Update on doctoral dissertation research: Validation of lake temperature and flux models

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Outline

- Background
- Model principle
- Motivation
- Model modification
- Preliminary results
- Future work

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Background

- Lake significantly affect the structure of atmospheric boundary layer and the surface fluxes of heat, water vapor and momentum.
- Weather and climate forecast in lake basins need to rely on lake models for surface momentum, heat and water fluxes as the boundary conditions.
- Vertical turbulent mixing is an important role in lakes, which controls the temperature profile and the distribution of dissolved oxygen, nutrients and phytoplankton.
- The structure of the hydro-dynamical part of one dimensional lake models can be classified into diffusive models with simple parameterization schemes and models based on turbulence closure schemes.

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Model principle

CLM4-LISSS model:

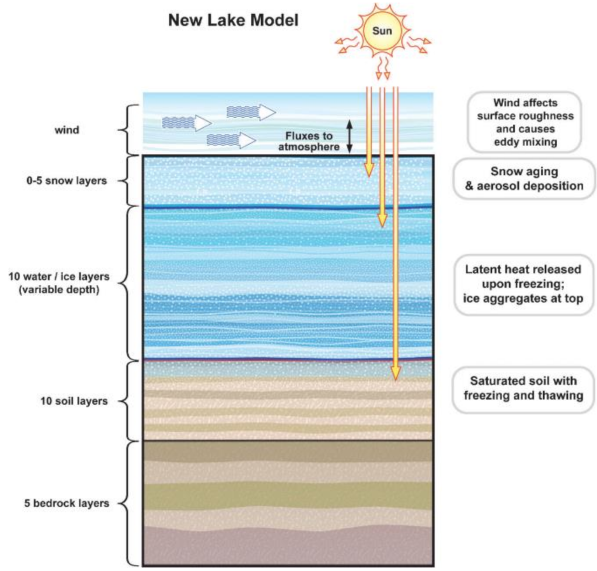

Figure 1 CLM4-LISSS model schematic (Subin 2012)

k- ε model:

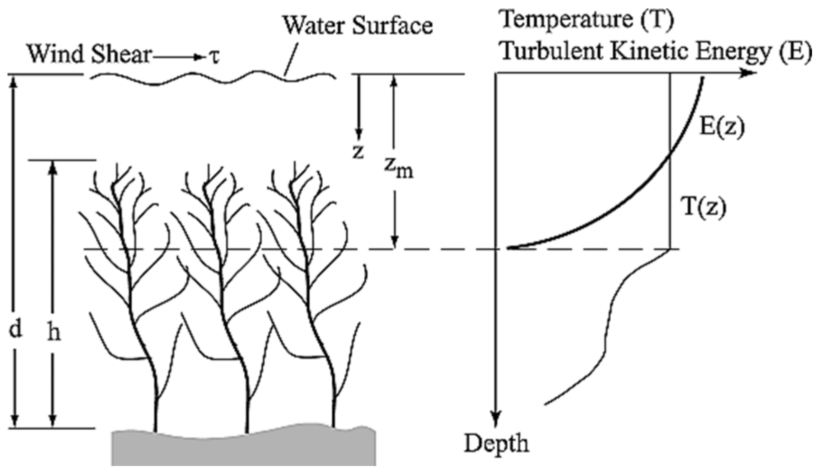

Figure 2 Parameterization of one-dimensional water column model with submerged macrophytes (Herb 2005)

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, 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 model, Herb, 2005	Multilayer/50 layers	Empirical equations	Calculate K using TKE equation	Zero heat flux

Model principle

CLM4-LISSS model:

Thermal diffusion equation: $\frac{dT}{dt} = \frac{d}{dz}\left((K_e+K_m)\frac{dT}{dz}\right) + \frac{1}{c_w}\frac{ds}{dz}$

k-ε model:

Heat transfer equation: $\frac{\partial T}{\partial t} = \frac{\partial}{\partial z}\left(K_z\frac{\partial T}{\partial z}\right) + \frac{H}{\rho c_P}$

TKE equation: $\frac{\partial E}{\partial t} = \frac{\partial}{\partial z}\left(K_z\frac{\partial E}{\partial z}\right) + K_z\alpha g\frac{\partial T}{\partial z} - 0.05PC_D E^{\frac{2}{3}}$

Data: acquired from The Taihu Eddy Flux Network, mainly BFG site from January 2012 to December 2013

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Motivation

- Validate the parameter and let k-ε model applicable in full year simulation.

- In Deng's paper, eddy diffusivity (K_e) is scaled down by a constant 2%. We need to verify whether this adjustment is appropriate by using k-ε model.

- Find out the distribution of surface eddy diffusivity (K_e) in different season and different weather condition. The diurnal variation of K_e? which meteorological factor affect variation of K_e?

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Model modification on Parameter adjustment

k- ε model:

Table 2 k-ε model parameter values

Parameter	Description	Nominal Value (units)
K_{wc}	light attenuation coefficient for water	$1\ \mathrm{m}^{-1}$
K_m	specific light attenuation coefficient for macrophytes	$0.01\ \mathrm{m}^{2}\mathrm{gDW}^{-1}$
d	water depth	2m
C_k	mixing length coefficient	0.1(Herb [2005])
C_D	drag coefficient	1.0 (Finnigan [2000])
K_h	hypolimnetic diffusivity	$0.03\ \mathrm{m}^2\ d^{-1}$(Herb [2005])
C_w	wind correction coefficient	1.0
nz	number of discrete depth increments	50
Δt	time increment	30min

month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Biomass (gdw/m^3)	0	0	0	20	40	60	80	100	75	50	25	0
Plant height (m)	0	0	0	0.32	0.64	0.96	1.28	1.6	1.2	0.8	0.4	0

CLM4-LISSS model:

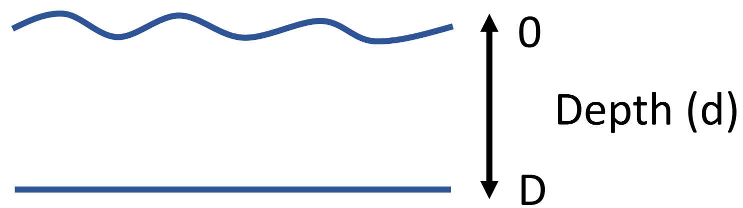
Parameter setting is roughly same with Deng's Paper

Model modification on eddy diffusivity

k- ε model: $K_z = C_k Z_m \sqrt{E}$

CLM4-LISSS model: $K_z = m_d(k_m + k_e);\ m_d$=0.02

$$K_e = K_{e0} f(R_i) \begin{cases} f(R_i) = (1 + 37R_i^2)^{-1} \\ \text{Neutral condition: } K_{e0} = k u_* z \leftarrow u_* = u_{*0}\exp(-k^* z) \leftarrow k^* = 6.6U_2^{-1.84}\sqrt{sin\varphi} \end{cases}$$



$K_{e0} = k u_* z$: $z \Downarrow D - d$

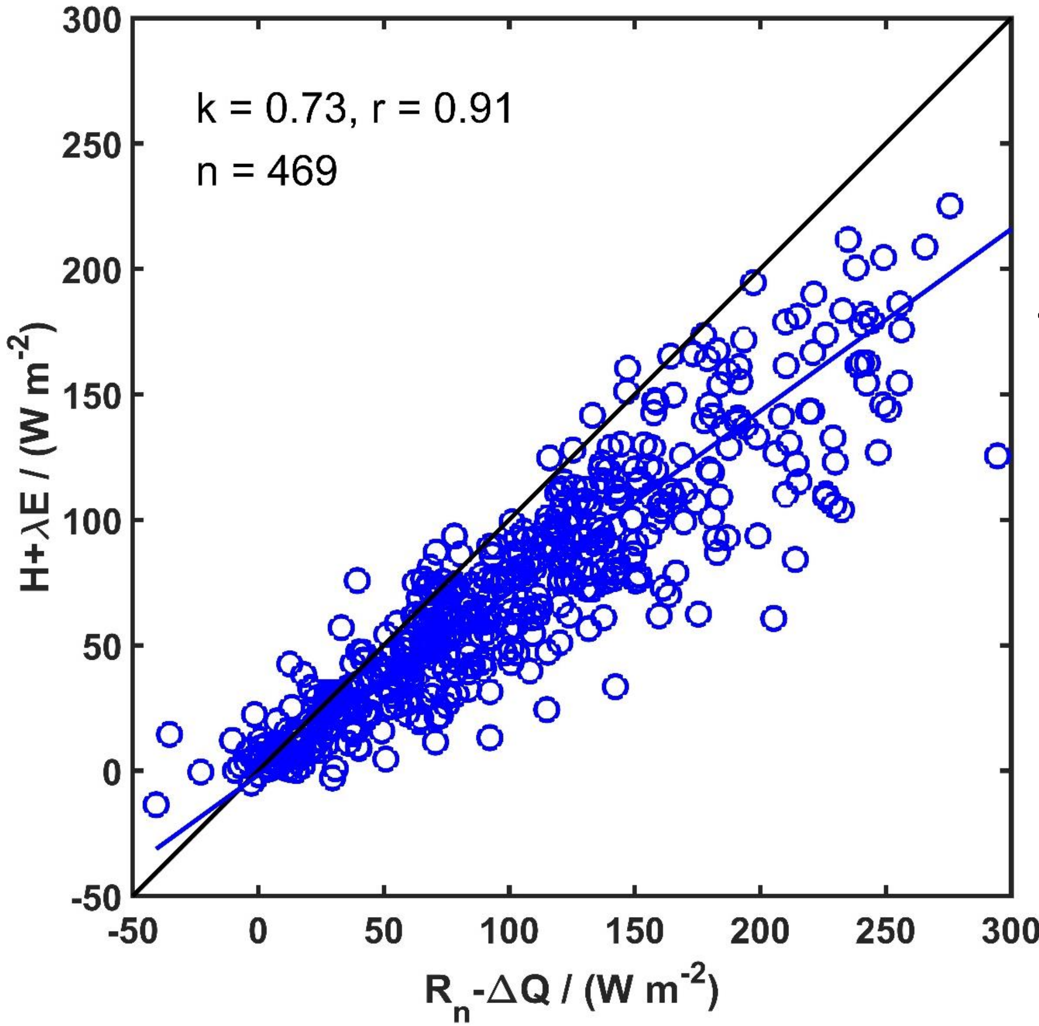
$u_* = u_{*0}\exp(-k^* z)$: $z \Downarrow d$

```
ke(j) =0.02_r8* vkc*ws(c)*z_lake(c,j)/p0 *exp(-ks(c)*z_lake(c,j)) / (1._r8+37._r8*ri(j)*ri(j))
```

$\Downarrow$

```
ke(j) =0.02_r8*vkc*ws(c)*(2-z_lake(c,j))/p0 * exp(-ks(c)*z_lake(c,j)) / (1._r8+37._r8*ri(j)*ri(j))
```

Observation modification on surface flux



Time span: January 2012-December 2013

Energy balance closure: 0.73

n=469
(if eight or more half-hour observation are missed, eliminate the day's value)

Figure 3 The relationship between daily mean surface energy fluxes and daily mean available energy

Forcing energy balance closure on daily scale

$$\beta = \frac{\mathrm{H}}{\lambda E}$$

$$\lambda E^* = \frac{R_n - \Delta Q}{1 + \beta}$$

$$H^* = R_n - \Delta Q - \lambda E^*$$

Annual mean sensible heat flux improves 2.2 W/m^2

Annual mean latent heat flux improves 28.2 W/m^2

(Twine et al., 2000)

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The Temperature Performance of model

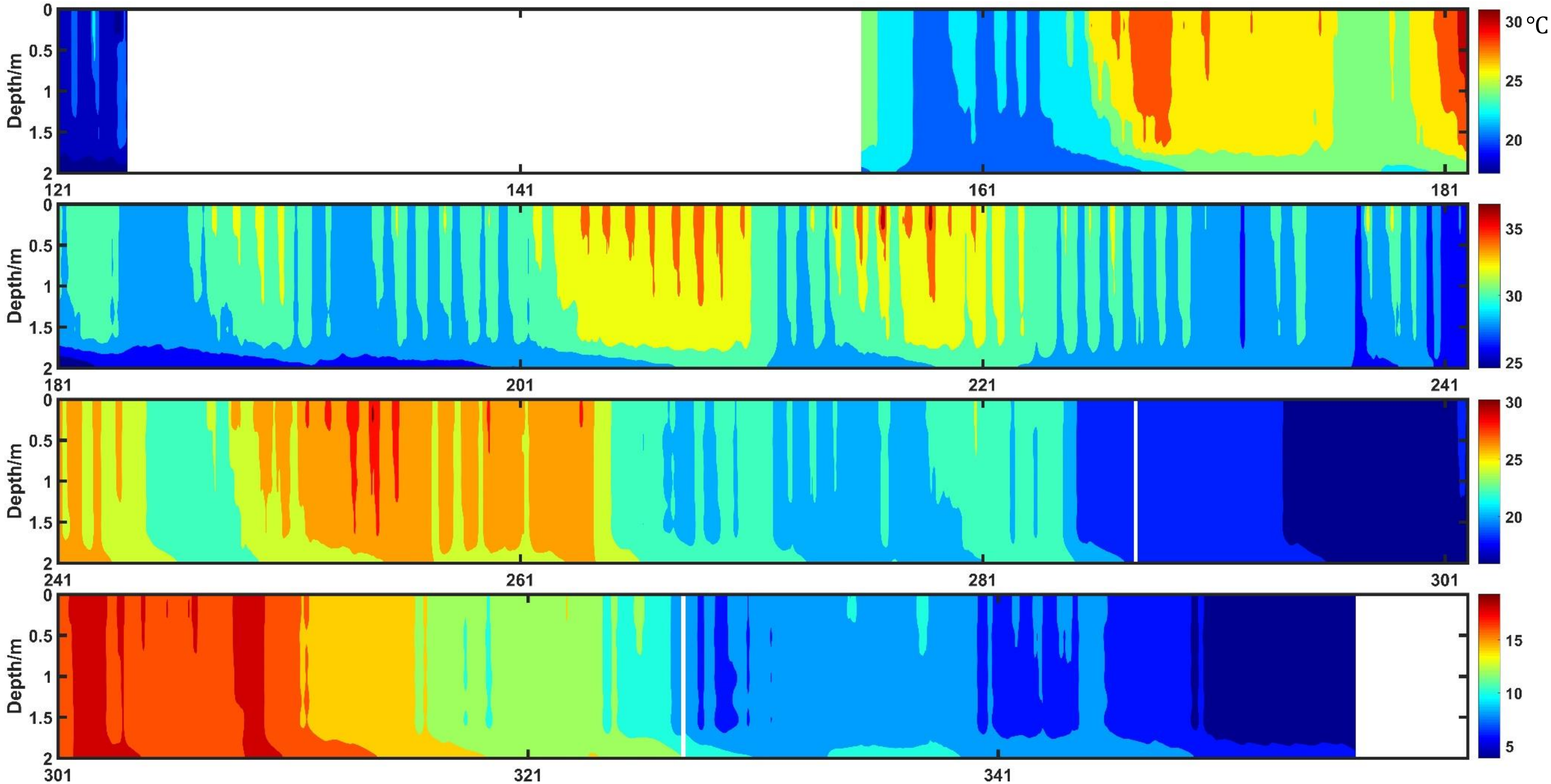


Figure 4 Time series of observed water temperature profile for DOY 121(2013)-365(2013) at BFG site

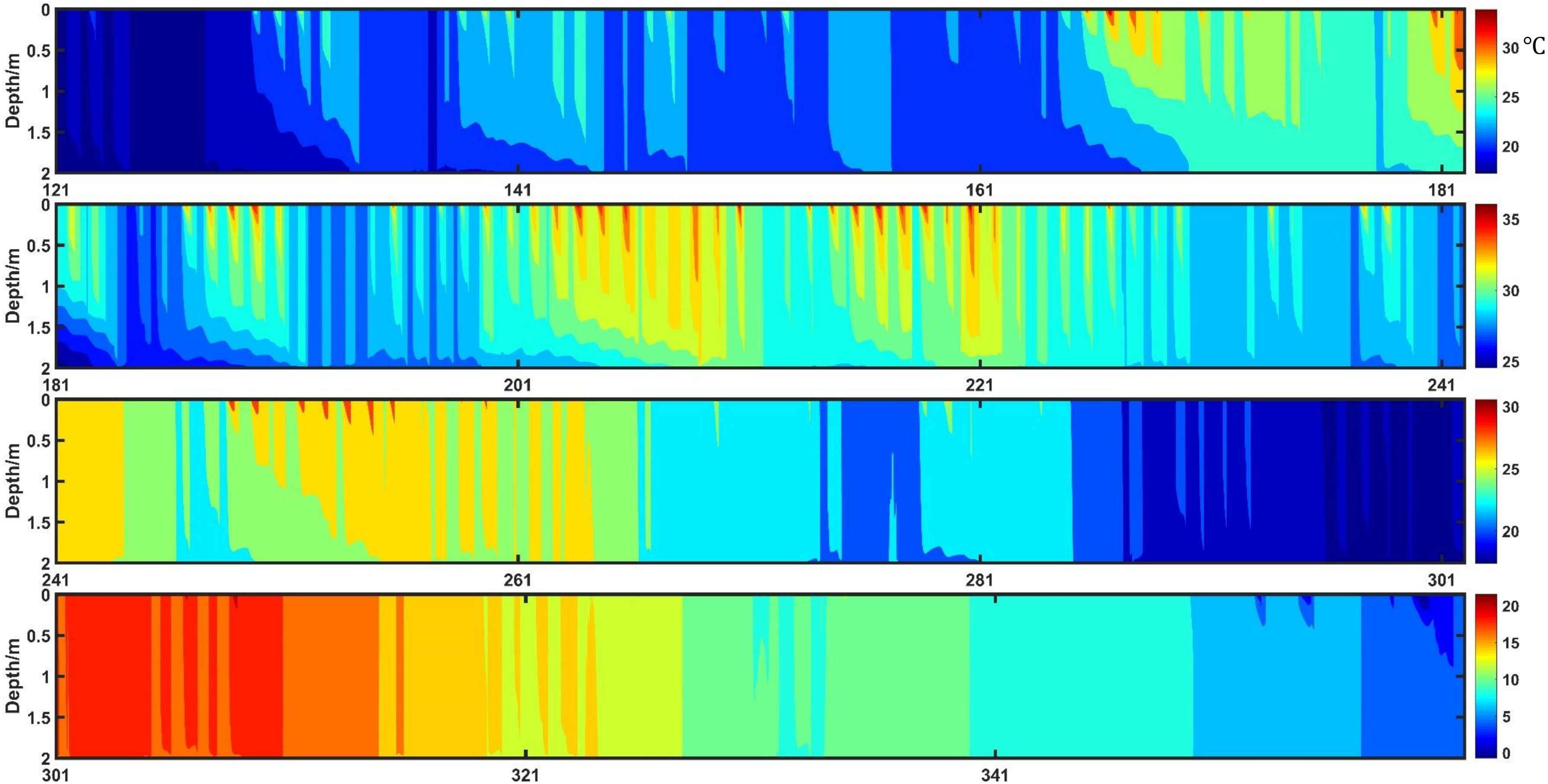


Figure 5 Time series of predicted water temperature profile for DOY 121(2013)-365(2013) at BFG site calculated by k- ε model

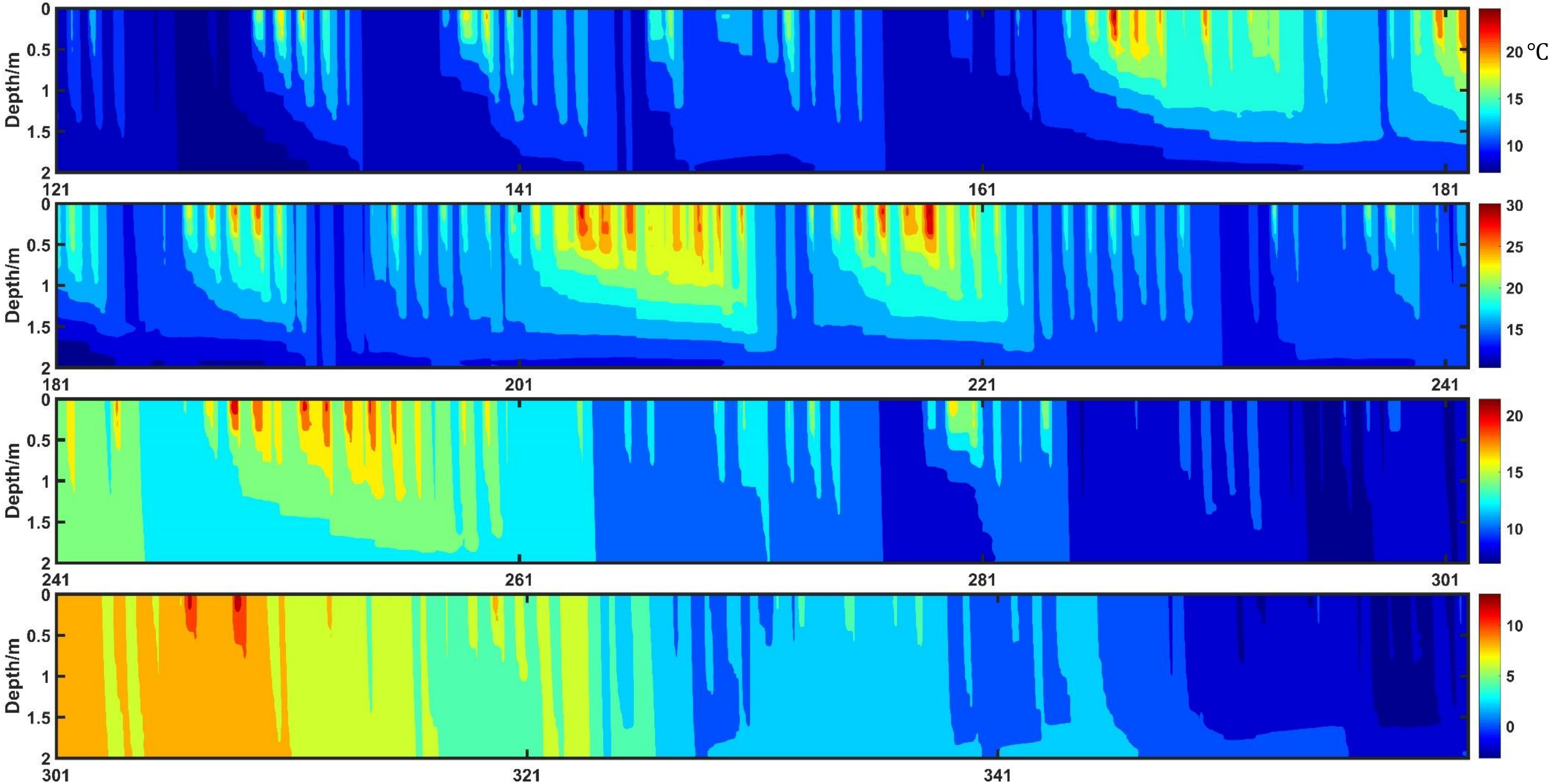


Figure 6 Time series of predicted water temperature profile for DOY 121(2013)-365(2013) at BFG site calculated by CLM4-LISSS model

Before calibration

After calibration

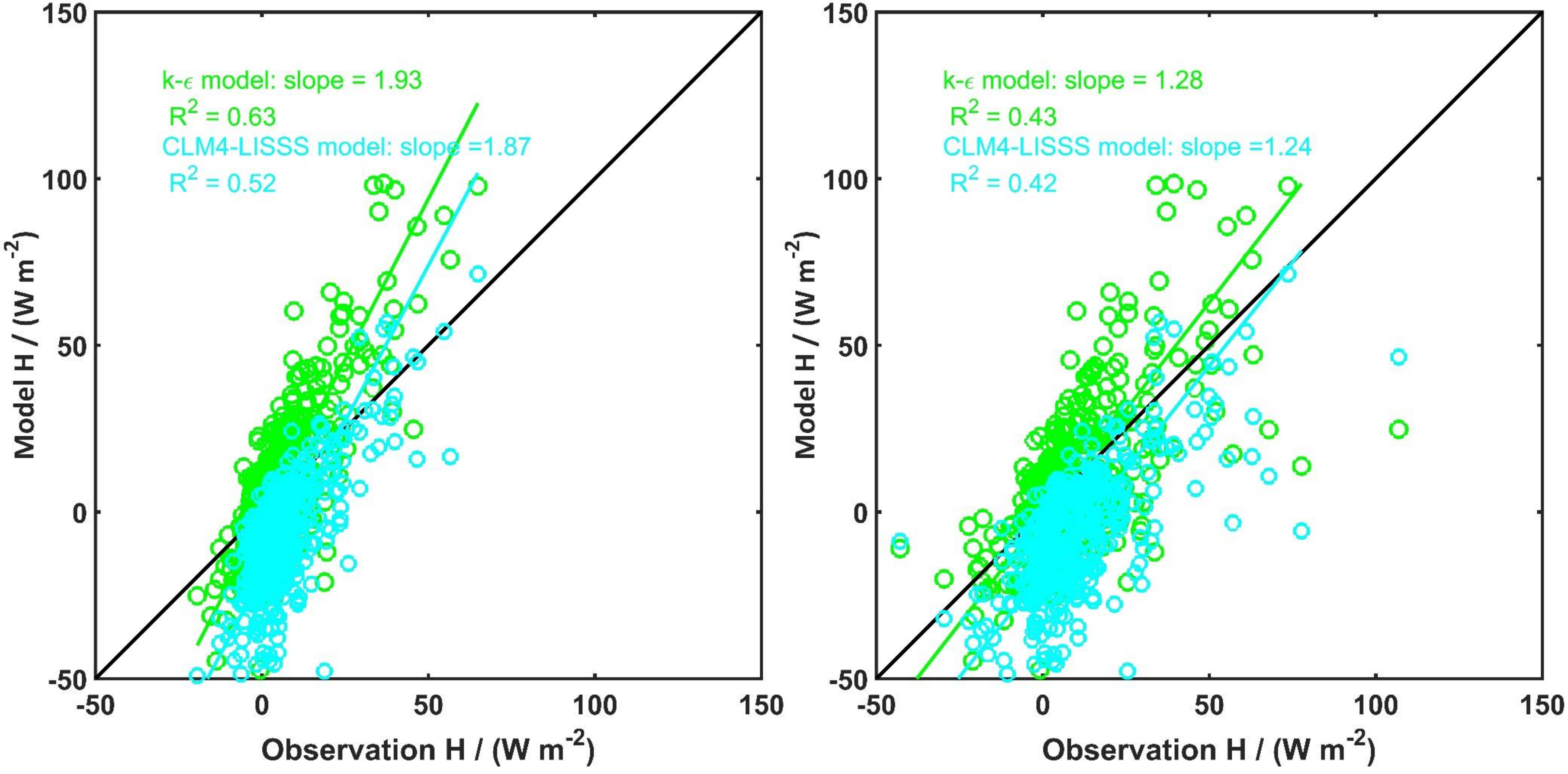
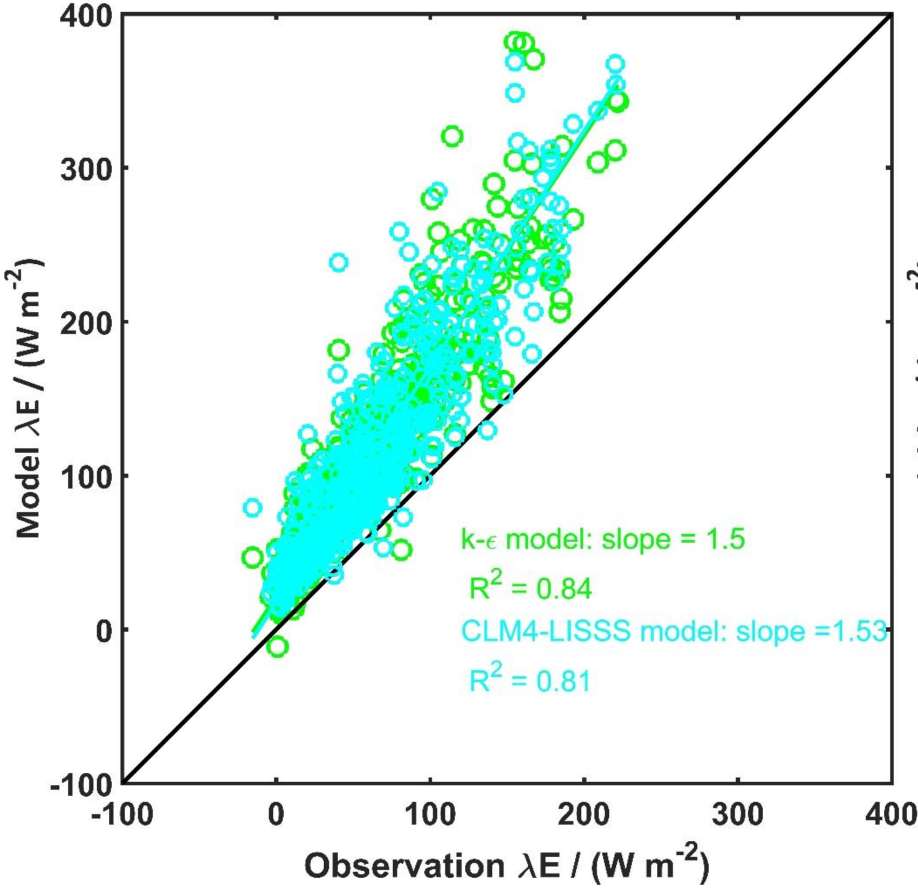


Figure 7 The relationship between measured Sensible heat flux and predicted Sensible heat flux in daily scale (green dots: k- ε model and cyan dots: CLM4-LISSS model)

Before calibration

After calibration



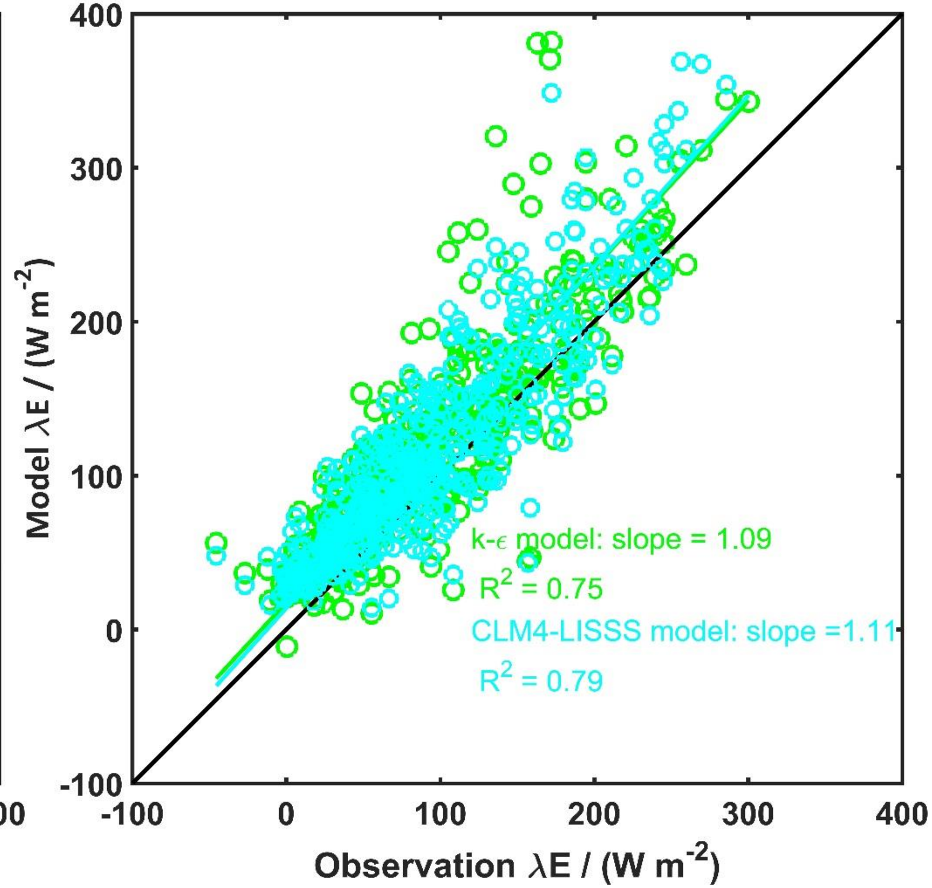


Figure 8 The relationship between measured Latent heat flux and predicted Latent heat flux in daily scale (green dots: k- ε model and cyan dots: CLM4-LISSS model)

The distribution of eddy diffusivity

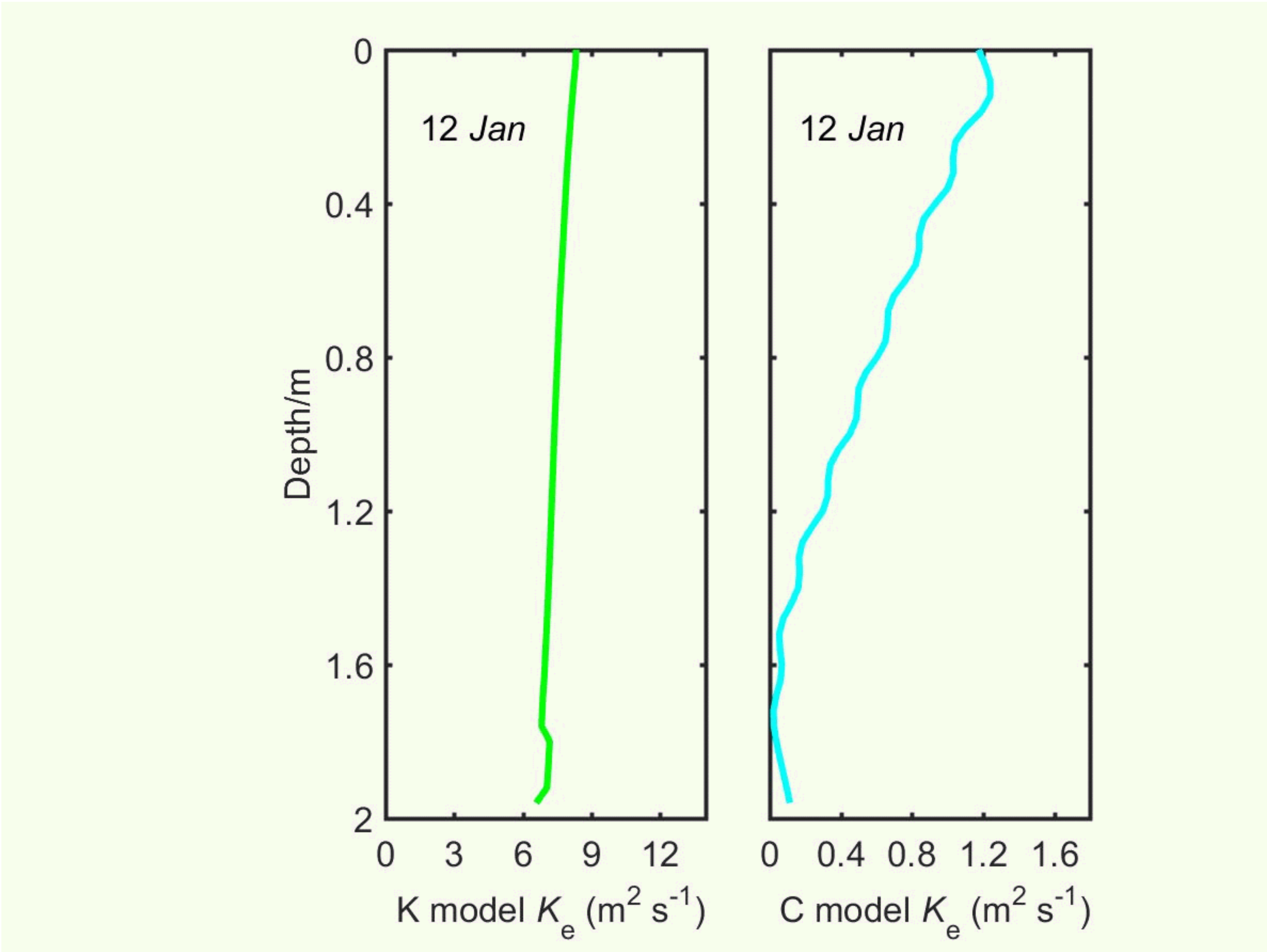


Figure 9 Monthly-average eddy diffusivity profile at BFG station simulated by CLM4-LISSS model (cyan line) and k- ε model (green line) over two full year cycle

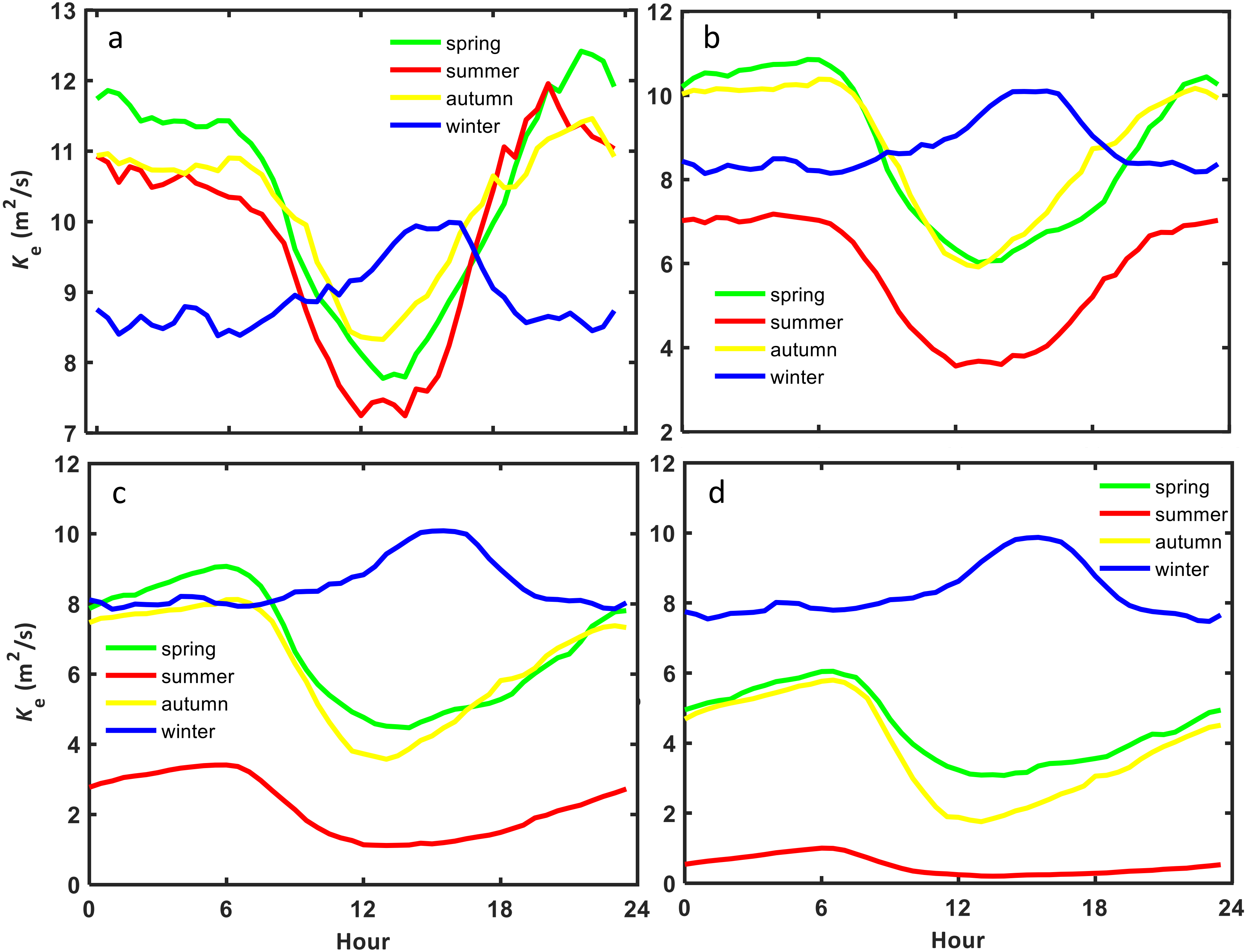


Figure 10 Diurnal composite of mean eddy diffusivity (a: 0-0.5m; b: 0.5-1m; c: 1-1.5m; d: 1-2m) simulated by k- ε model in different seasons at BFG station over two full year cycle.

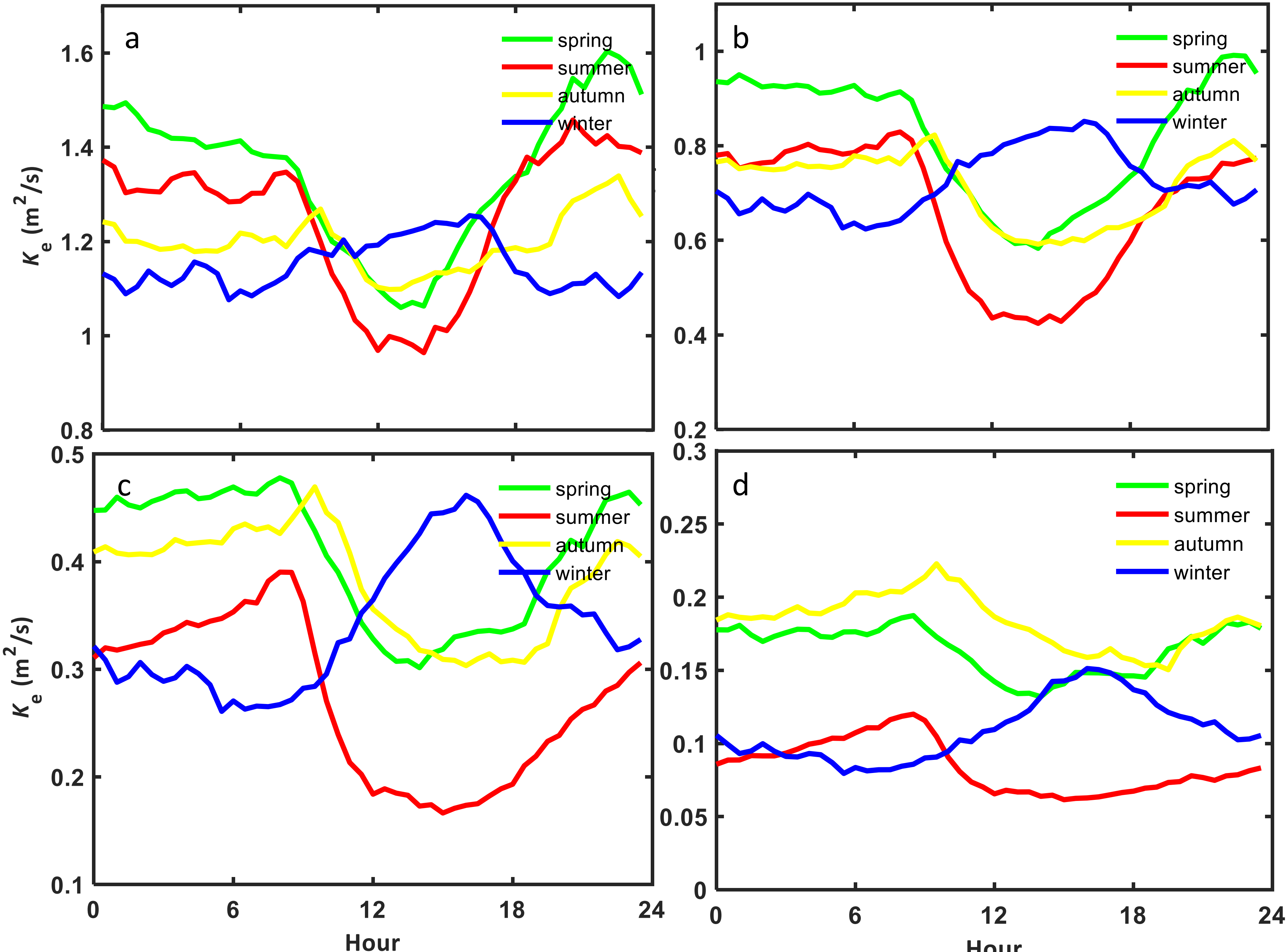


Figure 11 Diurnal composite of mean eddy diffusivity (a: 0-0.5m; b: 0.5-1m; c: 1-1.5m; d: 1-2m) simulated by CLM4-LISSS model in different seasons at BFG station over two full year cycle.

Cases analyses

Spring:

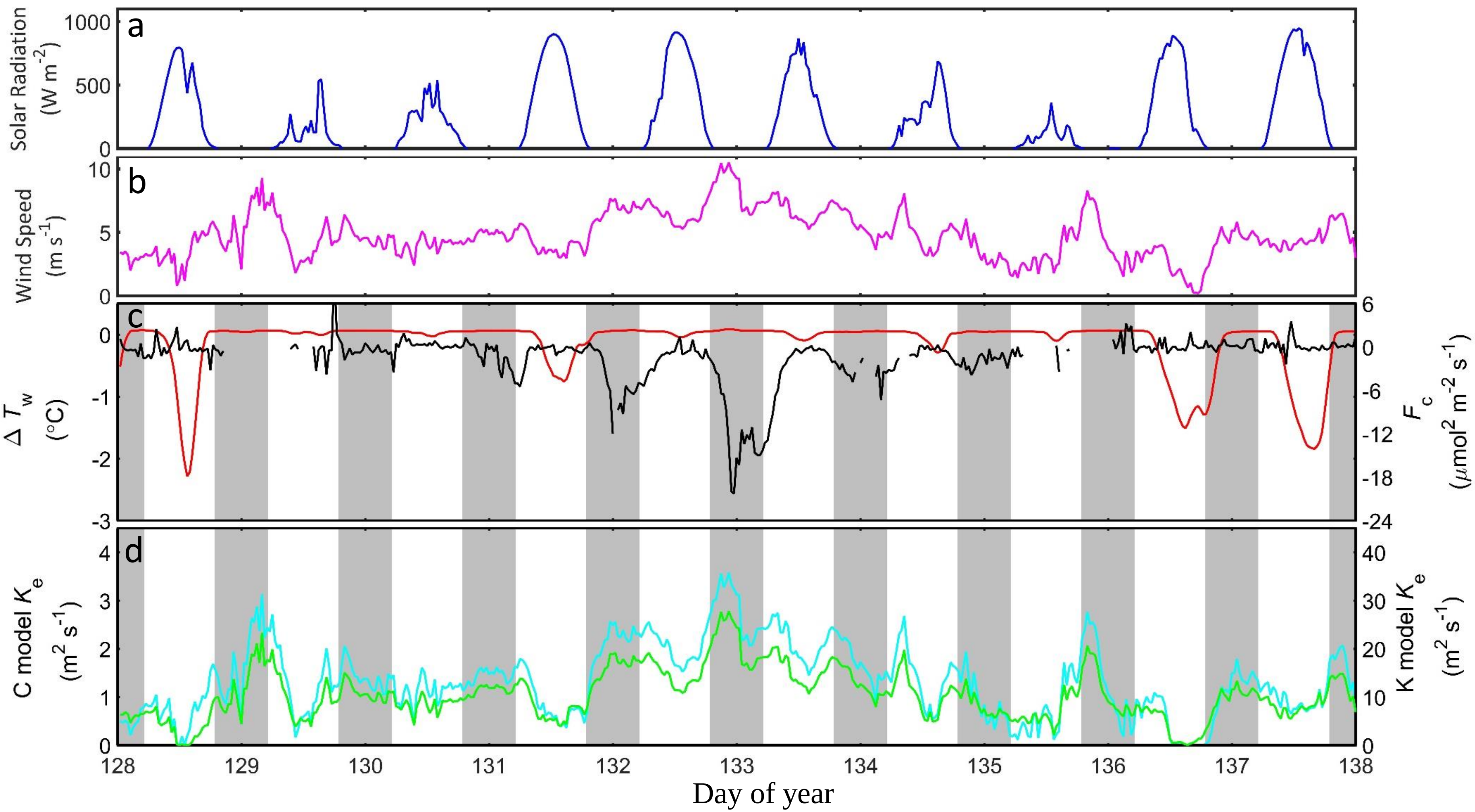


Figure 12 Time series of (a) solar radiation (blue line), (b) wind speed (pink line) ,(c) water temperature difference (1.0m temperature minus 0.2m temperature; pink line) and CO_2 flux (black line) and mean eddy diffusivity (0 - 0.5m) simulated by CLM4-LISSS model (cyan line) and k- ε model (green line) from DOY 128 to DOY 137 in 2012 (shaded area represents nighttime)

Summer:

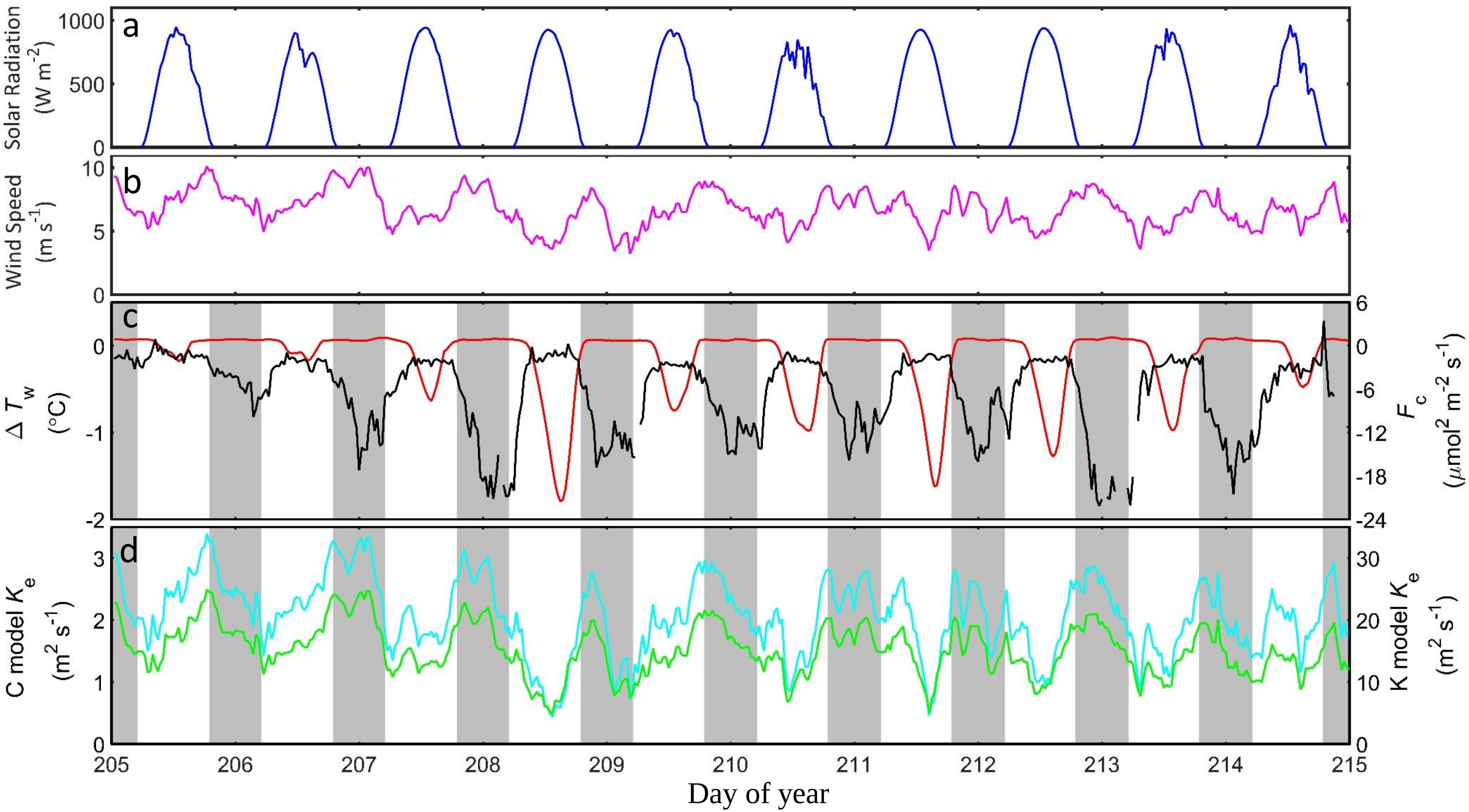


Figure 13 Time series of (a) solar radiation (blue line), (b) wind speed (pink line) ,(c) water temperature difference (1.0m temperature minus 0.2m temperature; pink line) and CO_2 flux (black line) and mean eddy diffusivity (0 - 0.5m) simulated by CLM4-LISSS model (cyan line) and k- ε model (green line) from DOY 205 to DOY 214 in 2012 (shaded area represents nighttime)

Autumn:

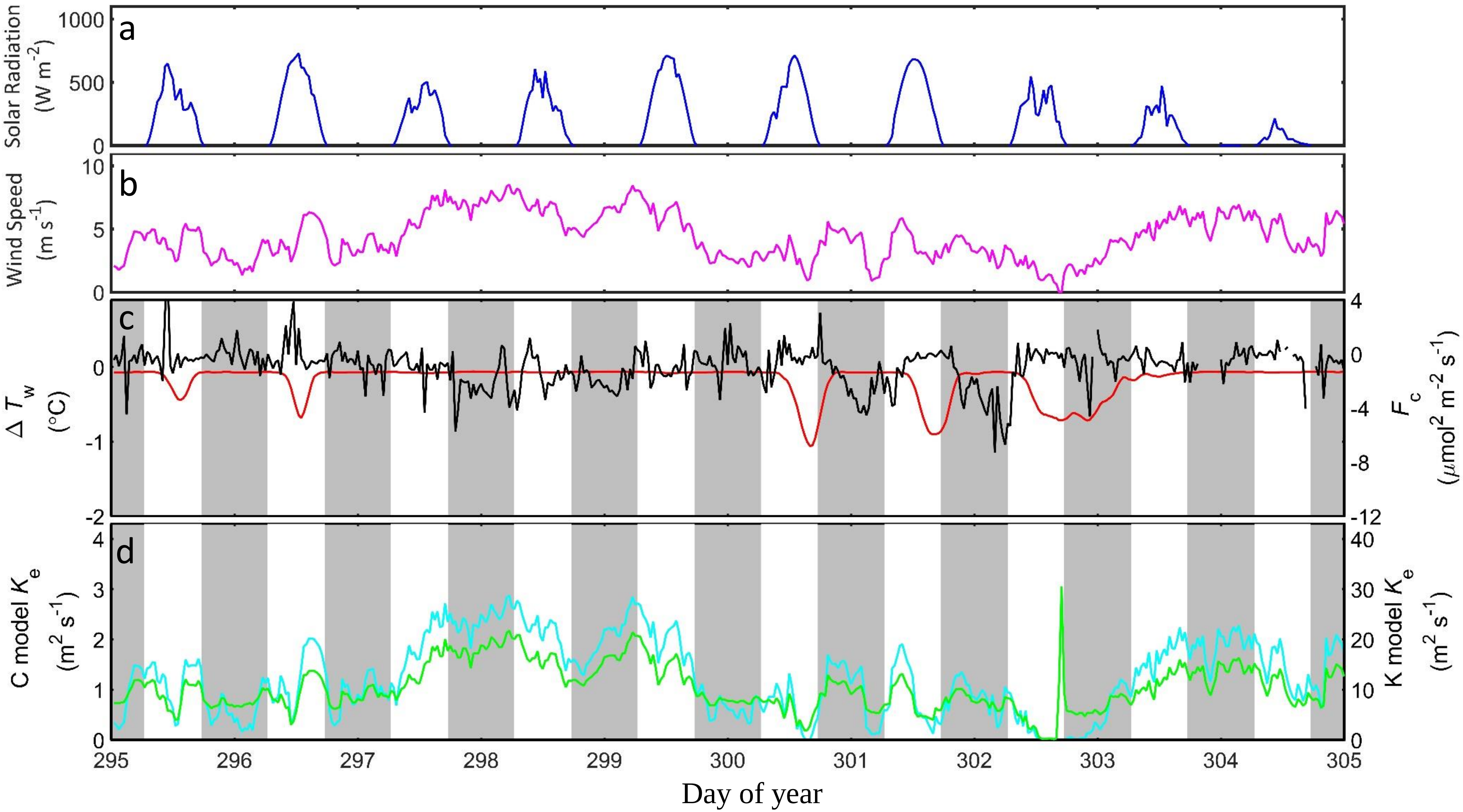


Figure 14 Time series of (a) solar radiation (blue line), (b) wind speed (pink line) ,(c) water temperature difference (1.0m temperature minus 0.2m temperature; pink line) and CO_2 flux (black line) and mean eddy diffusivity (0 - 0.5m) simulated by CLM4-LISSS model (cyan line) and k- ε model (green line) from DOY 295 to DOY 304 in 2013 (shaded area represents nighttime)

Winter:

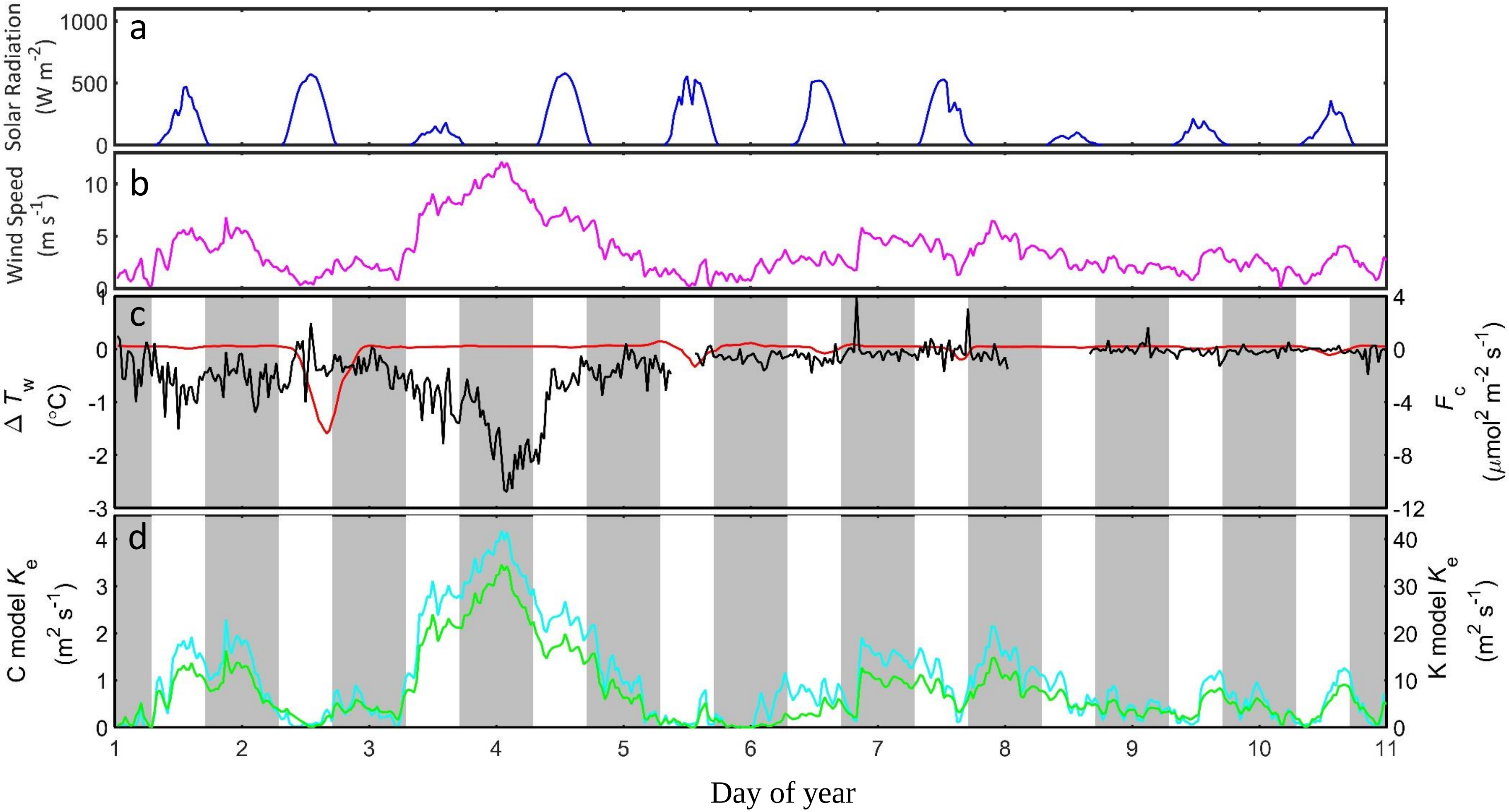


Figure 15 Time series of (a) solar radiation (blue line), (b) wind speed (pink line) ,(c) water temperature difference (1.0m temperature minus 0.2m temperature; pink line) and CO_2 flux (black line) and mean eddy diffusivity (0 - 0.5m) simulated by CLM4-LISSS model (cyan line) and k- ε model (green line) from DOY 1 to DOY 10 in 2012 (shaded area represents nighttime)

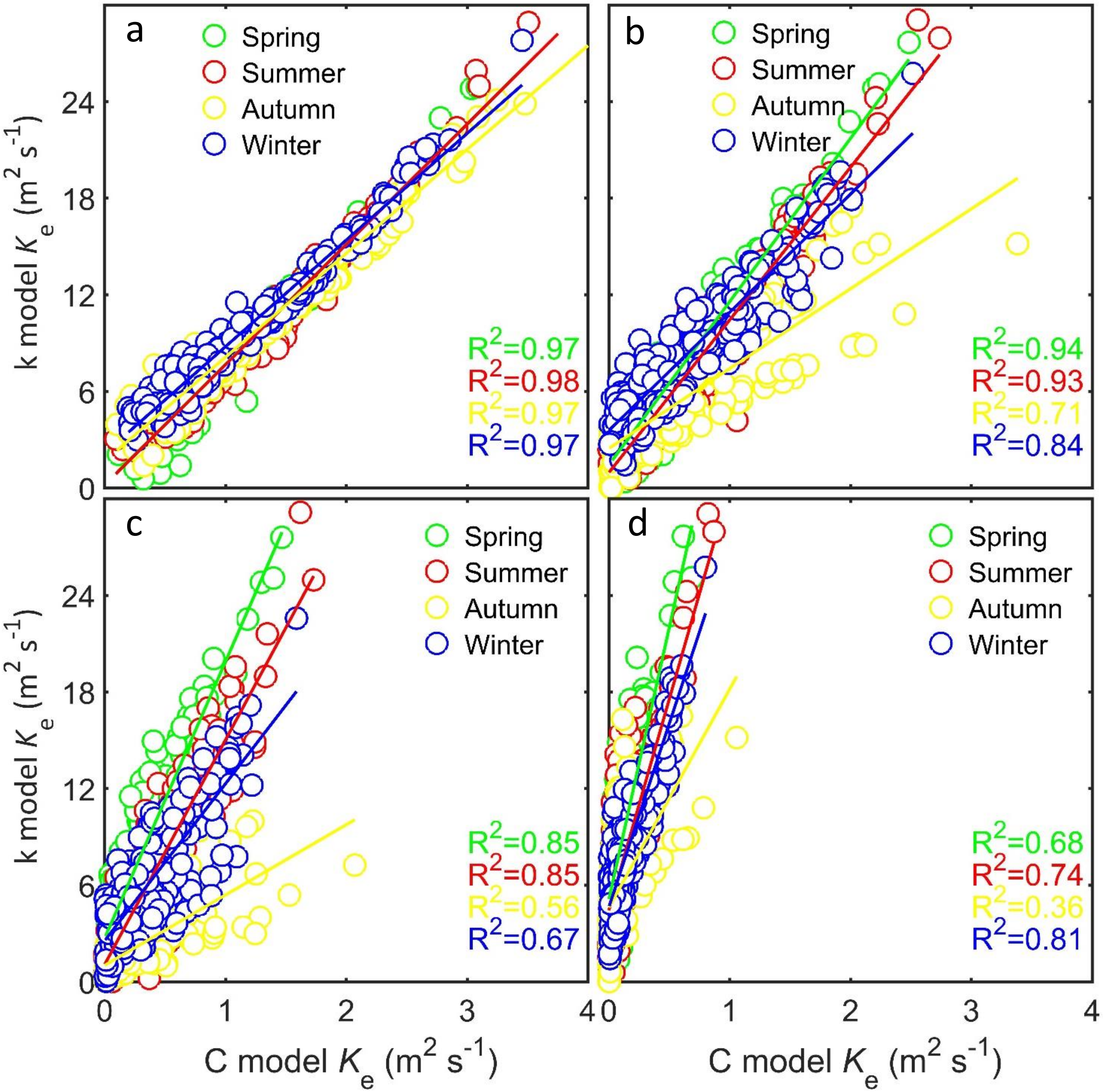


Figure 16 Comparison on daily-mean predicted eddy diffusivity (a: 0-0.5m; b: 0.5-1m; c: 1-1.5m; d: 1-2m) in different season (green dots: Spring; red dots: Summer; yellow dots: Autumn; blue dots: Winter) at BFG site between k- ε model and CLM4-LISSS model

Conclusions

- CLM4-LISSS model and k-ε model has good performance in water temperature and surface flux prediction.

- There exists similar diurnal composite of mean eddy diffusivity in spring, summer and autumn at BFG station, The trend of winter is reversed compared with other seasons.

- Eddy diffusivities simulated by both model exist difference in number but have well linear relationship, especially in shallow layer. However, tuned eddy diffusivity didn’t bring better water temperature performance results.

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Future work

- In order to optimize both model furtherly, clear the sensitivity of model parameters towards the output results, such as: all layers' water temperature and surface flux.

- Figure out the reason that bad performance of tuned K_e

- Investigate frequency of overturning events, microclimate and weather triggers of large eddy diffusivity.

Thank you