

## Water-Heat Flux Variation Characteristics and Influencing Factors in Typical Desert Ecosystems of Arid Inland River Basins (Postprint)

**Authors:** Xu Wentao, Yongjun Du, Zhang Heng, Tian Hao, Chai Wenguang, Bruce Lee, JIA Weikang, Yang Guang

**Date:** 2025-10-23T12:01:42+00:00

### Abstract

To address the issues of water resource stress and ecological responses in desert ecosystems of arid inland river basins under climate change, this study focuses on the typical desert ecosystem in the lower reaches of the Manas River Basin, an arid inland river in northwestern China. Using the eddy covariance method, we simultaneously monitored latent heat flux (LE), sensible heat flux (H), Bowen ratio (B), air temperature (TA), relative humidity (RH), vapor pressure deficit (VPD), and average wind speed (WS) at the southern edge of the Gurban-tunggut Desert. Pearson correlation coefficient analysis was employed to investigate the variation characteristics of water and heat fluxes and their environmental driving factors in the desert ecosystem from April to October of 2023 and 2024. The results indicate: (1) At the half-hour scale, both LE and H exhibit fundamentally unimodal patterns, with maximum values occurring between 13:00 and 15:00, and the LE maximum precedes the H maximum by 1-2 hours. The primary environmental factors influencing LE are TA (0.63) > VPD (0.62) > WS (0.51); those influencing H are WS (0.73) > VPD (0.61) > TA (0.56) > RH (-0.33); and the primary factor influencing B is WS, with  $r = 0.11$ . (2) At the daily scale, H and LE display pronounced seasonal variation characteristics, following a trend of initial increase followed by decrease, exhibiting a ‘U-shaped’ pattern, while B gradually stabilizes during the mid-growing season. The primary environmental factors influencing LE are TA and VPD, while those influencing H are WS and RH. (3) At the monthly scale, water and heat fluxes show similar trends, with H and LE approximately exhibiting unimodal patterns. Mean LE values are highest in July and August, reaching a minimum in October; mean H values are highest in June and July, also reaching a minimum in October. The primary environmental factors influencing LE are TA, VPD, and RH, all showing significant positive correlations, with TA

exhibiting the strongest positive correlation ( $r = 0.85$ ). The primary environmental factors influencing H are TA, VPD, and WS, with both TA and VPD showing relatively strong positive correlations ( $r = 0.85$  and  $0.83$ , respectively). The primary environmental factors influencing B are WS, TA, VPD, and RH, among which RH shows a negative correlation. The research results provide a theoretical basis for ecological restoration of desert ecosystems.

## Full Text

## Preamble

ARID ZONE RESEARCH Vol. 42 No. 9 Sep. 2025

### Characteristics and Influencing Factors of Water and Heat Flux Changes in Typical Desert Ecosystems of Arid Inland River Basins

XU Wentao<sup>1,2</sup>, DU Yongjun<sup>1,2</sup>, ZHANG Heng<sup>1,2</sup>, TIAN Hao<sup>1,2</sup>, CHAI Wenguang<sup>1,2</sup>, LI Xiaolong<sup>1,2</sup>, JIA Weikang<sup>3</sup>, YANG Guang<sup>1,2</sup>

<sup>1</sup>College of Water Conservancy & Architectural Engineering, Shihezi University, Shihezi, Xinjiang 832003, China

<sup>2</sup>Key Laboratory of Cold and Arid Regions Eco-Hydraulic Engineering of Xinjiang Production & Construction Corps, Shihezi, Xinjiang 832003, China

<sup>3</sup>Water Conservancy Project Management and Service Center of Shihezi, Shihezi, Xinjiang 832000, China

---

## Abstract

To address the challenges of water resource stress and ecological response in desert ecosystems of arid inland river basins under climate change, this study focuses on a typical desert ecosystem in the lower reaches of the Manas River Basin in northwestern China. Using the eddy covariance method, we simultaneously monitored latent heat flux (LE), sensible heat flux (H), Bowen ratio (B), air temperature (TA), relative humidity (RH), vapor pressure deficit (VPD), and average wind speed (WS) at the southern edge of the Gurbantunggut Desert. Pearson correlation coefficients were applied to examine the characteristics of water and heat flux variations and their environmental driving factors across half-hourly, daily, and monthly scales from April to October in 2023 and 2024.

The results show that: (1) At the half-hourly scale, LE and H exhibited unimodal diurnal patterns, with peaks occurring between 13:00-15:00. The LE peak consistently preceded the H peak by 1-2 hours. The primary environmental factors influencing LE were TA ( $r = 0.63$ ) > VPD ( $r = 0.62$ ) > WS ( $r = 0.51$ ), while H was mainly affected by WS ( $r = 0.73$ ) > VPD ( $r = 0.61$ ) > TA ( $r = 0.56$ ) > RH ( $r = -0.33$ ). The dominant factor for B was WS ( $r = 0.11$ ). (2) At the daily scale, H and LE showed distinct seasonal patterns, initially increasing then decreasing, while B displayed a “U-shaped” trend that flattened during

the mid-growth period. TA and VPD were the main drivers of LE, whereas WS and RH primarily influenced H. (3) At the monthly scale, H and LE followed similar unimodal trends, with LE peaking in July–August and reaching its minimum in October, while H peaked in June–July and also minimized in October. LE showed strong positive correlations with TA, VPD, and RH, with TA exhibiting the strongest correlation ( $r = 0.85$ ). H was primarily influenced by TA, VPD, and WS, with TA and VPD showing strong positive correlations ( $r = 0.85$  and  $0.83$ , respectively). The main environmental factors affecting B were WS, TA, VPD, and RH, with RH showing a negative correlation. These findings elucidate the multi-scale variation characteristics of water and heat fluxes and their relationships with environmental factors in desert ecosystems of arid inland river basins, providing a theoretical foundation for ecological restoration and management.

**Keywords:** desert ecosystem; eddy covariance; latent heat flux; sensible heat flux; Bowen ratio; environmental factors

---

## 1. Introduction

Water and heat cycling in terrestrial ecosystems represents the core of material and energy exchange between the land surface and atmosphere. The eddy covariance technique directly measures energy and mass exchange fluxes between vegetation canopies and the atmosphere by estimating high-frequency covariances of vertical wind speed and scalar fluctuations, offering a more reliable approach than lysimeter, Bowen ratio, or water balance methods. Due to its capability for long-term, high-frequency monitoring, this technique has been widely applied across various ecosystems including urban, wetland, farmland, and desert environments, effectively revealing water and heat variation characteristics and their driving mechanisms.

The southern edge of the Gurbantunggut Desert represents a typical temperate desert ecosystem with unique flora and fauna that maintain relative stability through self-regulation over long timescales, playing crucial roles in ecological balance, soil conservation, and water resource management. However, climate change and human activities have diminished its resilience and self-regulation capacity, making regional ecological security and sustainable development increasingly critical. While previous studies have focused primarily on forests, farmland, and meadows, the characteristics of water and heat flux variations and their relationships with environmental factors in typical desert ecosystems of arid inland river basins remain unclear. Most existing research emphasizes single environmental factors or specific temporal scales while neglecting interactions among factors across multiple scales.

Building upon micro-meteorological theory and employing eddy covariance methods, this study analyzes water and heat flux characteristics and their environmental controls in the Manas River Basin desert ecosystem from April

to October 2023–2024. The objectives are to: (1) characterize water and heat flux exchange patterns across multiple temporal scales, and (2) reveal how environmental factors regulate these fluxes in desert ecosystems, thereby providing theoretical support for ecological conservation.

---

## 2. Materials and Methods

### 2.1 Study Area

The study site is located at the southern edge of the Gurbantunggut Desert (45°01 N, 86°06 E) in the Manas River Basin of northwestern China. The region experiences a typical arid continental climate with scarce rainfall (117 mm annually) and high evaporation (1979.5 mm). The elevation ranges from 300–600 m, with an average annual temperature of 6.6 °C. The eddy covariance system was installed on flat, open terrain without tall buildings or obstructions, representing a homogeneous underlying surface. The tower height was 4 m, with dominant desert vegetation including *Haloxylon ammodendron*, *Haloxylon persicum*, and *Ephedra sinica*.

### 2.2 Data Sources and Processing

**2.2.1 Eddy Covariance System** The eddy covariance system (IRGASON, Campbell Scientific Inc., Logan, USA) integrated an open-path infrared gas analyzer with a three-dimensional sonic anemometer, simultaneously measuring CO<sub>2</sub>/H<sub>2</sub>O concentrations, air temperature, relative humidity, atmospheric pressure, vapor pressure deficit, wind speed, and wind direction at 10 Hz frequency. The system was oriented toward the prevailing wind direction.

**2.2.2 Flux Data Processing** The system calculates turbulent fluxes through direct measurement of covariances between atmospheric variable fluctuations and vertical wind speed fluctuations. The latent heat flux (LE) and sensible heat flux (H) were computed as:

$$LE = \rho_a \cdot L_v \cdot \omega' q'$$
$$H = \rho_a \cdot C_p \cdot \omega' T'$$

where  $LE$  is latent heat flux ( $W \cdot m^{-2}$ ),  $H$  is sensible heat flux ( $W \cdot m^{-2}$ ),  $\rho_a$  is air density ( $kg \cdot m^{-3}$ ),  $L_v$  is latent heat of vaporization ( $J \cdot kg^{-1}$ ),  $C_p$  is specific heat capacity at constant pressure [ $1004.67 J \cdot (kg \cdot K)^{-1}$ ],  $\omega'$  is vertical wind speed fluctuation,  $q'$  is specific humidity fluctuation, and  $T'$  is air temperature fluctuation.

The Bowen ratio (B) was calculated as:

$$B = H/LE$$

**2.2.3 Data Quality Control** To ensure data accuracy and continuity, raw 10 Hz data underwent rigorous quality control including spike removal, trend correction, coordinate rotation (double rotation), frequency response correction, sonic virtual temperature correction, and density fluctuation (WPL) correction. Data were screened using a friction velocity ( $u_*$ ) threshold of  $0.1 \text{ m} \cdot \text{s}^{-1}$ , with values below this threshold discarded. Flux footprint analysis using Kormann and Kljun models indicated that the upwind fetch ranged from 235.92–571.66 m, with mean contribution distances of 387.38 m, ensuring representative measurements.

**2.2.4 Gap-Filling** Missing data were gap-filled using the marginal distribution sampling method within the ReddyProc package in the R programming environment. The growing season was divided into three periods: early growth (April–May), mid-growth (June–August), and late growth (September–October).

---

## 3. Results

### 3.1 Environmental Factor Variations

**3.1.1 Half-Hourly Scale** At the half-hourly scale, environmental factors showed distinct diurnal patterns (Fig. 2). Air temperature (TA) exhibited a decreasing-increasing-decreasing trend, peaking at 14:00–16:00. Vapor pressure deficit (VPD) showed similar patterns but with greater variation across growth stages, with means of 18.21 hPa (early), 29.40 hPa (mid), and 15.09 hPa (late) in 2023, and 21.31 hPa, 17.64 hPa, and 33.33 hPa in 2024, respectively. Relative humidity (RH) displayed opposite trends to TA and VPD, while wind speed (WS) showed a decreasing-increasing-decreasing pattern.

**3.1.2 Daily Scale** Daily environmental variations showed unimodal seasonal patterns, increasing then decreasing with maxima in July and minima in January (Fig. 3). Annual ranges were TA:  $-2.57$ – $40.99 \text{ }^\circ\text{C}$ , VPD:  $0.2$ – $74.83 \text{ hPa}$ , and WS:  $0.12$ – $12.85 \text{ m} \cdot \text{s}^{-1}$ , with annual means of  $20.16 \text{ }^\circ\text{C}$ ,  $23.48 \text{ hPa}$ , and  $1.78 \text{ m} \cdot \text{s}^{-1}$ , respectively.

**3.1.3 Monthly Scale** Monthly variations revealed similar unimodal trends (Fig. 4). TA and VPD peaked in July, while RH decreased during the growing season. WS showed a “double-peak” pattern, increasing overall then decreasing.

## 3.2 Water and Heat Flux Variations

**3.2.1 Half-Hourly Scale** LE and H exhibited unimodal diurnal patterns with peaks at 13:00-15:00 (Fig. 5). The LE peak consistently preceded the H peak by 1-2 hours. In 2023, LE peaked at  $213.25 W \cdot m^{-2}$  while H reached  $78.62 W \cdot m^{-2}$ ; in 2024, LE peaked at  $60.50 W \cdot m^{-2}$  with H at  $52.89 W \cdot m^{-2}$ . During early growth, LE dominated energy consumption, while H dominated during mid- and late-growth periods.

**3.2.2 Daily Scale** Daily variations showed clear seasonal patterns (Fig. 6). LE and H increased then decreased, forming a “U-shaped” trend, while B flattened during mid-growth. In 2023, LE ranged from  $1.43-81.07 W \cdot m^{-2}$  and H from  $0.45-103.72 W \cdot m^{-2}$ ; in 2024, LE ranged  $4.88-96.39 W \cdot m^{-2}$  and H  $2.28-85.00 W \cdot m^{-2}$ . The large fluctuation ranges reflect strong turbulent transport under intense thermal forcing.

**3.2.3 Monthly Scale** Monthly LE and H showed unimodal patterns (Fig. 7). In 2023, LE ranged  $9.81-32.84 W \cdot m^{-2}$  (peak in July-August, minimum in October), while H ranged  $17.52-64.94 W \cdot m^{-2}$  (peak in June-July, minimum in October). In 2024, LE ranged  $17.05-64.94 W \cdot m^{-2}$  and H  $27.00-69.33 W \cdot m^{-2}$ . The Bowen ratio (B) showed a “U-shaped” pattern, decreasing during early growth, stabilizing mid-season, then increasing in late growth.

## 3.3 Correlation Analysis

**3.3.1 Half-Hourly Scale** Pearson correlations revealed that LE was significantly positively correlated with TA ( $r = 0.63$ ), VPD ( $r = 0.62$ ), and WS ( $r = 0.51$ ). H showed strong positive correlations with WS ( $r = 0.73$ ), VPD ( $r = 0.61$ ), and TA ( $r = 0.56$ ), and negative correlation with RH ( $r = -0.33$ ). B was primarily influenced by WS ( $r = 0.11$ ) (Fig. 8).

**3.3.2 Daily Scale** At the daily scale, LE was significantly positively correlated with TA and VPD ( $r = 0.85$  and  $0.83$ ). H showed strong positive correlations with TA ( $r = 0.85$ ) and VPD ( $r = 0.83$ ), and moderate correlation with WS ( $r = 0.56$ ). B was positively correlated with WS ( $r = 0.71$ ) and negatively with RH ( $r = -0.45$ ) (Fig. 9).

**3.3.3 Monthly Scale** Monthly correlations showed LE strongly positively correlated with TA ( $r = 0.85$ ), VPD ( $r = 0.83$ ), and RH ( $r = 0.81$ ). H was primarily influenced by TA ( $r = 0.85$ ), VPD ( $r = 0.83$ ), and WS ( $r = 0.56$ ). B showed positive correlations with WS ( $r = 0.71$ ) and TA ( $r = 0.45$ ), but negative correlation with RH ( $r = -0.45$ ) (Fig. 10).

## 4. Discussion

Water and heat fluxes represent the conversion of available energy into surface energy flux components, with land-atmosphere interactions propagating surface property changes into the atmosphere. Our eddy covariance measurements reveal distinct multi-scale patterns in this desert ecosystem.

The unimodal diurnal patterns of LE and H align with previous desert studies, though the LE peak preceding H by 1-2 hours reflects rapid surface energy exchange in response to net radiation. The large diurnal ranges (LE:  $-10.69$ – $165.99 W \cdot m^{-2}$ ; H:  $-14.31$ – $221.88 W \cdot m^{-2}$ ) indicate strong turbulent transport and intermittent fluxes. Nighttime positive LE and negative H values result from temperature inversions common in desert environments, where nocturnal surface temperatures drop below air temperature.

The dominance of H over LE (Bowen ratio  $> 1$ ) throughout the growing season is consistent with studies in the Taklamakan Desert and Central Asian deserts, attributable to low soil moisture, high surface albedo, and low heat capacity that convert absorbed radiation primarily into sensible heat. The seasonal “U-shaped” pattern of B reflects energy partitioning shifts: early growth instability with frequent energy exchange, mid-season equilibrium, and late-season deterioration reducing environmental controls.

Environmental factors showed scale-dependent influences. At half-hourly and daily scales, TA, VPD, and WS significantly promoted LE and H through enhanced turbulence and evapotranspiration. At monthly scales, RH became negatively correlated with LE as high temperatures accelerated evaporation, drying surface soils. The consistent positive correlation between TA and both fluxes across all scales confirms temperature as the primary driver of energy exchange.

Vegetation development modulated these relationships. During early growth, limited leaf area and surface moisture reduced LE's response to environmental factors. Mid-growth increases in leaf area index enhanced canopy conductance and photosynthetic activity, strengthening LE-VPD correlations. Late-season senescence weakened these relationships, particularly for B.

---

## 5. Conclusion

This study, based on eddy covariance measurements, investigated multi-scale variations of LE, H, and B and their responses to environmental factors in a desert ecosystem of an arid inland river basin. Key conclusions are:

1. **Half-hourly scale:** LE and H showed unimodal diurnal patterns peaking at 13:00-15:00, with LE preceding H by 1-2 hours. Early growth was LE-dominated, while mid- and late-growth were H-dominated. LE was primarily driven by TA, VPD, and WS; H by WS, VPD, TA, and RH; and B by WS.

2. **Daily scale:** Clear seasonal patterns emerged, with LE and H increasing then decreasing and B showing a “U-shaped” trend. TA and VPD dominated LE, while WS and RH primarily influenced H.
3. **Monthly scale:** Unimodal seasonal patterns peaked in summer (LE: July–August; H: June–July) and minimized in October. LE correlated strongly with TA ( $r = 0.85$ ), VPD, and RH; H with TA ( $r = 0.85$ ), VPD, and WS; and B with WS, TA, VPD, and negatively with RH.

These findings elucidate the complex multi-scale dynamics of water and heat fluxes in desert ecosystems, highlighting the dominant role of sensible heat flux and the scale-dependent influences of environmental factors. Future research should further investigate radiation and soil moisture effects and explore coupling between carbon and water fluxes to enhance understanding of desert ecosystem functioning under climate change.

---

## References

- [1] Xie Zhenghui, Chen Si, Qin Peihua, et al. Research on climate feedback of human water use and its impact on terrestrial water cycles—Advances and challenges[J]. *Advances in Earth Science*, 2019, 34(8): 801-813.
- [2] Wang Genxu, Xia Jun, Li Xiaoyan, et al. Frontier progress of terrestrial vegetation ecohydrological processes: From plant leaves to watersheds[J]. *Chinese Science Bulletin*, 2021, 66(Suppl.): 3667-3683.
- [3] Wang H, Yu L, Chen L, et al. Carbon fluxes and soil carbon dynamics along a gradient of biogeomorphic succession in alpine wetlands of Tibetan Plateau[J]. *Fundamental Research*, 2023, 3(2): 234-242.
- [4] Liu Ran, Wang Qinxue, Tang Lisong, et al. Seasonal variation in water, heat and CO<sub>2</sub> fluxes and its driving forces over a saline desert[J]. *Acta Ecologica Sinica*, 2009, 29(1): 67-75.
- [5] Yu Guirui, Sun Xiaomin. Spatial and Temporal Variation Characteristics of Terrestrial Ecosystem Carbon Flux Observation Technology in China[M]. Beijing: Science Press, 2008.
- [6] Zhu Yongtai, Chen Huiling, Xu Cong, et al. Characteristics and influencing factors of water and heat fluxes over a vineyard in arid desert oasis region in the Northwest China[J]. *Guihaia*, 2023, 43(5): 900-911.
- [7] Tang Jiaqi. Study on the Characteristics and Influencing Factors of Sensible Heat Flux over the Desert Steppe in Inner Mongolia[D]. Hohhot: Inner Mongolia Agricultural University, 2023.
- [8] Han Xin, Zhang Baozhong, Che Zheng, et al. Characteristics and impact factors of water and heat flux changes at different time scales during the growing

season of desert grasslands[J]. Transactions of the Chinese Society of Agricultural Engineering, 2024, 40(15): 65-75.

[9] Bao Hengxin, Zhang Mi, Xie Yanhong, et al. Dynamics and environmental controls of CO<sub>2</sub> flux with tall tower eddy covariance in heterogeneous agricultural landscape of Yangtze River Delta[J]. Acta Ecologica Sinica, 2024, 44(17): 7552-7568.

[10] Guo Wenzhang. Characteristics and Influencing Factors of Carbon Flux in Desert Steppe on the Northern Slope of Tianshan Mountains[D]. Urumqi: Xinjiang Agricultural University, 2022.

[11] Xue Zhixuan, Zang Li, Wang Xinjun, et al. Downscaling analysis of SMAP soil moisture products in Gurbantunggut Desert[J]. Arid Zone Research, 2023, 40(4): 583-593.

[12] Zhang Mengxiao, Wang Yu, Maimaitimin Maimaitiali, et al. Response of atmospheric boundary layer height to snow cover in winter in Gurbantunggut Desert and its surrounding areas[J]. 2022, 44(5): 1558-1569.

[13] Xu Guiqing, Wei Wenshou. Climate change of Xinjiang and its impact on eco-environment[J]. Arid Land Geography, 2004, 27(1): 14-18.

[14] Lowry A L, McGowan H A, Gray M A. Multi-year carbon and water exchanges over contrasting ecosystems on a sub-tropical sand island[J]. Agricultural and Forest Meteorology, 2021, 304-305: 108339.

[15] Du L T, Zeng Y J, Ma L L, et al. Effects of anthropogenic revegetation on the water and carbon cycles of a desert steppe ecosystem[J]. Agricultural and Forest Meteorology, 2021, 300: 108339.

[16] Wang H B, Li X, Xiao J F, et al. Carbon fluxes across alpine, oasis, and desert ecosystems in Northwestern China: The importance of water availability[J]. Science of The Total Environment, 2019, 697: 133978.

[17] Gong Wei, Hu Guanglu, Fu Pengcheng, et al. Soil moisture infiltration characteristics of different sand fixing plants in the desert-oasis transition zone in arid region of China[J]. Journal of Desert Research, 2020, 40(5): 200-208.

[18] Wutzler T, Lucas Moffat A, Migliavacca M, et al. Basic and extensible post-processing of eddy covariance flux data with ReddyProc[J]. Biogeosciences, 2018, 15(16): 5015-5030.

[19] Zhang Lu, Peng Yan, Li Qianhui, et al. Characteristics and dissimilarity of turbulent transport of heat and momentum in summer unstable atmospheric surface layer in Taklimakan Desert and its physical mechanisms[J]. Acta Scientiarum Naturalium Universitatis Pekinensis, 2023, 59(4): 581-592.

[20] Rotenberg E, Yakir D. Contribution of semi-arid forests to the climate system[J]. Science, 2010, 327(5964): 451-454.

- [21] Fan Yining, Liao Zilong, Long Yinhui, et al. Characteristics of vegetation net primary productivity change and its climatic driving forces in the Yinshanbeilu Steppe, Inner Mongolia[J]. *Water Resources and Hydropower Engineering*, 2024, 55(8): 38-50.
- [22] Zhang Simin. *Dynamic Characteristics and Influence Mechanism of Water, Heat and Carbon Fluxes in the Horqin Dune-Meadow Cascade Ecosystem*[D]. Hohhot: Inner Mongolia Agricultural University, 2024.
- [23] Qi Feifei, Mamtimin Maimaitiali, Huo Wen, et al. Characteristics of surface radiation and energy balance and microclimate in the hinterland of Taklimakan Desert[J]. *Journal of Arid Meteorology*, 2020, 38(1): 32-39.
- [24] Castellví F, Suvočarev K, Reba M L, et al. A new free convection form to estimate sensible heat and latent heat fluxes for unstable cases[J]. *Journal of Hydrology*, 2020, 586: 124917.
- [25] Zhu Wankuan, Wang Zhichao, Du Apeng, et al. Seasonal patterns of carbon and water fluxes and their environmental-biological control in the eucalyptus plantation in Zhanjiang of Guangdong Province[J]. *Scientia Silvae Sinica*, 2024, 60(9): 18-32.
- [26] You C, Wang Y, Tan X, et al. Seasonal and interannual variations of ecosystem photosynthetic characteristics in a semi-arid grassland of Northern China[J]. *Journal of Plant Ecology*, 2022, 15(5): 1024-1034.
- [27] Baldocchi D D. How eddy covariance flux measurements have contributed to our understanding of Global Change Biology[J]. *Global Change Biology*, 2020, 26(1): 242-260.
- [28] Han L, Wang Q F, Chen Z, et al. Spatial patterns and climate controls of seasonal variations in carbon fluxes in China's terrestrial ecosystems[J]. *Global and Planetary Change*, 2020, 189: 103175.
- [29] Zhang Q, Sun R, Jiang G, et al. Carbon and energy flux from a *Phragmites australis* wetland in Zhangye oasis desert area, China[J]. *Agricultural and Forest Meteorology*, 2016, 230-231: 45-57.
- [30] Zhou Liantong. Characteristics of temporal and spatial variations of sensible heat flux in the arid and semi-arid region of Eurasia[J]. *Transactions of Atmospheric Sciences*, 2010, 33(3): 299-306.
- [31] Zhang Xueqin, Jin Zheng, Shen Pengke, et al. Lake surface water heat flux variation and its correlation with meteorological factors in the Yamzhog Yumco, Xizang[J]. *Acta Geographica Sinica*, 2023, 78(11): 2797-2810.
- [32] Kannenberg S A, Anderegg W R L, Barnes M L, et al. Dominant role of soil moisture in mediating carbon and water fluxes in dryland ecosystems[J]. *Nature Geoscience*, 2024, 17: 38-43.
- [33] Yang Lei, Jiang Xiaowei, Zhang Zhiyuan, et al. Evapotranspiration rate in the Baiyangdian wetland based on the eddy covariance technique[J]. *Journal of*

Lake Sciences, 2025, 37(3): 1024-1034.

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

*Source: ChinaXiv – Machine translation. Verify with original.*