Long term monitoring of surface energy fluxes at Amdo in eastern Tibetan Plateau

By

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1. Introduction

In the Tibetan Plateau, several AWSs (Automated Weather Stations) have been continuously in operation after IOP (Intensive Observation Period). It is one of major goal to evaluate surface energy fluxes of Tibetan Plateau in seasonal or (inter-)annual scale. In this study, surface energy fluxes at one of AWS site of the Eastern Tibetan Plateau, Amdo, is estimated using bulk transfer coefficient and bowen ratio. The bulk transfer coefficient is generated from heat flux directly measured by eddy correlation and profiles by tower during IOP98.

2. Observation at Amdo PBL site

Amdo PBL site is located on the eastern Tibetan Plateau (31°18'N, 91°33'E) and about 4700m in elevation. The surface is sparsely covered with short grass during summer monsoon or is bare soil in other season. At the site, turbulent flux measurement by eddy correlation technique was taken during IOP (May 11, 1998 ～Sep. 10, 1998) and more than 4800 runs (every 10Hz-30minute sampling for each run) were obtained. The 14m profile tower and 4-component radiation measurement has been continuously working since IOP. The instrumentation of Amdo PBL site is introduced in detail by Tanaka et al. (2001)

3. Bulk Transfer Coefficient of sensible heat

The bulk transfer coefficient of sensible heat (C_h) is evaluated using the fluxes directly measured by eddy correlation and the profiles by the tower observation. The bulk coefficient of sensible heat flux is defined as follows;

$$H = -\bar{\rho} C_p \overline{w'T'} = \bar{\rho} C_p C_h U_{14m} \left(T_{sfc} - T_{14m} \right) \quad (1),$$

where variables of the middle terms are from turbulent observation and those of the right hand are from tower observation. C_p is the specific heat capacity of air (1005J/kgK). Subscripts $_{sfc,\ 14m}$ indicate the value at the ground surface and at 14m above the ground respectively.

For the classification of the coefficient in relation to the atmospheric stability, the bulk Richardson number (Ri_b) is used which is defined as

$$Ri_b = \frac{\Delta z C_p \left(T_{14m} - T_{sfc} \right)}{g U_{14m}^{\ 2}} \quad (2),$$

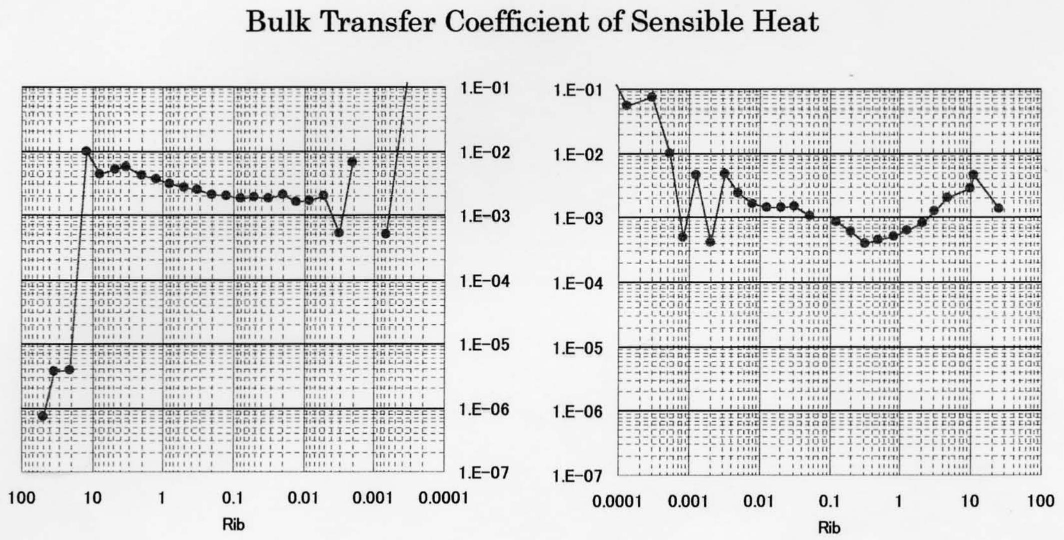

Figure 1. Relationship between the bulk transfer coefficient of sensible heat and bulk Richardson number.

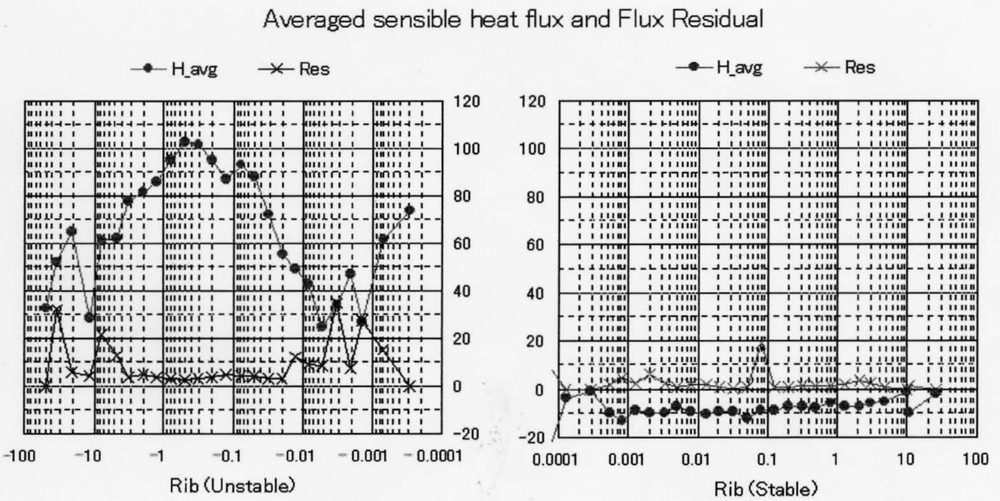

Figure 2. Averaged sensible heat flux (H_avg) and Flux Residual in Eq. (5) classified by Ri_b.

where Δz =13.75m is the height of sensors from surface.

The averaged bulk transfer coefficient of sensible heat is computed as a function of Ri_b as,

$$\overline{C_h} = \frac{\sum_{Ri_b \in I} -\rho C_p \overline{w'T'}}{\sum_{Ri_b \in I} \rho C_p U_{14m} \left(T_{sfc} - T_{14m} \right)} \quad (3)$$

where I is the range of Ri_b, separated logarithmically. They are shown in Figure 1.

Using the mean bulk coefficient of sensible heat, the sensible heat flux in each stability class is estimated by following equation,

$$\overline{H}_{bulk} = \overline{\rho C_p \overline{C_h} U_{14m} \left(T_{sfc} - T_{14m} \right)} \quad (4),$$

where over-bar represents the average for each stability class. In order to check the accuracy of this procedure, the residual of the sensible heat flux between eddy correlation method and bulk transfer method is calculated as

$$\mathrm{Res} = \sqrt{\left(H_{turb} - \rho C_p \overline{C_h} U_{14m}\left(T_{sfc} - T_{14m}\right)\right)^2} \quad (5),$$

and is shown in Fig. 2. In this figure, the residual is less than 20W/m^2 in quite a wide unstable range ($-10<Ri_b<-0.005$) and less than 10W/m^2 in almost all of stable range ($Ri_b>0$).

4. Surface flux estimation

As described above, the sensible heat flux can be obtained from the bulk transfer coefficient dependent of Ri_b as

$$H = \overline{\rho} C_p \overline{C_h} U_{14m}\left(T_{sfc} - T_{14m}\right) \quad (6).$$

The latent heat flux (lE), however, cannot be estimated by the bulk method, since it is difficult to estimate the surface specific humidity, q_{sfc}. Therefore, latent heat flux is estimated using bowen ratio (B)

$$lE = HB^{-1} \quad (7)$$

$$B = \frac{C_p\left(T_{14m} - T_{1.5m}\right)}{l\left(q_{14m} - q_{1.5m}\right)} \quad (8),$$

where l is the latent heat for evaporation and q is the specific humidity.

The net radiation flux (Rn) is obtained from 4-component radiation measurement as

$$Rn = SW^{\downarrow} - SW^{\uparrow} + LW^{\downarrow} - LW^{\uparrow} \quad (9)$$

where SW and LW represent the shortwave and longwave radiation flux, respectively.

Instead of estimating soil heat fluxes, the residual flux δ defined as Eq. (10) is used.

$$\delta = Rn - H - lE \quad (10).$$

5. Result

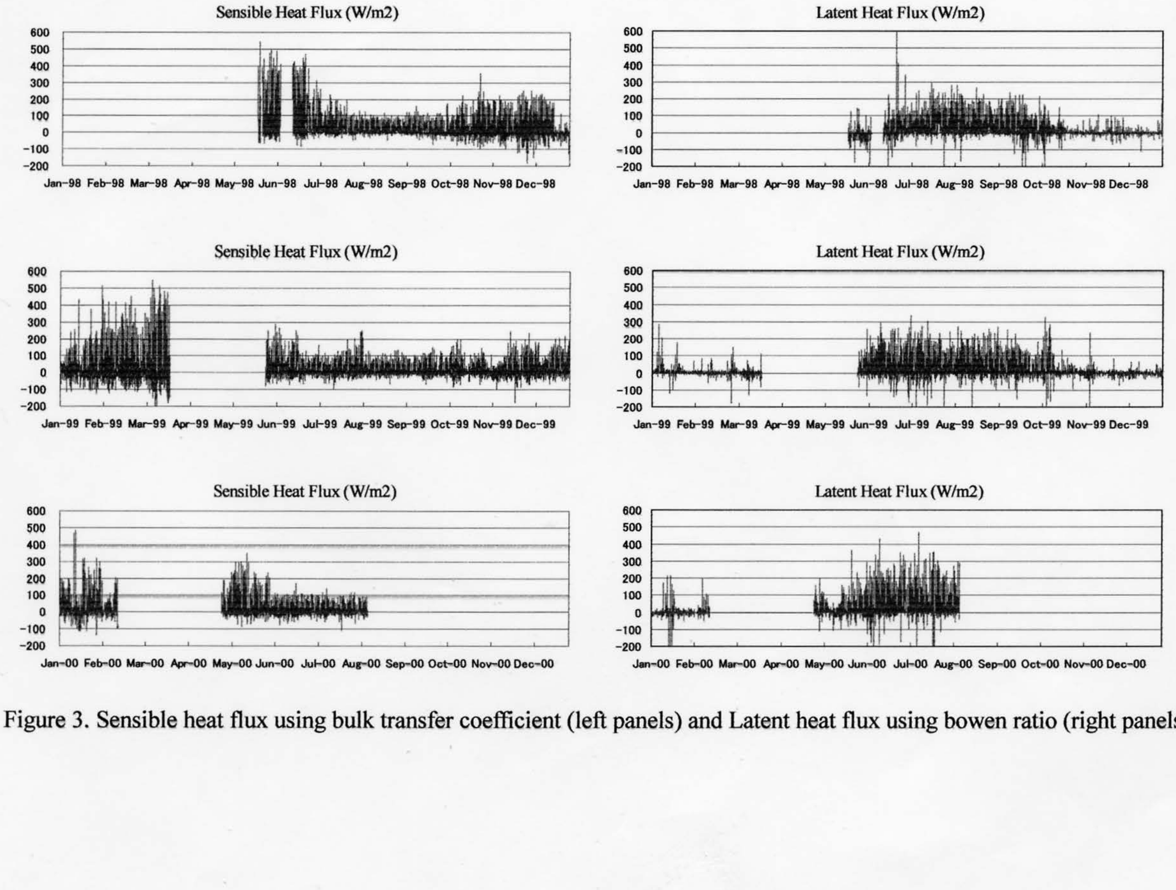

Figure 3. Sensible heat flux using bulk transfer coefficient (left panels) and Latent heat flux using bowen ratio (right panels).

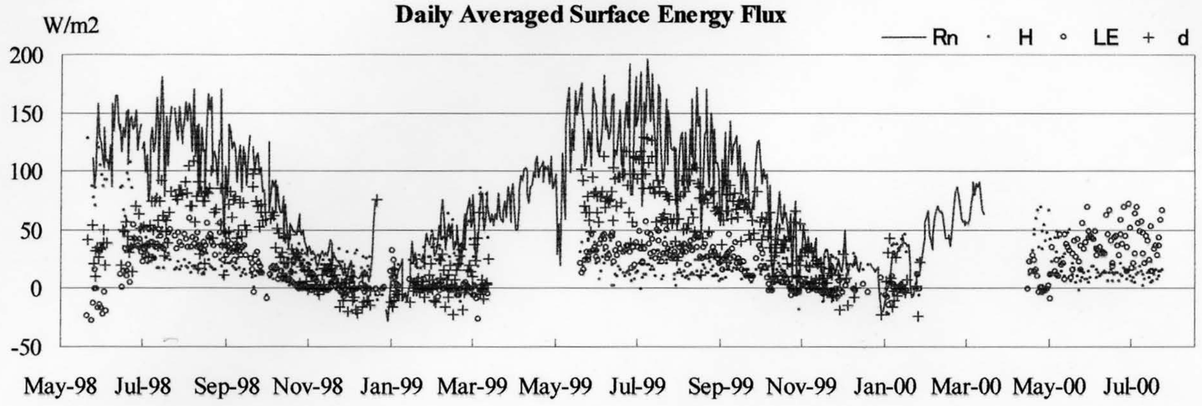

Figure 4. Daily averaged surface energy fluxes. d=Rn-H-lE.

Figure 3 shows sensible heat flux and latent heat flux using this method for every 30-minute data. The sensible heat flux gradually increased from January to March 1999. The sensible heat flux had maximum value just before the onset of the summer monsoon. As the summer monsoon progressed, the sensible heat flux rapidly decreased and the latent heat flux rapidly increased. During summer and early September, the sensible heat flux was about $100W/m^2$ and the latent heat flux sometimes reached $300W/m^2$ as diurnal maximum. The latent heat flux decreased during late September and October. The rapid change of sensible and latent heat flux as the progress of the summer monsoon is different in year by year: from middle of June to early July in 1998, but May in 2000.

The inter-annual variation of sensible heat flux can be also seen in spring. As compared 1999 and 2000, the increase of sensible heat flux seems very different. Heavy snow (or hail) in the season has a large impact in heating surface (e.g. a remarkable depression of *Rn* in May 1999 shown in Fig.4). But unfortunately, the tower data of spring season was not obtained enough.

The daily averaged fluxes are plotted in Figure 4. During winter, the residual δ was negative in the middle of winter. But as the sensible heat flux decreased and the latent heat flux increased after the onset of the summer monsoon, the δ increased and is more than 50% of the net radiation.

6. Conclusion

In this study, annual or inter-annual variation of the surface energy flux can be seen. There is a rapid change of sensible and latent heat flux during early summer, as the onset and the progress of the summer monsoon. The sensible heat flux varies year by year; when the summer monsoon is onset or how heavy precipitation occur. The residual of the daily averaged surface energy flux has sometimes negative in winter, but quite a large value in summer monsoon season.

References

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