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Effects of Climatic Change on Evapotranspiration in Zhalong Wetland, Northeast China

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Abstract: Evapotranspiration (*ET*) process of plants is controlled by several factors. Besides the physiological factors of plants, height, density, LAI (leaf area index), etc., the change of meteorological factors, such as radiation, temperature, wind and precipitation, can influence *ET* process evidently, thus remodeling the spatial and temporal distribution of ET. In order to illuminate the effects of meteorological factors on wetland *ET*, the *ET* of Zhalong Wetland was calculated from 1961 to 2000, the statistical relationships (models) between *ET* and maximum temperature (T_{max}), minimum temperature (T_{min}), precipitation (*P*) and wind speed at 2m height (U_2) were established, and the sensitivity analysis of the variables in the model was performed. The results show that T_{max} and T_{min} are two dominating factors that influence ET markedly, and the difference of rising rate between T_{max} and T_{min} determines the change trend of *ET*. With the climatic scenarios of four General Circulation Models (GCMs), the ET from 2001 to 2060 was predicted by the statistical model. Compared to the period of 1961-2000, the water consumption by ET will increase greatly in the future. According to the scenarios, the rise of T_{max} (about 1.5℃ to 3.3℃) and T_{min} (about 1.7℃ to 3.5℃) will cause an additional water consumption of 14.0%-17.8% for reed swamp. The ecological water demand in Zhalong Wetland will become more severe.
Keywords: climate change; evapotranspiration; General Circulation Model; Zhalong Wetland

1 Introduction

As a result of persistent increase in carbon dioxide in the atmosphere since the 1950s, global and regional climate features, such as temperature and precipitation, have obviously changed (Yu et al., 2002). The General Circulation Models (GCMs) provide potential climate scenarios by studying the effects of carbon dioxide on the temperature. Tickell (1993) predicted that the mean temperature will increase by 1℃ till the year 2050 and by 3℃ at the end of the 22th century. Some researches demonstrated that the temperature will increase by 1.5℃ to 4.5℃ when the content of carbon dioxide in atmosphere is doubled (Houghton et al., 1990). Although different GCMs give dissimilar predictions, the temperature is undoubtedly in the increasing trend. The impacts on hydrological processes and water resources brought from climate change have received much attention (Gleick, 1986; Burn, 1994). A considerable amount of works have been devoted to the research on the effects of climate change on the water resources system and crop water demand. Herrington (1996) analyzed the impacts of climate change on water demand in England and Wales, and came to the conclusion that about 1.1℃ rise in temperature will increase water demand for agriculture by 12%. Yu et al. (2002) studied the change trend of evapotranspiration (*ET*) from paddy fields in the southern Taiwan under two climatic scenarios, i.e., linear extrapolation of climatic trends and the predictions of GCMs. Liu and Lin (2004) proposed the change trend of the main crops in North China by using supposed climatic scenarios and the predicted climatic variables of Hadley model. Although many studies revealed that the irrigation water is particularly sensitive to the changes in temperature, they failed to discuss the inherent relationship between the temperature and the crop's demand for water, for example, why does the temperature increase in a period when the crop's demand for water decreases?

In wetland environment, ET of major aquatic plants is usually needed to be evaluated in water resources management to provide optimum water for wetland. Reed swamp is a typical underlying type of Zhalong Wetland, and is also the critical living condition for aquatic birds, such as crane and swan. In order to study the rules of ET change in wetland, and make scientific prediction for ET water requirement during different periods, a statistical model of *ET* and meteorological factors in wetland is established based on meteorological data from 1961 to 2000. By using this model, the *ET* from 2001 to 2060 is predicted with the GCMs climatic scenarios. Subsequently, it is concluded that the maximum temperature (T_{max}) and the minimum temperature (T_{min}) are two dominant variables to *ET* and the asymmetrical change of T_{max} and T_{min} determine the ET trend, and the confusion

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paradox mentioned above is made clear in reason.

2 Data and Methods

2.1 Study site

Zhalong Wetland (46°48′-47°31.5′N, 123°51.5′-124°37.5′E) (Fig. 1) was selected as study site, which lies in the north of Songnen Plain in Heilongjiang Province, Northeast China. This area includes reed swamps, open water and degenerative grasslands. The mean annual precipitation in the study site is 426mm, which mainly concentrates in July-September, and the normal annual evaporation from water nearly 900mm. Thus, it belongs to the typical semi-arid region. The water entering into the wetland is greatly declined in the recent years because of increasing agricultural and industrial water demands in surrounding areas. The main water loss in common years is due to evapotranspiration, except in 1998, in which year an extra flood made an excess water loss by runoff.

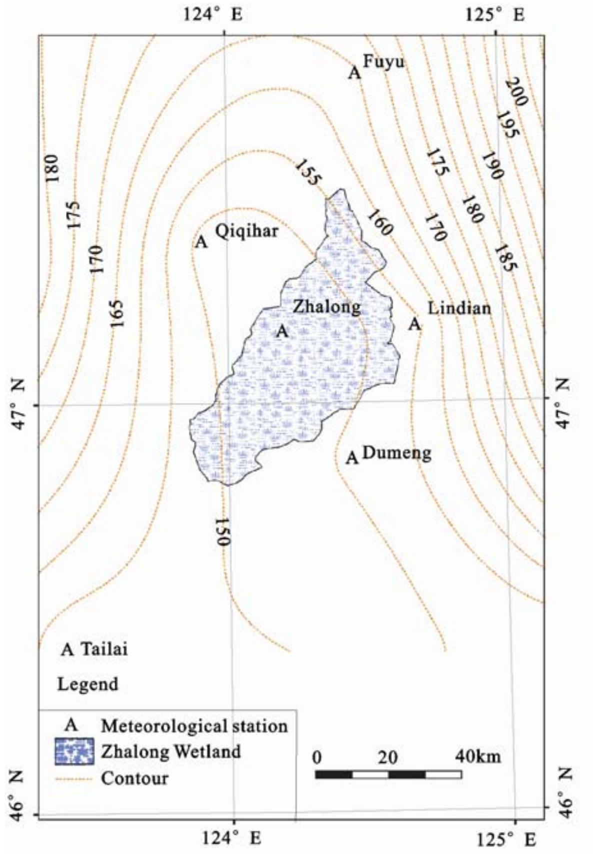

Fig. 1 Location of study area and meteorological stations in and around Zhalong Wetland

2.2 Data sources

In this study, meteorological data were collected from Zhalong Wetland meteorological station, which was established in July 2002, and five stations around the wetland (Fig. 1). The meteorological data include monthly T_{max}, T_{min}, P (precipitation), and U_2 (wind speed at 2m height) in 2002-2005 from Zhalong wetland station and in 1961-2000 from five neighboring stations. They were used to analyze the relationship between ET and meteorological variables in this study. The study results of climatic scenario, predictions of General Circulation Models (GCMs) from Intergovernmental Panel on Climate Change (IPCC), were taken to predict the future ET in the period of 2001-2060, and the change trend of ET with climate change was also analyzed.

2.3 Methods

2.3.1 Mann-Kendall test for meteorological factors

For the reason that no meteorological data was obtained in Zhalong Wetland before July 2002, a long series of data set from five stations around the wetland were used to interpolate the average values within the wetland. By analyzing 34-month values from August 2002 to May 2005, significant linear relationship between the interpolated values and recorded value of Zhalong Wetland was found. For the significance level $\alpha = 0.05$, the test statistics of *F*-test and *R*-test are both larger than the critical values, $f_{(1,n-2,1-\alpha)}$ and $r_{(n-2,1-\alpha/2)}$ (Table 1).

Table 1 Linear equations and their reliability tests

	Linear equation	*F-test*	$f_{(1,32,0.95)}$	$\lvert R \rvert$-test	$r_{(32, 0.975)}$
T_{max}	$T_{max(1)} = 0.92T_{max(2)} + 2.51$	23768	4.15	0.999	0.34
T_{min}	$T_{min(1)} = 0.94T_{min(2)} + 1.44$	16582	4.15	0.999	0.34
P	$P_{(1)} = 0.83P_{(2)} + 4.98$	64.5	4.15	0.818	0.34
U_2	$U_{2(1)} = 0.79U_{2(2)} + 0.76$	352.6	4.15	0.957	0.34

Notes: (1) presents interploted value; (2) recorded value

It means that the interpolated values and Zhalong's recorded values show substantial linear relation, and the interpolated values can represent the meteorological factors of wetland credibly.

Mann-Kendall (M-K) test, suggested by Zbigniew et al. in 2000, was used for meteorological factors trend detection of wetland area. It defines the standard normal variate, *T*, as Equation (1):

$$T = \frac{\gamma^*}{\sqrt{\sigma^2_{\gamma^*}}} \tag{1}$$

Where $\gamma^* = [\frac{4p}{n(n-1)}] - 1$, $\sigma^2_{\gamma^*} = \frac{2(2n+5)}{[9n(n-1)]}$, *P* is the number of pairs observations, for the samples x_i, x_j ($j>i$) in the time series, $x_j>x_i$ was calculated; n is the total number of samples for the significant level α=0.05，if $|T|>T_{\alpha/2}=1.96$, T has a trend. A positive value of T indicates an increasing trend in the time series, while a negative value indicates a decreasing trend. By the Mann-Kendall test, the historic change trend (1961-2000) of meteorological factors (T_{max}, T_{min}, U_2 and P) of wetland area is detected and then compared with climatic scenarios (2001-2060) predicted by GCMs.

2.3.2 ET calculation for reed swamp

The *ET* of Zhalong Wetland is estimated by FAO56 Penman-Monteith (P-M) method (Allen et al., 1998). The reference *ET* is calculated based on meteorological data, and is multiplied by the reed crop coefficient (K_c) to convert to actual *ET* of reed swamp.

Reed K_c, adjusted by wind speed and relative humidity, in each developing stages can be acquired in Table 2. The detail of this method is referred to Wang and Xu (2005).

Table 2 Reed K_c in different growing stages in Zhalong Wetland

Growing stage	Days of growth	K_c
Initial	1-15	1.200
Crop development	16-50	1.191
Mid-season	51-140	1.178
Late-season	141-165	1.083

The reference ET_0 is calculated by Equation (2):

$$ET_0=\frac{0.408\triangle(R_n-G)+\gamma\frac{900}{T+273}U_2(e_s-e_a)}{\triangle+\gamma(1+0.34U_2)} \quad (2)$$

ET_0— reference evapotranspiration (mm/d),
R_n — net radiation at the crop surface (MJ/(m^2·d)),
G — soil heat flux density (MJ/(m^2·d)),
T — mean daily air temperature at 2m height (℃),
U_2— wind speed at 2m height (m/s),
e_s— saturation vapor pressure (kPa),
e_a— actual vapor pressure (kPa),
e_s–e_a — saturation vapor pressure deficit (kPa),
△ — slope vapor pressure curve (kPa/℃),
γ — psychrometric constant (kPa/℃).

The calculating procedure can be seen in the literature by Allen et al. (1998).

3 Results and Discussion

3.1 Relationship between ET and meteorological variables

By analyzing the relationship between *ET* and each meteorological variable, a statistical model for estimating reference *ET* is established. The correlation coefficients (R^2) and root-mean-square error (RMSR) are chosen for evaluating the fitting to the P-M model (Equation (1)). After selecting among the meteorological variables that influence *ET* processes, the essential variables have been chosen and some collinearity variables have been removed. Through permuting and combining the essential variables and other potential variables, different combinations are introduced in various fitting expressions, finally, the one with the maximum R^2 and the minimum RMSR is selected.

The model can be expressed as:

$$ET_0=e^{(2\times10^{-2}R_a+7.01\times10^{-2}T_{max}-3.33\times10^{-2}T_{min})}\times e^{(-4.46\times10^{-4}P+1.086\times10^{-1}U_2-7.96\times10^{-1})} \quad (3)$$

where R_a is the extraterrestrial radiation (MJ/(m^2·d)); T_{max} is the mean monthly maximum temperature (℃); T_{min} is the mean monthly minimum temperature (℃); P is the total monthly precipitation (mm); U_2 is the mean monthly wind speed at 2m height (m/s).

It is proven that the empirical model reduces the demand for complicated parameters as P-M model, and the empirical model approximates P-M model in study site. Compared to P-M model, the average correlation coefficient is 0.997, the root-mean-square error is 0.101. In this study, ET prediction in future period is calculated by the empirical model.

3.2 Sensitivity analysis of meteorological factors

The change trend of reed ET is studied according to the sensitivity of each variable. The influences of T_{max} and T_{min} on the model's output are shown in Fig. 2. As demonstrated in Fig. 2, the model's output (*ET*) changes evidently with the climatic scenarios in which the temperature increases by about 1-4℃.

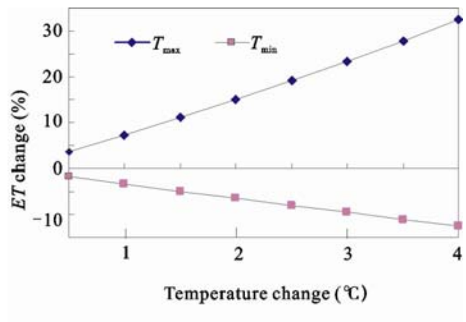

Fig. 2 Sensitivity curve of the maximum (T_{max}) and minimum (T_{min}) temperature to *E*

Figure 3 shows that the change of wind and precipitation may influence the *ET*, wind speed rises positively with *ET*, and precipitation is proven to be the least sensitive variable in the model. As a consequence, the T_{max} and T_{min} are two key factors that significantly control ET change trend.

3.3 Change trends of meteorological factors and GCMs predicted scenarios

The change trends of the four meteorological factors, T_{max}, T_{min}, U_2 and P, are detected by Mann-Kendall tests and the results are given in Table 3. The change trend of Zhalong Wetland (interpolated values) is determined by the test results of the five meteorological stations around

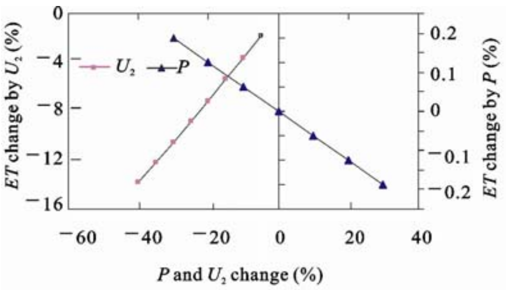

Fig. 3 Sensitivity curve of the wind speed (U_2) and precipitation (P) to ET

the wetland.

It is shown in Table 3 that T_{max} in Zhalong Wetland has non-significant rising trend; T_{min} takes on a significant rising trend; mean monthly wind speed at 2m height shows a significant decreasing trend; and total monthly precipitation shows an uncertain change trend (two stations to the west of Zhalong Wetland show increasing trend, however three stations in the east of Zhalong Wetland show decreasing trend).

The predictions of four climatic scenarios (HADCM3, CCSRNIES, CSRIO-Mk2, CGCm1) and their mean values in the coming 60 years (2001-2060) are shown in figs. 4, 5, 6 and 7 respectively. The data of the period

Table 3 Annual change trend of meteorological factors in the study region (1961–2000)

	Qiqihar	Tailai	Dumeng	Lindian	Fuyu	Zhalong Wetland
T_{max}	+ 0.116	+0.218	+0.230	+0.313	+0.259	+0.199
T_{min}	+3.E-06*	+3.E-07*	+5.E-08*	+1.E-08*	+1.E-07*	+5.6E-08*
U_2	-4.E-07*	-1.E-07*	-0.705*	-1.E-08*	-0.02*	-1.3E-06*
P	+0.74	+0.573	-0.34	-0.94	-0.14	-0.6

Notes: * a two-tailed test less than 0.025 indicates a significant tendency; +: increasing trend; -: decreasing trend

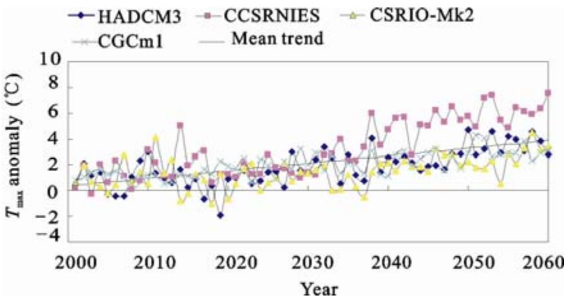

Fig. 4 Mean maximum temperature change in Zhalong Wetland

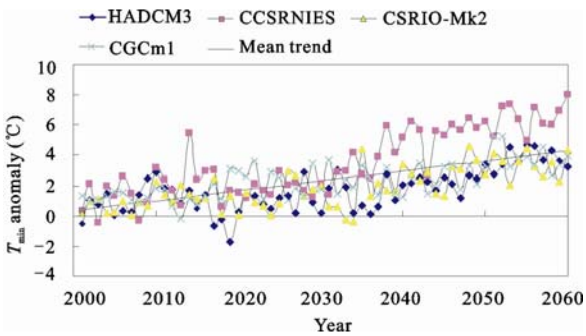

Fig. 5 Mean minimum temperature change in Zhalong Wetland

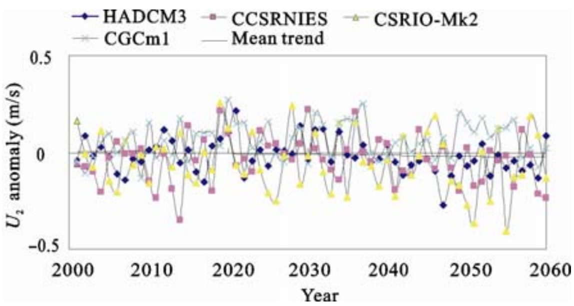

Fig. 6 Mean wind speed change in Zhalong Wetland

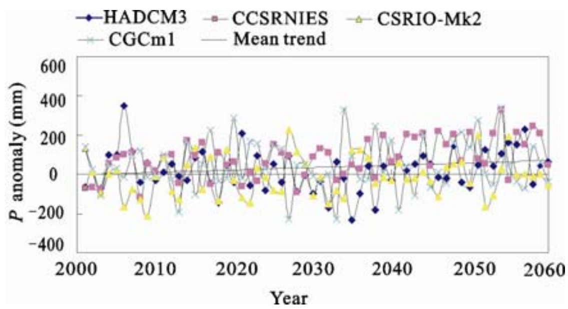

Fig. 7 Mean total precipitation change in Zhalong Wetland

2001-2060 are the change values with respect to that of 1961-2000.

It can be observed from Figs. 4, 5, 6 and 7 that T_{max} and T_{min} both show an increasing trend. According to the mean linear trends of T_{max} and T_{min}, shown in Table 4 (by F-test and R-test, the change trend of T_{max}, T_{min} can be expressed as two linear equations credibly), the trend of T_{min} is clearer than that of T_{max}, their changes show

Table 4 Linear fitting equations of T_{max}, T_{min} and their reliability tests

Linear equation	F-test	$f_{(1,58,0.95)}$	$\lvert R\rvert$-test	$r_{(32, 0.975)}$
T_{max}=0.058T-115.86	181	4.00	0.87	0.254
T_{min}=0.0654T-130.38	213	4.00	0.89	0.254

Note: T is the time series from 2001 to 2060 wind speed will decrease and annual total precipitation will increase in the future period. The predictive data issued by IPCC better reflects the actual change trend during 1961 to 2000.

3.4 Predictions of wetland ET in 2001-2060

By the empirical model, the *ET* in future 60 years is predicted. The GCMs climatic scenarios and the meteorological data are shown in Table 5, and the data are the change values with respect to that in 1961-2000.

Table 5 Mean changes of each meteorological factor and predicted evapotranspiration change in 2001-2060

	$\triangle T_{max}$ (℃)	$\triangle T_{min}$ (℃)	$\triangle U_2$ (m/s)	$\triangle P$ (mm)	$\triangle ET$ (mm)
HADCM3	1.8	1.7	-0.02	21.3	189.0
CCSRNIES	3.3	3.5	-0.04	82.6	169.9
CSIRO-Mk2	1.5	1.9	-0.05	-11.2	141.2
CGCM1	2.1	2.3	0.06	47.6	186.3
Average	2.2	2.4	-0.01	35.1	171.6

From Table 5, it can be concluded that the *ET* in Zhalong Wetland region will rise in future 60 years under all the scenarios. By the predictions of GCMs, viz. the increase in T_{max} (about 1.5℃ to 3.3℃) and T_{min} (about 1.7 ℃ to 3.5℃) will cause an additional *ET* requirement of 141mm to 189mm per year, compared to the period 1961-2000, the *ET* will increase about 14% to 17.8%.

4 Conclusions

In this study, an empirical model for reference *ET* estimating was established by statistical analysis. By sensitivity analysis, T_{max} and T_{min} are proved to be two crucial factors that significantly influence *ET* change. The M-K tests of past 40 years show that T_{min} presents significant increasing trend, however, T_{max} displays non-significant increasing trend, and their change shows asymmetry. According to Equation (2), in the periods that the rising rate of T_{min} exceeds that of T_{max} obviously, T_{min} counteracts the positive influence of T_{max} to *ET*, the *ET* can show a decreasing trend as a result, although the average temperature tends to rise in the periods. According to the GCMs climatic scenarios from IPCC, T_{max} will increase about 1.5℃ to 3.3℃ and T_{min} about 1.7℃ to 3.5℃ in the future 60 years. It will cause an increment about 14% to 17.8% for ET in Zhalong Wetland. As there is no obvious augment of precipitation (average 4.7% in wetland area by GCMs), the wetland surface will become dryer in the future due to climate change. Hence, more attention should be paid to dealing with the impact of climate change on the additional water consumption.

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References

Allen R G, Pereira L S, Raes D, 1998. Crop evapotranspiration: Guidelines for computing crop water requirements (FAO irrigation and drainage paper No.56). Rome: FAO.

Burn D H, 1994. Hydrologic effects of climatic change in the west-central Canada. *Journal of Hydrolog,* 160: 53-70.

Gleick P H, 1986. Methods for evaluating the regional hydrologic impacts of global climatic change. *Journal of Hydrology*, 88: 97-116.

Herrington P, 1996. Climate change and the demand for water resource. *Climate Change*, 37: 7-23.

Houghton J T, Jenkins G J, Ephraums J J, 1990. *IPCC: Climate Change: The IPCC Scientific Assessment*. Cambridge: Cambridge University Press.

Liu Xiaoying, Lin Erda, 2004. Impact of climate change on water requirement of main crops in North China. *Journal of Hydraulic Engineering*, 35(2): 77-87. (in Chinese)

Tickell C, 1993. Global warming and its effects. In: *Engineering for Climate Change.* UK: Inst. Civil Engineers. 9-16.

Wang Hao, Xu Shiguo, 2005. Calculation and analysis on reed swamp evapotranspiration in Zhalong Wetland. *Water Resources and Hydropower Engineering,* 36(2): 22-24. (in Chinese)

Yu P S, Yang T C, Chou C C, 2002. Effects of climate on evapotranspiration from paddy fields in southern Taiwan. *Climate Change*, 54(1-2): 165-179.

Zbigniew W Kundzewicz, Alic Robson, 2000. Detecting trend and other changes in hydrorological data. Switzerland: World Meteorogical Organization.