Yale-NUIST Center on Atmospheric Environment

Simulation of surface energy fluxes and stratification of the BFG Site in Lake Taihu by three lake models

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Outline

- Background
- Lake models
- Observation and model setup
- Preliminary results
- Conclusions
- On-going work

Background

- Lakes impact regional weather, and lake subroutines have been implemented in Numerical Weather Prediction models, leading to improved forcast skills (*Balsamo et al., 2012*). However, in climate application and limnological studies, we need know model peculiarities when adoping a particular lake model to a given lake.
- Some studies devoted to apply a set of 1-D models to Lake Sparking, Kossenblatter , Valkea-Kotinen (*Stepanenko et al., 2011*), and captured well both the seasonal and diurnal cycles of surface temperature. To the contrary, the discrepancy between water temperatures below the surface calculated by different models increased. Because the vertical temperature profile is largely influenced by turbulent diffusivity.
- Lake Taihu has two specials: (1) a large and shallow freshwater lake, (2) the east of Lake Taihu is dominated by submerged macrophytes.
- So the aim is to reveal these peculiarities for Lake Taihu and assess the significance of the phenomenon for lake model.

Lake models

Table 1 Comparison between different lake model's Parameterization schemes

Lake model	Vertical structure / number of layers	Parameterisation of turbulent fluxes at the lake-atmosphere interface	Turbulent mixing Parameterisation	Treatment of heat flux at the water-bottom sediments interface
CLM4-LISSS, Subin et al., 2012	Multilayer/10 layers	An extended scheme from CLM4 model, MOST	Henderson-Sellers parameterisation of eddy diffusivity, buoyant convection	Heat conductance in bottom sediments
k-ε lake model, Herb, 2005	Multilayer/50 layers	Empirical equations	Calculate eddy diffusivity using TKE	Zero heat flux
LAKE, Stepanenko et al., 2011	Multilayer/10 layers	Monin-Oboukhov similarity theory	Calculate eddy diffusivity using TKE	Heat conductance in bottom sediments

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
- $L\downarrow$: incoming longwave radiation
- $L\uparrow$: outgoing 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 T, TKE and dissipation(ε) :

k-ε lake model

$$\frac{\partial T}{\partial t} = \frac{\partial}{\partial z}\left(K_z \frac{\partial T}{\partial z}\right) + \frac{S}{c\rho}$$

- $\frac{\partial}{\partial z}\left(K_z \frac{\partial T}{\partial z}\right)$: vertical turbulent diffusion
- $\frac{S}{c\rho}$: Solar radiation penetrated into water

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

- $\frac{\partial}{\partial z}\left(K_z \frac{\partial E}{\partial z}\right)$: vertical turbulent diffusion
- B: buoyancy
- ε: dissipation

$$\varepsilon = \hat{a} C_D E^{3/2}$$

where, $B = K_z \alpha g \frac{\partial T}{\partial z}$

LAKE model

$$\frac{\partial T}{\partial t} = \frac{\partial}{\partial z}\left(\nu + \frac{\nu_t}{\sigma_T}\right)\frac{\partial T}{\partial z} + \frac{\partial S}{c\rho \partial z}$$

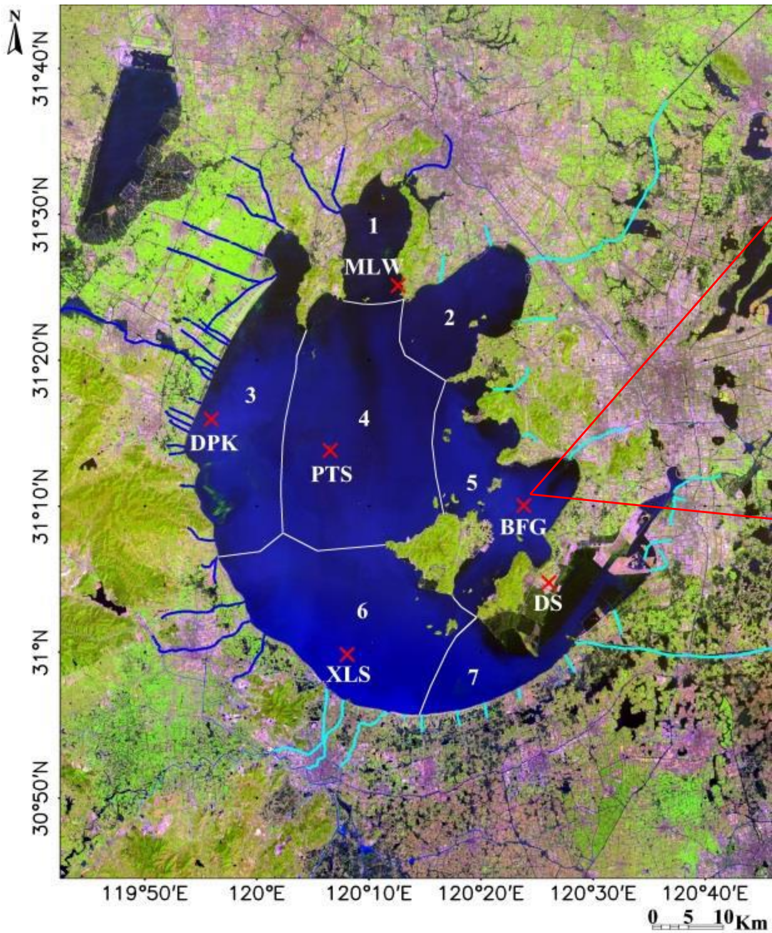
$$\frac{\partial E}{\partial t} = \frac{\partial}{\partial z}\left(\nu + \frac{\nu_t}{\sigma_K}\right)\frac{\partial E}{\partial z} + P + B - \varepsilon$$

- P: shear production

$$\frac{\partial \varepsilon}{\partial t} = \frac{\partial}{\partial z}\left(\nu + \frac{\nu_t}{\sigma_\varepsilon}\right)\frac{\partial \varepsilon}{\partial z} + \frac{\varepsilon}{k}(c_{1\varepsilon}P + c_{3\varepsilon}B - c_{2\varepsilon}\varepsilon)$$

where , $p = \nu_t\left[\left(\frac{\partial u}{\partial z}\right)^2 + \left(\frac{\partial v}{\partial z}\right)^2\right]$, $B = -\nu_{t,\rho}\frac{g}{\rho_0}\frac{\partial \rho}{\partial z}$, $\nu_t = C_t\frac{k^2}{\varepsilon}$, $\nu_{t,\rho} = C_{t,\rho}\frac{k^2}{\varepsilon}$

Observation data



Site: BFG

Time: August, 2013

Data sources:

- micrometeorology system
- temperature probes
- eddy covariance system

Fig.1 the location of BFG site in Lake Taihu (from Lee et al.,2014)and photograph showing submerged macrophytes

Model setup

Table2 Model parameter values

	CLM4-LISSS	k-ε lake model	LAKE model
August in 2013			
water light extinction coefficient（m^{-1}）	3	1	3
plant light extinction coefficient（m^{-1}）	----	2	----
plant height（m）	----	1.7	----
eddy diffusivity（$m^2 s^{-1}$）	1.4%Ke	----	----

Preliminary results

- Surface energy fluxes
- Temperature profiles
- Eddy diffusion

The energy balance equation: $\beta R_S + (L\downarrow - L\uparrow) = H + LE + Q_g$

Heat storage: $Q = (1-\beta)R_S + Q_g$

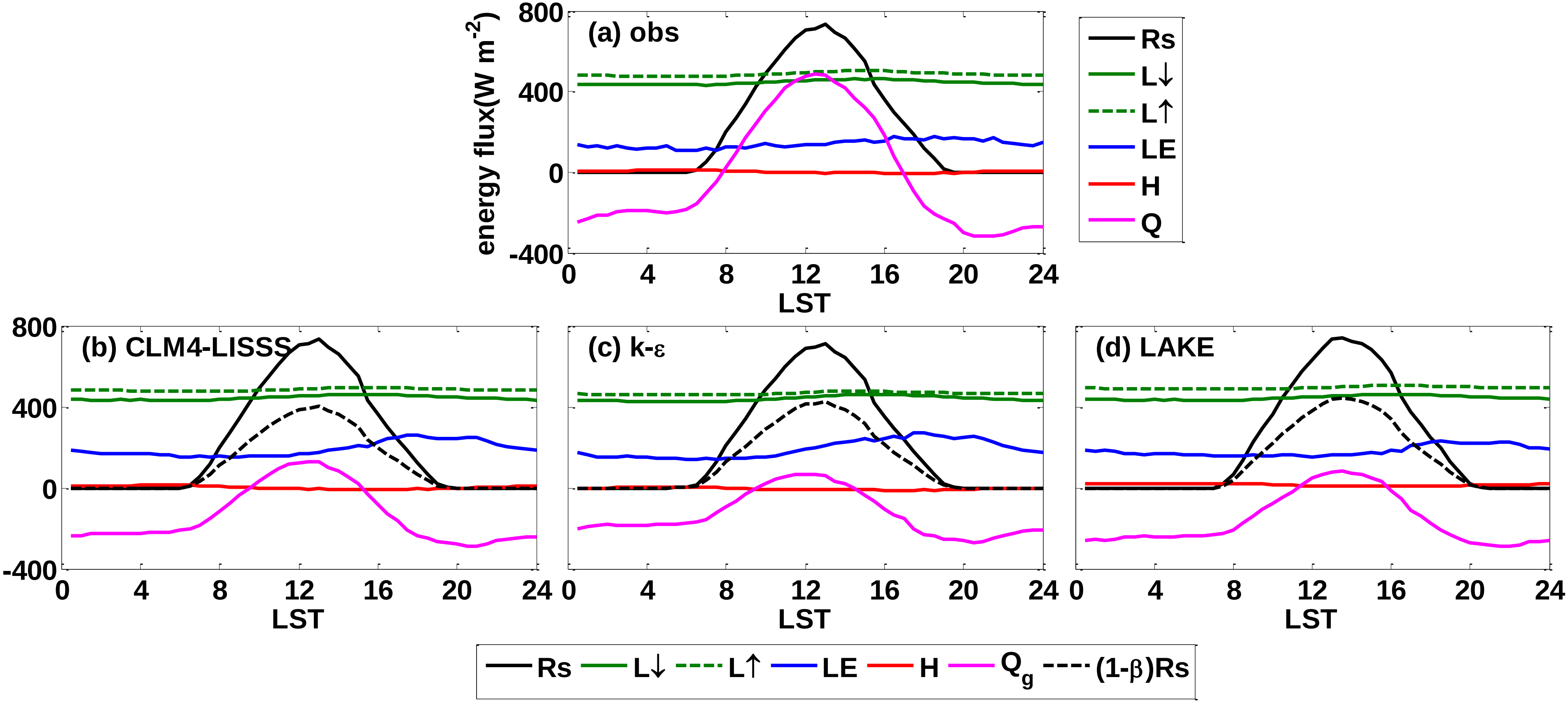


Fig.2 Diurnal composite of radiation and energy balance components for August 2013:(a) observation, simulation of CLM4-LISSS (b), k-ε lake model (c) and LAKE model (d)

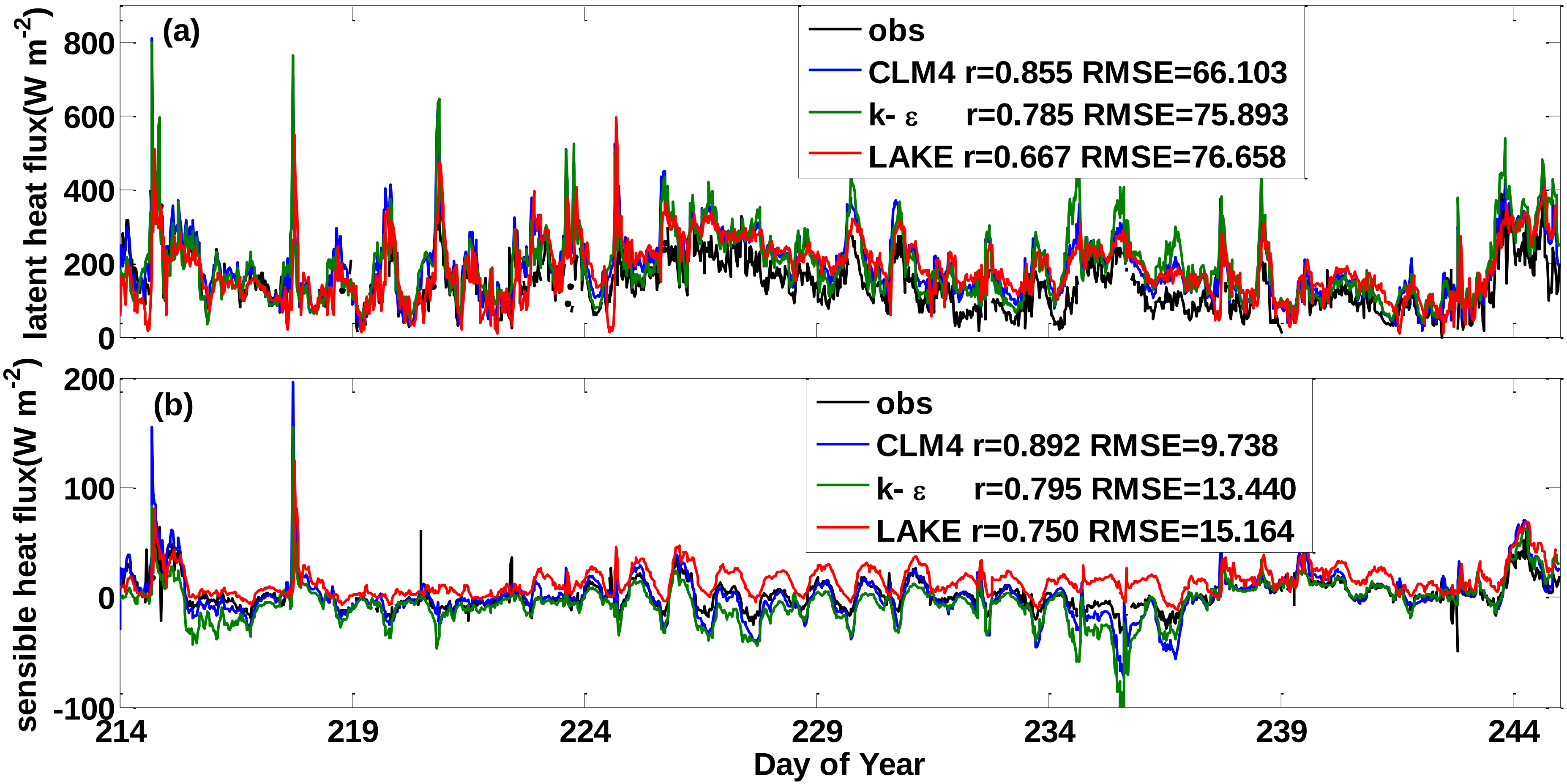


Fig.3 Comparison between the observed and the model-predicted (a) latent heat flux and (b) sensible heat flux in August 2013

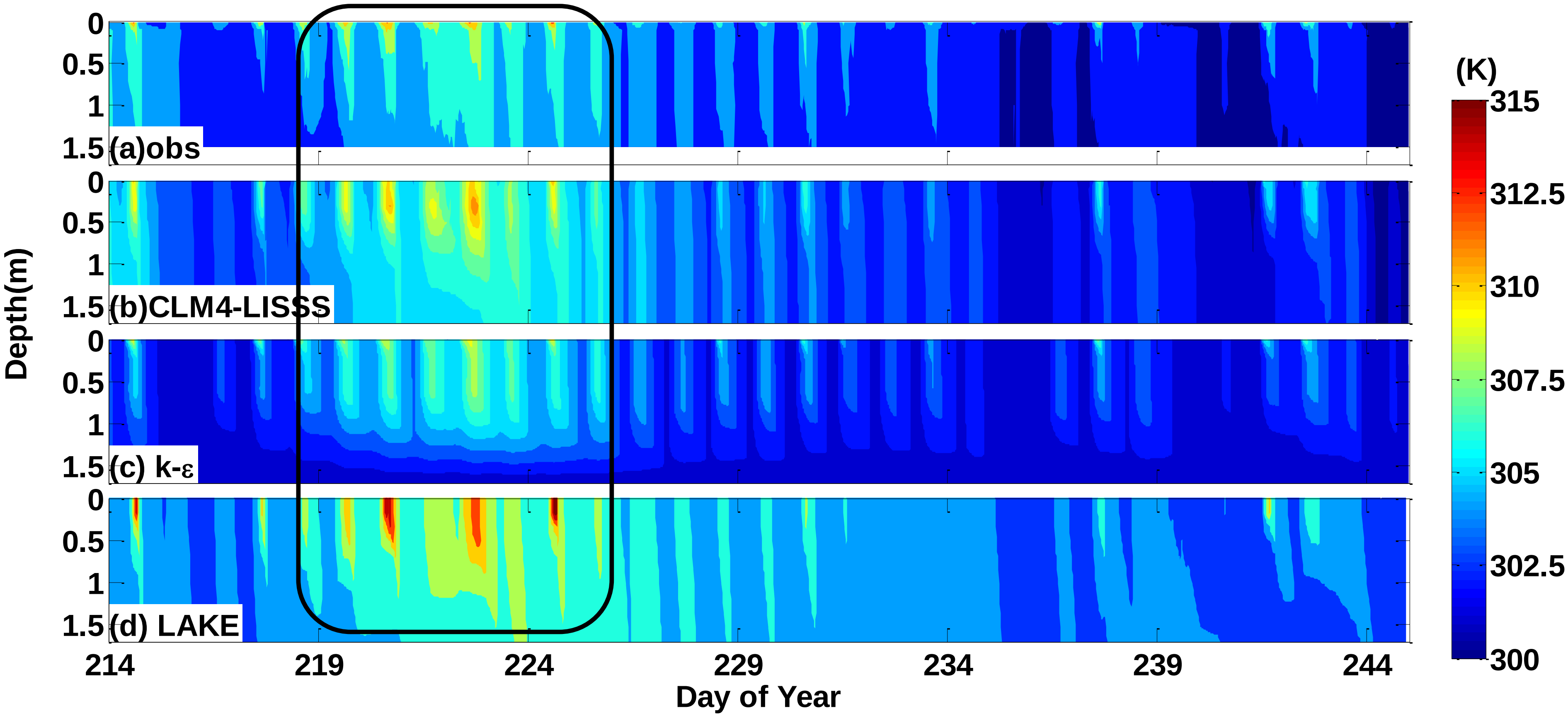


Fig.4 Temperature comparison for August 2013: contour plot of (a) observed temperature, simulated temperature by (b) CLM4-LISSS, (c) k –ε lake model and (d)LAKE model

Table 3 The correlation coefficient and root-mean-square errors of measured and predicted at BFG site in August, 2013

	CLM4-LISSS		k-ε lake model		LAKE model	
	r	RMSE (K)	r	RMSE (K)	r	RMSE (K)
Surface temperature	0.95	1.04	0.94	1.38	0.87	1.70
Temperature at 20cm	0.93	1.42	0.92	1.09	0.91	1.81
Temperature at 50cm	0.92	1.55	0.91	0.90	0.91	1.84
Temperature at 100cm	0.93	1.33	0.90	1.07	0.89	1.70
Temperature at 150cm	0.90	1.54	0.92	1.88	0.86	1.78

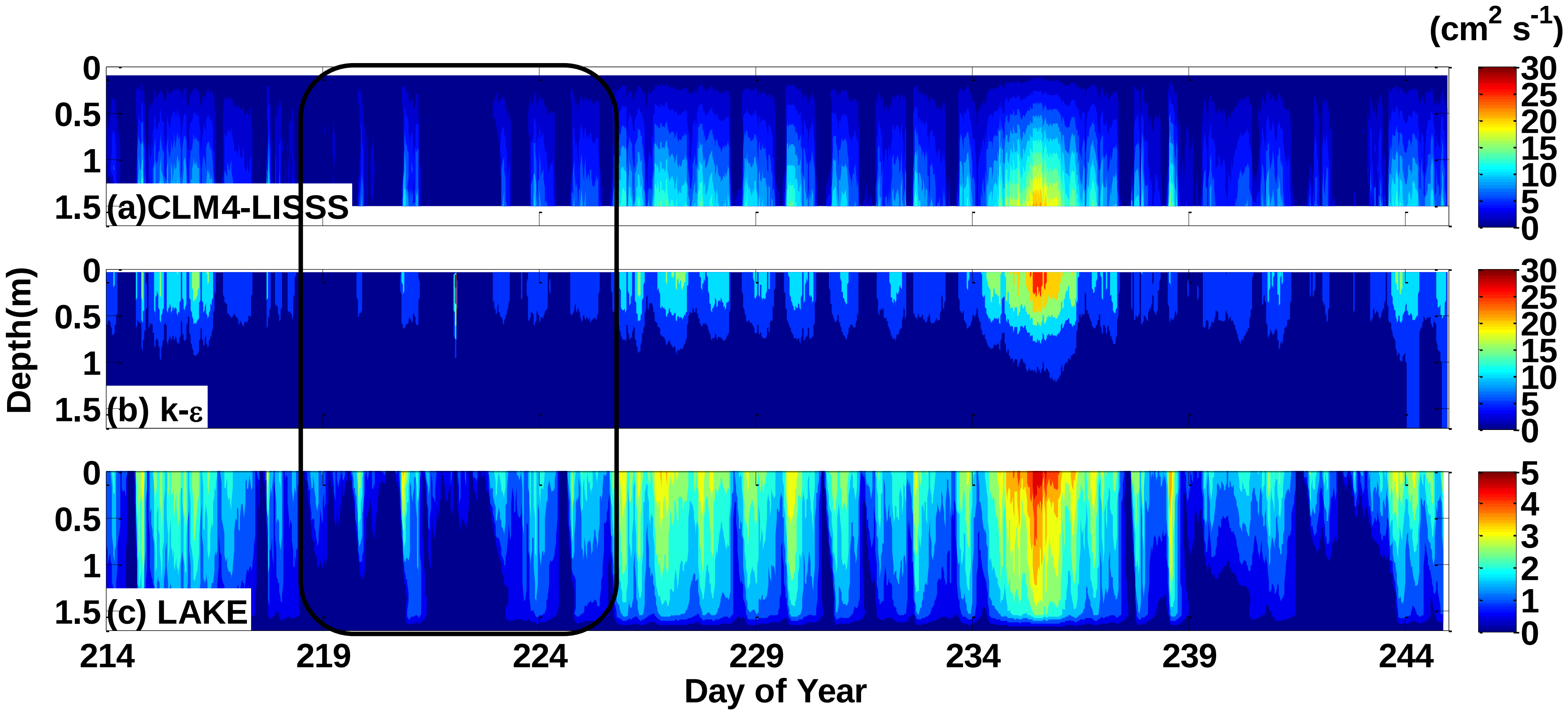


Fig.5 Contour plot of eddy diffusivity calculated by (a) CLM4-LISSS, (b) k – ε lake model and (c) LAKE model

Calculate turbulent diffusivity in CLM4-LISSS

eddy diffusivity: $k_e = \frac{kw^* z_i}{P_0(1+37Ri^2)} exp(-k^* z_i)$

Richardson number:

$$\begin{cases} R_i = \dfrac{-1+\sqrt{1+\dfrac{40N^2k^2z_i^2}{w^{*2}\exp(-2k^*z_i)}}}{20} \\ R_i = -0.05 \end{cases}$$

Where, $N^2 = \frac{g}{\rho_i}\frac{\rho_{i+1}-\rho_i}{z_{i+1}-z_i}$;

$w^* = 0.0012u_2; k^* = 6.6u_2^{-1.84}\sqrt{|sin\phi|};\ u_2 = \frac{u_*}{k}\ln(\frac{2}{z_{0m}})$

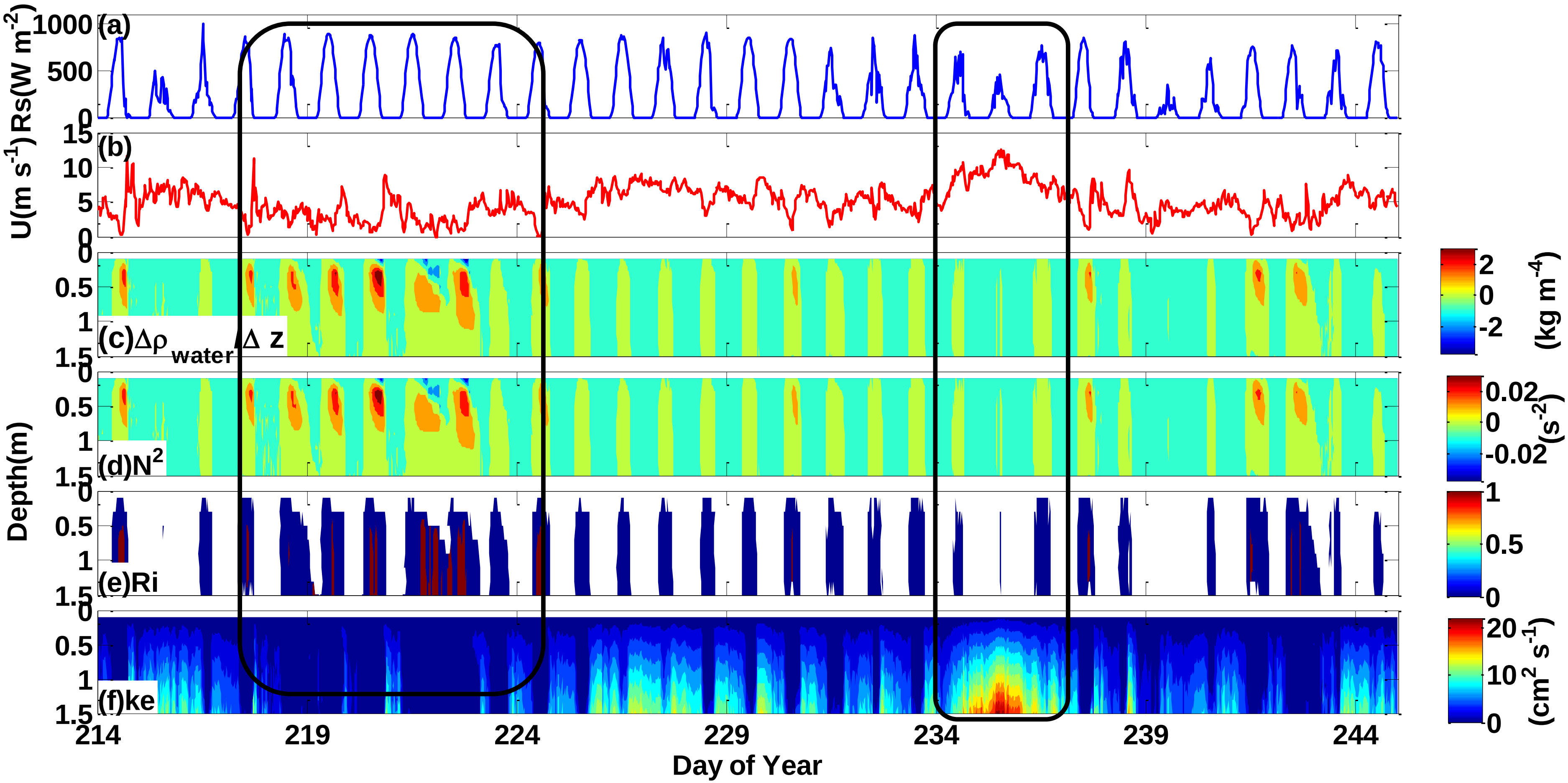


Fig.6 Time series for DOY 214 – 245 (2013) at BFG sites: (a) net solar radiation, (b) wind speed, (c) water density difference versus depth, (d) N^2, (e)Richardson number and (f) eddy diffusion

Calculate turbulent diffusivity in LAKE

$$ke=\frac{TKE^2}{\varepsilon}$$

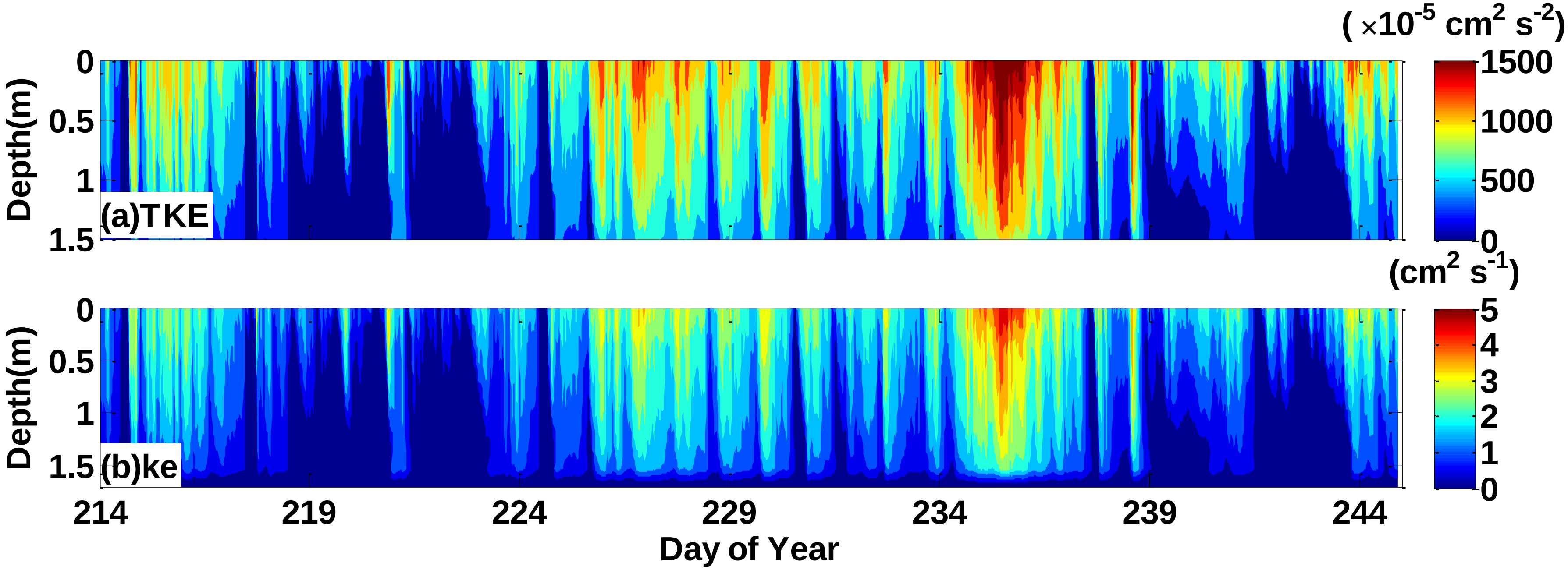


Fig.7 Contour plot of (a) turbulent kinetic energy and (b) eddy diffusivity by LAKE model

Conclusions

- The energy fluxes distributions of three lake models are nearly the same. Compared with k-ε lake model and LAKE model, CLM4-LISSS has best performance on latent heat flux and sensible heat flux.
- The vertical temperature profile in Lake Taihu is largely influenced by turbulent diffusivity. The results from CLM4-LISSS model correspond reasonably well to the observations.

On-going work

- Find the rationality of turbulent diffusivity output in CLM4-LISSS
- Simulate long-term (2012-2016) evaporation for BFG site by CLM4-LISSS .
- Compare and discuss the simulated evaporation by CLM4-LISSS under different scenarios (RCP2.6, RCP4.5, RCP6.0 and RCP8.5).

Thank you