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Influence of environmental factors on evapotranspiration in a peatland ecosystem in Central China

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Abstract: Environmental factors affect evapotranspiration and usually cause a serious loss of water content from wetland ecosystems. Accurate estimation of evapotranspiration is vital to determine the amount of water necessary to preserve wetlands, particularly peatlands in Central China. The period studied was 24 months. The highest value (0.157 mm/hr) occurred in first growing season, and the lowest value (0.045 mm/hr) occurred in the non-growing season of 2017. Seasonal differences in evapotranspiration occurred in the active growth seasons June through October. The peak value of net radiation was 369 W.m² in September 2017. There was a clear relationship between evapotranspiration and air temperature but a weak correlation with precipitation; annual precipitation was 19 mm. The Bowen ratio showed no correlation with evapotranspiration. The average rate of evapotranspiration throughout the study period was 80%–95%. The eddy covariance technique was used to determine the effect of certain environmental factors on wetland evapotranspiration.

Keywords: energy flux; eddy covariance; seasonal variation; environmental variable; wetland ecosystem.

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1 Introduction

Wetlands occupy 3% of Earth's surface and are among the most valuable ecosystems on the planet because of their biodiversity and ability to sequester carbon, regulate water flow, and maintain water quality by trapping toxins in the soil for further degradation. For this reason, they are sometimes referred to as the 'kidneys' of the landscape (Mitsch and Gosselink, 2016).

Peatlands are wetlands in which production of vegetation exceeds decomposition and peat (partially decomposed vegetable matter) accumulates beneath the living vegetation on the surface (Clymo, 1984). There are two main types of peatlands: fen peatlands fed by groundwater and bog peatlands in which precipitation is the main source of water (Rydin and Jeglum, 2006).

Evapotranspiration (ET) plays a key role in maintaining water balance in wetland ecosystems, especially peatlands (Hussey and Odum, 1992; Lafleur, 2008) and Evapotranspiration is a good indicator of water loss (Parasuraman et al., 2007). However, direct mensuration of evapotranspiration is difficult, costly, and infrequently performed, but field studies on evapotranspiration are important in the development of meaningful evapotranspiration models.

Previous research on evapotranspiration focused on eddy covariance measurements as described in Drexler et al. (2008) for Twitchell Island in California, USA. Wu and Shukla (2014) examined evapotranspiration for peatlands in subtropical Florida for two and a half years. They estimated evapotranspiration using eddy covariance, the most direct method of measuring evapotranspiration is with the eddy covariance technique in which fast fluctuations of vertical wind speed are correlated with fast fluctuations in atmospheric water vapor density. This directly estimates the transfer of water vapor (evapotranspiration) from the land (or canopy) surface to the atmosphere.

Evapotranspiration released 80–95% mm to the atmosphere through a respiration and Liljedahl et al. (2011) proves that, in Arctic coastal peatlands, the majority of evapotranspiration (55–85%) lost due to respiration from mosses and open water directly to the atmosphere. In addition to respiration of living plants, evapotranspiration also varies due to changes in physical and chemical environmental factors and water conditions (Shimoyama, 2003; Lafleur et al., 2005), such as latent heat flux (LE), sensible heat flux (H), relative humidity (RH), net radiation (Rn), air temperature (T_a), and precipitation (P) (Iwata et al., 2015; Yu et al., 2017).

Peatlands of Shennongjia in Central China, the largest subtropical wetlands in the mountainous areas along the middle reaches of the Yangtze River (Alfadhel et al., 2020), cause rapid rates of evapotranspiration to occur because of seasonal changes in environmental variables and vegetative respiration. The primary objectives of this study were to assess how environmental factors (T_a , P, RH, etc.) affect evapotranspiration using the eddy variance technique to measure variations in evapotranspiration throughout the year to capture seasonal effects and trends for growing and non-growing seasons.

2 Materials and methods

2.1 Study area

The Dajihu peatlands of Shennongjia are wide and extend through a series of mountains and subalpine wetlands in Hubei province, Central China. Measurements were made at a weather station located in the neighbourhood of nine great lakes (31°28'44.45"N, 110°00'14.61"E). This plant community is dominated by peat moss and a shrub layer approximately 2 m thick and represented by communities of *Sphagnum palustre*, *Carex fulvorubescens*, *Festuca rubra*, *Euphorbia esula*, *Sanguisorba officinalis*, *Polytrichum commune*, *Drosera rotundifolia*, and *Geranium rosthornii* (Alfadhel et al., 2019).

2.2 Eddy covariance

An eddy covariance system was installed to measure evapotranspiration in the study area, particularly in the centre of the peatland about 3 m from the edge of dry ground. A three-axis sonic anemometer was installed to measure the velocity of the wind and a gas analyser to measure evapotranspiration (LI 7500, LI-COR). Data from a 10 Hz raw data machine were corrected for fluxes in evapotranspiration. Thermocouples were used to gage the air temperature and air pressure with a humidity-temperature probe (Vaisala HMP155) to measure RH. Net radiometers (CNR4, Kipp and Zonen, Delft, the Netherlands) were used to derive R_n . A gratuity-pail rain measure (TR-525USW, Texas Electronics, Texas, USA) was based on an extreme rainfall event.

Other environmental variables measured included soil temperature (T_s) at depths of 5, 10, and 20 cm and soil water content (SWC) using a Delta-T device (Delta-TML2x, Cambridge, UK). The sensors recorded the data every 15 sec and averaged them every 30 min with a data logger (CR3000-XT, Campbell Scientific, USA); the data were retrieved using a removable USB device.

An Eddy covariance gas analyser (LI-COR7500) was used to measure evapotranspiration between the atmosphere and the vegetation. The software for the machine, Eddy Pro version 5.2.1, was used to analysis and gage the ET data (Alfadhel et al., 2019).

2.3 Eddy flux data and gap filling

During sampling, the sensing element in the eddy covariance device failed due to weather conditions and compromised our results. The half-hour evapotranspiration data were gaged by eddy covariance using the meteorological sensor on the station's tower. Overall, the gap filled around one 25th of the absence data during the research period (Falge et al., 2001).

3 Data analysis

Variations in the data were calculated based on 30 min averages of observations made at 15 sec intervals. Evapotranspiration data distinguished two distinct patterns in ET correlated with seasonal changes in the atmosphere (growing and non-growing) in the peatland ecosystem for the period of the study (two years). Daily and seasonal variations

in evapotranspiration were analysed. To gauge the regulation of evapotranspiration at daily and seasonal levels, the correlation between evapotranspiration and environmental factors were analysed.

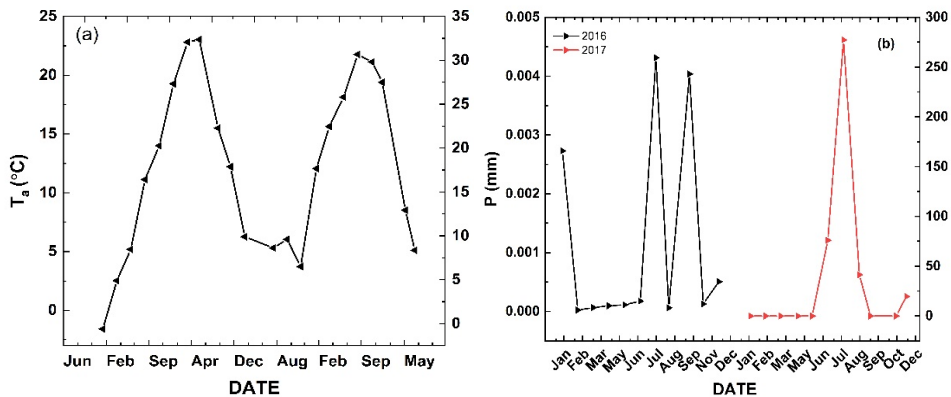
Evapotranspiration data were reworked using the standard deviation whereby variables were modified by means to avoid large variations and gaps in the original data (Sun et al., 2018). The data were analysed using Microsoft Excel 2016 and Origin Pro 2018 for fitting the figures.

4 Results and discussion

4.1 Variations in air temperature and precipitation

Two different patterns in time, were identified in the data depending on plant growth activity and the general physical state of the wetlands: the first pattern or phase was seasonal from early May through August, with the period between July and the end of August being the peak evaporation rising season (Alfadhel et al., 2019). The peak air temperature was 23°C in August 2016, whilst the coldest value of T_a was -1.5°C in January 2016 [Figure 1(a)]. The Max variation in precipitation was less than 277 mm in mid-July 2017 and the Min was 0.0027 mm in January 2016 [Figure 1(b)], with a climate of wet summers and cold dry winters. The annual precipitation was 19 mm during the study period, and the identical mean annual air temperature (MAAT) was 12.1°C.

Figure 1 Seasonal variation of (a) air temperature (b) precipitation from January of 2016 till December 2017 (see online version for colours)

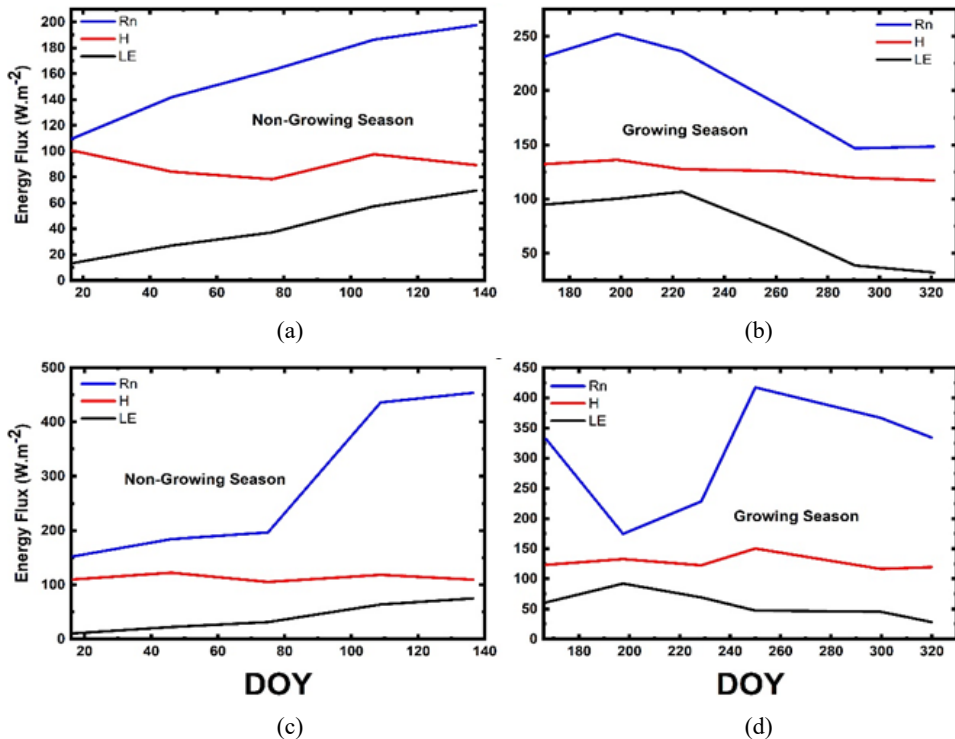


4.2 Patterns of energy flux

The study area was characterised by different patterns of energy flux, depending on daily and seasonal variations which demonstrated that the energy flux has a large effect on growing season (Figure 2). These results agree with previous research by Liljedahl et al. (2011) in Arctic coastal wetlands between 1999 and 2003 and explain the seasonal and inter-annual variations in midday energy partitioning across the 'thaw' season, suggesting a consistent partitioning of variations in energy factors. Figure 2(a) illustrates a stable increase in values of LE and Rn but limited increase in H from day 1 of the year (DOY 1)

in the non-growing season 2016 to DOY 140 in the same season. Daily variations in LE during the non-growing seasons showed the lowest value (10 W.m^2) in January 2017 [Figure 2(c)], and the peak value was 106 W.m^2 which occurred in August 2016 during the growing season [Figure 2(b)]. A report of results similar to these results in a marsh in north-east China showed the highest value was 30 W.m^2 during the growing season (Zhou and Zhou, 2009). The H was 58 W.m^2 (the highest) in September 2017 [Figure 2(d)], and the lowest value was 21.4 W.m^2 in October 2016 [Figure 2(b)] which is consistent with previous research showing that H is closely related to the development and senescence of the plant canopy and was lowest in January through March before canopy development (Goulden et al., 2007). The peak of Rn loss was 369 W.m^2 in the growing season of 2017 and the lowest was 33.6 W.m^2 in January 2017 [Figures 2(c) and 2(d)]. Siedlecki et al. (2016) demonstrated that the loss of available radiation energy ranged from 30% in March and April to 60% in July and August in wetlands of Biebrza Valley, Poland.

Figure 2 Daily variation of latent heat flux, sensible heat flux and net radiation from January of 2016 till December 2017 (see online version for colours)



4.3 Evapotranspiration

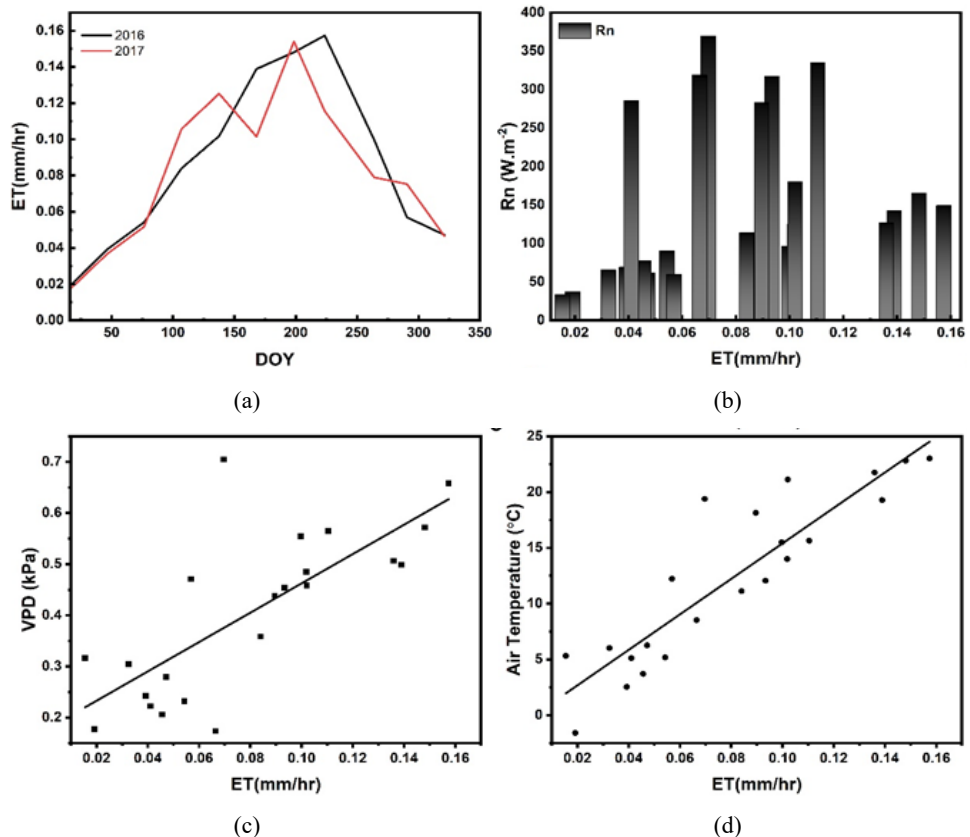
Evapotranspiration showed a daily significant during the growing stage for the two-year period and was extremely dependent upon air temperature. Figure 3(d) illustrates the relationship between evapotranspiration and air temperature during the study period. The annual value of evapotranspiration in the first year was 0.09 mm/hr (Table 1) and the

second year was 0.07 mm/hr (Table 1). The highest value of evapotranspiration within the first growing season occurred on DOY 223. During the second growing season, there was a clear increase in the daily values of evapotranspiration on DOY 179 [Figure 3(a)] which faded by DOY 264, and reached its lowest value of 0.015 mm/hr from DOY 16 [Figure 3(a)] through the end of the rainy season. Siedlecki et al. (2016) agreed that in the wetlands of Biebrza Valley, the maximum evapotranspiration was observed during hot sunny weather, whereas low daily totals were associated with cloudy weather and advection of cold air masses.

Table 1 The highest and lowest value of evapotranspiration and the annual for two years from January of 2016 till December 2017

Evapotranspiration(mm/hr)	2016	2017
Growing season	0.157	0.135
Non-growing season	0.054	0.045
Annual	0.093	0.077

Figure 3 Variation during growing and non-growing seasons from January of 2016 till December 2017 of (a) daily evapotranspiration, (b) correlation between net radiation and evapotranspiration, (c) correlation between vapour pressure deficit and evapotranspiration, (d) correlation between air temperature and evapotranspiration and the bar is 1:1 (see online version for colours)



Furthermore, evapotranspiration occurs because of the time lag in peak Rn [Figure 3(b)], which results from a higher vapour pressure deficit (VPD). Meteorological variables were monitored for seasonal variations in evapotranspiration and the peak occurred when Rn was 149 W.m^{-2} (Sumner et al., 2012). Another study in Arctic coastal wetlands demonstrated that Rn was the primary control in evapotranspiration and measurements showed quite large variability over the short term in mid-summer (Liljedahl et al., 2011). The VPD in our study showed a significant positive correlation with evapotranspiration. Figure 3(c) illustrates the stable increase in evapotranspiration with variations in VPD, and the lowest value was 0.02 mm/hr when VPD was 0.17 kPa and the peak of evapotranspiration was 0.16 mm/hr when VPD was 0.65 kPa because of the available energy that affects the daily rate. A previous investigate by Cao et al. (2020) were consistent with this research and showed that VPD played a significant role in monthly evapotranspiration and explained at least 80% of the variance in monthly evapotranspiration.

Overall, the annual rate of evapotranspiration was 95% in the first year and 80% in the second year. A previous study presented similar results in Arctic coastal wetlands in 2011 and the average evapotranspiration rate was only 75% of the potential evapotranspiration rate (Liljedahl et al., 2011).

Figure 4 Variation from January of 2016 till December 2017 for (a) daily variation of evapotranspiration with precipitation of 2016 and (b) daily variation of evapotranspiration with precipitation for the 2017 (see online version for colours)

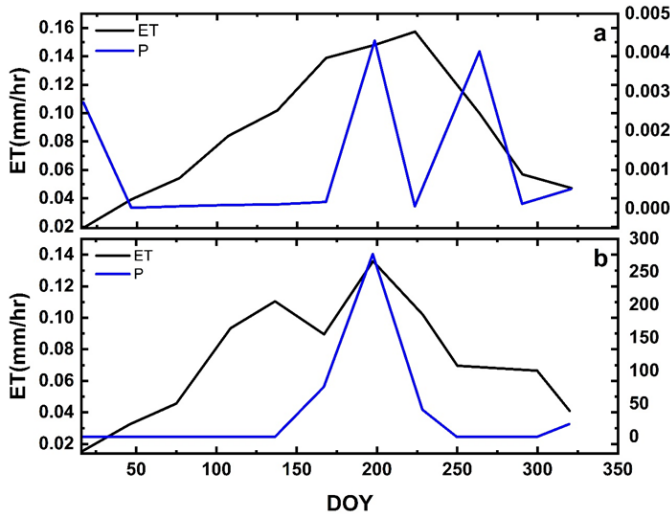
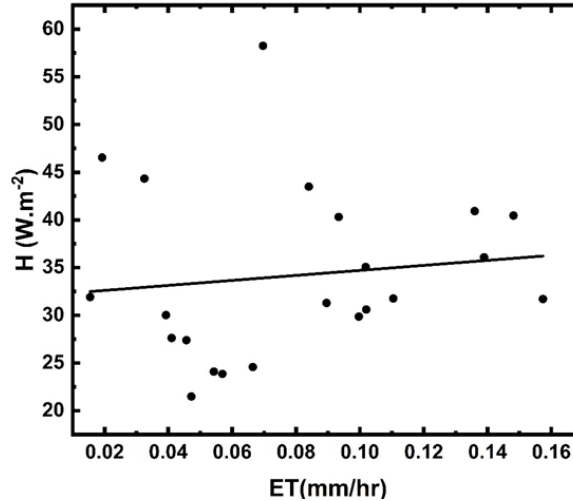


Figure 4 shows a weak but statistically significant relationship between evapotranspiration and precipitation. The data showed that evapotranspiration increased with precipitation during the non-growing season in the first year [Figure 4(a)]. In contrast, Figure 4(b) shows an increased in evapotranspiration with precipitation in the growing season for the second year and the positive relationship diminished. These results contrast with research in the upper reach of Jialing River, Sichuan Province, south-west China by Smith et al. (2020) shown over the whole study period, the annual evapotranspiration was found to have a nonsignificant relationship with annual precipitation.

Based on Figure 5 illustrated an increase in H affects variations in evapotranspiration. These results are consistent with a study in a restored marsh in the Sacramento-San Joaquin Delta, California, USA by Drexler et al. (2008) which showed that evapotranspiration in 2003 was high during the summer because of a greater contribution of sensible heat flux.

Figure 5 The relationship between evapotranspiration and sensible heat flux during the two years from January 2016 until December 2017 the bar is 1:1 (see online version for colours)



Mean evapotranspiration rates in peatlands studied in different wetlands changed depending on the methodology, sampling frequency, and vegetation type (Acreman et al., 2003; Goulden et al., 2007). Overall, evapotranspiration is small outside the growing season, and the cumulative evapotranspiration during this period was mean ($\pm$ SE) 0.07 ± 0.04 mm/hr.

4.4 Environmental factors control evapotranspiration

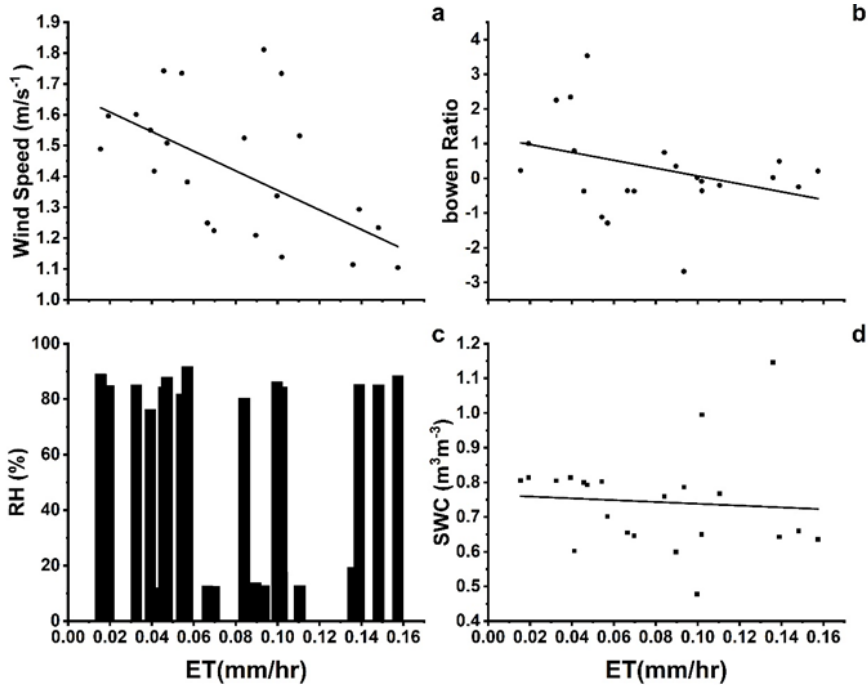
Evapotranspiration is affected by wind speed which had a negative relationship with evapotranspiration during the study period. Maximum wind speed was 1.8 m.s^{-1} and the minimum was 1.1 m.s^{-1} (Table 2). According to the data [Figure 6(a)], the highest value of evapotranspiration was 0.16 mm/hr when wind speed was at its lowest value of 1.1 m.s^{-1} due to its effect on stomatal function. A report by Lu et al. (2020) demonstrated that the major factors that correlated negatively with evapotranspiration in the Genhe River Basin in China included wind speed. The highest Bowen ratio was 3.5 when evapotranspiration was 0.04 mm/hr (Table 2), and the lowest was -2.6 when evapotranspiration was 0.09 mm/hr [Figure 6(b)] and there was no correlation between evapotranspiration and the Bowen ratio. Siedlecki et al. (2016) demonstrated that the average Bowen ratio in summer months reached levels of 3–3.5, characteristic of evapotranspiration in other wetlands (e.g., Europe, Canada, and Siberia). Figure 6(c) illustrated a correlation between RH and ET. RH has increased with ET and the Max value of RH with the Min value was 88–71% during the study period. Smith et al. (2020) in riparian wetland rehabilitation sites east of Berlin (in Brandenburg, Germany) showed

that the annual RH remained near 80%. Evapotranspiration showed a correlation with SWC as shown in Figure 6(d), with a maximum SWC of $1.1 \text{ m}^3\text{m}^{-3}$ and a minimum value of $0.5 \text{ m}^3\text{m}^{-3}$ (Table 2). A previous study demonstrated that, in Arctic coastal wetlands, the soils displayed a statistically significant trend in summer 2003 and 2007; apparently, the reduced SWC suppressed evapotranspiration (Liljedahl et al., 2011).

Table 2 The maximum and minimum of wind speed, bowen ratio, RH and SWC during two years from January of 2016 till December 2017

Factor	Maximum	Minimum
Wind speed (m.s^{-1})	1.8	1.1
Bowen ratio	3.5	-2.6
RH (%)	88	71
SWC (m^3m^{-3})	1.1	0.5

Figure 6 The relationship between evapotranspiration and (a) wind speed (b) bowen ratio (c) related humidity and (d) soil water content during two years from January 2016 until December 2017 the bar is 1:1



5 Conclusions

The eddy covariance technique was used to determine the effect of environmental factors on evapotranspiration in a peatland ecosystem in Central China. The average rate of evapotranspiration during the study period (January 2016 through December 2017) was 80–95% of the water input into the system each year evaporates. The rate of

evapotranspiration corresponded to seasonal variations throughout the year. The evapotranspiration increased in summer time due to active growth of vegetation which peaked in August 2016 on DOY 223. The VPD and T_a primarily controlled seasonal variations in evapotranspiration. The results reveal how environmental variables affect evapotranspiration in a peatland ecosystem in Central China. Future long-term studies will help to illuminate our understanding of how these factors impact evapotranspiration in other peatland ecosystems and wetlands in general in the face of climate change.

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