Atmósfera 30(1), 39-52 (2017)
doi: 10.20937/ATM.2017.30.01.04

Effects of soil heat storage and phase shift correction on energy balance closure of paddy fields

Xiaoyin LIU,[a] Shihong YANG,[*a] Junzeng XU,[a] Jiangang ZHANG[b] and Jintao LIU[a]

[a] *State Key Laboratory of Hydrology-Water Resources and Hydraulic Engineering, Hohai University, 210098, Nanjing, Jiangsu Province, People's Republic of China*
[b] *Kunshan Water Conservancy Engineering Quality and Safety Supervision and Water Technology Popularization Station, 215300, Kunshan, Jiangsu Province, People's Republic of China*
[*] *Corresponding author; ysh7731@hhu.edu.cn*

Received: August 2, 2016; accepted: December 4, 2016

RESUMEN

Se utilizó el método de covarianza eddy para medir los flujos de energía en un arrozal con ahorro de agua de riego en la Llanura del Sur de China, durante la etapa de crecimiento del arroz en 2013. También se analiza la respuesta del balance de energía superficial al cambio de almacenamiento térmico en el suelo entre las placas de flujo térmico enterradas a una profundidad específica y la superficie, y la corrección del desfase de los componentes del balance de energía, por medio de tres métodos estadísticos: mínimos cuadrados ordinarios (MCO), proporción del balance de energía (PBE) y remanente del balance de energía (D). Los resultados muestran que la curva de los MCO se incrementó 8.8% en promedio y el PBE medio diario aumentó 0.5% después de considerar el cambio en el almacenamiento térmico del suelo. El rango de las magnitudes de D registradas cada media hora varía de –129-260 W m^{-2} a –102-194 W m^{-2}, y los valores absolutos de D decrecieron 9.9% en promedio. Tomando en cuenta la fase de corrección, el incremento en los coeficientes de regresión de los MCO (con un promedio de 11.3%) y el decremento de D en las mediciones realizadas cada media hora (que van de –61 a 176 W m^{-2}), ambos indicaron que la corrección de la fase de desplazamiento mejor**ó** el cierre del balance de energía superficial en escalas de media hora, especialmente entre el amanecer y el mediodía, pero careció de utilidad en la escala diaria. Esto indica que ambos métodos son útiles para mejorar el grado del cierre del balance de energía, representado en diferentes escalas temporales con un índice de evaluación adecuado. Es necesario realizar investigaciones ulteriores que presten mayor atención a otros aspectos de la corrección.

ABSTRACT

The eddy covariance technique was used to measure the energy fluxes of a paddy field under water-saving irrigation in the South China Plain for the stage of rice growth in 2013. This study analyzed the energy balance components and evaluated the energy balance closure. The study also discussed the response of surface energy balance to the change in soil heat storage between the heat flux plates buried at a specific depth and the surface, and the phase shift correction of energy balance components, by using three different statistical methods, namely ordinary least squares (OLS), energy balance ratio (EBR), and energy balance residual (D). The results showed that the OLS slope increased by an average of 8.8%, and the mean daily EBR increased by 5.0% after considering the change in soil heat storage. The range of half-hourly D over a four-month period decreased from –129 - 260 W m^{-2} to –102 - 194 W m^{-2}, and the absolute value of D decreased by 9.9% on the average. Considering the phase correction, the increase in OLS regression coefficients with an average of 11.3% and the decrease in half-hourly D, ranging from –61 to 176 W m^{-2}, both indicated that phase shift correction improved the surface energy balance closure at the half-hourly scale, specifically in the period from sunrise to noon, but had no use in the daily scale. Thus, the two correction methods are useful in improving the degree of energy balance closure shown in different temporal scales with proper evaluation index. Moreover, further research should be given with more attention for other correction aspects.

Keywords: Water-saving irrigation, paddy field, eddy covariance, energy balance, soil heat storage, phase shift correction.

1. Introduction

The accurate determination of surface energy balance components in different terrestrial ecosystems is an essential prerequisite to understanding and modeling the interaction between ecosystems and ambient environments, which are linked with the hydrological cycle, climate change, plant productivity, and carbon budgets (Wilson et al., 2002; Castellvi et al., 2008; Bormann, 2011). Eddy covariance (EC) has been deemed as a preferred method for measuring surface energy flux and balance (Mauder et al., 2007). However, the lack of energy closure is unresolved, and a full guidance on experimental set up and raw data processing for the EC system is still unavailable. Typically, independent measurements of fluxes accounted for 70-90% of measured net radiation, as reported by studies in the last decade (Wilson et al., 2002; Jacobs et al., 2008; Leuning et al., 2012). Generally, the failure in the energy balance closure was attributed to the discrepancy of the source among various flux components; inhomogeneous surface cover and soil characteristics; flux divergence arising from transport that is multi-dimensional; the missed very low and/or high-frequency fluctuations of fluxes; turbulent dispersive fluxes; measurement errors related to the sensor separation; frequency response; alignment problems, and interference from tower or instrument-mounting structures (Cleugh and Roberts, 1994; Foken and Oncley, 1995; Laubach and Teichmann, 1999; Twine et al., 2000; Wilson et al., 2002; Masseroni et al., 2012).

The accurate estimations of surface soil heat flux and phase correction are both important aspects in improving surface energy closure for the results of the EC system. Soil heat flux (G) measured at the soil surface was different than the underlying soil at a specific depth, and surface soil heat flux performed better in energy balance closure (Kustas et al., 2000; Heusinkveld et al., 2004; Russo, 2008; Yao et al., 2008; Masseroni et al., 2014, 2015). Thus, several methods were developed to estimate the surface soil heat flux (G_0) based on soil heat flux measured by heat flux plates (G_s). The first method is based on the phase delay in soil heat flux and temperature with the change in soil depth, or based on the principle that the amplitude of soil heat flux and temperature decay exponentially with the change in soil depth (van Wijk and de Vries, 1963; Heitman et al., 2010). The second method consists in analyzing ground temperature via the harmonic method with the insertion of heat flux plates at the surface, and calculating the soil thermal conductivity via the approximation method (Heusinkveld et al., 2004). In the third method, soil heat storage (Q), calculated on the basis of soil temperature and moisture data, is integrated with the G_s measured at a specific depth (Gao, 2005; Masseroni et al., 2015). This latter method is the one we have chosen.

Energy balance components and net radiation might vary out of synchronization with the 24-h daily cycle, which led to the systematic energy imbalance. Hence, phase correction was another important practice in improving the surface energy balance closure (Foken et al., 2006; Guo et al., 2008; Leuning et al., 2012; Sun et al., 2013; Wohlfahrt and Widmoser, 2013). Gao et al. (2010) presented a theoretical analysis of the phase difference in diurnal variation of soil surface temperature, soil temperature, soil surface heat flux, soil flux measured by heat flux plates, and soil heat storage, to examine the impact of the phase difference between soil surface heat flux and temperature on the surface energy closure; they concluded that the phase difference in soil surface heat flux vs. net radiation, sensible heat, and latent heat fluxes was an inherent source of soil surface energy imbalance. Guo et al. (2008) concluded that turbulent energy flux with forward phase displacement of about half an hour contributes to the energy balance closure about 1.4%-2.5% in a maize field. Li et al. (2008) reported that latent heat, sensible heat, and soil heat flux were half an hour lagging behind the net radiation in an alpine meadow. The slope of ordinary least squares (OLS) regression increased with a great improvement of 49.1%, from 0.53 to 0.79 after phase shift correction. Leuning et al. (2012) concluded that the sum of eddy fluxes with half-hourly averages of sensible and latent heat was