Estimating Surface Heat Fluxes in Changwu of China

Yuanbo LIU
Graduate School of Environmental Studies, Nagoya University, Japan

1. Introduction

The global environment changed drastically during the last century, especially in the last two decades. The change is dominated by human influences, which are now large enough to exceed the bounds of natural variability [*Karl and Trenberth*, 2003]. In turn, this change has exerted the significant influences on numerous natural processes [*Houghton et al.*, 2001]. Hydrological cycle is one of the fundamental natural processes; since it links both water and energy transfer processes [*Chahine*, 1992]. Central to the hydrological cycle is evaporation/evapotranspiration [*Huntington*, 2006], by which water returns into atmosphere and the available energy is separated and transformed into latent heat and sensible heat [*Brutsaert*, 1982].

The contemporary theory of evaporation was founded on the pioneering work of *Penman* [1948]. The theoretical development can be traced over several decades through reviews by *Slatyer and McIlroy* [1961], *Monteith* [1973], *Thom* [1975], *Monteith* [1981], *Brutsaert* [1982], *Monteith and Unsworth* [1990], *McNagughton and Jarvis* [1991], *Parlange et al.* [1995], and *Raupach* [2001]. With the help of similarity theory [*Obukhov*, 1946], numerous efforts after *Penman* [1948] have been made through theoretical and observational study in modeling water and heat transfer in the atmosphere boundary layer (ABL). Experimental technologies have also progressed including the invention of the eddy correlation method. Furthermore, many comprehensive field experiments such as FIFE, HAPEX-SAHEL, and SGP have been performed for studying water transport and the interaction between the land surface and the atmosphere. Yet, the contemporary theory remains as a diagnostic [*Brutsaert*, 1982]. Accurate predication of evaporation over the land surface remains daunting tasks [*Henderson- Sellers et al.*, 2003].

The global-scale satellite datasets have been available including NOAA pathfinder AVHRR, in which contains 20-year record with a spatial resolution of 8-km. Retrieval of evaporation from the datasets involve scale and temporal influence issues, besides evaporation estimation method. We have reported our improved understandings on these issues [e.g. *Liu et al., 2006a; Liu et al., 2006b*]. On a belief of the simplicity in general principles, this report proposed a new method for estimating evaporation. Compared to the contemporary theory, this method is quite simple but with firm physical basis.

2. Methodology

Land and atmosphere always interact with each other in the boundary layer. As an open system, it exchanges energy and mass with the inner soil and the outer boundary layer. External forces (e.g. solar radiation) make the thermodynamic system out of equilibrium. As a system with coupled atmosphere and land interactions, it rarely reaches the equilibrium state of evaporation even supplied with sufficient water. To a natural surface, it should be always away from the equilibrium evaporation.

Land surface temperature (LST) is a key factor controlling most physical, chemical, and biological processes of the Earth system. The kinetic temperature, as an intensive thermodynamic variable, indicates the thermodynamic state of the surface. It results from the absorption of the solar energy, which increases the internal energy of the surface layer. Variation of LST results in variation of the temperature differences between air and land, and subsequently variation of sensible heat flux. It should mention that LST is not an external but internal variable of the system. Following the thermodynamic extremum principles, we may derive that

$$\lambda E = \underbrace{\Delta/(\Delta+\gamma)(R_n - G)}_{first-component} - \underbrace{4\varepsilon\sigma T_s^3(T_s - T_a)}_{second-component} \tag{1}$$

$$H = \underbrace{\Delta/(\Delta+\gamma)(R_n - G)}_{first-component} + \underbrace{4\varepsilon\sigma T_s^3(T_s - T_a)}_{second-component} \tag{2}$$

In equation (1), the first-component is the equilibrium evaporation. To a non-equilibrium system, the second-component indicates how far λE would be away from the equilibrium state of evaporation. Likewise, the first-component in equation (2) is the sensible heat flux generated accompanying equilibrium evaporation. The second-component indicates how much H could be generated to keep it in that state.

3. Materials and data processing

The data were obtained from a flux and radiation observation system (FROS), which accurately measures radiation components and turbulent fluxes in the atmospheric surface layer. The FROS was installed at the Changwu Agro-Ecological Experimental Station of The Chinese Academy of Sciences in May 2004. The station is located on a flat, semiarid tableland in the mid-south of the Loess Plateau, China (35°12'N, 107°40'E), with mean annual precipitation of 576.1 mm and air temperature of 9.2°C.

The T_a, R_n and G values were 30-minute means measured at a 2-m height, while the λE and H values were 30-minute means at 2 m, estimated using eddy-correlation techniques. Through partitioning the observed available energy (R_n-G) into new λE to H values using the ratio of the observed λE to H values, the observed λE and H values were thus corrected so as to account for surface energy imbalance. T_s is measured using the infrared thermometer, in which surface emissivity ε is assumed to be 1.0. The assumption holds for vegetation (ε=0.98-0.99), but would induce large errors for bare soil (ε=0.9-0.94 or low). The data spanned the period from May 2004 to September 2005. All the data were examined, but the detailed analysis was performed for May 2005, during which is the intensive observation period (IOP) at the site.

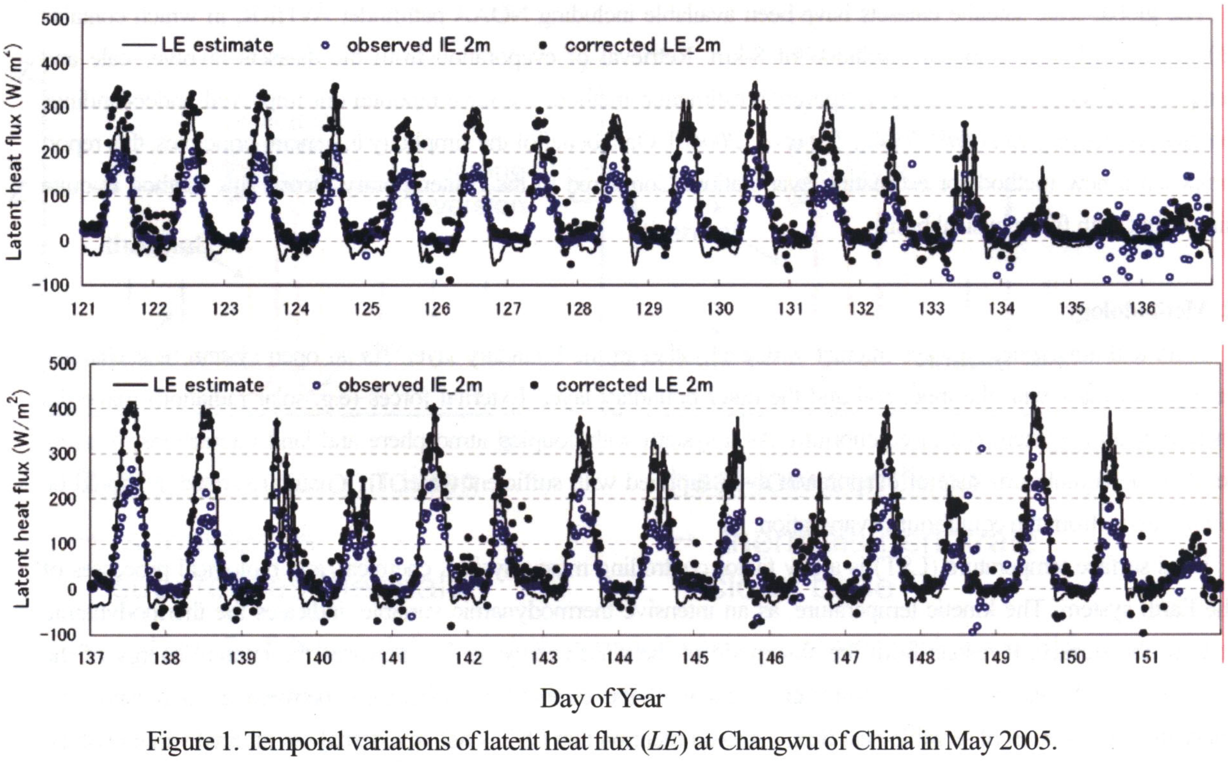

Figure 1. Temporal variations of latent heat flux (*LE*) at Changwu of China in May 2005.

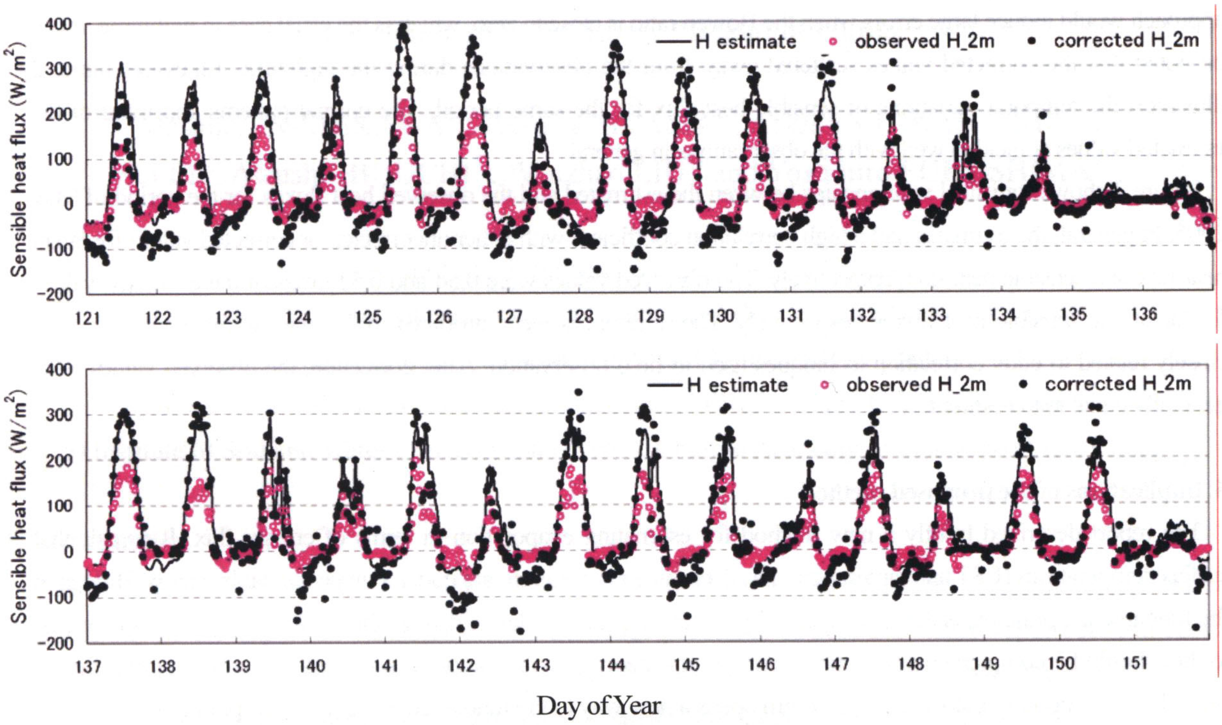

Figure 2. Temporal variations of sensible heat flux (*H*) at Changwu of China in May 2005.

4. Results and discussions

The estimated heat fluxes agreed surprisingly well with the values corrected from the observed data for all the period. Figure 1 shows the temporal variations of latent heat flux in May 2005. The estimates reproduced the diurnal patterns of heat flux and the long-time trend, even during the cloudy and rainy periods (e.g. day of year (DOY) 134-137). Notably, the heat fluxes were underestimated for nighttime. This might be attributed to the instrumental errors in infrared thermometer and the correction approach used to account for energy imbalance. The infrared

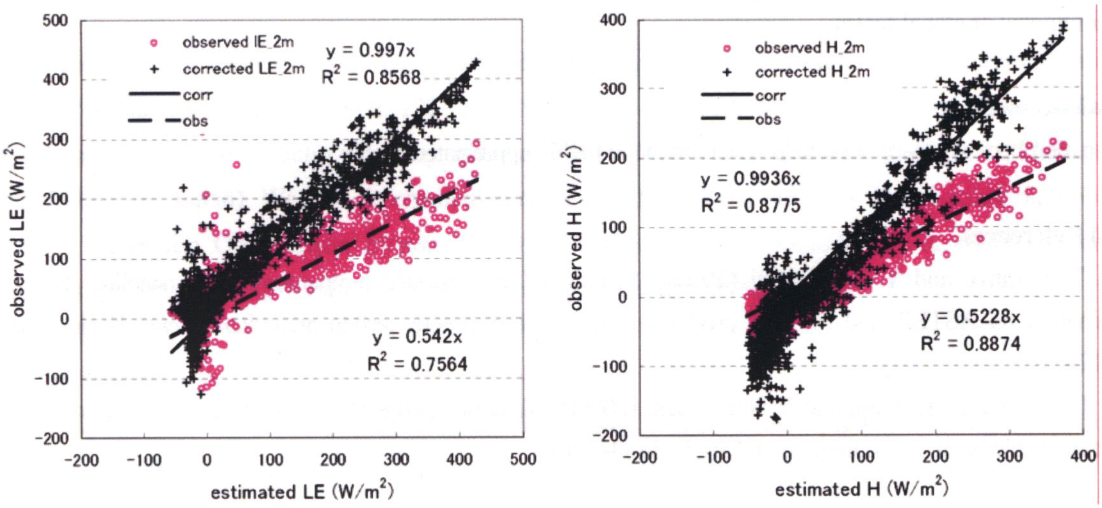

Figure 3. Statistical relationships of heat fluxes between the estimated and the observed values at Changwu of China in May 2005.

thermometer's readings might be erroneous when the environment experiences a sharp change. The correction approach would induce large errors when the Bowen ratio is close to zero, which is the usual case in nighttime. It can be noted that the corrected values scattered away from the observations during the nighttime. Likewise, figure 2 illustrates the temporal variations of sensible heat flux for the same period. The diurnal patterns and trend of the estimated values coincided well with the observations in general.

Figure 3 shows statistical relationships between the estimated and the observed heat fluxes for the period of May 2005. In general, the estimates had a high correlation coefficient with either uncorrected or corrected values for latent heat flux and sensible heat flux, respectively. The observed values were 0.54 and 0.52 times of the estimated values for latent and sensible heat fluxes, respectively. The differences were attributed to the energy imbalance, which is closely related to eddy correlation techniques used in field observation. After correction, the observed values were generally equal to the estimates.

5. Implications of the proposed method

The report described briefly a new method for estimating evaporation in terms of energy flux. It reveals that surface temperatures (LST and air temperature) determine evaporation rate under a given available energy. Hidden in the fundamental principle is that LST is actually a comprehensive index of diverse interactions. This is not in contrast to, but should be complementary to the contemporary theory of evaporation. It provided a new paradigm different from the contemporary theory. This paradigm opens a new way to the fundamental theory of evaporation.

The method is very simple but reproduced the results agreed surprisingly well with that of field observation. The necessary inputs are net radiation, soil heat flux, surface emissivity, land surface temperature, and surface air temperature. Unlike surface resistance used in the contemporary theory, all of the inputs have the rigorous physical meanings and can be measured in field easily. Furthermore, the simplicity and clarity of the method make it highly valuable to modeling, remote sensing, and other applications, in addition to fundamental theory. The method might benefit the simplification and improvement of GCMs, in which commonly adopted the parameterization schemes. Besides, with the development of the increased accuracy of satellite retrieval techniques for the necessary input parameters, this method offers a practical way with a high accuracy for long-term monitoring of surface evaporation on either regional or global scales.

Acknowledgement

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Selected References

Liu, Y., T. Hiyama, and Y. Yamaguchi (2006a). Scaling of land surface temperature using satellite data: An examination on ASTER and MODIS products over a heterogeneous terrain area. *Rem. Sens. Environ.* 105, 115–128.

Liu, Y., T. Hiyama, R. Kimura, and Y. Yamaguchi (2006b). Temporal influences on Landsat-5 Thematic Mapper image in visible band. *Int. J. Rem. Sens.* 27(15), 3183–3201.