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Thermal structure of a shallow lake with submersed macrophytes: a case study of Lake Taihu

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Outline

1. Background

2. Methods and Data
- ✓ model description
- ✓ model development
- ✓ Sensitivity analysis

3. Two Lake Models Comparison

4. On-going work

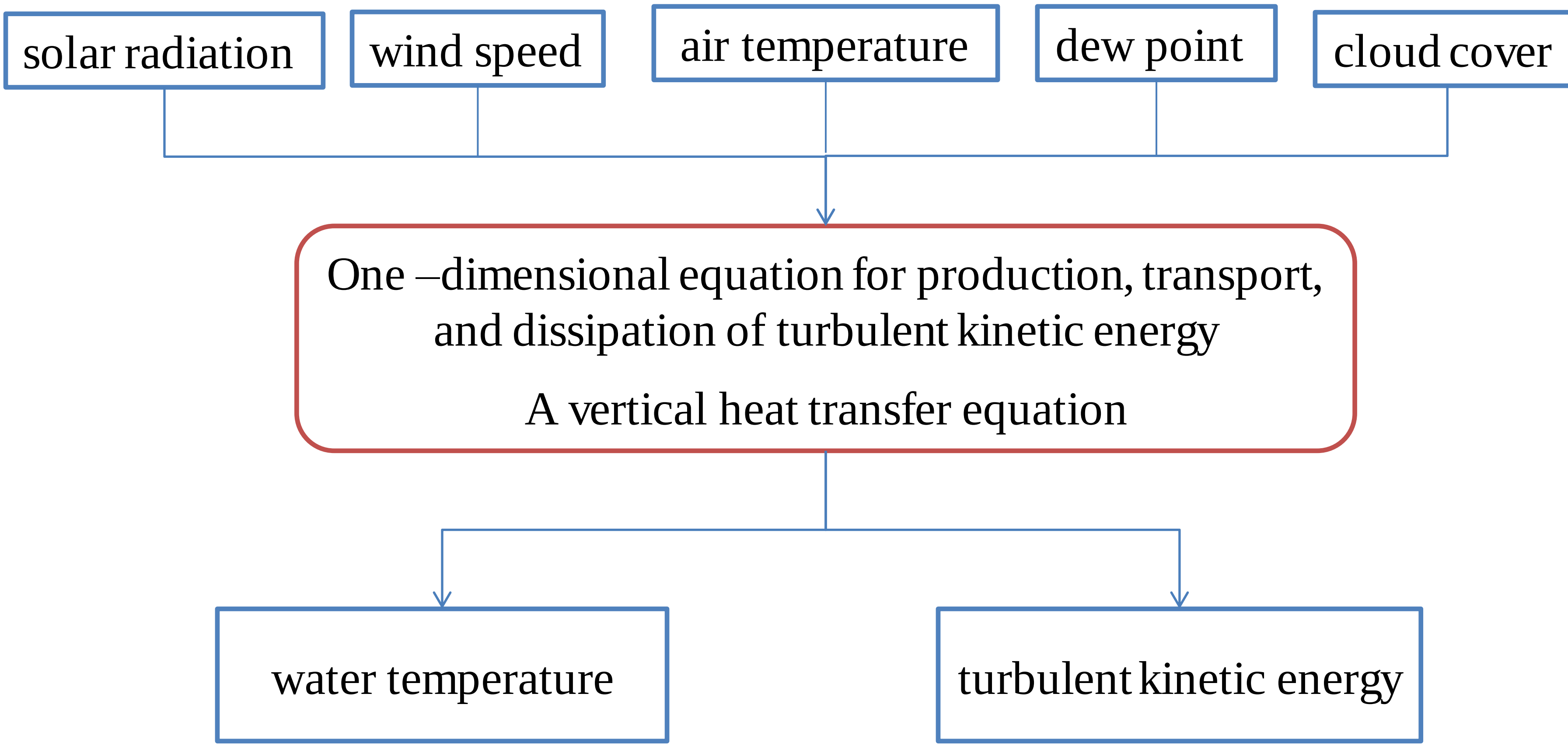
Background

- The vertical eddy diffusivity is important for the description of the vertical transfer of substance in various numerical models. Bin Deng et al. parameterized the eddy diffusivity k_e . Piao Meihua evaluated the performance of the calibrated CLM4-LISSS across the BFG site, the effect of macrophytes is not considered.

- Willian R. Herb et al. developed and explored a mechanistic model of stratification and vertical diffusion in a shallow lake with rooted plants. This model is based on coupled equations for heat transfer and turbulent kinetic energy. *(Willian R. Herb et al.,2005).*

Methods and Data

- E-ε closed lake model description



Q_o is the heat transfer rate at the water surface

$$Q_o = Q_s + Q_a - Q_c - Q_e - Q_b$$

Q_s : net solar radiation

Q_a : long-wave atmospheric radiation

Q_c : sensible heat flux Q_e : latent heat flux

Q_b : back radiation

$$Q_c = 0.47 f(W)(T_s - T_a)$$

$$Q_e = \beta_e f(W)(T_s - T_d)$$

$$f(W) = 20.6 \times (9.2 + 0.46W^2)$$

$$\beta_e = 0.35 + 0.015\left(\frac{T_d + T_s}{2}\right) + 0.0012\left(\frac{T_d + T_s}{2}\right)^2$$

W: wind speed *Ts*: surface water temperature

Ta: air temperature *Td*: dew point temperature

A one-dimensional heat transfer equation which is coupled to the TKE equation :

$$\frac{\partial T}{\partial t} = \frac{\partial}{\partial x}\left(K_z \frac{\partial T}{\partial z}\right) + \frac{H}{\rho c_p}$$

ρ: the density c_p: specific heat of water

H: internal heat generation from solar radiation

$$H(z) = (1-\alpha_l)(1-\beta)I_s exp(-(K_{wc} + K_m p)z)$$

α_1: the albedo

β: the IR fraction of total radiation

K_{wc}: the light attenuation coefficient for water plus dissolved and suspended substances

K_m: the specific light attenuation coefficient for macrophytes

p : the plant mass per unit volume

An equation for production, diffusion, and dissipation of TKE (turbulent kinetic energy).

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

E: turbulent kinetic energy per unit mass

K_z: vertical turbulent diffusion coefficient

g: acceleration of gravity α: the thermal expansion coefficient

t: time z: depth ε: dissipation

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

$\hat{a}$: the plant surface area per unit volume C_D: the total drag coefficient

$$\hat{a} = 0.05p$$

p is the plant mass per unit volume

$$K_z = C_k Z_m \sqrt{E}$$

C_k: a constant of the order of 0.1

Z_m: the mixed layer depth

Observation Data

Site: BFG

Time: August, 2013

Data sources:

- micrometeorology system
- China meteorological data sharing service system
- temperature probes
- eddy covariance system

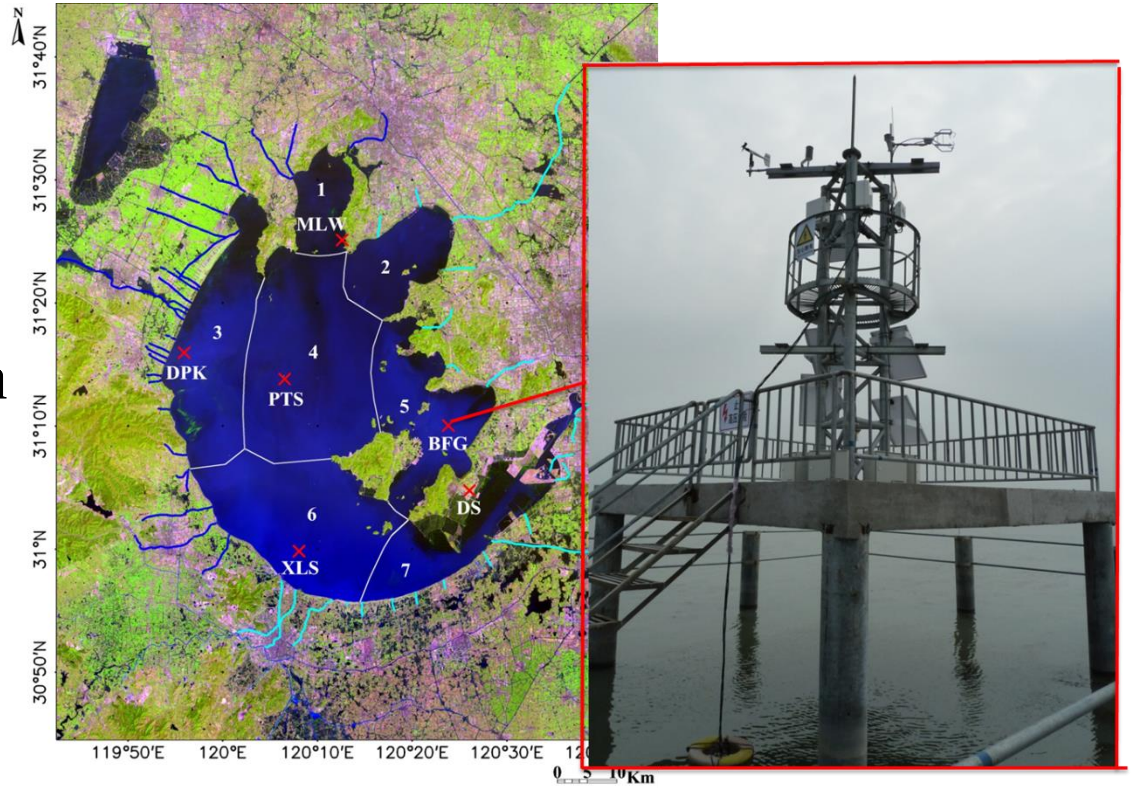


Table 1. Model parameter values

Parameter	Description	Nominal Value (units)	source
T_{sed}	Temperature at sediment/water interface	30.49℃	measured
K_{wc}	light attenuation coefficient for water	$2m^{-1}$	calibrated
K_m	specific light attenuation coefficient for macrophytes	$0.02m^2gdw^{-1}$	*Westlake* [1964]
P	macrophyte biomass density	$300gdwm^{-3}$	calibrated
h	macrophyte stand height	1.2m	calibrated
d	water depth	2 m	measured
C_k	mixing length coefficient	0.1	*Herb* [2005]
C_D	drag coefficient	1.0	*Finnigan* [2000]
K_h	hypolimnetic diffusivity	$0.03m^2d^{-1}$	*Herb* [2005]
C_w	wind correction coefficient	1.0	
nz	number of discrete depth increments	50	
Δt	time increment	30 min	

Model development

- Introducing the observed temperature at sediment-water interface(T_{sed}) into model.
- Introducing the water temperature profile of initial field.

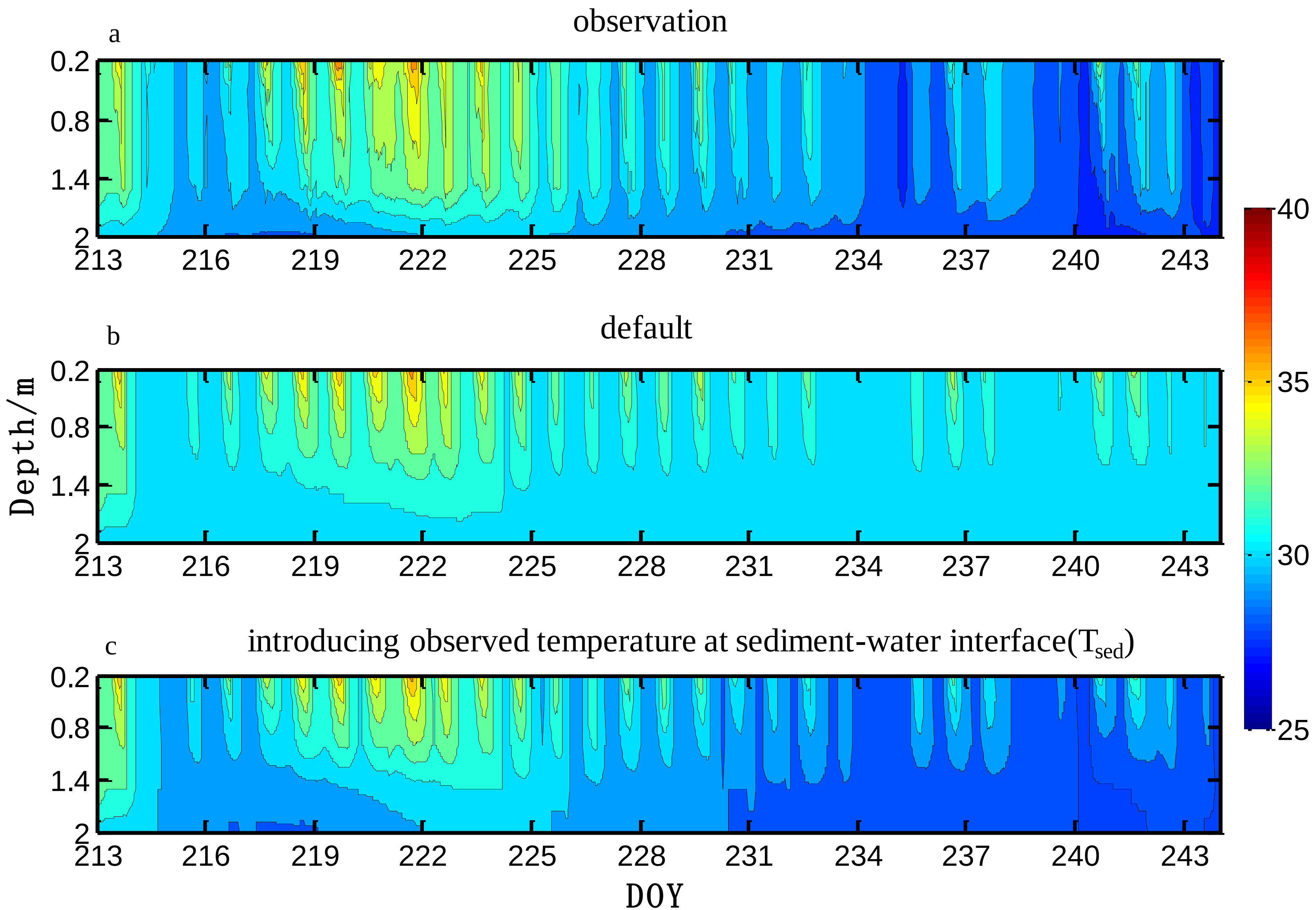


Figure 1. Temperature comparison for DOY 213-243, 2013

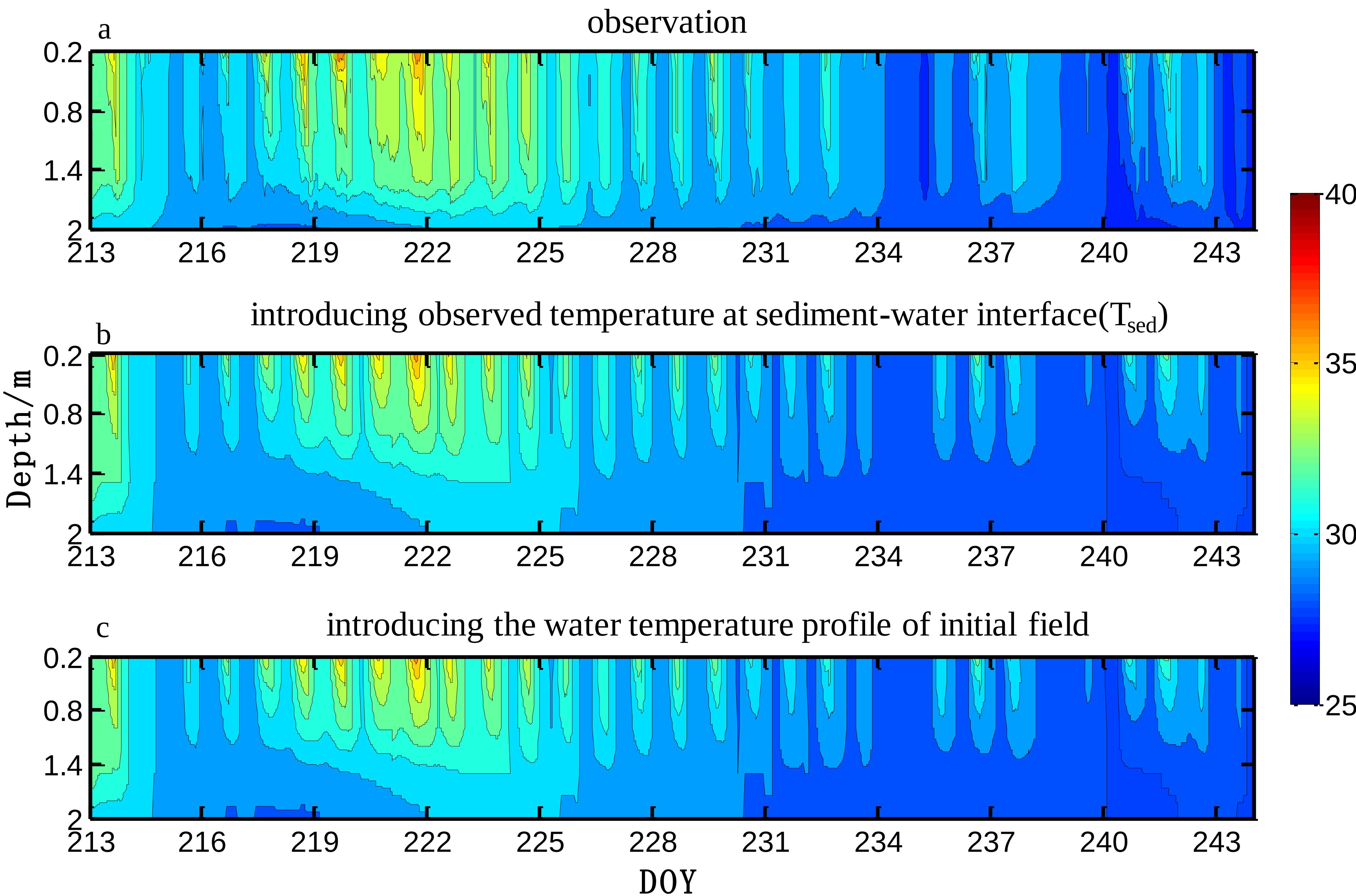


Figure 2. Temperature comparison for DOY 213-243, 2013

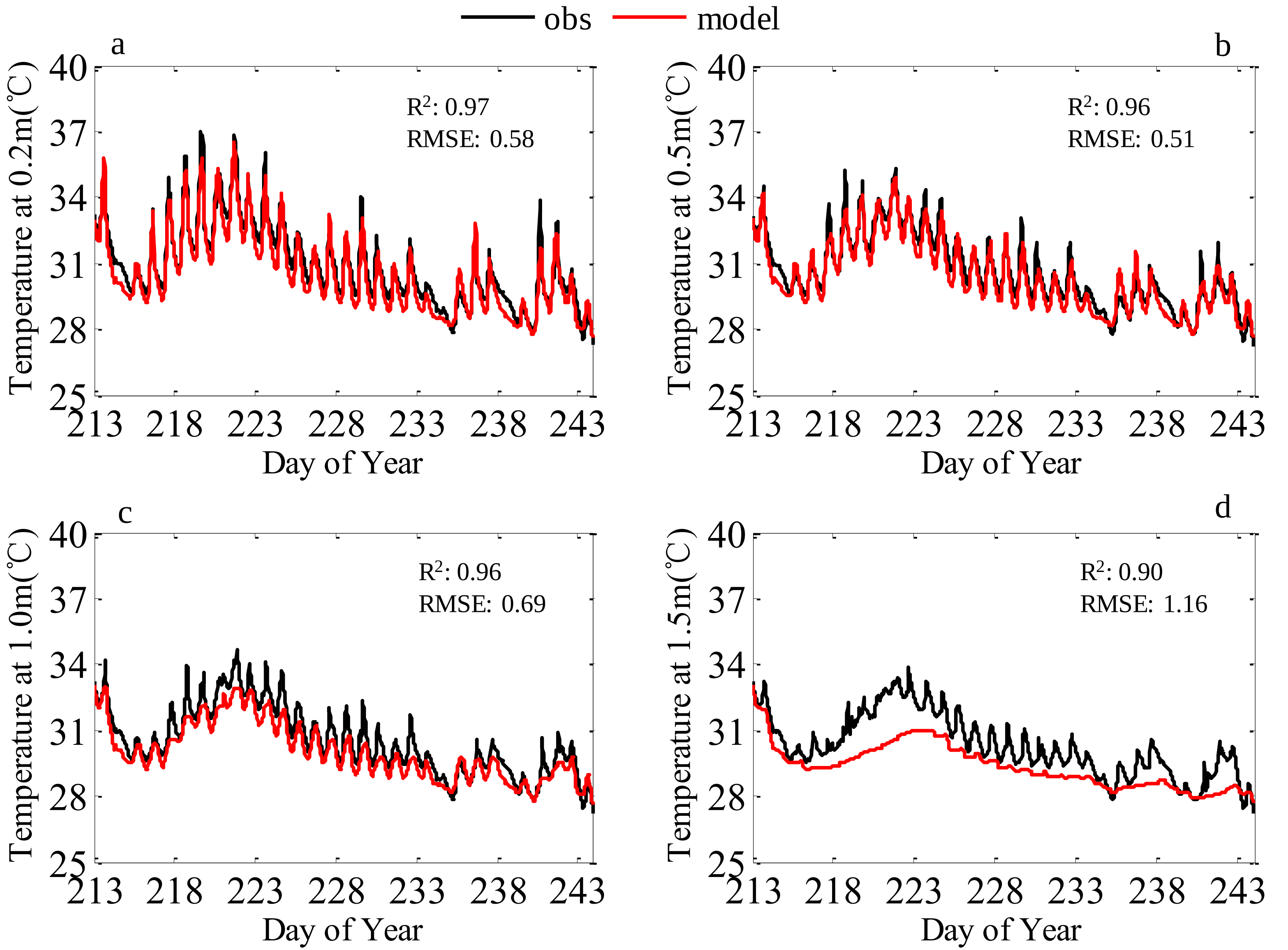


Figure 3: Temperature versus time and depth for BFG site for DOY 213-243, 2013. Measured water temperatures and model simulations.

Sensitivity analysis

- Macrophyte stand height (*MH*)

  MH: 0.2m, 1.2m, 1.6m, 2.0m

- Macrophyte biomass density(*P*)

  P: 0gDW/m^3, 100gDW/m^3, 300gDW/m^3

- Mixing length coefficient(C_k)

  C_k: 0.1, 3.0, 5.0

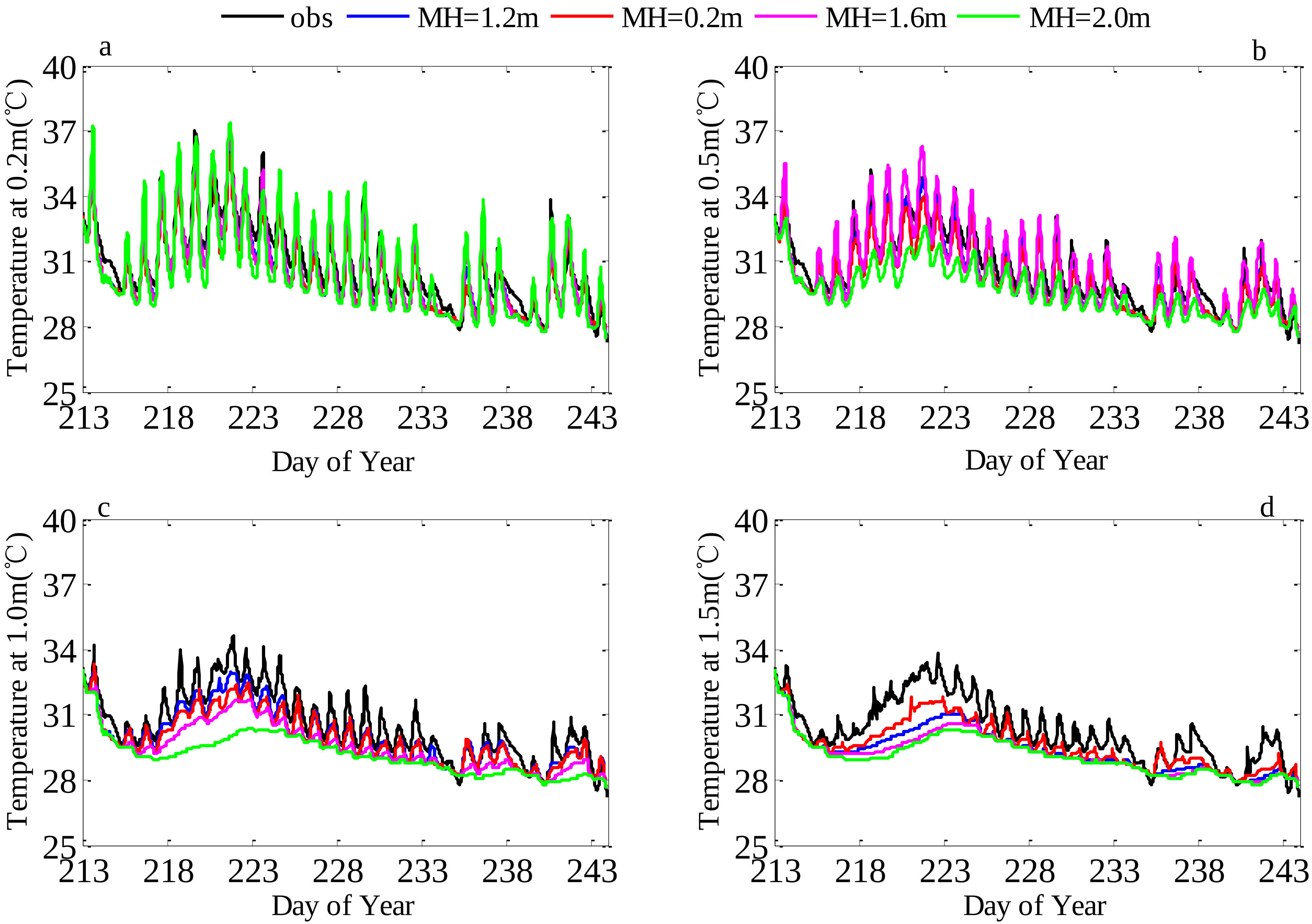


Figure 4. water temperature versus time for macrophyte stand height *MH*=0.2, 1.2, 1.6, 2.0m at different depth for DOY 213-243, 2013.

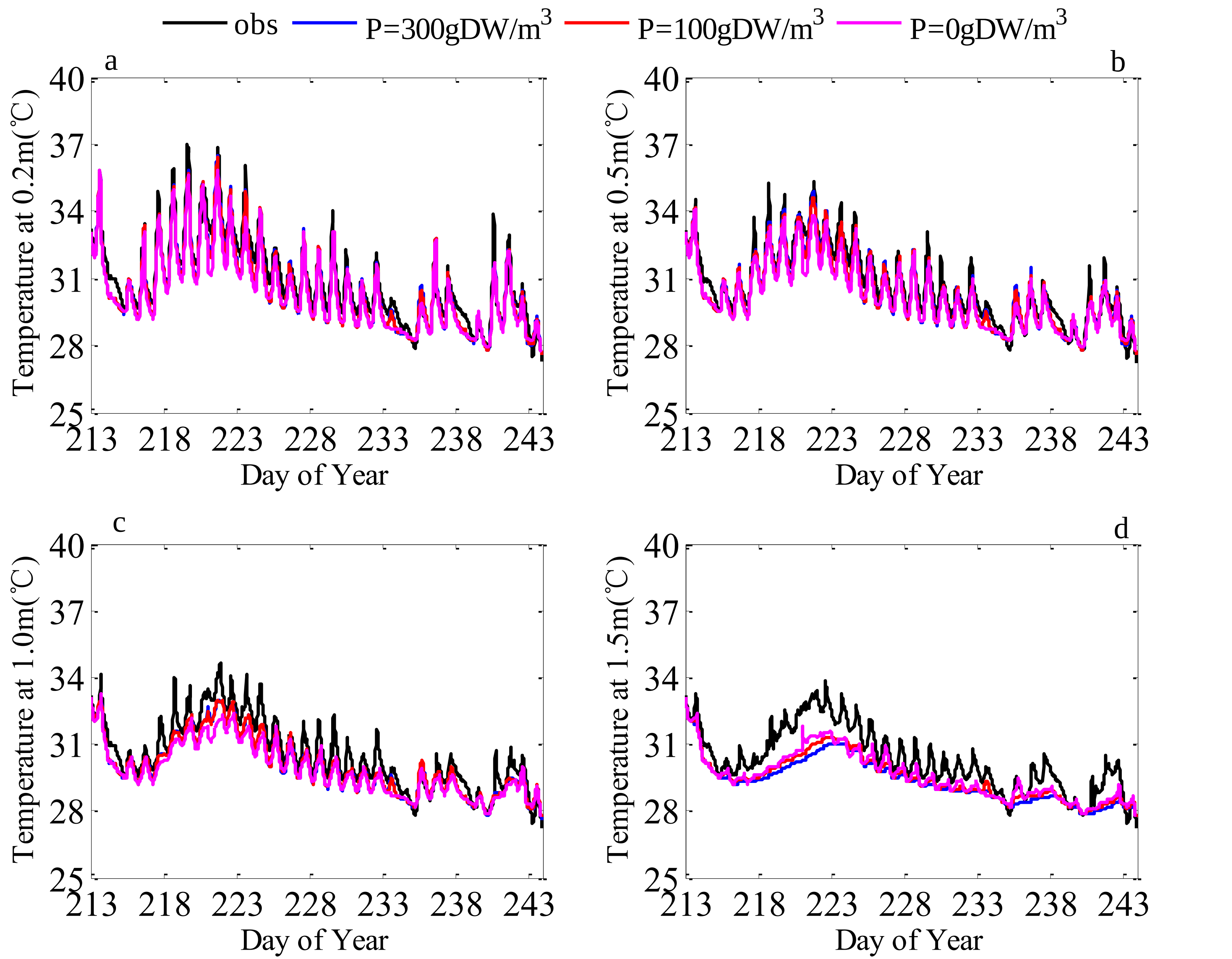


Figure 5. water temperature versus time for macrophyte biomass density P =0gDW/m^3, 100gDW/m^3, 300gDW/m^3 at different depth for DOY 213-243, 2013.

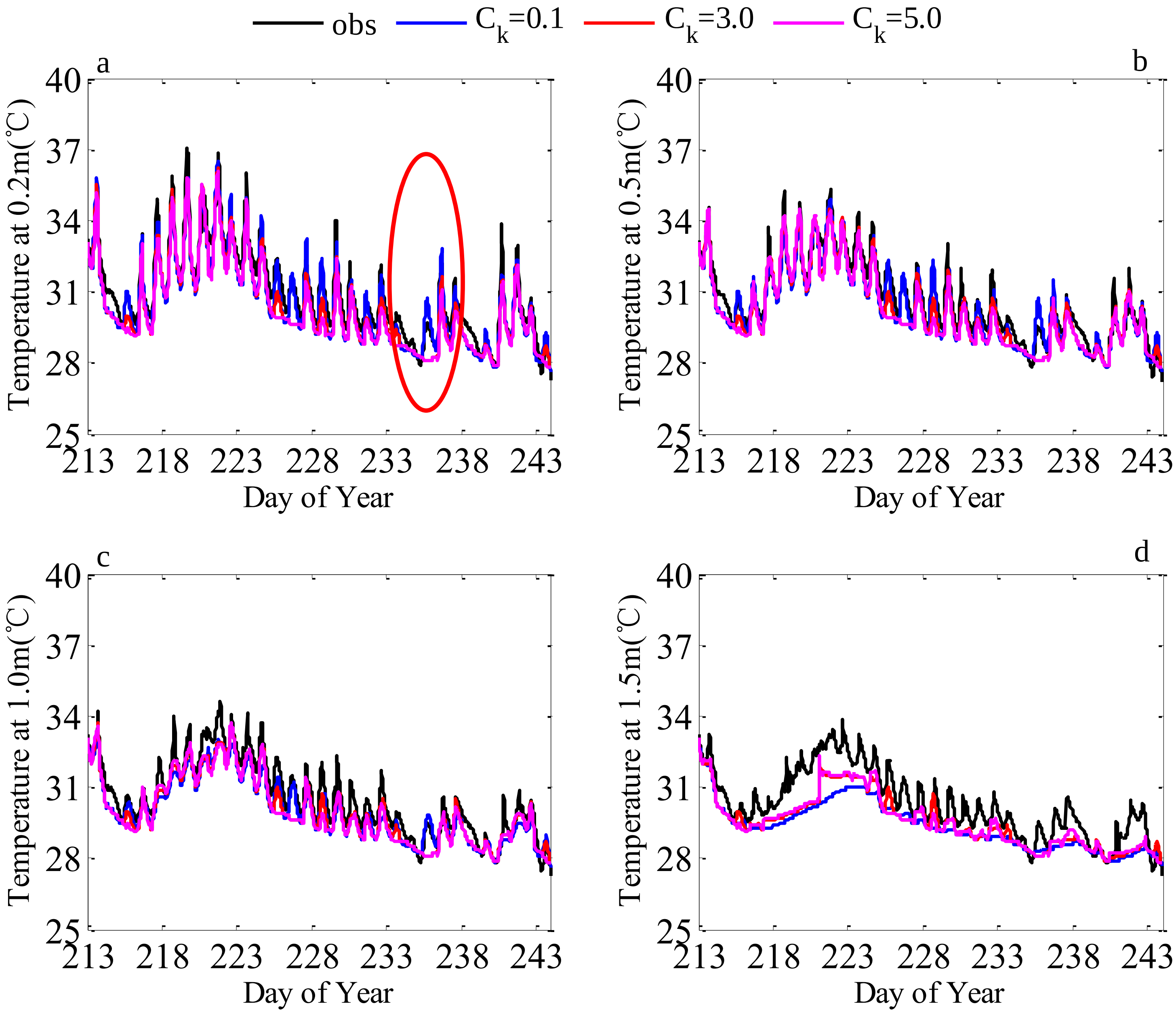


Figure 6. water temperature versus time for mixing length coefficient C_k=0.1, 3.0, 5.0 at different depth for DOY 213-243, 2013.

Two Lake Models Comparison

- Water temperature
- Sensible heat flux
- Latent heat flux
- u_*

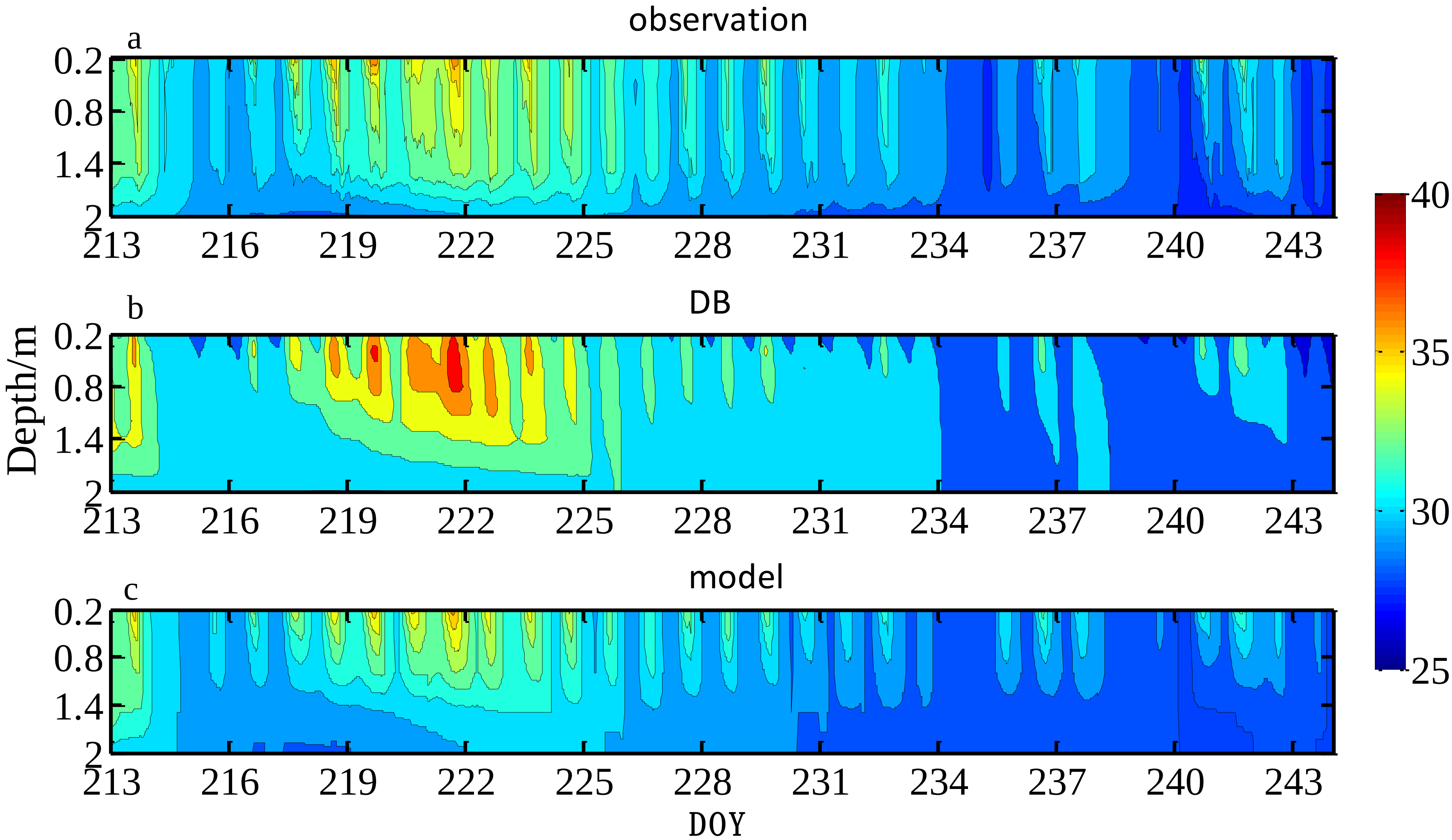


Figure 7. Comparison between the observed and the model-predicted water temperature from DOY 213 to DOY 243,2013

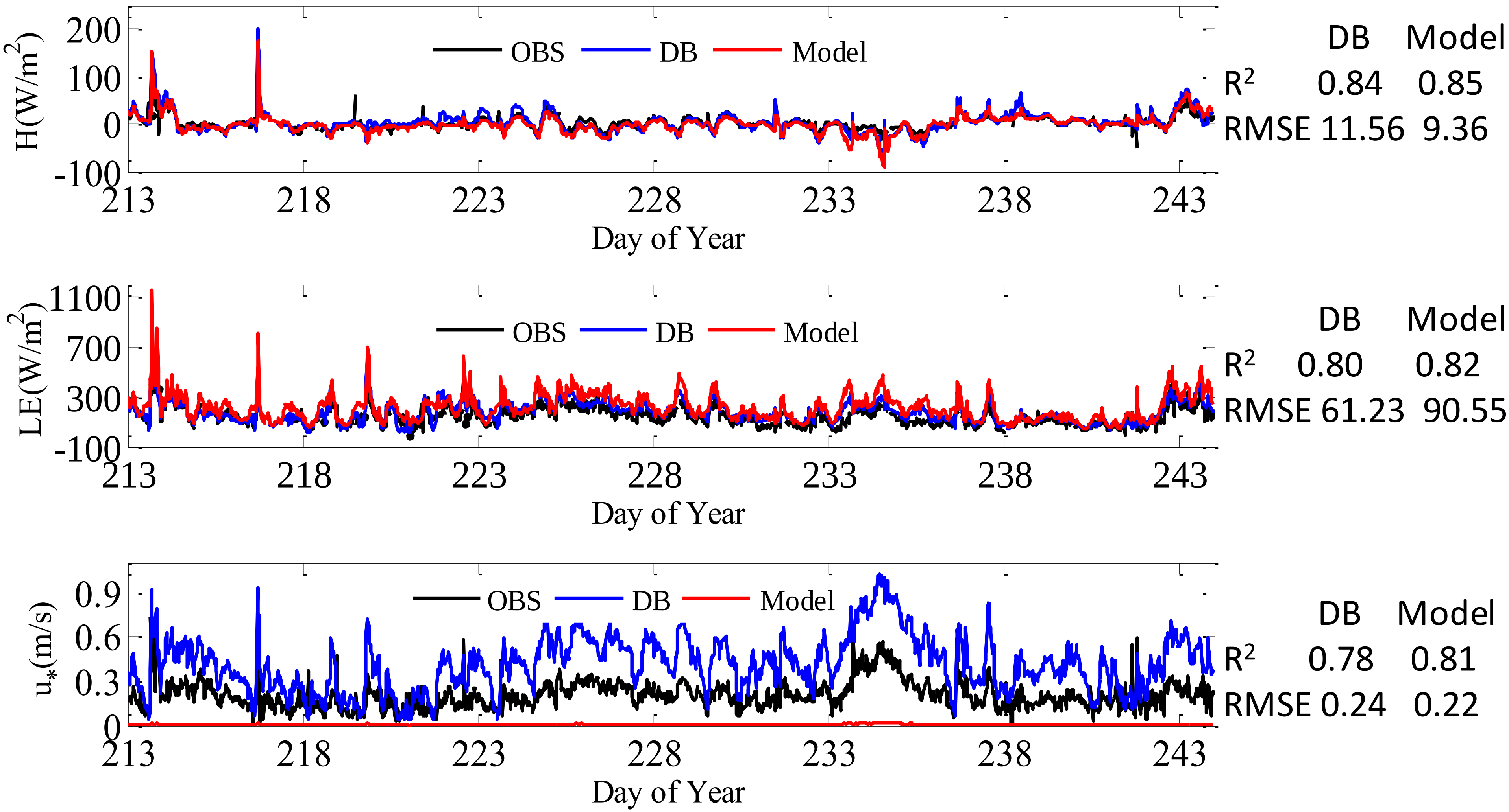


Figure 8. Comparison between the observed and the model-predicted sensible heat flux, latent heat flux and friction velocity from DOY 213 to DOY 243,2013

On-going work

- Studying the thermal and dynamic characteristics of BFG site in different growing periods.

- Developing the computation modules for radiation and u_*.
- Simulating the vertical turbulent diffusivity(K_z), making comparative analysis of two model.

Thank you