Yale-NUIST Center on Atmospheric Environment

Variability of Evaporation from Lake Taihu and its Response to Climate Change

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Outline

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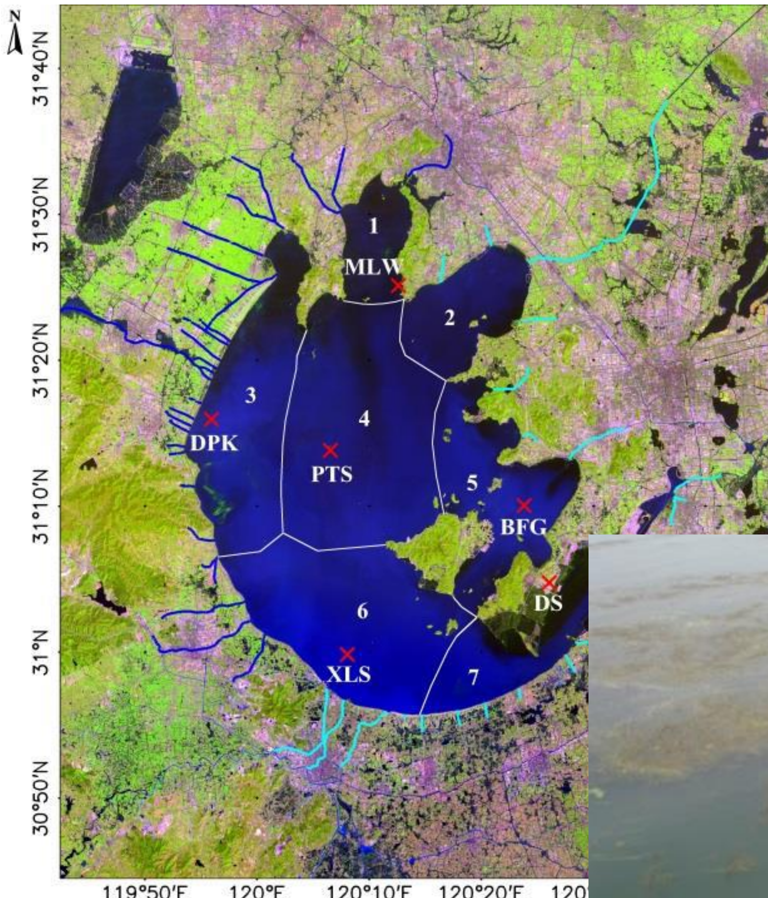
Background

- The evaporation of Lake Taihu accounts for 26-50% of the total water expenditure of the lake (Qin et al., 2007). The study of the evaporation of Lake Taihu can accurately quantify the lake water cycle and serve as an important indicator of climate change.
- Eddy covariance in lake platform can measure the latent heat flux directly and then convert it into the evaporation. This method is more accurate. Because the long-term observation data on the lake is difficult to obtain, it is not a lot to study the characteristics of evaporation on a large and shallow lake.
- Numerical simulation is also an effective method to estimate the evaporation of lakes, but weather lakes model is suitable for the simulation of Lake Taihu is not known.
- Hu et al. (2016) reported that show a significant increasing trend of annual lake evaporation from 1979 to 2013. So, the future of Lake Taihu evaporation trends and historical trends are consistent with the temperature increase? What is the sensitivity of evaporation to temperature in different climate scenarios?

Data and Method



➢ **observation data**

Site: BFG

Time: 2012

Data sources:

- micrometeorology system
- temperature probes
- eddy covariance system

Fig1 the location of BFG site in Lake Taihu (from Lee et al.,2014)and photograph showing submerged macrophytes

➢ introduction of lake models

The energy balance equation of the lake surface lager:

$$\beta R_S + (L\downarrow - L\uparrow) = H + LE + Q_g$$

- βR_S: remaining net solar radiation
- $(L\downarrow - L\uparrow)$: net longwave radiation
- H: sensible heat flux
- LE: latent heat flux
- Q_g: diffusion heat flux between surface layer and the rest

The prognostic equations for Tw:

$$\frac{\partial T_W}{\partial t} = \frac{\partial}{\partial z}\left(K_z + K_e \frac{\partial T_W}{\partial z}\right) + \frac{S}{c_p \rho_w}$$

- $K_z + K_e$: vertical turbulent diffusion and molecular diffusion
- $\frac{S}{c_p \rho_w}$: Solar radiation penetrated into water

- **CLM4-LISSS lake model**

vertical turbulent diffusion：

$$K_Z = \frac{kw^* z_i}{P_O(1 + 37R_i^2)} \exp(-k^* z_i)$$

- **K-ε lake model**

The prognostic equations for TKE:

$$\frac{\partial E}{\partial t} = \frac{\partial}{\partial z}\left(K_z \frac{\partial E}{\partial z}\right) + B - \varepsilon$$

vertical turbulent diffusion

buoyancy

dissipation

The parameterization equation for dissipation (ε) : $\varepsilon = \hat{a} C_D E^{3/2}$

- **Lake model**

The prognostic equations for TKE:

$$\frac{\partial E}{\partial t} = \frac{\partial}{\partial z}(K_z + K_e)\frac{\partial E}{\partial z} + P + B - \varepsilon$$

Turbulence and diffusion molecular induced kinetic energy

shear production

The prognostic equation for dissipation(ε) :

$$\frac{\partial \varepsilon}{\partial t} = \frac{\partial}{\partial z}(K_z + K_e)\frac{\partial \varepsilon}{\partial z} + (c_{1\varepsilon}P + c_{3\varepsilon}B - c_{2\varepsilon}\varepsilon)$$

➢introduction of future climate data

- The HadCEM2-ES climate model (http://cmip-pcmdi.llnl.gov/cmip5/) of the fifth Phase of the Coupled Model Intercomparison Project (CMIP5), which is developed by the Hadley Centre and the National Center for Atmospheric Research,
- the spatial resolution is $1.875^{0} \times 1.25^{0}$,
- the temporal resolution is 1month,
- Different Representative Concentration Pathways (RCP) climate simulation data for 2010-2100.

Results

- **Diurnal variation of energy flux and evaporation in various seasons in Lake Taihu in 2012**

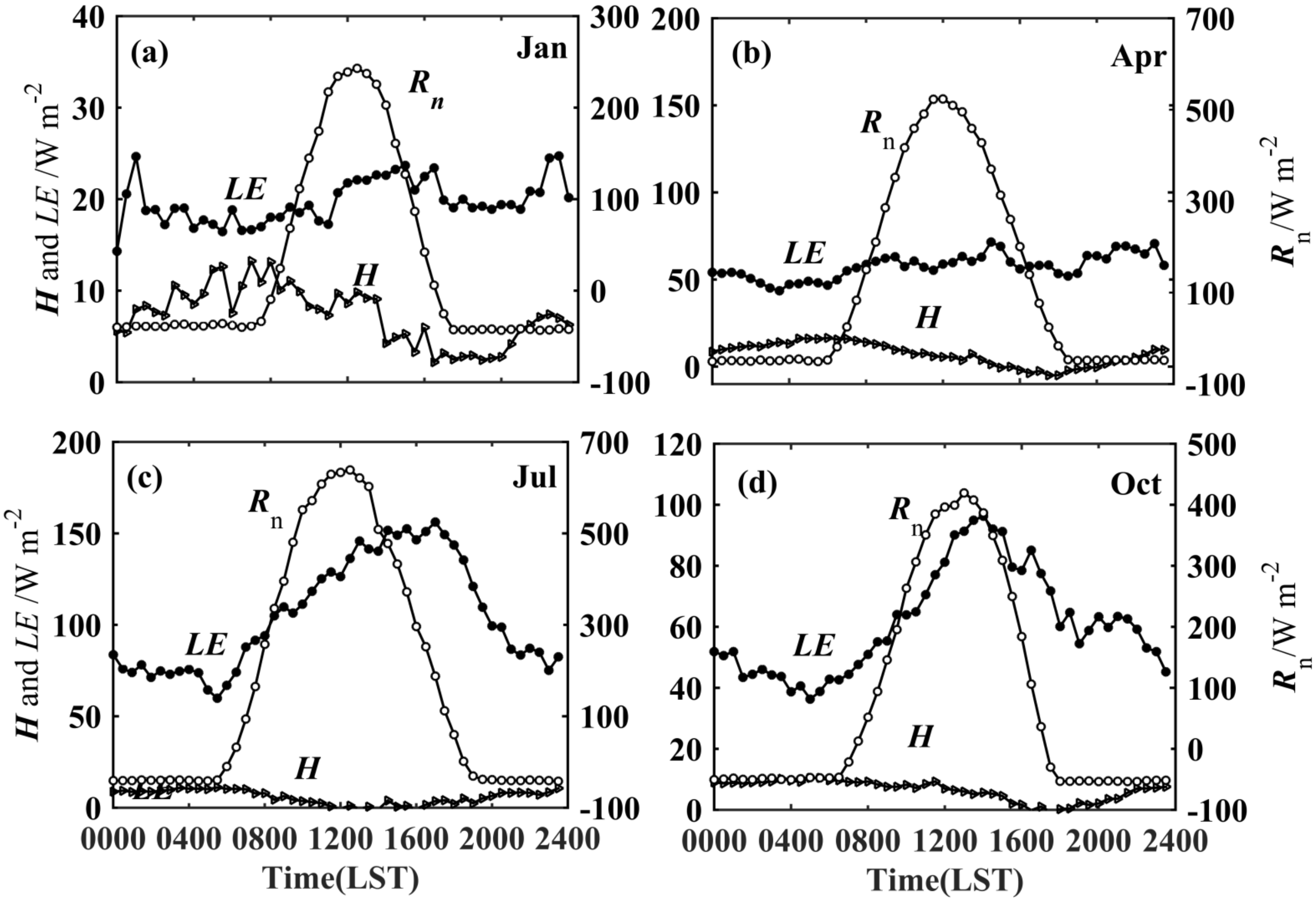


Fig2 Average diurnal variation of radiation flux and turbulent fluxes in various seasons in Lake Taihu in 2012: (a) January; (b) April; (c) July; (d) October

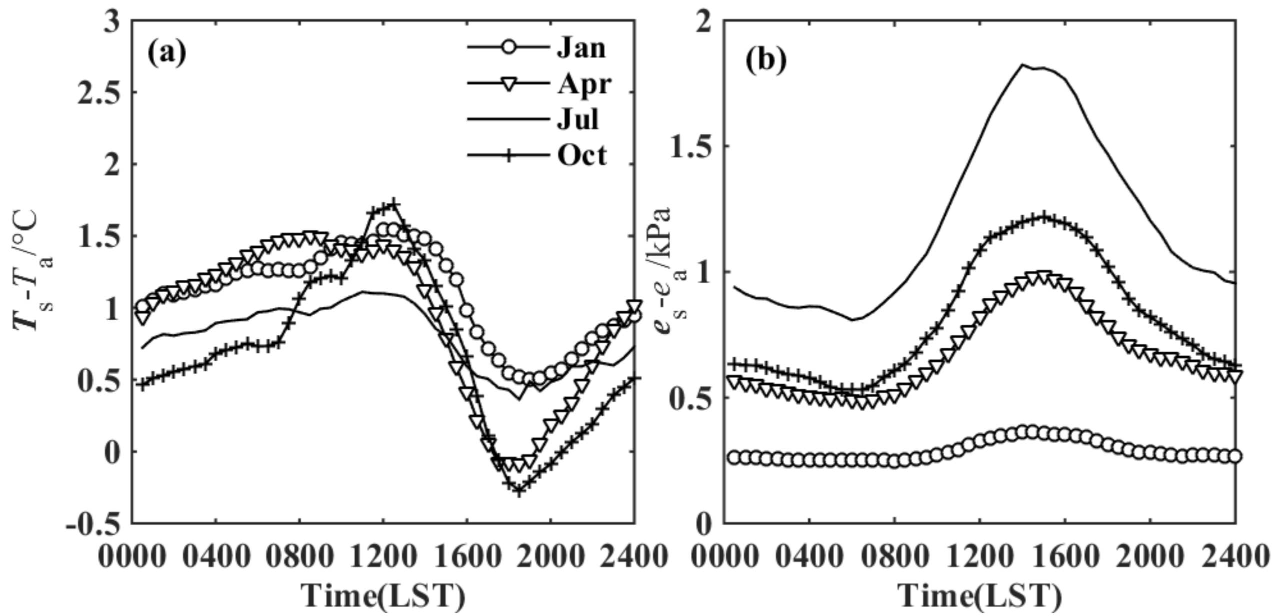


Fig3 Average diurnal variation of (a) temperature difference between the water surface and the overlying air and (b) vapor pressure difference, in various seasons of 2012 in Lake Taihu

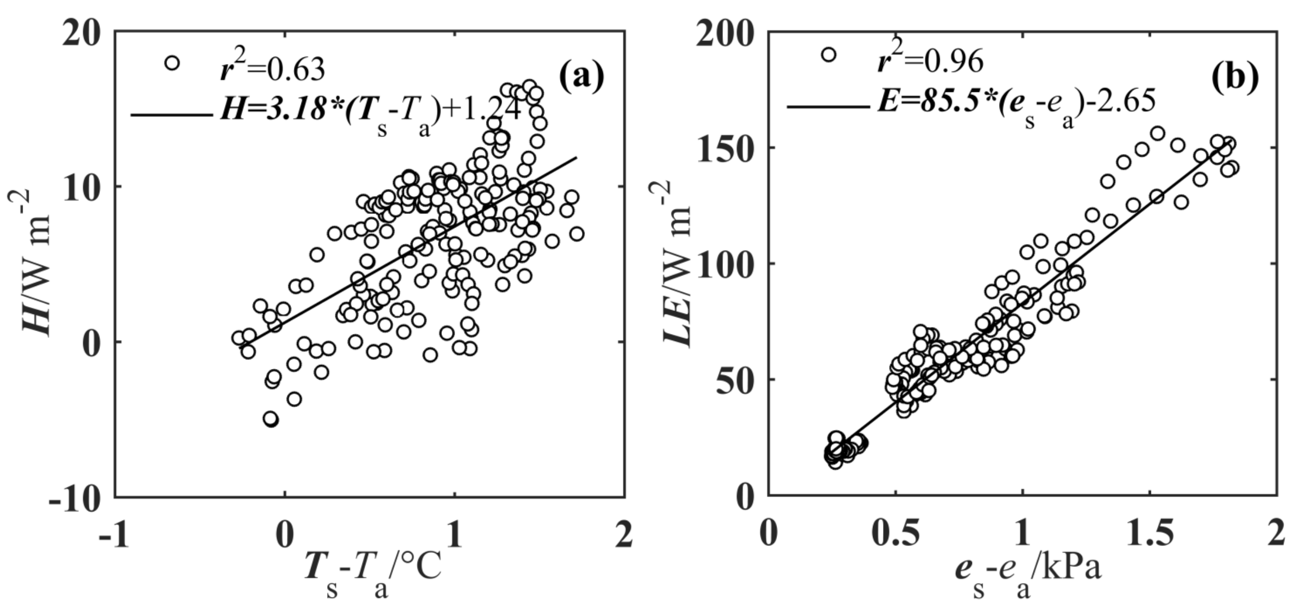


Fig4 Relationship between (a) sensible heat flux and the temperature difference between the water surface and the overlying air and (b) latent heat flux and vapor pressure difference

- **Monthly mean variation of energy fluxes in Lake Taihu in 2012**

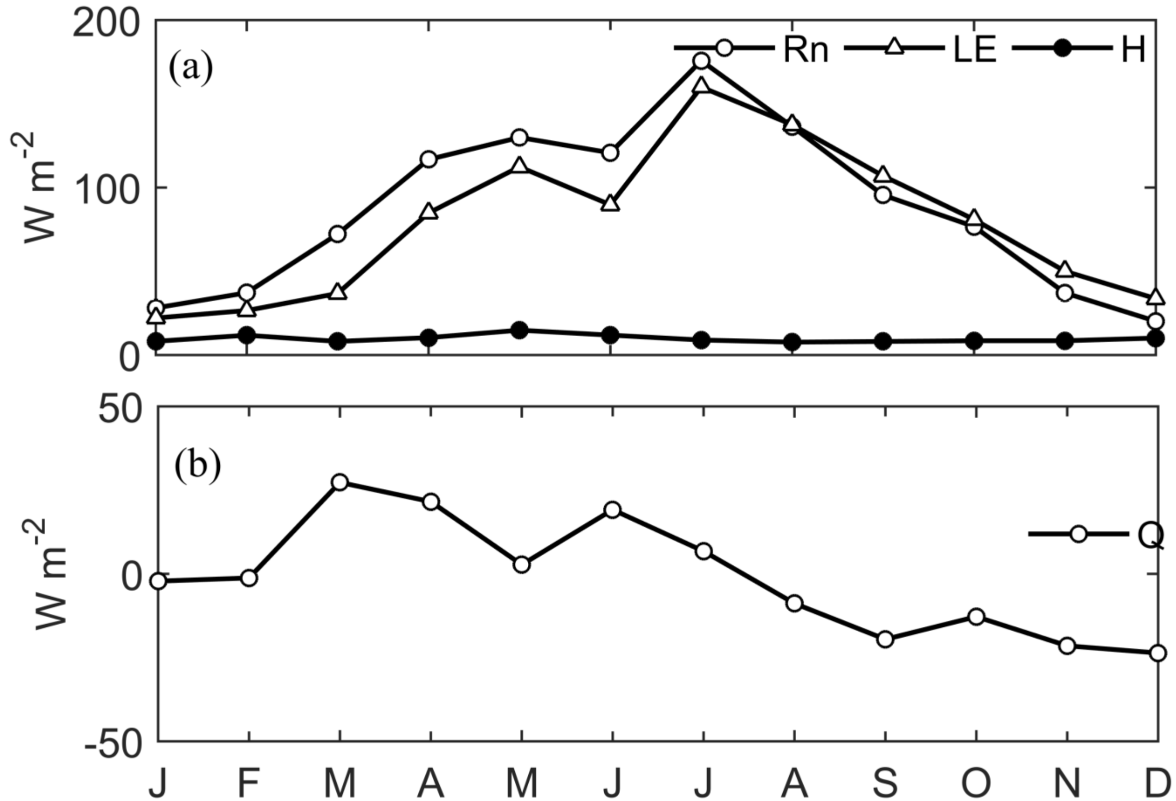


Fig5 Monthly mean variation of energy fluxes in Lake Taihu in 2012 (a) net radiation(Rn), sensible heat flux(H) and latent heat flux(LE), (b)heat storage (Q)

• Total evaporation of Lake Taihu in 2012

Table1 Annual means of energy fluxes and total evaporation of inland open water using eddy covariance

Lake name	Location	Time	Rn W m^{-2}	LE W m^{-2}	LE/Rn	E mm	Reference
Erhai Lake	25° 46'N 100° 10'E	2012.1-12				1165	Liu et al.（2014）
Lake Taihu	31° 15'N 119° 55'E	2012.1-12	87.2	78.4	0.90	1019.2	
Ross Barnett Reservoir	32° 26'N 90° 02'W	2008.1-12	108.4	87.1	0.81	1078	Liu et al. (2012)
Lake Superior	47° 10'N 87° 14'W	2009.10-2010.9	84.9	57.1	0.67	645	Blanken et al. (2011)
Great Slave Lake	61° 55'N 113° 44'W	1999.6.12–12.18	84.6	54.0	0.60	417	Rouse et al. (2003)

● **Evaluation of three lake model at water temperature**

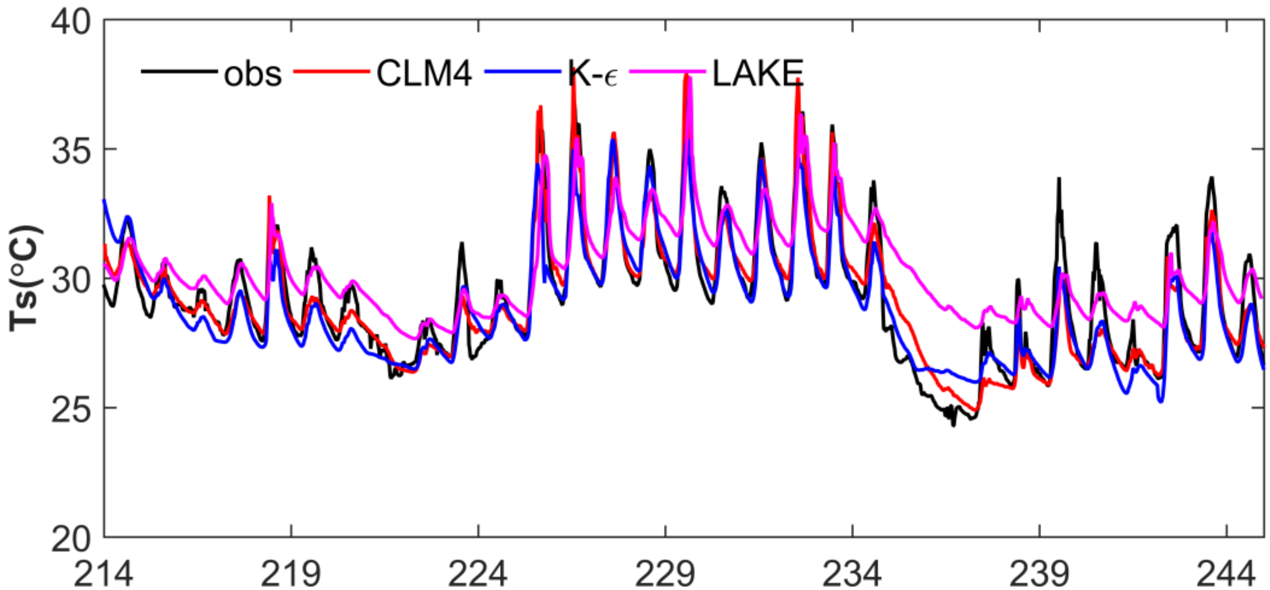


Fig6 Comparison between the observed and the model-predicted surface temperature in August 2012

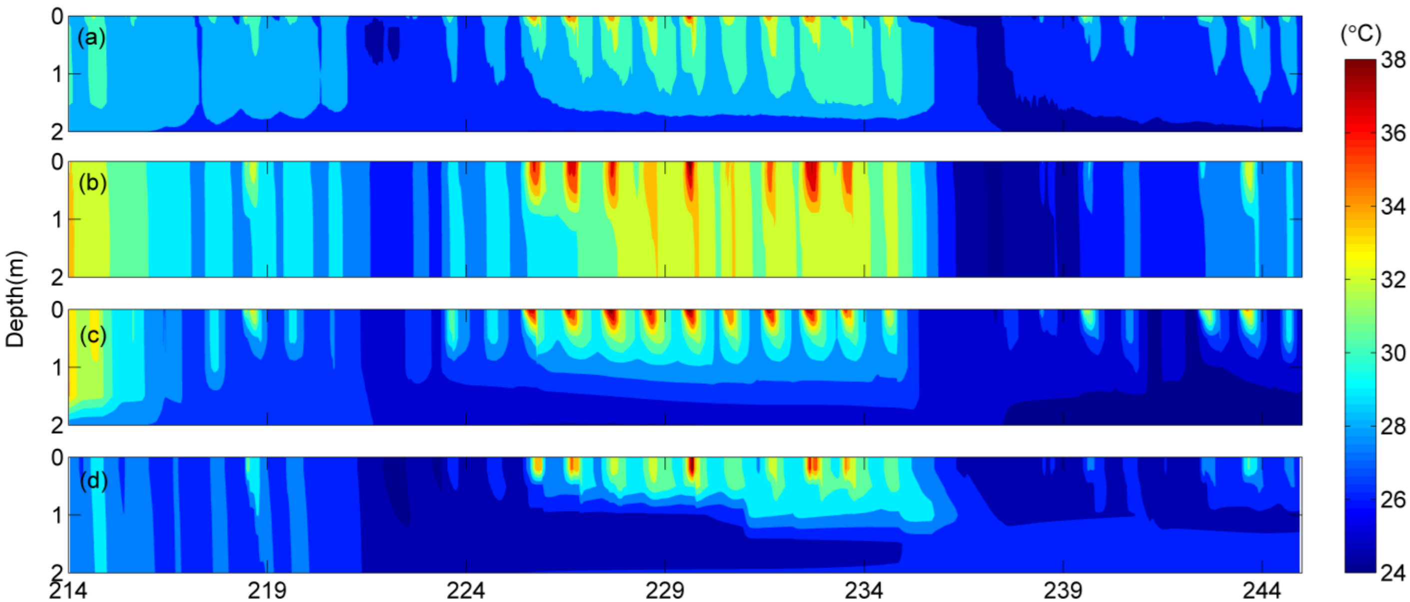


Fig7 Temperature comparison for August 2012: contour plot of (a)observed temperature, simulated temperature by (b)CLM4-LISSS, (c)k–ε lake model and (d) LAKE model

Table2 The correlation coefficient and root-mean-square errors of measured and predicted at BFG site in August, 2012

	correlation coefficient					root-mean-square errors				
	TS	TW20	TW50	TW100	TW150	TS	TW20	TW50	TW100	TW150
CLM4	0.94	0.94	0.94	0.96	0.95	0.85	0.64	0.59	0.42	0.53
K-ε	0.93	0.93	0.92	0.90	0.8	0.98	0.68	0.66	0.65	1.03
LAKE	0.82	0.93	0.89	0.58	0.06	1.45	0.64	0.78	1.20	1.49

● Evaluation of three lake model at surface energy fluxes

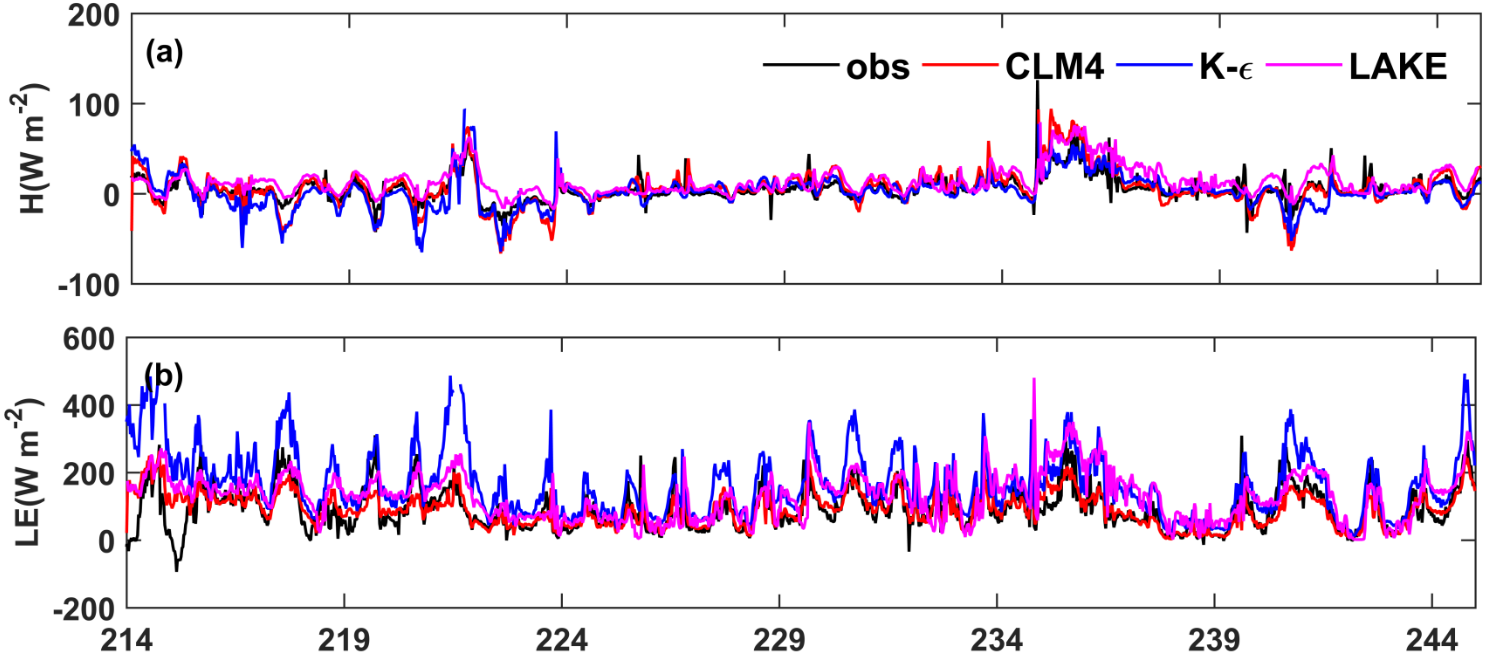


Fig8 Comparison between the observed and the model-predicted (a)sensible heat flux and (b) latent heat flux in August 2012

Table3 The correlation coefficient and root-mean-square errors of measured and predicted at BFG site in August, 2012

	correlation coefficient		root-mean-square errors	
	H	LE	H	LE
CLM4	0.86	0.78	11.61	55.32
K-ε	0.77	0.72	11.56	64.53
LAKE	0.71	0.55	10.96	61.96

● Evaluation of CLM4-LISSS lake model for monthly evaporation

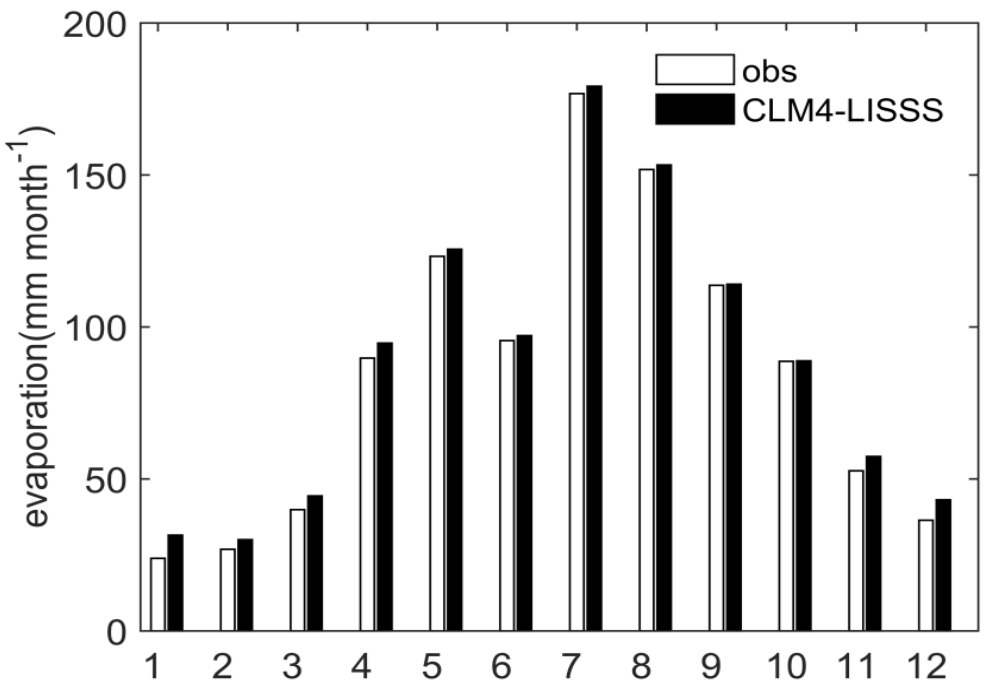


Fig9 Monthly total evaporation comparison for 2012

- **Characteristics of evaporation in Lake Taihu under different Representative Concentration Pathways**

  - **Meteorological data of climate models output**

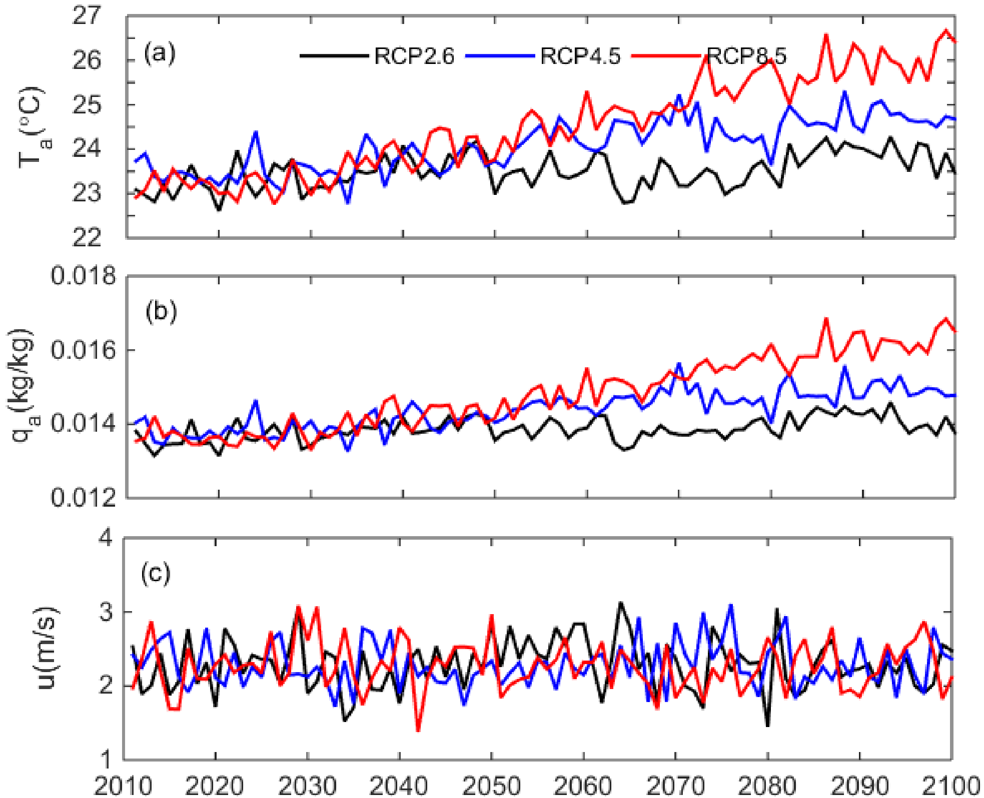


Fig10 Average annual air temperature (a), specific humidity (b), wind speed (c) from 2010-2100

RCP2.6: 0.011 $^{o}C\ yr^{-1}$
RCP4.5: 0.028 $^{o}C\ yr^{-1}$
RCP8.5: 0.043 $^{o}C\ yr^{-1}$

- **evaporation variation under different climate scenarios**

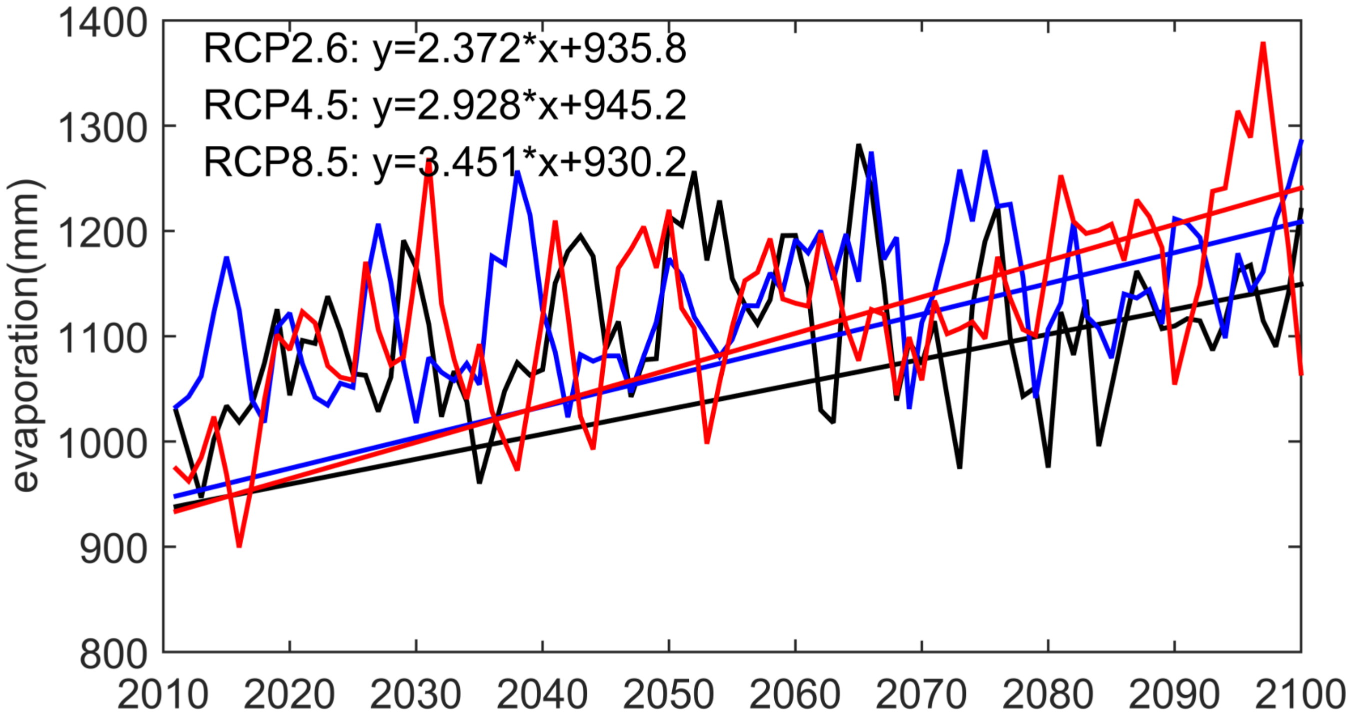


Fig11 Total annual evaporation by CLM4-LISSS simulation of future climate scenarios (during 2010-2100)

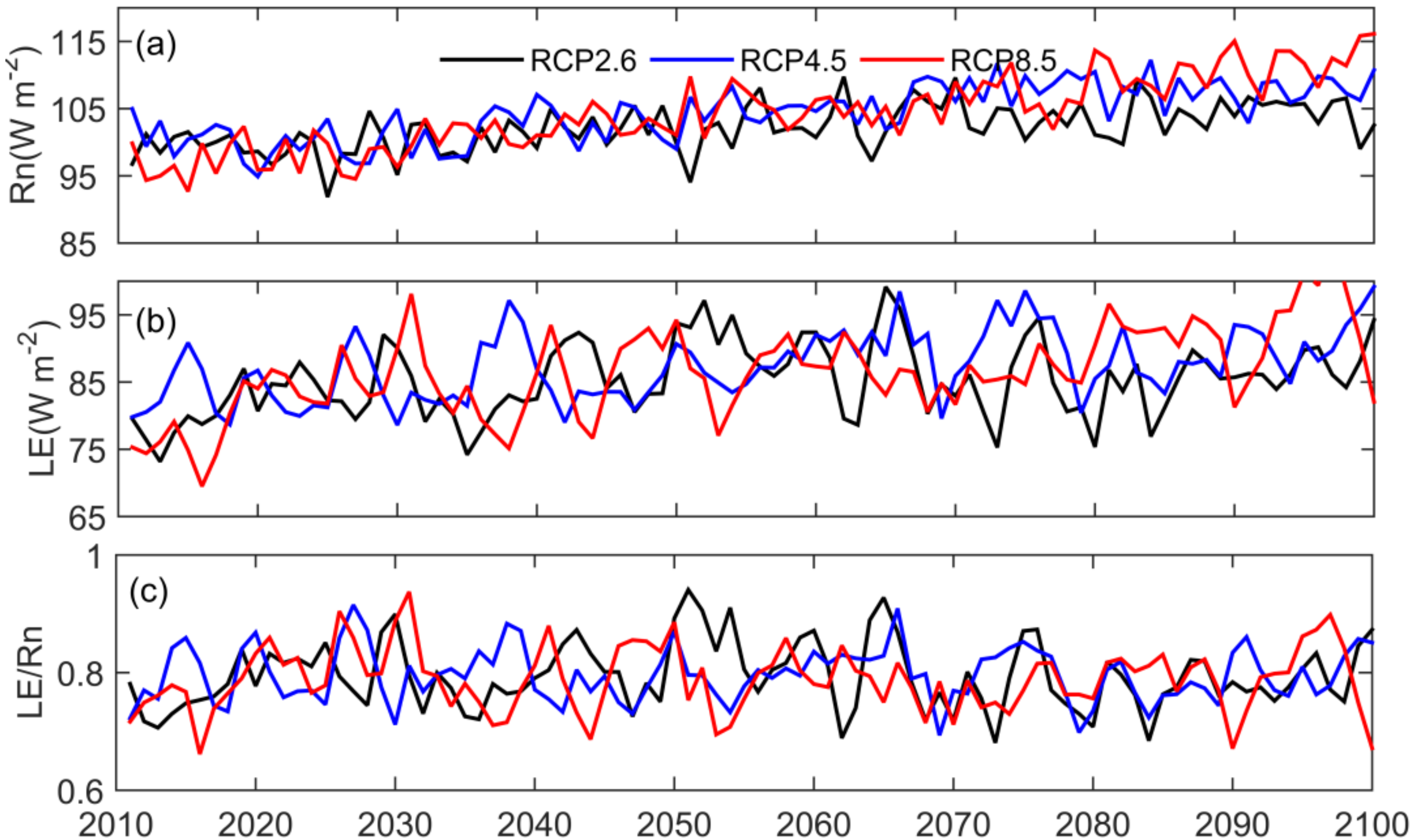


Fig12 Interannual variability of (a) net radiation flux, (b) latent heat flux, (c) evaporation ratio under future climate scenarios

Conclusions

- The annual evaporation of Lake Taihu in 2012 is 1019.2mm. The latent heat flux was the dominant term of the net radiation energy, which occupied about 90% in 2012. The water body stores heat in the period from March to July, after which the net radiation increases to a maximum in July, and evaporation also reaches a maximum. Thereafter, net radiation reduces to a minimum in December, stored heat is released, and evaporation reaches a minimum in January.

- CLM4-LISSS, K-ε and LAKE lake models can simulate the diurnal variation characteristics of latent heat flux in August 2012, the best simulation is CLM4-LISSS lake model. The correlation coefficient between the observed value and the simulated value is 0.78, and the root mean square error is 55.32W m^{-2}.

- In the period of 2010-2100, the evaporation of Lake Taihu increased under different greenhouse gas emission scenarios. According to the scenarios of RCP2.6, RCP4.5 and RCP8.5, the increase of evaporation per decade was 23.7mm, 29.2mm and34.5mm, respectively. Evaporation rate increases with increasing amount of radiative forcing increases.

- The temporal resolution of meteorological data from climate models is 1 month. This is a problem.

Thank you