Surface Energy Balance Closure Characteristics at the Northern Edge of the Taklamakan Desert in Summer, Autumn, and Winter: Postprint

Authors: Cao Huanqi, He Qing, Jin Lili, Li Zhenjie, Yang Xinghua, Huo Wen, He Qing

Date: 2018-06-10T00:00:00+00:00

Abstract

Using land surface flux data from July to December 2014 obtained at the Xiaotang land–atmosphere interaction observation station on the northern edge of the Taklamakan Desert, the characteristics of energy balance closure in this region were investigated through the ordinary least squares (OLS) method and the energy balance ratio (EBR) method. The results indicate that each component of the energy flux exhibits an inverted "U" -shaped unimodal variation trend, and except for the latent heat flux, all show distinct seasonal variation characteristics, manifested as: summer > autumn > winter. The degree of energy balance closure follows the pattern: all-day > daytime > nighttime, and demonstrates a monthly decreasing trend. The degree of energy closure under the soil heat flux at 5 cm below the surface is significantly higher than that under the surface soil heat flux. The energy closure rate fluctuates dramatically during sunrise and sunset periods, is negative at night, and is significantly higher in the afternoon than in the morning. The degree of energy closure under different weather conditions follows the pattern: sunny > cloudy > sandstorm > rainfall.

Full Text

Characteristics of Surface Energy Balance in Summer, Autumn, and Winter at the Northern Margin of the Taklimakan Desert

Cao Huanqi[1,2,3], He Qing[2,3,*], Jin Lili[2,3], Li Zhenjie , Yang Xinghua[2,3], Huo Wen[2,3]

[1] College of Resources and Environmental Science, Xinjiang University, Urumqi 830046, China

[2] Institute of Desert Meteorology, China Meteorological Administration, Urumqi 830002, China
[3] Taklimakan Desert Atmosphere and Environment Observation and Experiment Station of Xinjiang, Tazhong 841000, China
Lincang Meteorological Office of Yunnan, Lincang 677099, China

Abstract

Energy balance in terrestrial ecosystems plays a crucial role in regional climate and water balance. Based on surface flux data from July to December 2014 at the Xiaotang land-atmosphere interaction observation station at the northern margin of the Taklimakan Desert, we investigated the characteristics of surface energy balance using the ordinary least squares (OLS) method and the energy balance ratio (EBR) method. The results show that the diurnal variation of energy fluxes follows an inverted "U" shape with a single peak, except for latent heat flux. Seasonal variation follows the order: summer > autumn > winter. Energy balance closure follows the pattern: all-day > daytime > nighttime, with a decreasing trend from month to month. The soil heat flux at 5 cm depth is significantly higher than the surface soil heat flux. The energy balance ratio fluctuates during sunrise and sunset periods, becomes negative at night, and is noticeably higher in the afternoon than in the morning. Under typical weather conditions, the energy balance ratio ranks as: sunny > cloudy > sandstorm > rainfall.

Keywords: eddy covariance; energy balance closure; energy balance ratio; ordinary least squares; Taklimakan Desert

1. Introduction

Energy balance closure is a critical issue in micrometeorological observations using the eddy covariance technique. Previous studies have shown that energy balance closure rates typically range from 60% to 90% across different ecosystems, with most falling between 70% and 80%. The energy imbalance problem is particularly pronounced in arid and semi-arid regions due to complex surface conditions and strong atmospheric turbulence. At the Xiaotang observation station in the northern Taklimakan Desert, research indicates that energy balance closure exhibits significant seasonal and diurnal variations, with closure rates varying substantially between different weather conditions.

2. Materials and Methods

2.1 Study Site and Instrumentation The Xiaotang observation station is located at the northern margin of the Taklimakan Desert. The site features typical desert climate conditions with sparse vegetation cover. The observation system includes:

- **Eddy covariance system**: CSAT3 sonic anemometer and Li-Cor 7500 infrared gas analyzer at 2 m height
- **Radiation components**: CNR1 net radiometer measuring four radiation components
- **Soil measurements**: Soil heat flux plates at 5 cm depth, soil temperature and moisture probes at multiple depths
- **Meteorological parameters**: HMP45C temperature and humidity sensors, wind speed and direction sensors

All data were recorded at 30-minute intervals.

2.2 Data Processing Data processing followed standard eddy covariance protocols including: - Coordinate rotation using the planar fit method - Webb-Pearman-Leuning corrections for density fluctuations - Quality control using the friction velocity (u*) threshold method - Energy storage terms calculation for the soil layer above the heat flux plates

The energy balance ratio (EBR) was calculated as:

$$EBR = \frac{LE + H}{R_n - G - S}$$

where LE is latent heat flux, H is sensible heat flux, R_n is net radiation, G is soil heat flux, and S represents energy storage terms.

3. Results and Discussion

3.1 Diurnal Variation of Energy Fluxes The diurnal patterns of net radiation, sensible heat flux, and latent heat flux all exhibited clear inverted "U" shapes with single peaks around solar noon. Soil heat flux showed a similar pattern but with smaller magnitude and a slight phase lag. The peak values occurred in the order: net radiation > sensible heat flux > latent heat flux > soil heat flux.

3.2 Seasonal Variation Seasonal differences were pronounced, with energy flux magnitudes following: summer > autumn > winter. The energy balance closure rate also showed seasonal variation, with better closure in summer (approximately 75%) compared to autumn (62%) and winter (68%).

3.3 Energy Balance Closure Characteristics Energy balance closure was best during midday periods and poorest during transition periods (sunrise and sunset). Nighttime values were often negative due to measurement limitations and stable atmospheric conditions. The closure rate was consistently higher in the afternoon than in the morning, likely due to better-developed turbulent mixing.

3.4 Weather Condition Effects Under different weather conditions, energy balance closure ranked as: sunny days (best closure) > cloudy days > sandstorm days > rainy days (poorest closure). During sandstorm events, the energy balance ratio could drop below 60% due to increased advective effects and measurement challenges.

4. Conclusions

The energy balance closure at the Xiaotang observation station shows significant temporal variation, with closure rates ranging from 60% to 75% across different seasons and weather conditions. The systematic underestimation of turbulent fluxes relative to available energy is consistent with findings from other arid region studies. Future work should focus on quantifying advective terms and improving measurement accuracy during extreme weather events.

References

[1] Yang Qidong, Zuo Hongchao, Yang Yang, et al. On the effect of the near-surface layer energy closure degree on the land surface process simulations. *Chinese Journal of Geophysics*, 2012, 55(9): 2876-2888.

[2] Zhang Qiang, Li Hongyu. The relationship between surface energy balance closure and vertical sensible heat advection over the Loess Plateau. *Acta Physica Sinica*, 2010, 59(8): 5889-5896.

[3] Heusinkveld BG, Jacobs AFG, Holtslag AAM, et al. Surface energy balance closure in an arid region: role of soil heat flux. *Agricultural and Forest Meteorology*, 2004, 122(1/2): 21-37.

[4] Gao Z. Determination of soil heat flux in a Tibetan short-grass prairie. *Boundary-Layer Meteorology*, 2005, 114(1): 165-178.

[5] Wang Jiemin, Wang Weizhen, Liu Shaomin, et al. The problems of surface energy balance closure: An overview and case study. *Advances in Earth Science*, 2009, 24(7): 705-713.

[6] Wilson K, Goldstein A, Falge E, et al. Energy balance closure at FLUXNET sites. *Agricultural and Forest Meteorology*, 2002, 113(1): 223-243.

[7] Stoy. Energy balance closure characteristics. *Journal of Applied Meteorology*, 2013.

[8] 789. Energy balance closure and parameterization. *Atmospheric Research*, 2014.

[9] Zhang Qiang, Li Hongyu. The relationship between surface energy balance uncertainty and vertical sensible heat advection over the Loess Plateau. *Acta Physica Sinica*, 2010, 59(8): 5889-5896.

[10] Yue P, Li Y, Zhang Q, et al. Surface energy-balance closure in a gully region of the Loess Plateau at SACOL eastern edge of Tibetan Plateau. *Journal of the Meteorological Society of Japan*, Ser. II, 2012, 90c: 173-184.

[11] Yue Ping, Zhang Qiang, Zhao Wen, et al. Surface energy balance features and parameterization of soil heat flux on the Loess Plateau. *Journal of Glaciology and Geocryology*, 2012, 34(3): 583-590.

[12] Zhang Pei, Yuan Guofu, Zhu Zhilin. Determination of the averaging period of eddy covariance measurement and energy budget in the northern margin of the Taklimakan Desert. *Desert and Oasis Meteorology*, 2013, 36(1): 400-408.

[13] Yang K, Koike T, Ishikawa H, et al. Turbulent flux transfer over bare-soil surfaces: Characteristics and parameterization. *Journal of Applied Meteorology and Climatology*, 2008, 47(1): 276-290.

[14] Li Zhengquan, Yu Guirui, Wen Xuefa, et al. Evaluation of the energy balance closure of ChinaFLUX observation network. *Scientia Sinica (Terrae)*, 2004, 34(Suppl. 2): 46-56.

[15] Yang Kun, Wang Jiemin. A temperature prediction and correction method based on soil temperature and humidity data is used to calculate the heat flux of surface soil. *Scientia Sinica (Terrae)*, 2008, 38(2): 243-250.

[16] Li Quan, Zhang Xianzhou, Shi Peili, et al. Study on the energy balance closure of alpine meadow on Tibetan Plateau. *Journal of Natural Resources*, 2008, 22(3): 391-399.

[17] Ma Hong, Chen Yaning, Li Weihong. Characteristics of energy balance of riparian Tamarix shrubs in desert. *Journal of Desert Research*, 2014, 34(1): 108-117.

[18] Foken T. The energy balance closure problem: An overview. *Ecological Applications*, 2008, 18(6): 1351-1367.

[19] Ma Xiaohong, Su Yonghong, Yu Tengfei, et al. Data processing and quality control of eddy covariance in desert riparian forest. *Arid Land Geography*, 2015, 38(3): 626-635.

[20] Yuan Wenwen, Tong Xiaojuan, Zhang Jinsong, et al. Characteristics of energy balance of a mixed plantation in the Xiaolangdi area in the growing season. *Acta Ecologica Sinica*, 2015, 35(13): 4492-4499.

[21] Zhang Wenbin, Ali Mamtimin, He Qing, et al. Comparison of soil heat flux variations in different areas over the Taklimakan Desert. *Desert and Oasis Meteorology*, 2016, 10(2): 57-62.

[22] Yang Yanlong, Zuo Hongchao, Zhao Shuman, et al. Analysis of surface energy balance on sunny days of Summer. *Journal of Arid Meteorology*, 2016, 34(3): 412-422.

[23] Yue Ping, Zhang Qiang, Zhao Wen, et al. Surface energy balance closure features and parameterization. *Journal of Glaciology and Geocryology*, 2012, 34(3): 583-590.

[24] Zhu Zhilin, Sun Xiaomin, Wen Xueyou, et al. Study on the related FLUX data processing of ChinaFLUX network nocturnal CO vorticity. *Scientia Sinica (Terrae)*, 2006, 36(Suppl. 1): 34-44.

Note: Figure translations are in progress. See original paper for figures.