Evapotranspiration change under Short-term Experimental Warming in a Swamp Meadow Ecosystem of the Qinghai-Tibet plateau

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Abstract: The impact of climate change on the cold region ecosystem is deepening, especially in the Qinghai-Tibet plateau(QTP), with its impacts on the water cycle. Evapotranspiration (ET), as an important part of the hydrological cycle in terrestrial ecosystems. Thus, we analyzed the influence of experimental warming on ET through observed data of 2008 under two open top chambers (OTC-1 and OTC-2) plots and ambient air (Control) plot. The study showed that the potential and actual ET of OTCs were higher than that of Control, due to increase in vapor pressure deficit, warmer air temperature, increase in ground surface soil moisture and temperature compared to the outside. ET is largest component of water loss from alpine ecosystem, accounted for 74.6% of the annual total precipitation. Elevated CO_2 concentration had no significantly affected at ET rate in our study. The results will be helpful for future climate change study in the QTP.

1. Introduction

The impact of climate change on the cold region ecosystem is deepening, especially in the Qinghai-Tibet plateau(QTP). [1,2]In addition, climate warming significantly influences the stability of the alpine swamp meadow ecosystem.[3]Evapotranspiration (ET), reflects the dry and wet condition of the eco system, as an important part of the hydrological cycle in terrestrial ecosystems, have a huge impact on the local climate and even the global water cycle, and directly determines how much water dissipated in the ecosystem. [4] Therefore, quantifying the ET change under climate change is important for upstanding the impact of global climate change on water budgets in the cold regions. [5]

Fei et al. conducted a field experiment to investigate infrared radiation experiment warming on ET in an alpine meadow ecosystem in the QTP,[6] results showed that annual ET enhanced with the increase of air temperature and plant transpiration accounted for most of the ET change due to soil surface drying. Sorokin et al. conducted chambers experiment with elevating CO_2concentration in a semi-arid grassland,[7] results showed that there had no significant differences in ET during the growing season. Zhang et al. suggested that ET are projected to increase under climate warming but vary across different ecosystems.[8]

However, rare studies focus on the ET change under experimental warming in the swamp meadow ecosystem, especially in QTP, due to poor test environment and shortage of observation. The purpose of this study was to clarify the ET change and its impact factors under experimental warming in a swamp meadow ecosystem in the QTP.

2. Materials and Methods

2.1. Site description
The study site located in the Fenghuoshan Watershed(92°50'-93°3' E and 34°40'-34°48' N), a tributary of the Yangtze River, with typical swamp meadow ecosystem, was chosen for study. [9]The alpine swamp meadows accounted for a large proportion of the main vegetation type in the QTP. [10]As shown in Table 1, the main soil type is swamp meadow soil, and the parent material is mostly quaternary sediment).[9]

Table 1. Soil property in different manipulations plots of the swamp meadow ecosystem

Soil profile /cm	Bulk density /mg.cm^{-3}	Granularity >0.05 mm /%	Granularity <0.002 mm /%	Organic matter /%	Available nitrogen /g.kg^{-1}
0-10	0.83(±0.11)	47.77	11.55	8.75(±2.2)	112(±7.6)
10-20	0.94(±0.21)	50.94	11.58	4.32(±1.3)	97(±4.4)
20-30	1.19(±0.12)	47.96	12.94	2.46(±2.1)	23(±5.3)

2.2. Methodology
The open-top chamber (OTC),used by the International Tundra Experiment (ITEX) for experimental warming study in the high altitude and latitude region. [11] There have no significant differences ($p>0.4$) of vegetation coverage (90%) and soil property between the three experimental plots (Table1).

The materials of OTC were PMMA fiber. The structure of OTC presented the cube structure(1.5 m × 1.5 m × 1.7 m height). OTC-1 plot, with a partial closed top chamber, have a 0.6 m diameter hole on the top, which was used by Havstrom *et al*. in Abisko and Svalbard. [12] OTC-2 plot, with a complete open top, represents a traditional OTC. Control plot, keeping the original stage, was taken as an outdoor control group.

In the three plots, temperature sensors and moisture probes were placed to observe soil temperature and moisture at 5 cm and 20 cm depth, respectively. In the OTCs, the thermal and hygrometer sensors was installed to measure air temperature and relative humidity. The probes and sensors were connected to Campbell CR1000 dataloger (Campbell Scientific Ltd., USA).The meteorological data was obtained from a standard meteorological station, situated near the experiment plots. The observed data was collected in one-year period of 2008.

The lysimeter method was used to observe actual ET of alpine meadow under 92% vegetation coverage near the experiment plots. The CO_2concentration of the atmosphere under OTCs and Control were also observed using CO_2 sensor (Veisala GMT222, Finland) in the growth season from May 1st, 2008 to September 29th, 2008.

The Penman-Monteith equation is used to calculate the ET rates under different manipulations. [13]

3. Results and discussion

3.1. Microclimate

3.1.1. Precipitation and topsoil moisture. The total precipitation of 2008 was 490.1mm and the precipitation of rainy-warm season from May to September accounted for 87.4% of the total precipitation. During early spring and winter, only several rainfall events occurred with rainfall less than 3mm (Figure 1). Soil moisture at 5 and 20cm depth was related to precipitation. The response of soil moisture to precipitation and the response time of OTCs and the control were almost identical to each other. The fluctuation cycle of OTCs was slightly larger than Control and the rainfall replenishment was slightly higher than the Control at 5cm depth. They may account for higher surface moisture in OTCs.

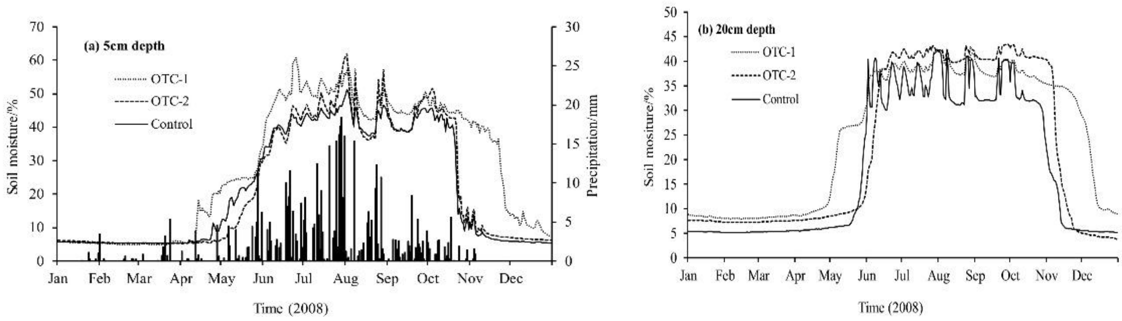

Figure 1. Annual variations of precipitation, soil moisture at 5 and 20cm depth under Control and OTCs warm treatments

3.1.2. Air temperature and soil temperature in 5 cm depth. Annual mean air temperatures of OTC-1 and OTC-2 were 6.70℃ and3.48℃warmer than the Control, respectively (Figure 2a). Kimballand Marion reported that the air would be warmer than outside about 6℃ under the full sun, roughly equal to the OTC-1. [14,15] due to generally transpiring rate, [16] as this is the case with OTC-2.

As shown in Figure 3b, the annual mean soil temperature of Control, OTC-2, and OTC-1 were -1.71℃, -1.64℃ and -0.05℃ in 5cm depth, respectively. The annual mean soil temperature of OTCs was warmer than Control in all periods.

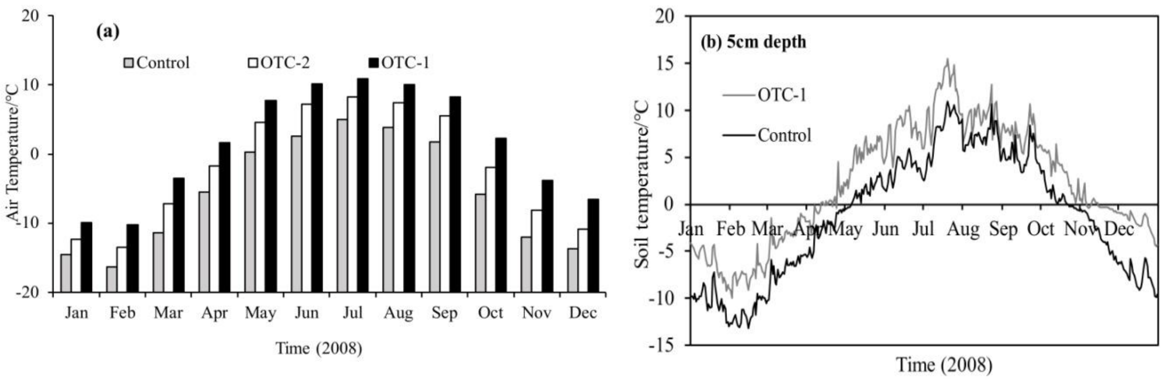

Figure 2. Monthlyvariations of air temperature (a) and annual variation soil temperature in 5 cm depth (b)under different manipulations.

3.1.3. Relative humidity and air vapor pressure. Annual mean relative humidity of OTCs was less than Control (Figure 3a).Marion also suggested that there had a universality lower relative humidity inside chambers. [15] This is due to the increasing in air vapor pressure caused by air warming.

Annual mean actual air vapor pressure of OTC-1 and OTC-2 were 41% and 16%larger than that of Control (Figure 3b), respectively. Weinstock found that the air vapor pressure in OTC is about 14% higher than the outside, [17] which is the case with OTC-2. We suppose that the higher air vapor pressure in OTC-1 can be attributed to its higher air temperature and comparably low water vapor passing through the chamber in a relatively enclosed space.

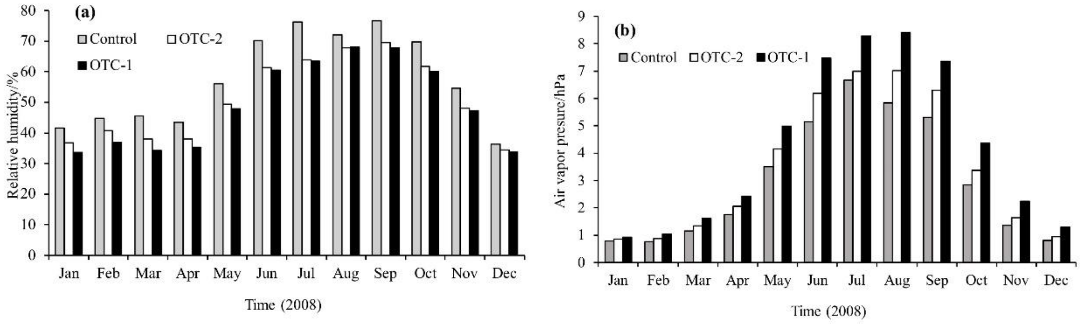

Figure 3. Distribution of Relative humidity (a), air vapor pressure (b) under different manipulations.

3.2 Potential evapotranspiration

More measurements on the fluxes of net radiation, soil heat flux, wind speed, and other environmental factors in OTCs and Control would be helpful to estimate evapotranspiration more accurately. However, that would not be practical, since they were costlier and would disturb the environment in OTCs. Therefore, the meteorological factors measured in a standard meteorological station near the experiment plots were adopted for replacing some environmental meteorological elements of the OTCs.

The calculated potential evapotranspiration (ET_p) using PM-equation under OTCs and Control is shown in Figure 4. The annual potential evapotranspiration of Control, OTC-2 and OTC-1 were 688.0, 785.6 and 811.6mm, respectively. The maximum potential ET of OTC-1, OTC-2 and Control were 74.1, 87.3 and 92.9 mm, respectively, all appearing in June. Meanwhile, the minimum ET of OTC-1, OTC-2 and Control were 34.4, 39.5 and 43.1 mm, respectively, all appearing in February.

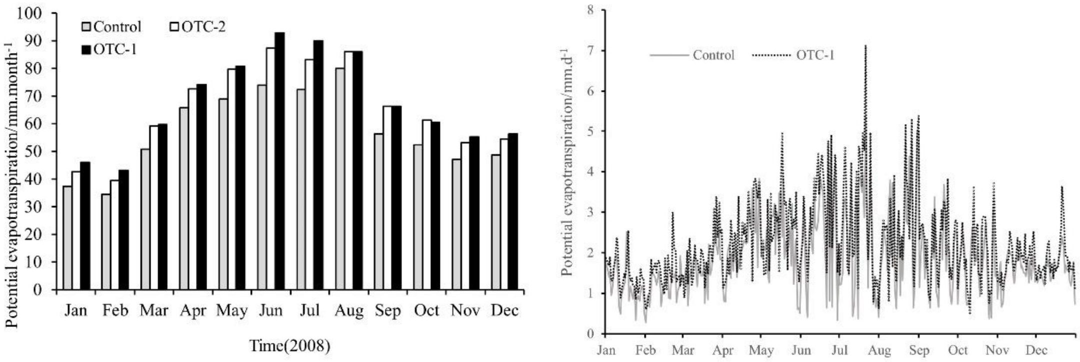

Figure 4. Annual variation of potential evapotranspiration under different manipulations.

3.3 The relationship between actual ET, water surface evaporation and potential ET

The lysimeter method is used to observe actual ET of alpine meadow under 92% vegetation cover plot near the experiment plot. The total actual ET (ET_a) under 92% coverage of 2008 was 365.6 mm (Figure 6a), approximated to be the actual ET of Control.

The Penman hypothesis is a common method to reduce potential ET to actual ET in response to the water availability, given by a function of soil water stress and vegetation conditions.[13] The formula is $ET_a=f_c\times ET_p$, where f_c is soil water supply capacity and vegetation coefficient. Therefore, the relationship between the actual ET and potential ET is compared in the Control plot (Figure 6b). The annual actual ET is about 0.54 times of the potential ET and the f_c is 0.54. Although there is no observed data under OTCs manipulations, based on the $f_c$of the Control, the actual ET of OTCs could be preliminary estimated. The actual ET of OTC-2 and OTC-1 were approximately 424.4 mm and 438.2 mm.

Water surface evaporation (E_{ws}) is an important index to measure the evaporation capacity of land surface and is an indispensable factor in the study of regional water balance and water circulation. In addition, water surface evaporation, is an indicator of potential evaporation. The relationship of potential ET and water surface evaporation was shown in Figure 6c, and the regression equation is proposed.

$$ET_p=0.44E_{ws}+0.39 \quad (1)$$

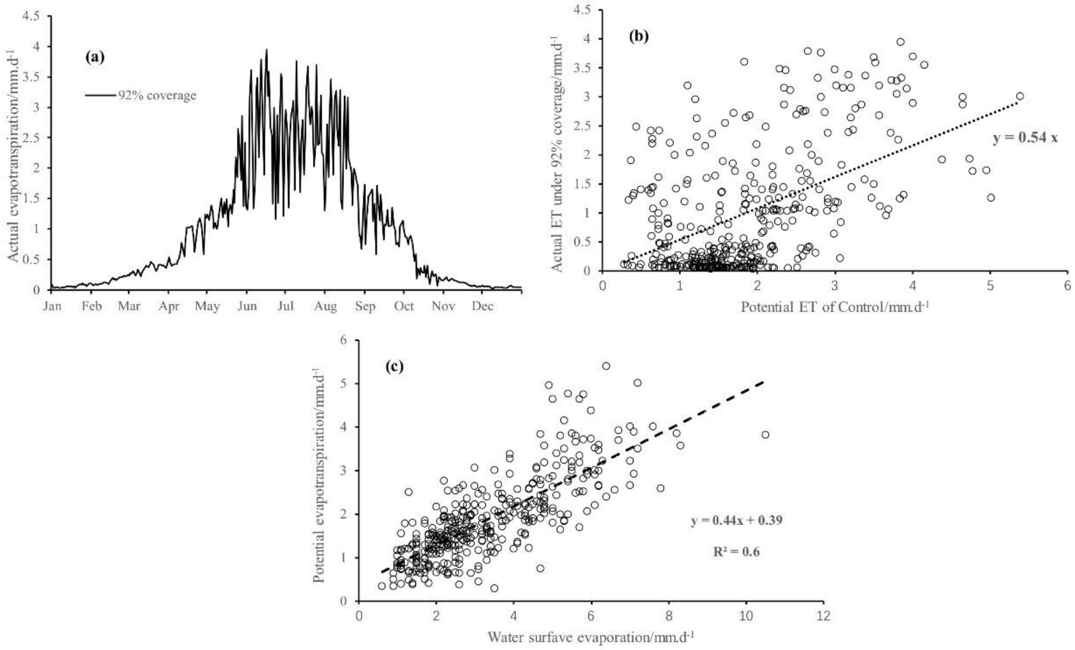

Figure 5. Annual variation of actual evapotranspiration under 92% coverage (a) which is similar with Control Plot, and the relationship between actual ET under 92% coverage and potential ET of Control plot (b), and the relationship between potential ET of Control plot and water surface (pan) evaporation.

4. Discussion

4.1 The ET change response to experimental warming

The ET change under experiment warming depends on air temperature, relative humidity, stomatal conductance, soil moisture, and plant phenology. [6]The observed actual ET (365.6 mm under 93% coverage, similar with Control) was higher than the study in an alpine meadow ecosystem of QTP (311 mm), [6] where annual precipitation (318 mm) is much lower. Our study confirmed that ET is maximum component of water loss from swamp meadow ecosystem, [18] accounted for 74.6% of the annual total precipitation of our study (490.1 mm). ET was assumed to increase under climatic warming in mountainous regions, which is consistent with the results of this study. As shown in Figure 7, the increasing in ET could be explained by increase in vapor pressure deficit(VPD), due to which is positively correlated with ET. [6] The 14.2% and 17.9% increase in actual ET of OTC-2 and OTC-1 with 3.48℃ and 6.7℃ experimental warming were lower than relative ET increase (29.8%) with 3.19℃ experimental warming in an alpine meadow ecosystem. As the air temperature increase, it is expected that near surface air should be drier, which would result in increasing in evaporation rate from ground surface.

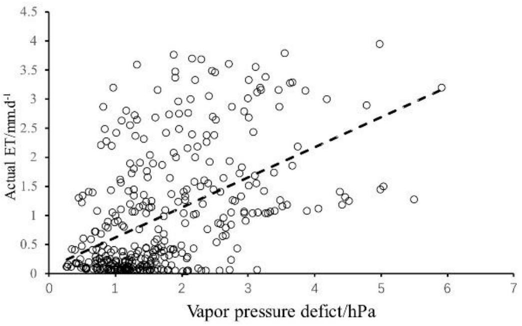

Figure 6. The relationship between actual ET under 92% coverage and VPD

4.2 The effect of CO_2 concentrations on ET

As shown in Figure 8, the CO_2 concentrations inside the OCTs are found to be slightly larger than outside, [15] because air movement inside OTCs was less than outside, resulting in CO_2 accumulation in OTCs. High CO_2 concentration and high temperature made ET increase in high（55% ~ 65% field water capacity）soil moisture regimes, which similar with the swamp meadow system(Figure 2).Costa and Foley reported that ET decreased by 2.8% in a doubling CO_2 concentrations experiment. [21] The OTC conditions favor growth of vegetation, which would prompt the plant transpiration. In general, elevated CO_2 concentration and temperature had not significantly affected at ET rate in our study.

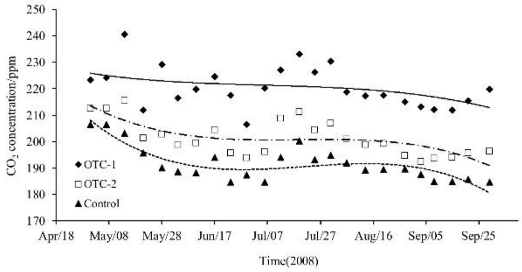

Figure 7. Distribution of CO_2 concentrations under different manipulations.

5. Conclusions

This study describes the evapotranspiration change and its impact factors under experimental warming in a swamp meadow ecosystem in the QTP. The results showed that annual mean air temperatures of OTCs were warmer than the Control， and a universality lower relative humidity inside chambers. The annual mean potential ET of Control, OTC-2 and OTC-1 were 688.0 , 785.6 and 811.6 mm, respectively. The total actual ET wereapproximately365.6 mm, 424.4 mm and 438.2 mm under Control, OTC-2 and OTC-1 manipulations.ET is largest component of water loss from alpine ecosystem, accounted for 74.6% of the annual total precipitation.

The increasing in ET could be explained by increase in vapor pressure deficit(VPD), due to which is positively correlated with ET. Elevated CO_2 concentration and temperature had not significantly affected at ET rate in our study. The increasing in ground surface soil moisture and temperature might reinforce the positive effect on ET.

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