Surface Flux Estimation Using In Situ Measurement

H. Ishikawa¹, K. Tanaka², Y. Oku¹, MA Yao-ming³, HU Ze-yong ⁴, LI Mao-shan ⁴, MA Wei-qiang ⁴
(1. Disaster Prevention Research Institute, Kyoto University, Kyoto Japan; 2. Kumamoto University, Kumamoto Japan; 3. Institute of Tibetan Plateau, CAS, Beijing 100085, China; 4. Cold and Arid Regions Environmental and Engineering Research Institute, CAS, Lanzhou 730000, China)

Abstract: Sensible and latent heat fluxes from the plateau surface are of great importance in the Asian monsoon system. Since the plateau occupies a wide area and the environmental conditions are severe to perform surface observation, the satellite remote sensing is inevitably a practical tool to estimate these fluxes from whole plateau surface. The in situ flux estimation is, however, necessary as a ground truth for the satellite remote sensing. It also gives scientific information in constructing land surface-atmosphere model, which shares an important part of data assimilation system using satellite data. There are several different approaches in estimating in situ heat fluxes. The simplest method uses operational observation and experimental parameters, and it gives steady continuous estimation. The more sophisticated Bowen ratio or profile observation gives the more precise information. The estimation with turbulence measurement together with the measurement of radiation and soil heat fluxes give detailed description of land surface-atmosphere interaction suitable to model development. Since 1998, a combination of these methods has been applied to the Tibetan plateau. The efforts of these in situ flux observation and the current understandings are summarized in this presentation.

Key words: Tibetan plateau; Surface heat flux; In situ measurement; Satellite remote sensing.

CLC number: P412.27  Document code: A

1 Introduction

Tibetan plateau has been thought to play a very important role in the progress of Asian monsoon as discussed by many authors. The impact of the plateau on surrounding region has been discussed on for its orographic effect and for the thermal effect as an elevated heat source (or sink) in the mid-troposphere. The plateau blocks the tropospheric circulation, and contributes to the development of the monsoon circulation in summer and the formation of the Siberian high-pressure system in winter (e.g., Manabe and Terpsta¹). The surface of the plateau is strongly heated from incoming solar radiation in daytime (and cooled in the night due to strong longwave radiation), so that the air over the plateau is relatively warmer (or cooler) than that of surrounding air at same altitude. Flohn² discovered that the high temperature anomaly at 500 hPa level over the plateau. Thus, it is important to estimate the heat flux from the plateau surface to the atmosphere to understand the mechanism of energy cycle over Asian Monsoon region.

Receive date: 2006-10-23.
Biography: H. Ishikawa E-mail: ishikawa@storm.dpri.kyoto-u.ac.jp
Before the GAME/Tibet, the First Global Atmospheric Research Program (CARP) Global Experiment (FGCE) \( (e.g., \) Yeh and Gao\(^3\) \) and the Chinese Qinghai-Xizhang plateau Meteorology Experiment (QXMEX) were conducted \( (e.g., \) Johnson, et al.\(^4\), Yeh\(^5\), Ji, et al.\(^6\) \). With these data several indirect methods have been employed to estimate surface energy fluxes by Chinese scientists. They estimated the surface flux using Bowen Ratio Technique. The surface heat and moisture fluxes were also estimated indirectly with the use of the upper-air observation data. In this, both sensible and latent heat fluxes were estimated as the residual of the vertically integrated heat or moisture budget equation. Yanai and Li\(^7\) reviewed those studies and summarized that they had demonstrated the presence of positive temperature anomalies over the Tibetan plateau and the large-scale vertical circulation induced by the plateau throughout the nine months from winter to summer, and that before the onset of the summer monsoon, the heat source on the plateau was surrounded by intense cooling in the adjacent regions.

Although these previous studies have unveiled the features and the roles of the plateau boundary layer to a considerable extent, the present knowledge is not enough to contribute to the development of prognostic model for the land-atmosphere processes over the plateau. In the GAME/Tibet, intensive observations of land surface-atmosphere interaction were conducted at several sites. These observations have provided a mass of surface flux information on the Tibetan plateau.

In parallel with the in situ flux measurements, efforts have been made to estimate surface fluxes using satellite remote sensing. If we combine detailed in situ measurements and the satellite remote sensing, we could have an aerial information of surface fluxes over the wide Tibetan plateau. In this paper we summaries the achievement of GAME/Tibet and the succeeding researches.

2 Ground-based measurement at Amdo

The turbulent flux measurements were carried out at several sites, Amdo, MS3437, south of Naqu during the GAME/Tibet IOP in 1998. The TIPEX project also conducted turbulent flux measurement at Qamdo, Damxung and Gerze. Among these, the Amdo has the longest record from late May to early September. Further, the tower profile observation has been continued after the IOP at the Amdo site, so that the site is suitable to estimate long term variation of surface fluxes. Amdo is located on the eastern Tibetan plateau along the Xizang-Qinghai highway. The site \( (31^\circ 14.468^\prime \text{N}, 91^\circ 37.507^\prime \text{E}) \) is about 6 km to the west of the town of Amdo. The altitude is about 4 800 m. The surface is almost bared with soil in pre-monsoon dry season, but it is covered with scattered short grasses during summer monsoon season.

2.1 Turbulent flux measurement

Tanaka, et al.\(^{8,9}\) have reported the results of turbulent flux measurements at the Amdo site. The turbulent flux measurement system was composed of a sonic anemometer-thermometer (DAT-300, Kajo) and an infrared hygrometer (AH-300, Kajo). A clinometer was also used to measure sensor inclination. The infrared hygrometer was used to detect the high frequency fluctuation. A capacity-type hygrometer and thermometer (Pt-100) were also set near the infrared hygrometer, which were used to measure the low frequency fluctuation of the specific humidity. The sensor assembly was set up on the top of a pole (sensor height is about 2.8 m) about 20 m apart from the tower. The data were sampled in 10 Hz and recorded in magnetic optical disks. During the IOP, more than 4 800 thirty-minute data were obtained.

The Fig. 1 shows a plot of 30 minute fluxes for all of the measurements from May the 23 rd to September the 10th. Although only the daily maximum and the minimum could be seen in the plot, the figure clearly shows the seasonal change of surface fluxes. Before the onset of monsoon in early June the sensible heat flux reaches 400 W/m\(^2\) in the daytime, which is nearly 10 times greater than the latent heat flux. As summer monsoon progresses, the latent heat flux increases gradually to 300 W/m\(^2\), however, the sensible heat flux decreases and falls to 150 W/m\(^2\) at daily maximum. This kind of seasonal change has been suggested by previous studies, and was confirmed by the direct measurement of fluxes.

Since the turbulent fluxes are estimated in every
30 minutes, some detailed features were also captured by the flux measurement. For example, Fig. 2 shows the diurnal variation of fluxes on September the 5th that the start of upward heat fluxes in the morning is delayed by several tenth of minutes as compared with the start of positive net radiation. This delay nearly corresponds to the period that the surface temperature is around freezing point, so that we suppose that the delay corresponds to the melting of near surface soil water.

In addition to the flux estimation, the Monin-Obukhov similarity was confirmed in a wide range as shown in Fig. 3. This was possible because of the extremely unstable or stable condition over the plateau boundary layer, especially in dry season.

**Fig. 1**  Seasonal variation of sensible and latent heat flux in 1998

Surface energy flux (W/m²) (1998–09–05)

- $R_n$
- $H$
- $E$
- $R_n-H-E$
- $G(10 \text{ cm})$

**Fig. 2**  Diurnal change of surface fluxes at Amdo on September the 5th, 1998

**Fig. 3**  The similarity for $\sigma_v/|u'|$ (left) and for $\sigma_T/|T'|$ (right)
2.2 Tower measurement and the inter-annual change of surface fluxes

At the Amdo site tower profile observation has been continued since 1998. Tanaka\textsuperscript{[15]} used this observation to estimate annual and inter-annual variation of surface fluxes. In order to this, he computed bulk transfer coefficient as a function of bulk-Richardson number by comparing bulk-transfer formulation,

\[ H = \left( \rho_d C_{pd} + \rho_e C_{pe} \right) C_\lambda \left( \bar{u}(z_2) - \bar{u}(z_1) \right) \times \]
\[ \left( \bar{T}(z_1) - \bar{T}(z_2) \right) \]

With this bulk transfer coefficient and the tower observation, sensible heat flux was computed from 1998 to 2003. The latent heat flux was computed through surface energy balance with observed net radiation and carefully estimated surface soil heat flux from soil heat flux at 10 cm and the soil temperature profile including surface skin temperature observed by long-wave radiation measurement.

With sensible heat, \( H \), measured by eddy-correlation method. According to the experimentally obtained values for \( C_\lambda \) in Fig. 4, an asymptotic form is proposed as,

\[ C_b = \begin{cases} 
C_{bn} \left( 1 - 1.44 Ri_b \right)^{\frac{3}{2}} & \left( -15 < Ri_b < 0 \right) \\
C_{bn} \left[ \frac{0.1 + Ri_b}{0.1 + 5Ri_b + 25Ri_b^2} \right] & \left( 0 < Ri_b < 0.5 \right)
\end{cases} \]

![Fig. 4: Bulk transfer coefficient for sensible heat flux](image)

Fig. 5 shows the comparison of annual change of 5-day averaged Bowen-phase,

\[ \phi = \tan^{-1} \left( \lambda E / H \right) \]

From 1998 to 2003. It is seen that the IOP year, 1998, was not an normal year when the on set of monsoon was delayed by about one month as compared with other years, although the termination of wet season was almost identical.

3 Satellite estimation of regional surface fluxes

Although in situ flux observation gives detailed information at the observation site, the regional distribution of surface fluxes and hence the regional integration of surface fluxes could not obtained solely. Therefore, we have to use satellite remote sensing. Ma, \textit{et al.}\textsuperscript{[10-12]} estimated the surface fluxes over the Tibetan plateau using Landsat data. Considering a wide range of diurnal variation of surface fluxes, however, a quasi-continuous estimation is required. For this purpose, Oku, \textit{et al.}\textsuperscript{[13,14]} has developed a method estimating the surface fluxes using hourly measurement from geostationary satellite. Oku, \textit{et al.}\textsuperscript{[13]} first developed a method to estimate the land surface temperature using split-window data from GMS-5. The algorithm of Ma, \textit{et al.}\textsuperscript{[10]} was modified to meet the GMS-5 data considering the satellite zenith angle and the contribution from the precipitable water. The regional distribution of precipitable water is estimated using water vapor channel data. A new cloud removal scheme was also introduced. Ex-
amples of scatter diagram between satellite derived and in situ observed surface temperature are shown in Fig. 6 and the distribution of monthly mean daily maximum surface temperature is shown in Fig. 7 (Plate VII).

![Bowen Phase (5-day mean)](image)

Fig. 5 Comparison of annual variation of Bowen Phase from 1998 to 2003

![Fig. 6 Comparison of measured and satellite derived surface temperature at Shiquanhe (left) and Tuotuohe (right)](image)

Oku\[14\] estimated the surface fluxes over the Tibetan plateau using the surface temperature described above with SEBS model\[16\]. Since the meteorological measurement is very limited over the plateau, they use the objective analysis with careful error estimation. Fig. 8 (Plate VII) is an example of diurnal change of surface fluxes. The Fig. 9 is the comparison of observed fluxes at Amdo and the satellite derived surface fluxes with meteorological sounding data and with ECMWF ERA40 reanalysis data. Although, there still exist a large scatter as compared with in situ observation, the satellite retrieval technique follows the in situ observation. It must be also considered that the representative area of satellite estimation is considerably larger than that of in situ observation.

4 Concluding remarks

Both from the in situ observation and from the sat-
ellite data retrieval, we manage to estimate the surface fluxes over the Tibetan plateau. We have got plenty of understanding of the surface fluxes over the Tibetan Plateau. These are, however, still in the research stage. In order to estimate the quantitative contribution of Tibetan plateau surface fluxes to the Asian monsoon, the continuous monitoring of surface fluxes is required.

The major difficulty exists in the estimation in winter months. The in situ turbulent flux estimation is limited in summer months in the GAME/Tibet Project. The contribution from cold surface in winter months needs to be measured directly. For this issue, the turbulent flux measurement started in 2002 at the south of Naqu as a part of Coordinated Enhanced Observation Period. The measurement was not fully successful in winter months because of the severe condition, a considerable amount of turbulence data of good quality have been accumulated. For satellite estimation, it is sometimes difficult to discern low level cloud from cold surface. The recent satellites, FY2C and MTSAT, have near-infrared channel. There may be a possibility to use this channel to increase the cloud removal algorithm.

![Fig. 9 Comparisons of satellite derived fluxes with sonde observation (left) with ERA-40 field (right) with in situ flux estimation at Amo](image)

**Acknowledgements**

Finally, we express our gratitude to many persons who help us in the laborious field observation over the Tibetan plateau.

**References**:


利用地面观测计算地表通量

H. Ishikawa¹, K. Tanaka², Y. Oku¹, 马耀明¹，
胡泽勇⁴，李茂善⁴，马伟强⁴

(1. Disaster Prevention Research Institute, Kyoto University, Kyoto Japan; 2. Kumamoto University, Kumamoto Japan;
3. 中国科学院青藏高原研究所, 北京 100085; 4. 中国科学院寒区旱区环境
与工程研究所, 甘肃 兰州 730000)

摘 要: 高原地表的感热和潜热通量在亚洲季风系统中有很重要的作用。由于高原地域辽阔,自然环境较严酷,不利于建立完善的地面观测系统。因此,卫星遥感观测就成为测算高原整体感热和潜热通量的有效工具。地面场地的观测结果作为地表通量的真实值,对于卫星遥感测算是非常重要的。它也为构建陆面—大气模型提供了科学依据,是卫星资料的资料同化系统中的重要组成部分。

计算场地热量通量有几种不同的处理方法。最简单的方法利用有效的观测和试验的参数,可以给出稳定连续的估计。愈精确的 Bowen 比或者摩擦的观测能给出愈精确的信息。综合了湍流测量及辐射测量、土壤热通量的观测结果的估计对陆面—大气相互作用进行了详细的描述,以适应模式的发展。从 1998 年开始,这些方法联合应用到青藏高原; 地表通量观测方面的成果以及目前对其理解将在本文中做一概述。

关 键 词: 青藏高原; 地表热通量; 地面观测; 卫星遥感
Fig. 3 The diurnal trends of both estimated surface soil heat flux and observed soil heat flux at 20 cm depth below the ground at Anduo in August 1998. The estimated soil heat flux is derived from the measurements at 20 m depth under the surface. The solid curves (green and red) are the average diurnal trends of the estimated soil heat flux and soil heat flux at 20 cm depth below the ground, respectively.

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Fig. 7 Horizontal distribution of monthly mean daily maximum surface temperature in 1998.
Fig. 8: An example of satellite-derived surface fluxes (April 25th, 1998).

Soil heat flux

Latent heat

Net Radiation

Sensible heat