solar radiation flux was estimated in the present study from sunshine duration; long-wave radiation flux is a function of solar radiation flux, surface air temperature, and humidity (Kondo and Xu, 1997a).

2.2. Data

The calculations were conducted for 14 sites in 1997 and 17 sites in 1998. Eight sites were common to both 1997 and 1998. Input datasets originated from routine meteorological data as follows:

・daily mean air temperature T_{AM}; temperature range $T_{A,MAX}$-$T_{A,MIN}$; sunshine duration *N*; precipitation amount Pr; wind speed U_{OBS}; vapor pressure e; surface pressure p_s.

・The following output data were estimated from calculations: downward solar radiation flux $S^{\downarrow}$; downward long-wave radiation flux $L^{\downarrow}$; latent heat flux ιE; sensible heat flux *H*; evaporation *E*; potential evaporation Ep; soil water content θ; wetness index WI= Pr/Ep; calculated surface temperature T_{SE}.

・The comparison datasets include: observed long-wave radiation flux from the IOP of the GAME-Tibet automated weather station (AWS) dataset; NDVI dataset from CEReS; precipitable water (mm) from NVAP.

2.3. Verification of long wave radiation

Observed and calculated solar radiation, soil water contents, ground surface temperatures, and sensible and latent heat fluxes were compared in Section 4 of Xu and Haginoya 2001. Verification of the long-wave radiation flux is provided in the present study. Figure 1 shows the seasonal variation of the daily mean downward long-wave radiation flux $L^{\downarrow}$ at Shiquanhe for 1998. Open circles are observations and the solid line is calculated. Calculations and observations show good agreement. Long wave radiation flux has an annual mean of about 237.2W/m^2 and ranges from about 160W/m^2 in winter to about 310W/m^2 in summer. Shiquanhe has an annual precipitation of about 60mm. The long-wave radiation there is relatively small in the Tibetan Plateau.

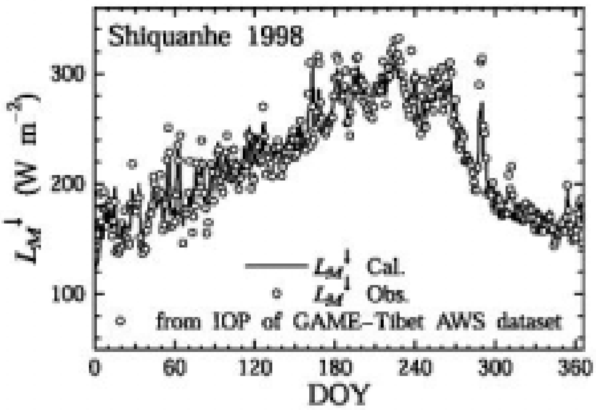

Fig. 1: Calculated and observed long wave radiation over Shiquanhe in 1998. The solid line is the calculated $L^{\downarrow}$, the circles are observed $L^{\downarrow}$.

3. Heat and water balance

Model calculations were carried out for 14 sites in 1997 and for 17 sites in 1998. Datasets of daily and seasonal variations for these two years have been established. Heat and water balances can be inferred from the datasets.

3.2. Seasonal variations (Nagqu)

Nagqu (31 ° 29'E, 92 ° 04'N) is the nearest meteorological observatory to Amdo, a planetary boundary layer (PBL) observation site for IOP GAME-Tibet. Figure 2 compares the calculated seasonal variations for 1997 and 1998 at Nagqu. Horizontal axes represent the day of the year (DOY). Daily mean net radiation, sensible heat and latent heat fluxes, surface air temperature, volumetric soil-water content and precipitation are shown. Annual total precipitation was 558mm in 1997, and 526mm in 1998, but the onset of the rainy season (i.e., the monsoon) was late in 1998 (Fig.2k, l). Changes in the latent heat flux (Fig.2i, j) suggest that the differences between the dry and rainy seasons were greater in 1998. The latent heat flux is small in the dry season because of a lack of water; evaporation occurs mainly during the rainy season. Most of the net radiation converts to sensible heat flux during the dry season. In contrast, latent heat flux dominates the heat balance during the rainy season. Observed surface air temperatures differed between 1997 (annual mean -2.4℃) and 1998 (annual mean -0.1℃), which suggests that the heat flux was also different. Net radiation and sensible heat fluxes were frequently negative in 1997, but rarely so in 1998 (Fig.2a-d). Volumetric soil-water content was high (wet) in 1997 and low (dry) in 1998 (Fig.2g, h) because of warmer, drier conditions in 1998. Soil-water content increases with rainfall.

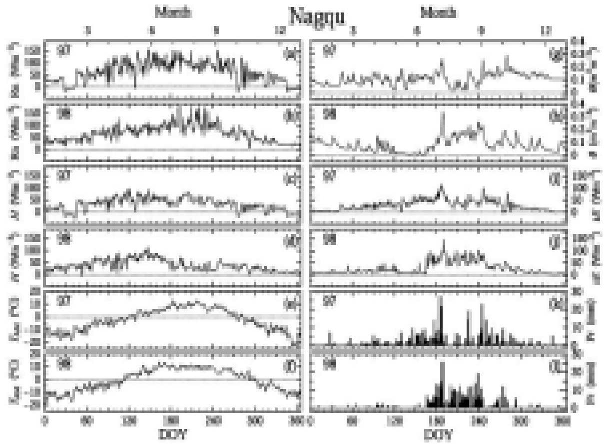

Fig. 2: Comparisons of the calculated seasonal variations at Nagqu for 1997 and 1998. Daily mean net radiation (W/m^2) in 1997 (a) and 1998 (b); Sensible heat flux (W/m^2) in 1997 (c) and 1998 (d); Surface air temperatures (℃) in 1997 (e) and 1998 (f); Volumetric soil-water content in the surface layer (0.01 m) in 1997 (g) and 1998 (h); Latent heat flux (W/m^2) in 1997 (i) and 1998 (j); Precipitation (mm) in 1997 (k) and 1998 (l).

3.2. Heat balance

Figure 3 shows the seasonal variation in heat fluxes over the Tibetan Plateau. A block with curves and two axes represents the heat balance for each station. The figure legend is in the lower left. Annual mean net radiation fluxes range from about 50 to 80W/m^2 over the plateau, changing from about 25W/m^2 in the winter to 110W/m^2 in June or July. Peaks in net radiation flux were greater in 1997 than in 1998 over western Tibet (Shiquanhe, Gerze and Baingoin), but smaller in 1997 than in 1998 over eastern Tibet (Nagqu, Lhasa, Xigaze, Qamdo), except at Nyingchi. In arid areas and during the dry season, sensible heat flux is larger than latent heat flux and dominates the energy balance. At the most arid station, Shiquanhe, more than 90% of the net radiation becomes sensible heat flux because so little water is available to evaporate. Peaks in H appear in May just before the monsoon season. The contribution of latent heat flux to total energy flux gradually increases when, or where, precipitation is relatively large. As rain wets the surface, latent heat flux increases to a value about the same as *H*. The curved shape of the latent heat flux line resembles the curve in the seasonal change in precipitation (Fig.4). The latent heat flux due to precipitation in 1997 was larger in the east and smaller in the west than in 1998.

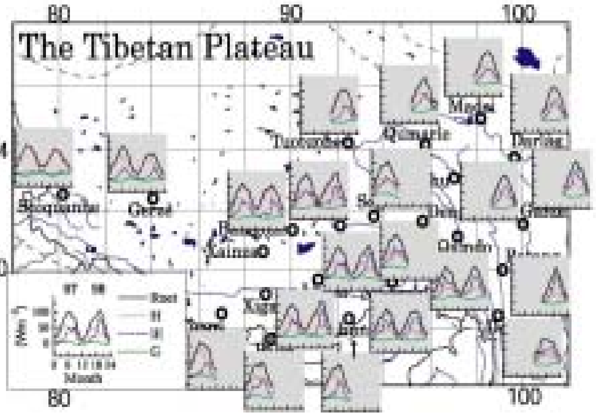

Fig. 3: Heat balance over the Tibetan Plateau during 1997-1998. The net radiation flux Rn(solid lines), the sensible heat flux *H*(dotted lines), the latent heat flux ιE(broken lines), and the heat flux into the ground *G*(dashed chains) are shown in one block for each observatory. Figure legend is at lower left.

3.3. Water balance

Xu and Haginoya (2001) have shown that the climate over the Tibetan Plateau is arid in the west and semi-arid or semi-humid in the east (Fig.6). Precipitation ranges from about 56 mm over western Tibet to almost 1000 mm over eastern Tibet. Figure 4 shows the seasonal variation in the water balance of the Tibetan Plateau during 1997-1998. The differences between potential evaporation and evaporation (*Ep-E*) are large over western Tibet and small over eastern Tibet. Over southwestern Tibet, precipitation was relatively heavy in September 1998, resulting in a larger *WI* in 1998. At stations in western Tibet, such as Shiquanhe and Gerze, evaporation changes with the precipitation because there is almost no drainage. From January to May, rainfall and evaporation totals are both small. Most precipitation and evaporation occurs during the monsoon season (June to September), and the value of Pr is near, or greater than, the potential evaporation Ep. Eastern Tibet is humid or semi-humid during this season.

Figure 5 shows the monthly mean values of the common 8 sites of the seasonal variations of heat and water balance over the whole plateau during 1997-1998. Sensible heat flux dominated the heat balance in the pre-monsoon season, and latent heat flux dominated it in the monsoon season. Peaks of net radiation Rn appear in July of the monsoon season. The rainfall pattern influenced the amount of the drainage. Comparing with 1997, the rainfall events were more concentrated in the monsoon season of 1998. The amount of rainfall available for runoff was larger, and ground soil layers were wetter in 1998.

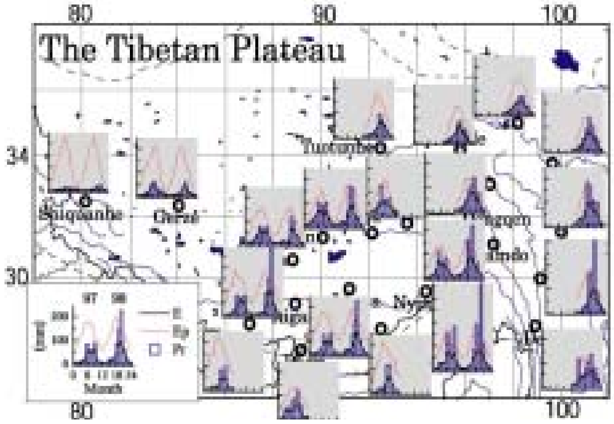

Fig. 4: Water balance over the Tibetan Plateau during 1997-1998. As in Fig. 3 except for the monthly total precipitation Pr (histogram), the potential evaporation *Ep* (dotted lines), and the evaporation *E* (broken lines).

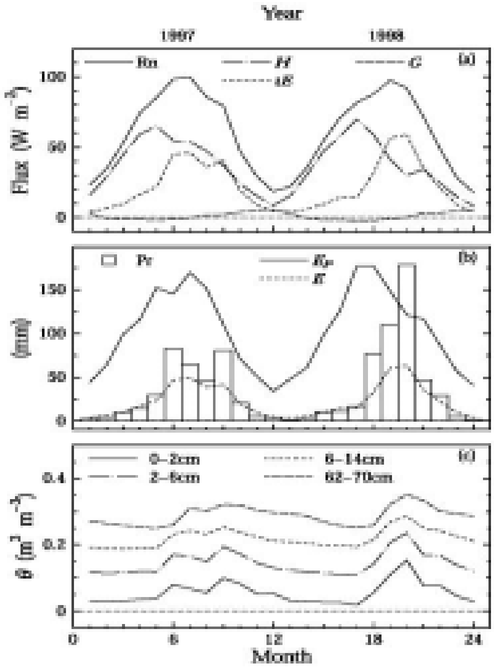

Fig. 5: Seasonal variations of heat and water balance over the Tibetan Plateau in 1997 and 1998. (a) the monthly mean net radiation Rn(solid line), the sensible heat flux *H*(dotted chaine), the latent heat flux ιE(broken line), and the heat flux into the ground *G*(dashed chain); (b) the monthly total precipitation Pr (histogram), the potential evaporation Ep (solid line), and the evaporation *E*(broken line); (c) the monthly mean values of the volumetric soil-water content at the depths of 0-2cm, 2-6cm, 6-14cm and 62-70cm.

4. The relationship between *WI* and NDVI

Climate affects, and is affected by, the biosphere. The use and management of water resources strongly depend upon the climate. The Tibetan Plateau features a very complex topography, and the vegetation on the plateau is therefore highly variable. The *WI* constitutes a comprehensive value that represents atmospheric conditions, including temperature, radiation, and wind. Xu and Haginoya (2001) showed how *WI* is calculated. A *WI* dataset for the plateau was prepared for 1997-1998.

The NDVI measures vegetation. An NDVI dataset was acquired from the ``Twenty-year global 4-minute AVHRR NDVI dataset" produced by CEReS, using a transformed version of the Pathfinder global 10-day composite 8-km NDVI data from the Advanced Very High Resolution Radiometer (AVHRR). The data were transformed from an Interrupted Goode Homolosine map projection to a Plate Carree map projection to simplify data usage. In addition, NDVI temporal changes were smoothed using the Temporal Window Operation (TWO). The annual mean and May-October mean NDVI in 1998 were calculated for each 1°×1° grid box over the Tibetan Plateau. Figure 6 shows the distributions of annually averaged *WI* and NDVI in 1998. The NDVI distribution is in color. Lines representing the *WI* are overlain on the NDVI map. The two fields match very well. The climate is very arid where the *WI* < 0.3 and NDVI values are small. Wetness index (*WI*) and vegetation (NDVI) increases gradually from the west to east over Tibet. Figure 7 shows the regression relationship between *WI* and NDVI over the Tibetan Plateau in 1998. The solid line is the regression line for the annual mean and the broken line is for May-October. *WI* and NDVI are correlated with each other.

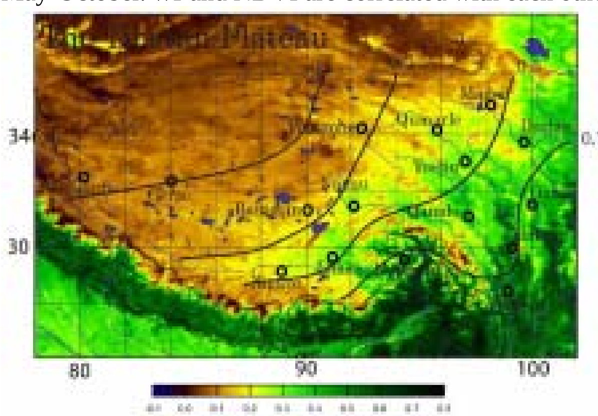

Fig. 6: The distribution of annual averaged WI (lines) versus NDVI (color) in 1998. Color bar shows the value of NDVI.

5. Summary and conclusion

A dataset including heat and water balances has been developed for the Tibetan Plateau for the period 1997-1998. A multi-layer soil model was used to facilitate the calculations. NDVI and NVAP data were compared to the present dataset.

1) Calculated long wave radiation flux agreed with observations at Shiquanhe in 1998. The annual mean long wave radiation flux was 237.2W/m^2; it ranged from 160W/m^2 in winter to 310W/m^2 in summer. Shiquanhe receives annual precipitation of about 60 mm. Long wave radiation is relatively low over the Tibetan Plateau.

2) Surface air temperatures were higher and precipitation

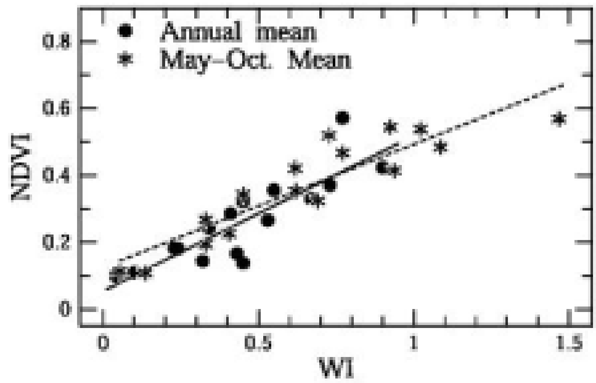

Fig. 7: Regression analysis of *WI* and NDVI over the Tibetan Plateau, 1998. The solid line is the regression for the annual mean; the broken line is for

was less in western Tibet than in eastern Tibet in 1998, as compared to 1997. Western Tibet was relatively dry and eastern Tibet was relatively wet in 1998. In 1998, monsoon onset was delayed relative to 1997.

3) The *WI* distribution was similar to the NDVI distribution. NDVI values were small where *WI* was small (arid climates), and large where *WI* was large (humid areas).

4) Sensible heat flux dominated the heat balance in the pre-monsoon season, and latent heat flux dominated it in the monsoon season. Peaks of net radiation Rn appear in July of the monsoon season. The rainfall pattern influenced the amount of the drainage. Comparing with 1997, the rainfall events were more concentrated in the monsoon season of 1998. The amount of rainfall available for runoff was larger, and ground soil layers were wetter in 1998.

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