Comparison of historical trends of pan evaporation and modeled lake evaporation in Lake Taihu catchment

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Outline

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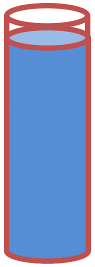


Background

- Global warming has become a worldwide indisputable fact since the late 19th century. Rising global surface temperatures are likely to increase the water holding capacity and water vapour transport in the atmosphere, which in turn cause the changes in atmospheric circulation [Menzel and Bürger 2002; Bates et al., 2008].
- However, contrary to the expectation , many studies have shown that observed pan evaporation and calculated ETr were declining in many places in the world , which is known as ‘evaporation paradox’[Peterson et al., 1995; Lawrimore and Peterson, 2000; Roderick and Farquhar,2002, Chen et al., 2005; Roderick et al.,2009].

About ‘evaporation paradox’

Most studies concluded that the decreasing trend of solar radiation and wind speeds would be the major causes, whereas temperature actually plays a lesser role. [Thomas 2000; Gong et al., 2006; Xu et al.,2006; Fan and Thomas, 2013].

Roderick and Farquhar, (2002) thought decrease in pan evaporation was consistent with the observed decrease in sunshine hours, which resulted from the increasing cloudiness or aerosols concentration (global dimming). Liu et al. (2004) suggested that the aerosol caused decrease in solar irradiance [sunshine duration (SD)] was most likely the driving force for the reduced pan evaporation in China.

As theorized by Brutsaert and Parlange [1998] that in non-humid environments, measured pan evaporation is not a good measure of potential evaporation; moreover, in many situations, decreasing pan evaporation actually provides a strong indication of increasing terrestrial evaporation. Hobbins and Ramı´rez [2004] point the solution to the paradox turns on the relation of ET_{pan} to ET_a.Depending on moisture availability in the region around the pan.

Study region

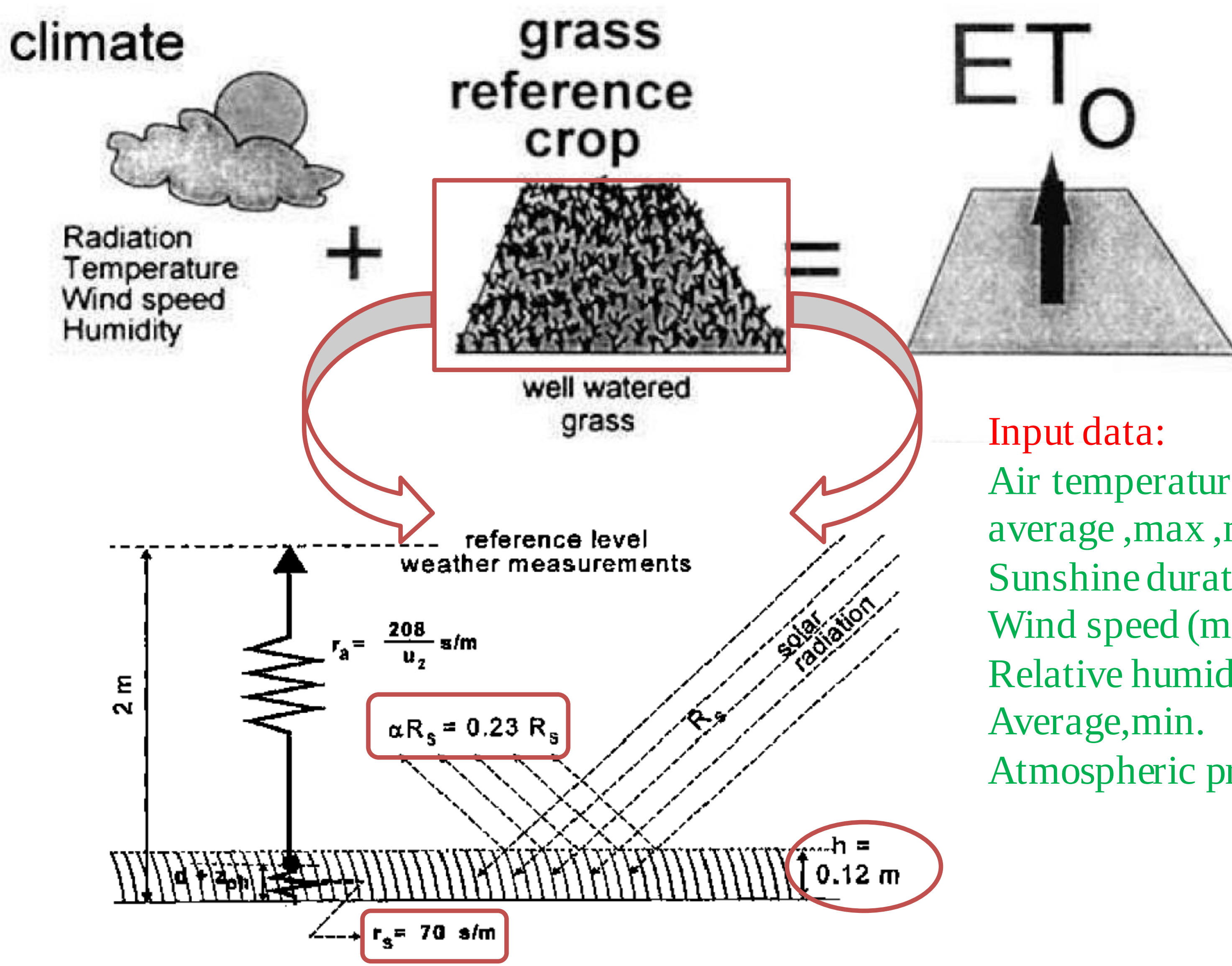
- The average annual precipitation varies between 1050mm and 1250mm.
- It locates in temperate and humid northern subtropical climate .
- Plains constitutes 4/6 part of Lake Taihu catchment area, waters 1/6 ,the other is hills and mountains.

Figure 1.Sketch map of the Lake Taihu catchment with distribution of 11 meteorological stations and 1 EC station (named DPK)in Taihu.

Methods and Materials

Figure from Baidu

Figure 2.Small evaporation pan: it's installed 70cm above the ground by a hollow support. The area of the pan is 314 cm^2 ,depth of water in it is 2cm,this kind of pan is widely used in China since the beginning of pan evaporation measuring, and most of them are replaced from 1998 on with a new type called E601.



Input data:

Air temperature (℃):
average ,max ,min.
Sunshine duration(h)
Wind speed (m/s)
Relative humidity(hPa):
Average,min.
Atmospheric pressure (hPa)

Figure 3. Characteristics of the hypothetical reference crop. *Intercepted from FAO,1998*

Penman-Monteith ET_0 Equation

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

$$R_s = [a_s + b_s(\tfrac{n}{N})]R_a$$

$$a_s = 0.25, b_s = 0.50$$

$$N = (24/\pi)\omega_s = 7.64\omega_s$$

$$R_{ns} = (1-\alpha)R_s$$

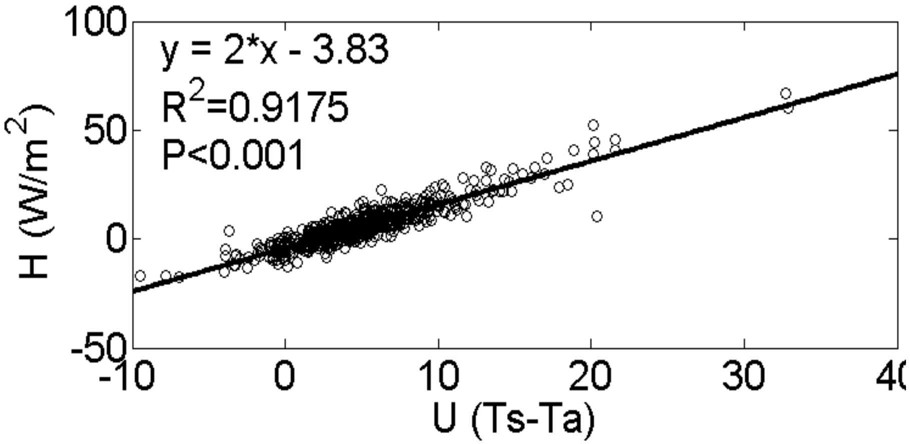
$$G = 0.1(T_i - T_{i-1})$$

$$R_{nl} = -f\varepsilon'\sigma \frac{T_{kx}^4 + T_{kn}^4}{2}$$

$$f = a_c \frac{R_s}{R_{s0}} + b_c$$

$$R_{s0} = (0.75 + 2\times 10^{-5} z)R_a$$

$$\varepsilon' = 0.34 - 0.14\sqrt{e_a}$$



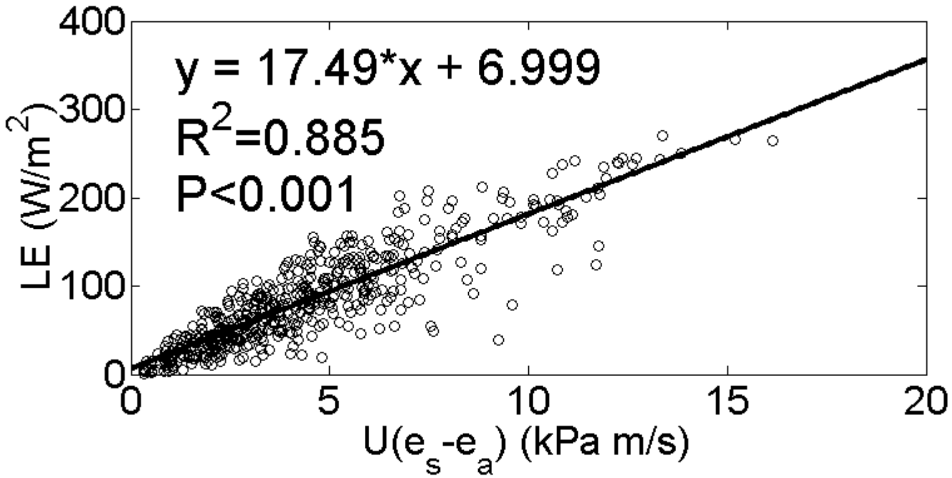


Figure 4. Gap filling method of latent heat H (left),latent heat LE (right);
U is wind speed ,Ts and Ta are temperature of lake surface and air respectively.
es and ea are vapor pressure at the temperature of lake surface and air.

evaporation paradox?

EC observation of Lake Taihu evaporation
(2011.9-2013.12)

Pan evaporation
(1961-2012)
Around Taihu

Comparison

Reference evapotranspiration
(1961-2009)

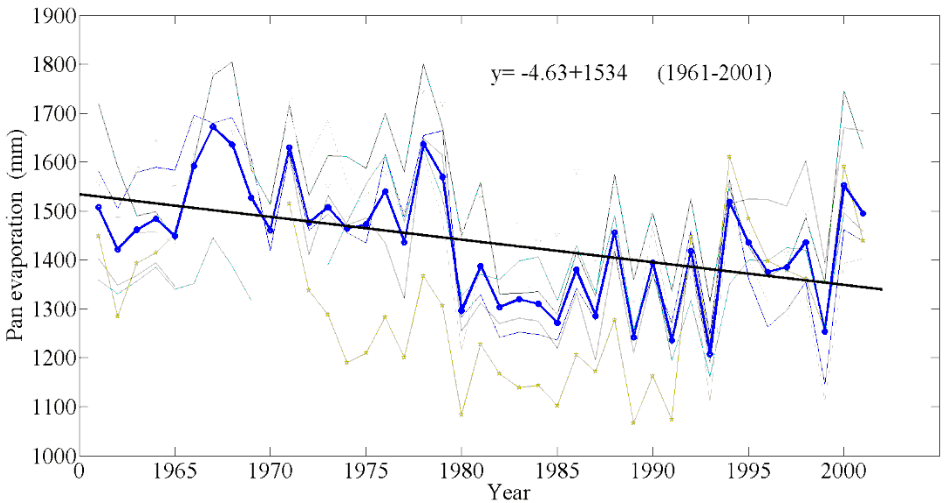
Modeled Tai lake evaporation
(1979-2013)

Conventional
meteorological data

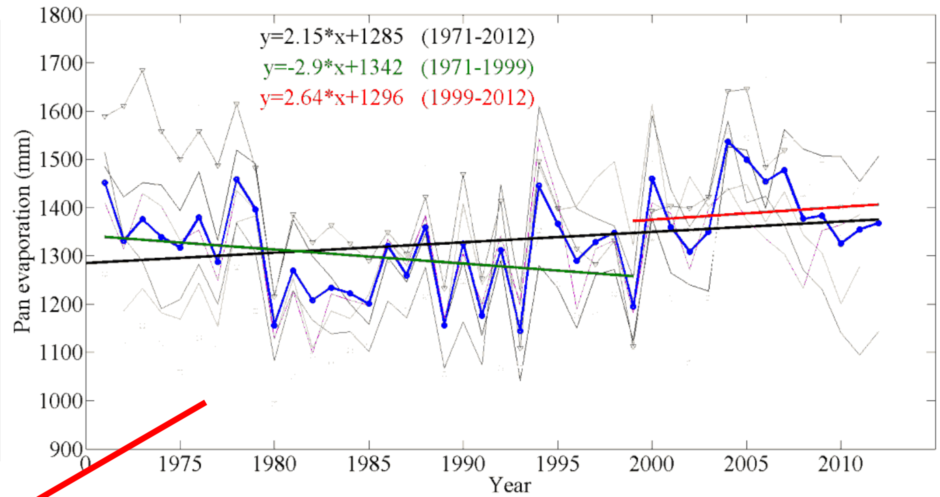
Calibrated MERRA reanalysis data

Results and Discussion

group1



group2



a(mm/year)	Jintan	Changshu	Anji	Deqing	Changxing	Wuxi	Yixing	mean
1971-2012	1.1	0.6	8.7***	5.7*	0.9	-3.0***	2.2	2.15
1971-1999	-11***	-7.6***	2	8.5**	-2.3	-12***	2.6	-2.9
1999-2012	24.8	5.2	28	-5.8 ***	2.4	NaN	-26***	2.6

Figure 5.left:annual pan evaporation of 7 stations (Liyang,Changzhou,Dongshan, Changshu,Wuxi,Yixing,Wuxian); right :the other 7 stations(Jintan, Changshu,Anji, Deqing,Changxing,Wuxi,Yixing.The blue line represents average annuanl of 7 stations in each group. (*Delineate significance at 0.05.**Delineate significance at 0.01. ***Delineate significance at 0.001)

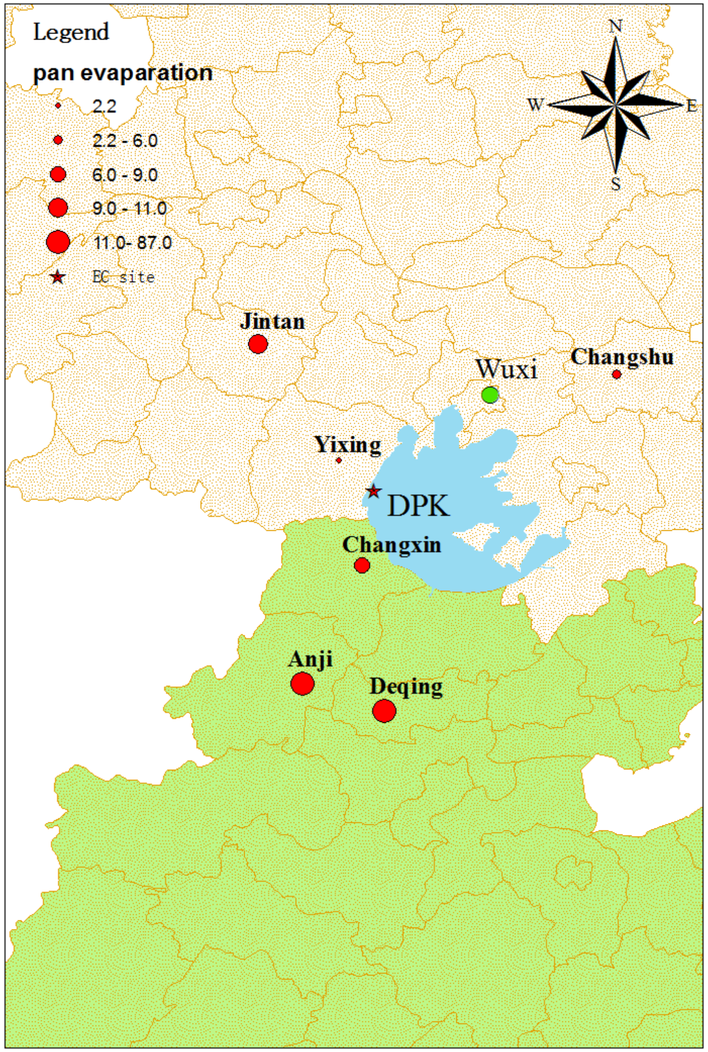
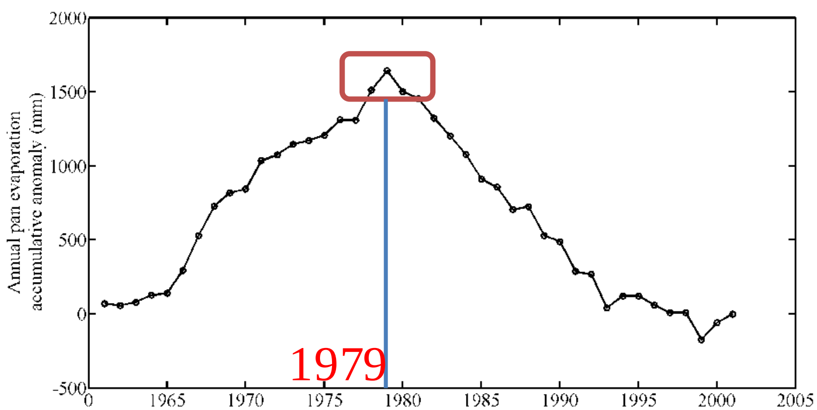


Figure 6.Sketch map of the Lake Taihu catchment with distribution of 7 pan evaporation from 1971 to 2012,red means increasing trend, with green means decreasing.



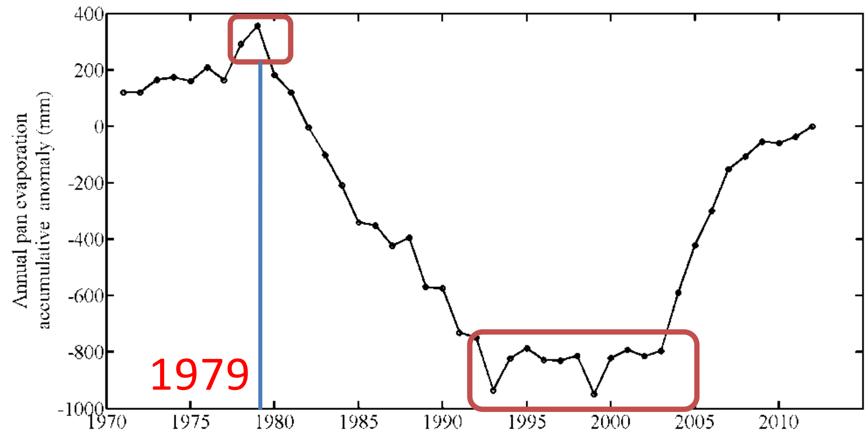


Figure 7. The accumulative anomaly from 1961 to 2001 for group1(left),from1971 to 2012 for group2(right).

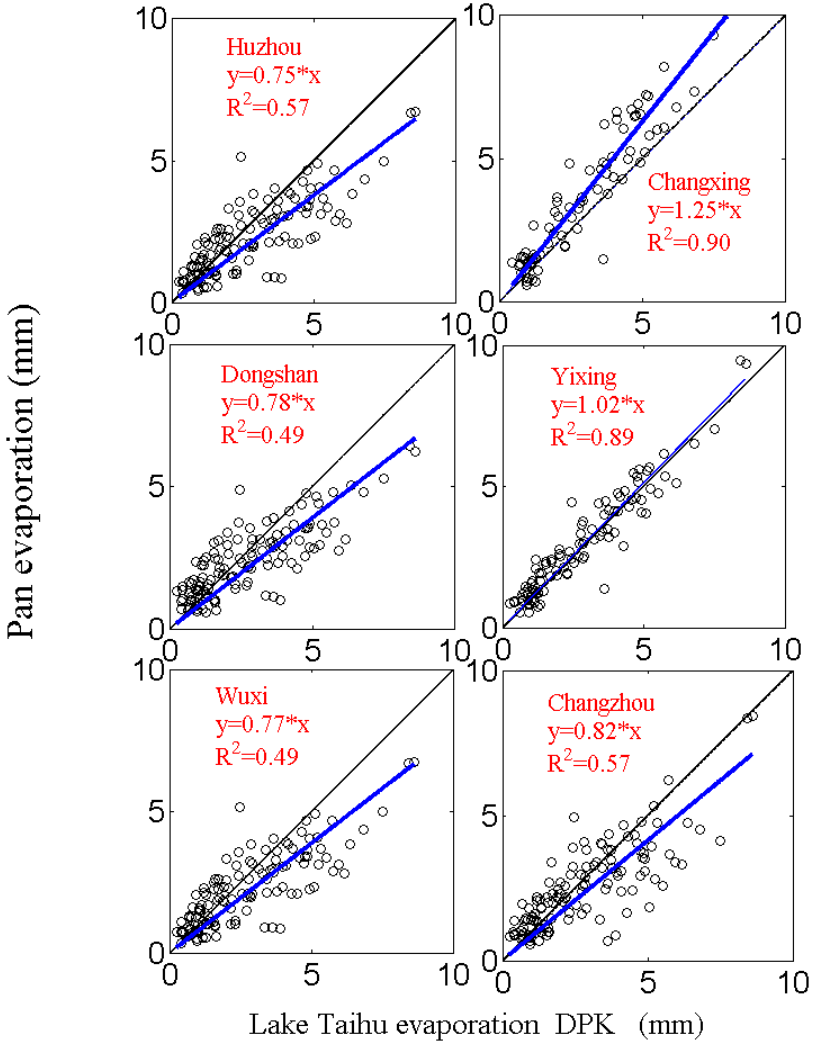


Figure 8. Regression plot of Lake Taihu (impose energy closure by Bowen ratio method) and pan evaporation in 6 stations. 5 days average is done to ignore the heat stored in lake. Blue line is the fitting line ,black for 1:1 line.

Reference evapotranspiration

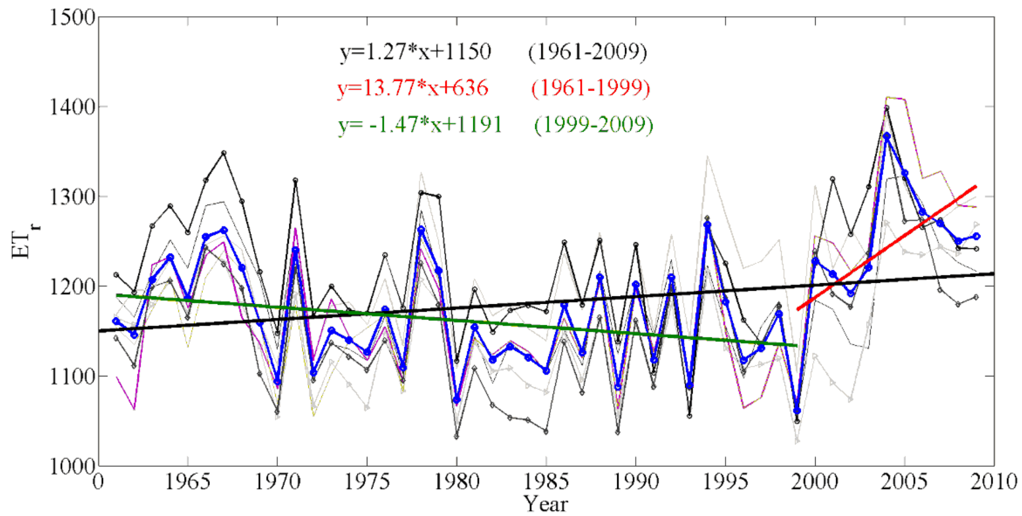


Figure 9. Time series of reference evapotranspiration of 7 stations in Lake Taihu catchment.

a(mm/year)	Changshu	Changzhou	Liyang	Dongshan	Wuxian	Wuxi	Yixing	mean
1961-2009	0.05	2.04***	0.5	0	2.4*	2.6*	1.3	1.27
1961-1999	-2.3*	0.57	-1.8 *	-3.1***	-1.3	-1.1	-1.2	-1.47
1999-2009	15.4	10.4	22.9***	8.3	14.3	16.8	5.91	13.77

Table1. The changing ratio and Mann–Kendall trend test for the reference evapotranspiration of 3 different period (1961-2009,1961-1999,1999-2009).

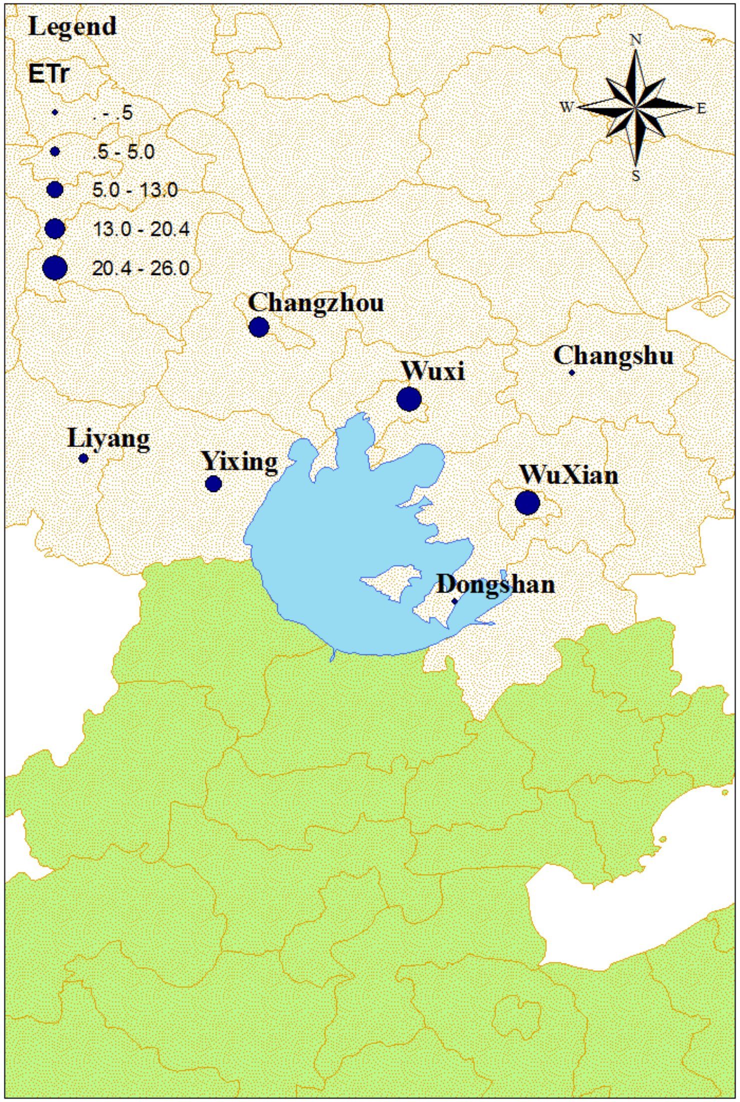


Figure 10.Sketch map of the Lake Taihu catchment with distribution of 7 ETr sites from 1999 to 2009.

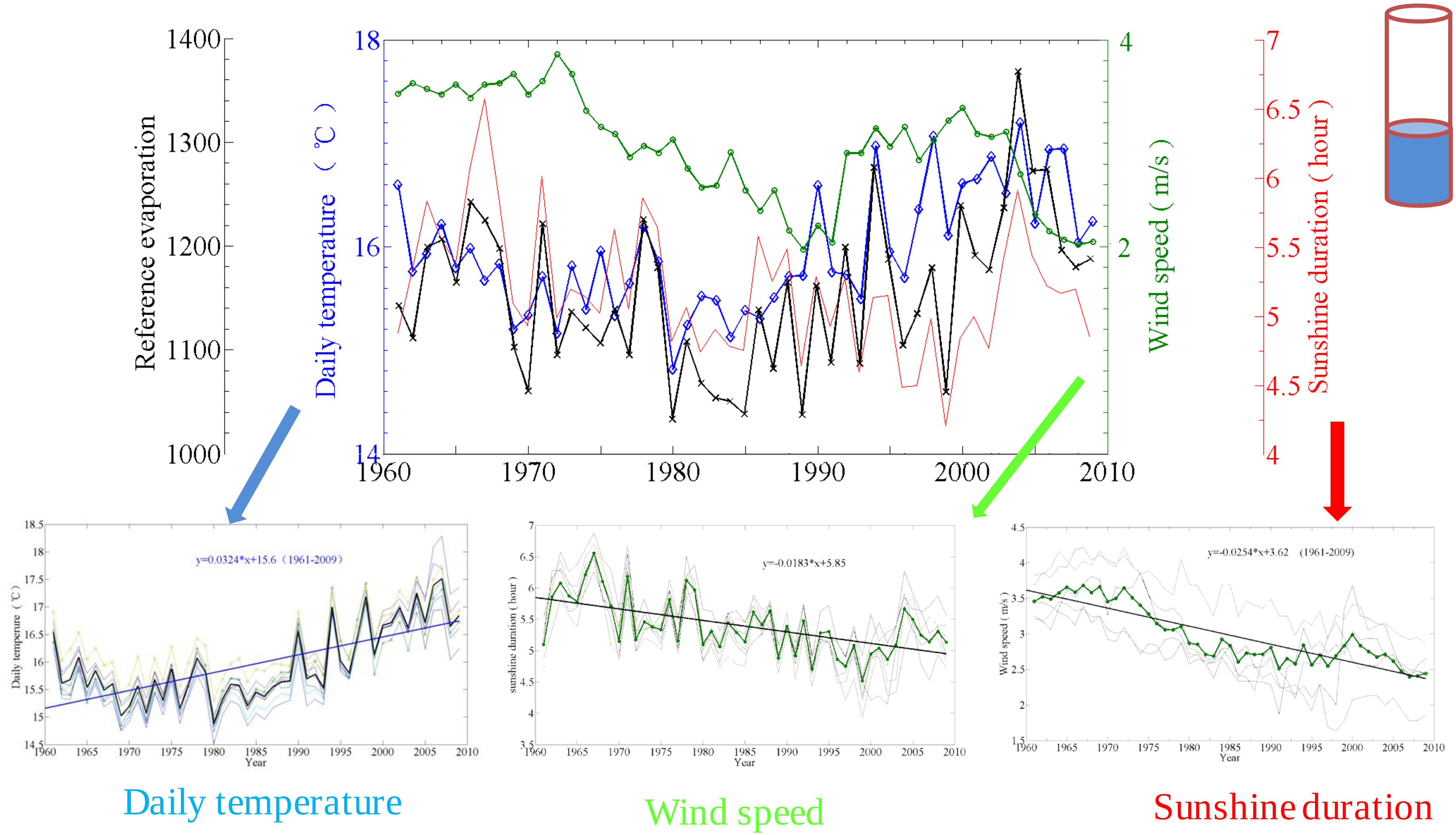
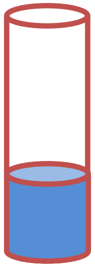
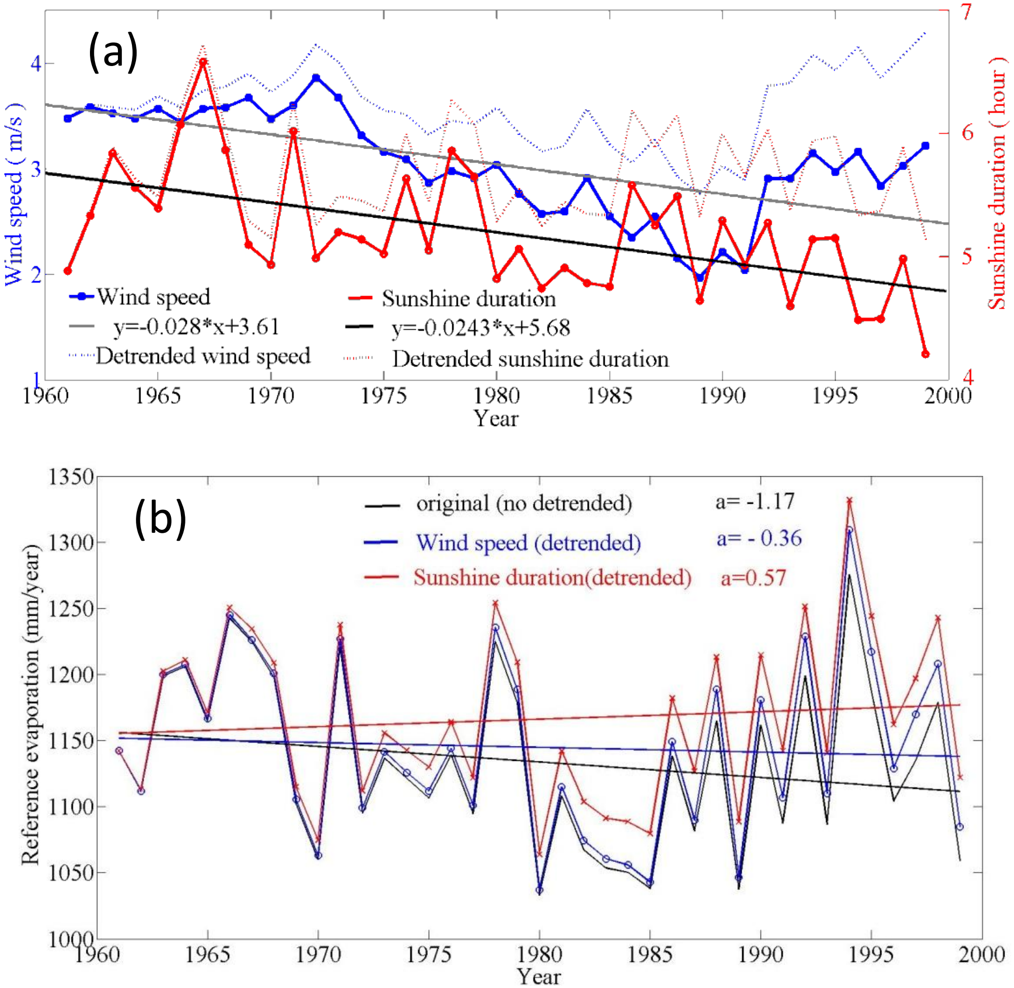


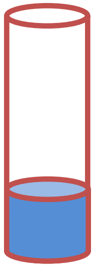
Figure 11. Time series of Conventional meteorological data from 1961 to 2009:Daily temperature with blue color ,Wind speed in green , Sunshine duration in red. comparison with reference evapotranspiration.



a(mm/10year)	Wuxi	Changzhou	Wujiang	Liyang	Yixing	Dongshan	Changshu	Mean
Temperature(℃)	0.41 ***	0.33 ***	0.46 ***	0.33 ***	0.21 ***	0.26 ***	0.35 ***	0.32 ***
Wind speed(m/s)	-0.22 ***	-0.14 ***	-0.18 ***	-0.35 ***	-0.25 ***	-0.25 ***	-0.38 ***	-0.25 ***
Sunshine (hour)	-0.11 **	-0.05	-0.03 ***	-0.24 ***	-0.12 **	-0.27 ***	-0.37 ***	-0.18 ***

Table 2. Standardized stepwise regression coefficient for climatic variables of each station across the catchment. (*Delineate significance at 0.05.**Delineate significance at 0.01.***Delineate significance at 0.001)





The black line at the bottom is the reference evapotranspiration calculated by using original data for all meteorological variables; the blue line is the reference evapotranspiration calculated by using the wind speed data with trend removed and original data for other variables; and the red line is the reference evapotranspiration calculated by using the net radiation data with trend removed and original data for other variables.

Figure 12. The plot of Yixing station original annual values in figure (a):trend and the recovered stationary series for wind speed and net radiation(b) shows the comparison of the original mean annual reference evapotranspiration with the recalculated evapotranspiration.

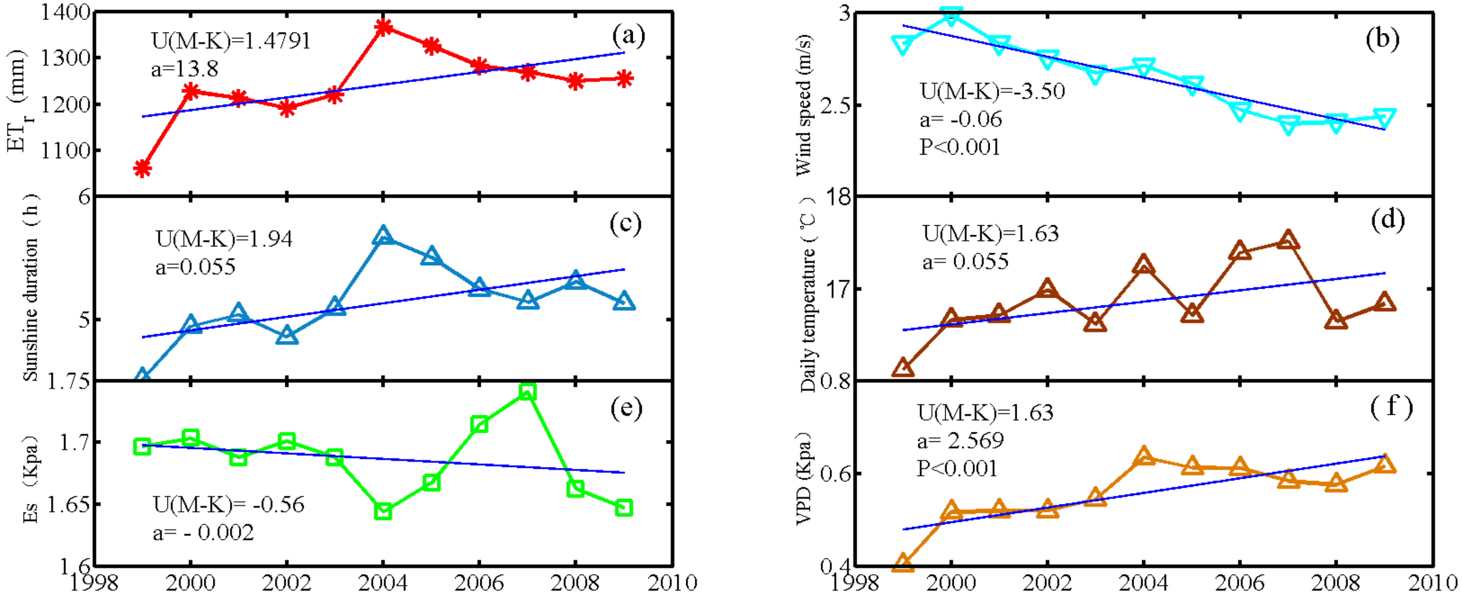


Figure 13. Annual variation of the reference evapotranspiration (a) , wind speed(b) sunshine duration(c),daily temperature (d), vapor pressure (e),VPD(f)and their long term trends for the catchment(7 stations).

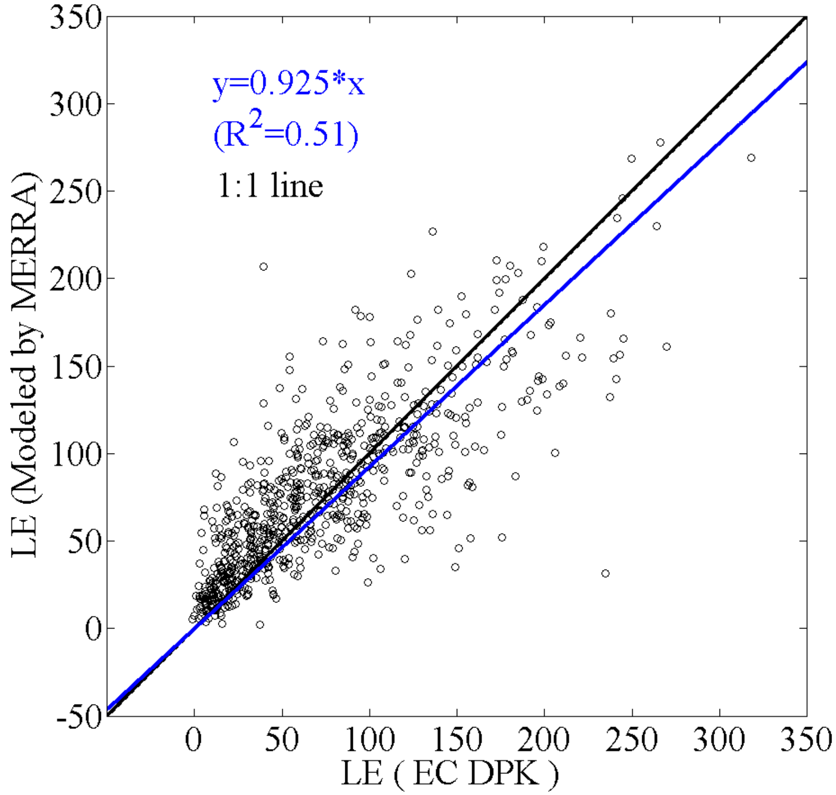


Figure 14. Comparison of observed and calculated lake evaporation rates. The lake model was forced with MERRA reanalysis. Best fit regression; y = 0.925x, R^2 = 0.51, n =746 (1:1 line shown). The RMSE is 33.9 $Wm^{-2}day^{-1}$. (Note that 1 Wm^{-2} *1day=0.0352$mmday^{-1}$.)

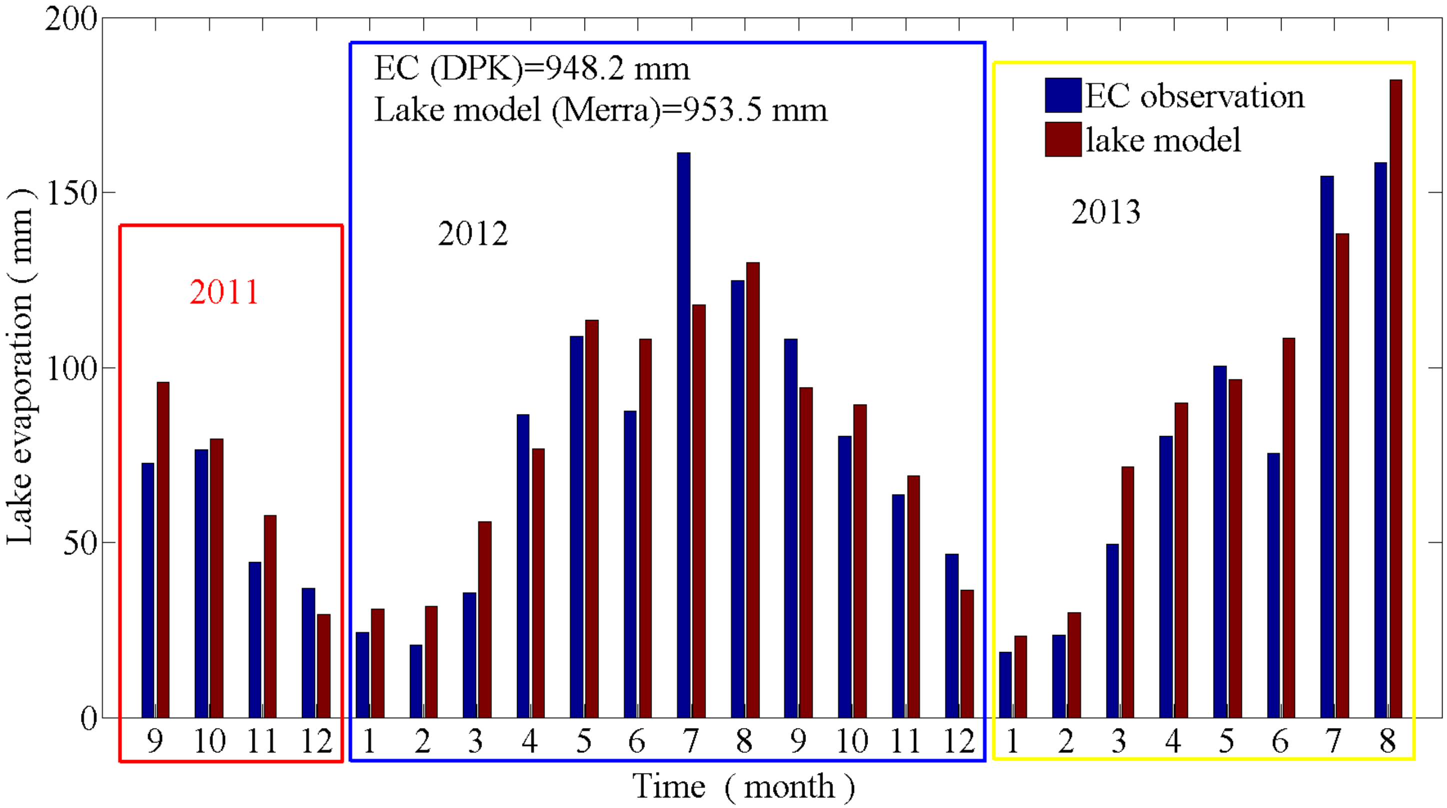


Figure15. Comparison of observed and calculated lake evaporation from Sep 2011 to Aug 2013.

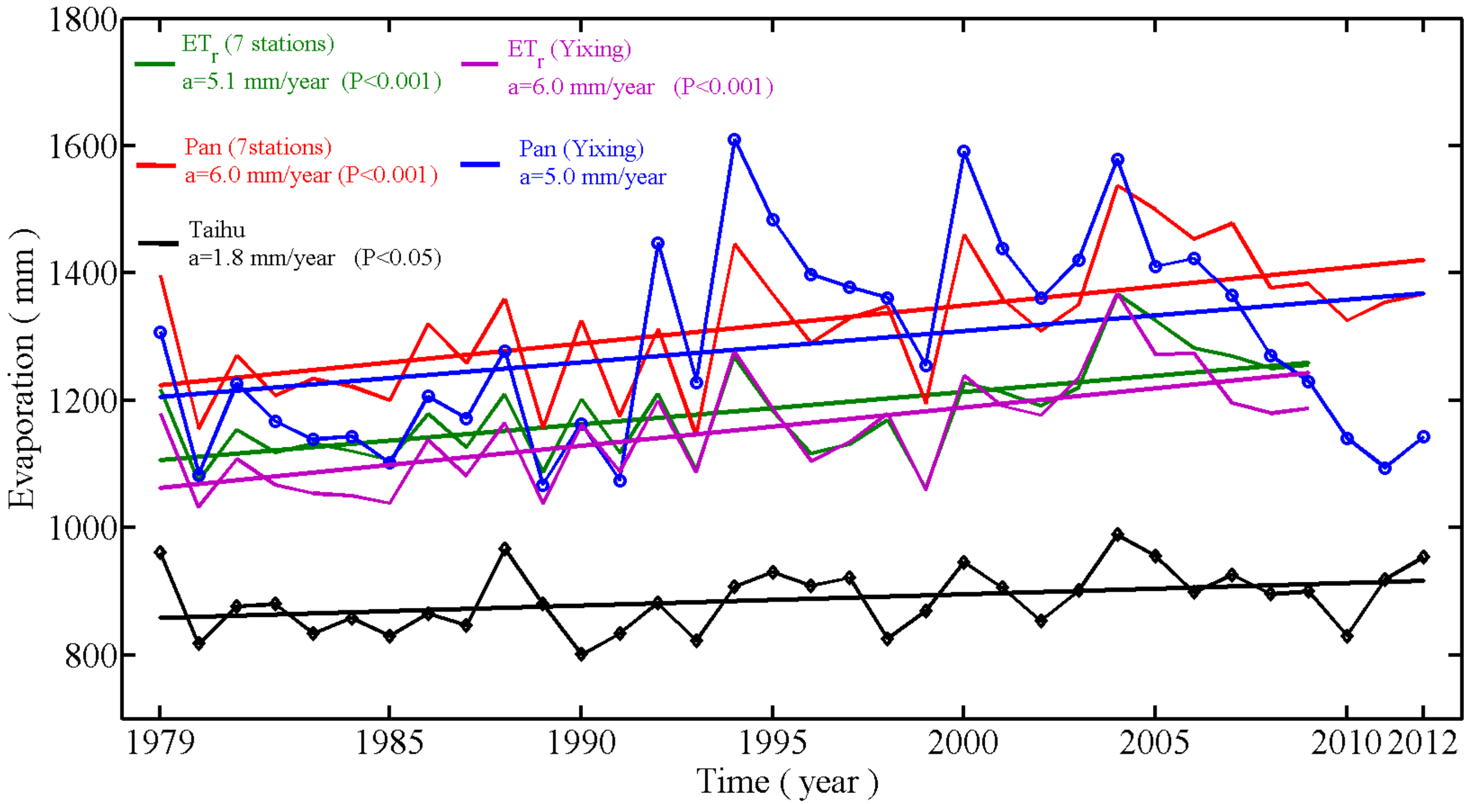


Figure 16. Annual variation of lake evaporation and their long term trends for the catchment.

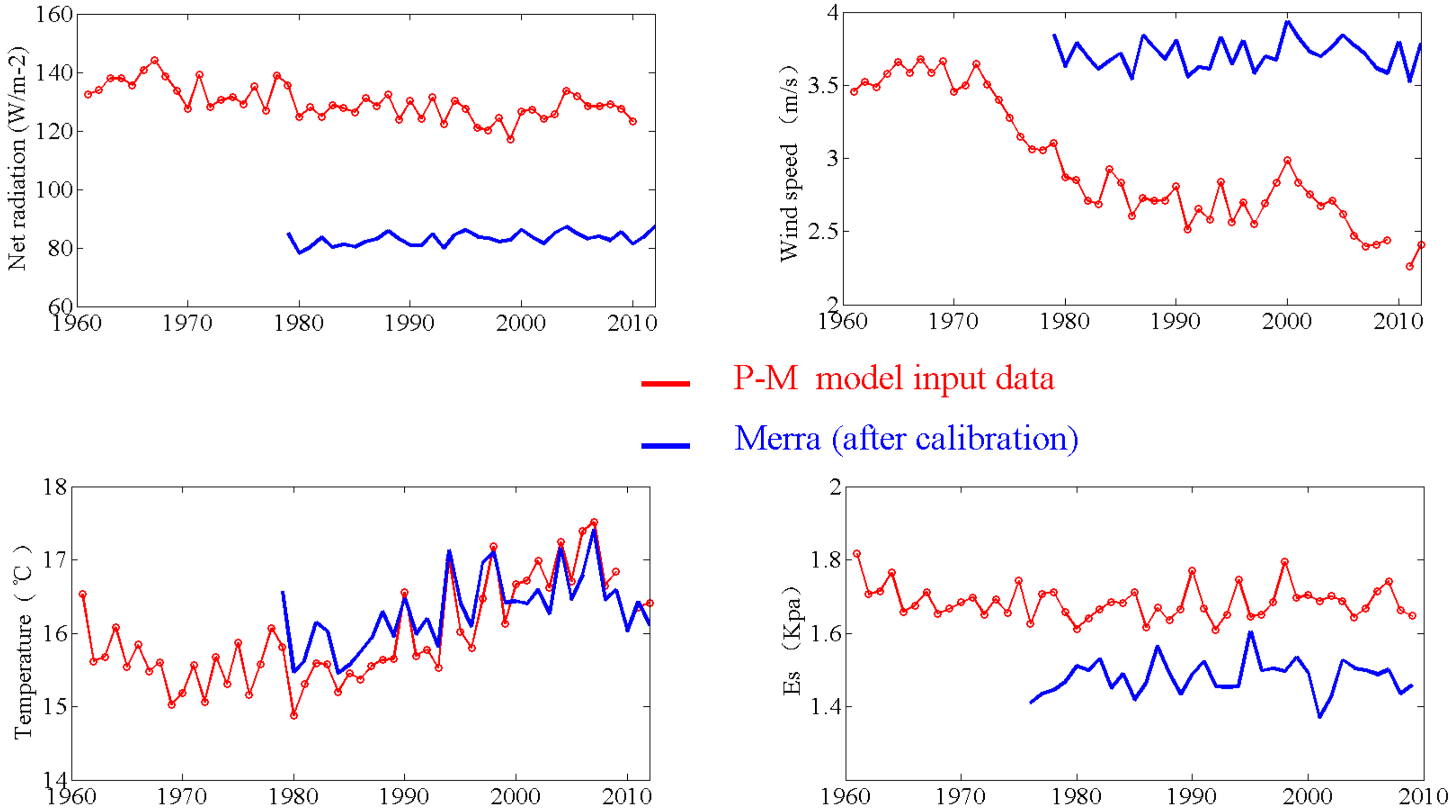


Figure 17. Time series of meteorology data of 7 stations and MERRA.

Conclusion

- For the Lake Taihu catchment, there is a similar decreasing trend in the reference evapotranspiration and pan evaporation from 1961 to 1999.The main cause of this decreasing trend is the net total radiation(calculated by sunshine duration) followed by wind speed, having a significant decreasing trend in the region for the study period; But from 1999 to 2009, both of reference evapotranspiration and pan evaporation reverse to increasing trend ,this is led by increasing net total radiation and temperature, even though the decreasing factor caused by decreasing wind speed.

- Taking 1961 to 2012 as a whole period ,the trend of both reference evapotranspiration and pan evaporation appear to be increasing ,which comes from the result of increasing temperature.

- For the Lake Taihu catchment, the evaporation of lake and pan appear to be the same increasing trend, as the function of increasing temperature.

Thanks.