Analysis of the surface temperature distribution at Badain Jaran Desert using fully coupled hydro-thermal method

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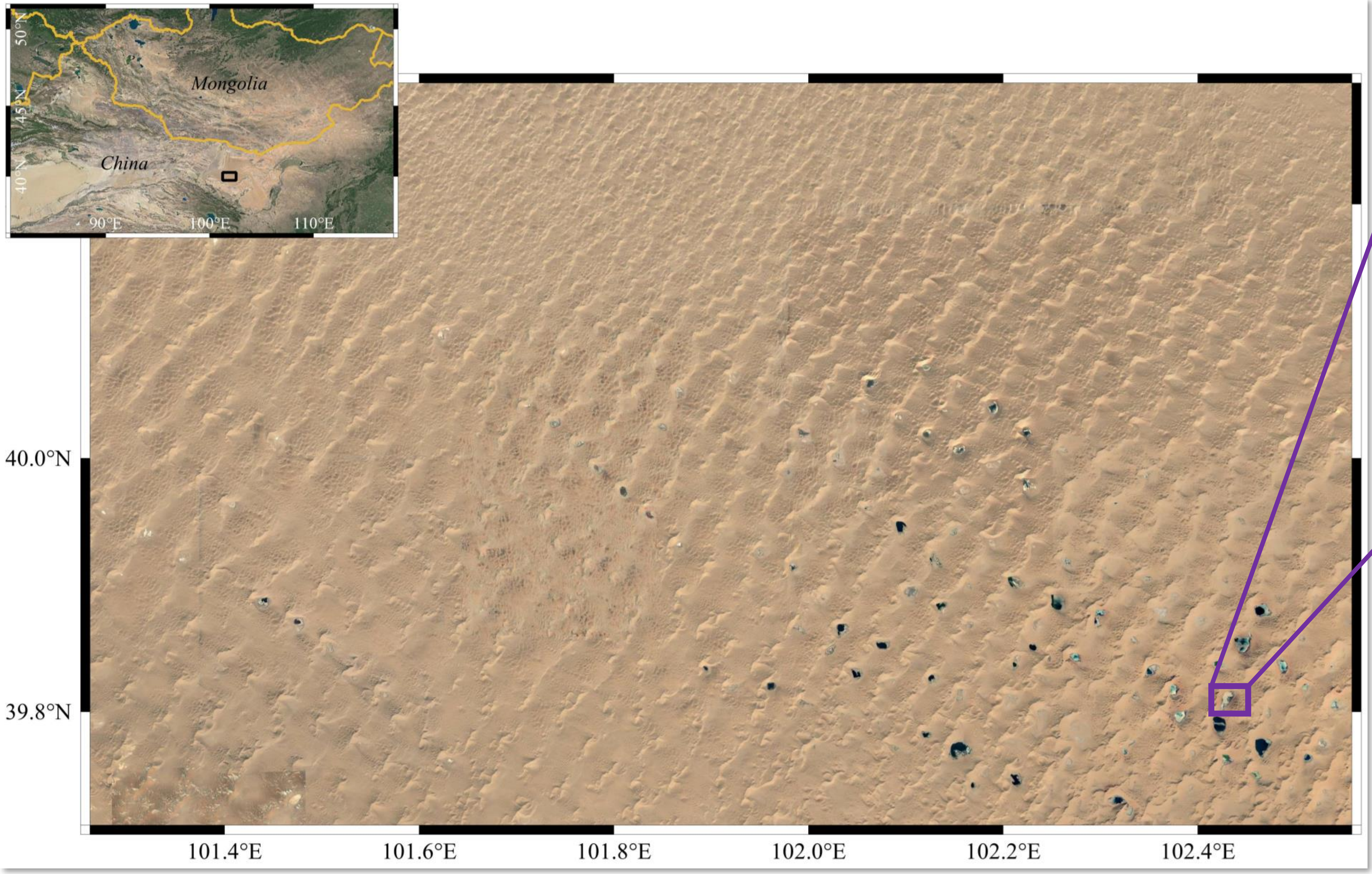
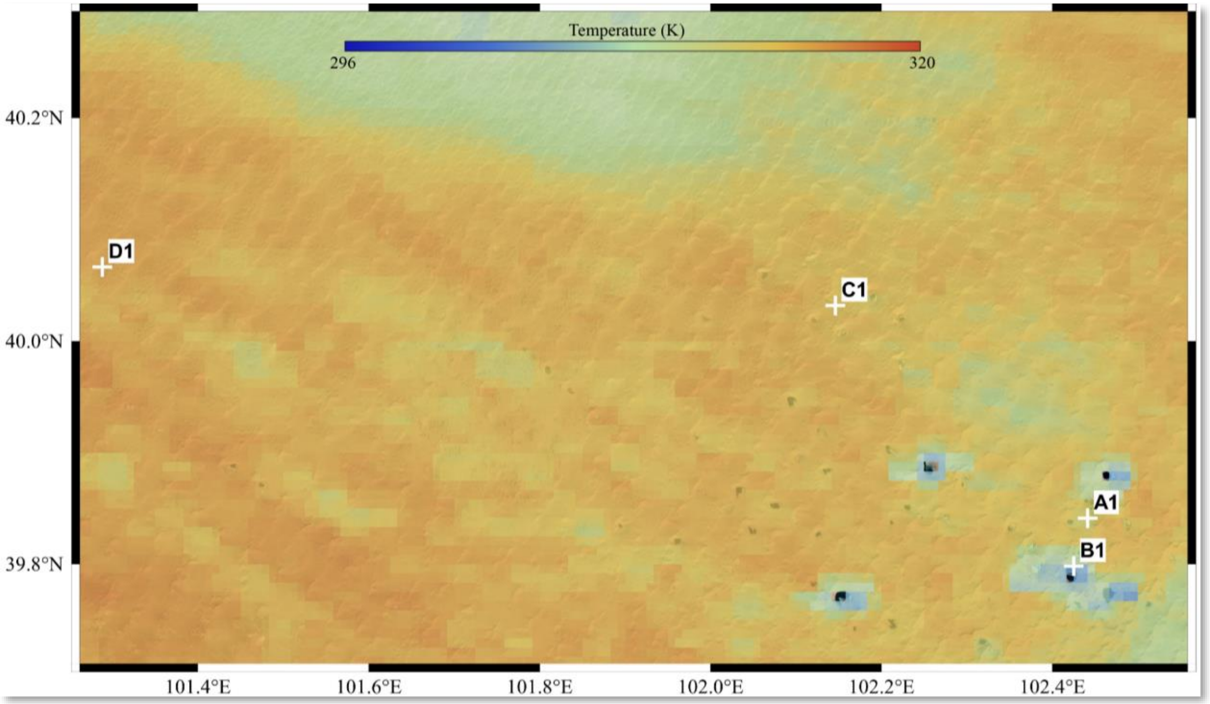
Contents

Badain Jaran Desert site



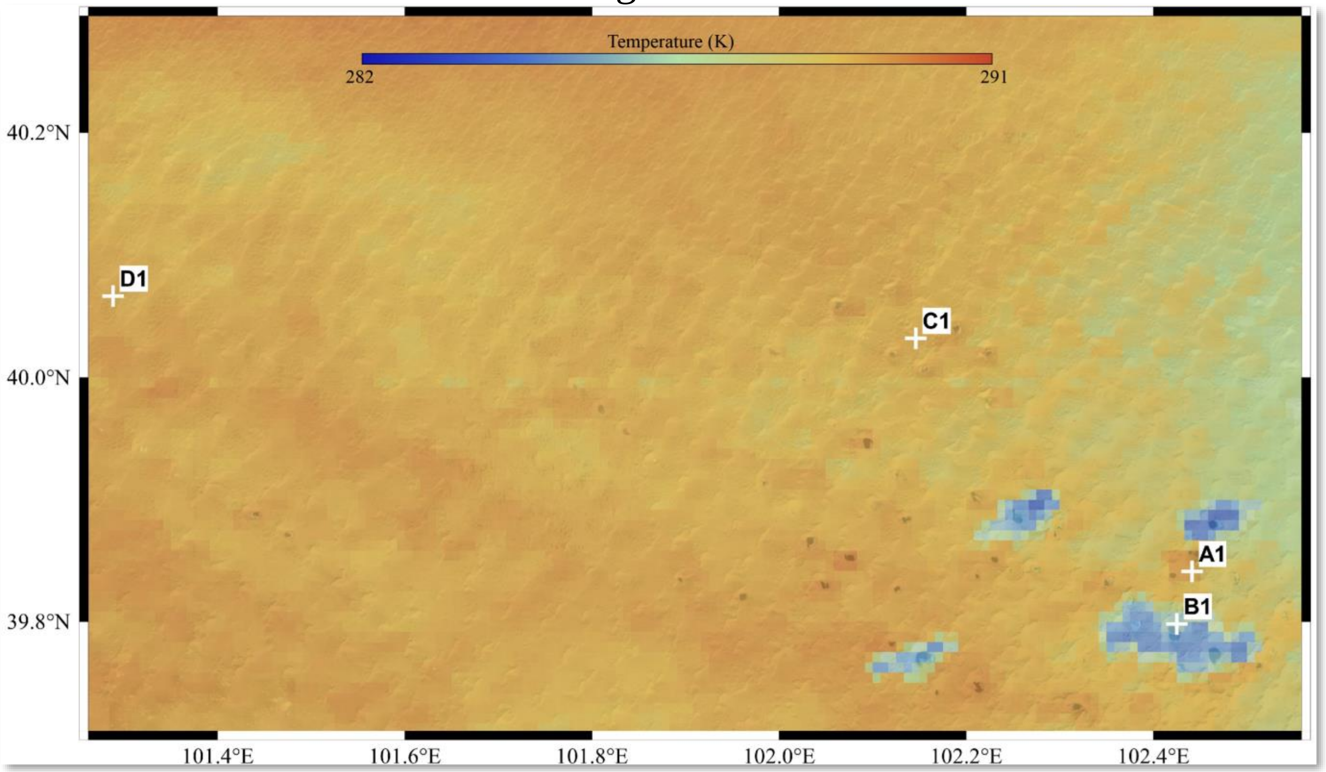
Surface Temperature at the site

31st August 2008
(MODIS TERRA)

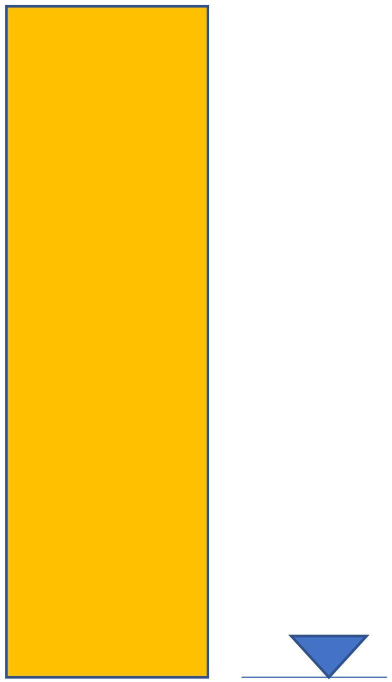


Daytime

Nighttime



Motivation



Water table depth /m ← **Surface temperature T_s ?**

0.5

…

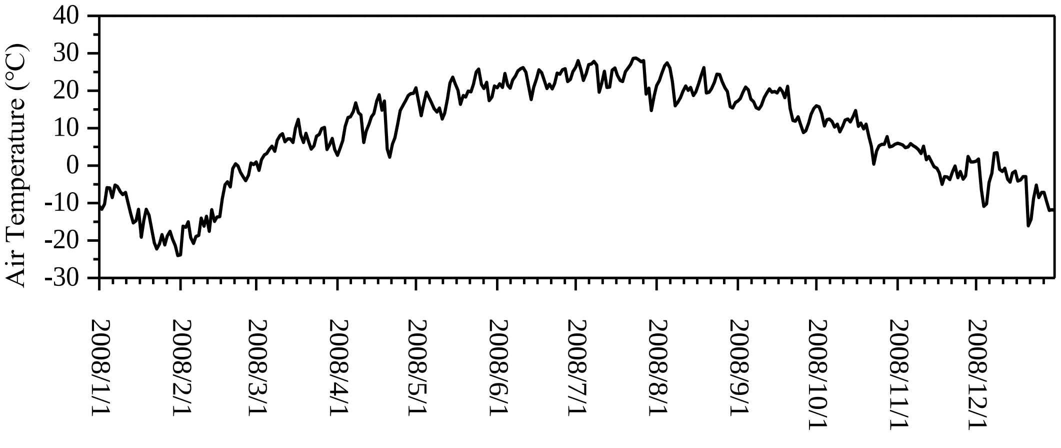
32

…

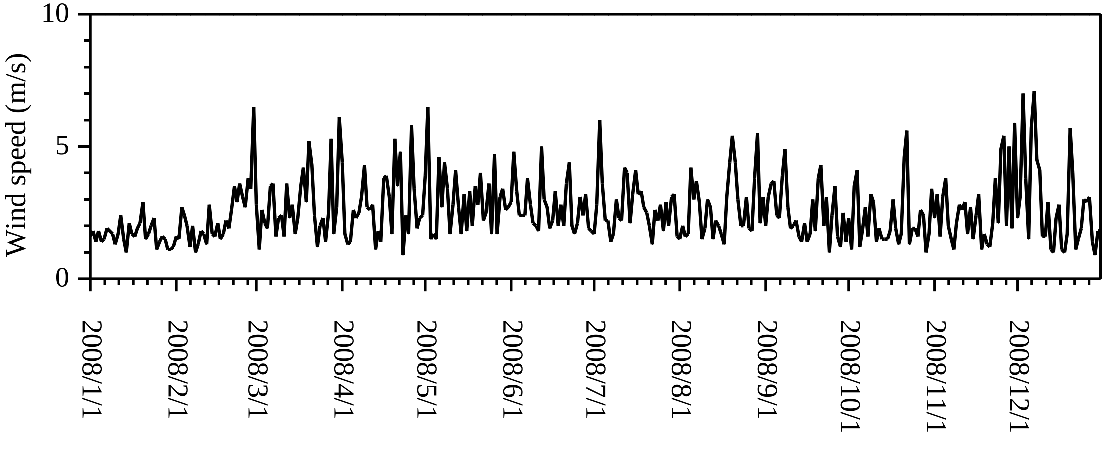
165

Meteorological Data

Minqin station

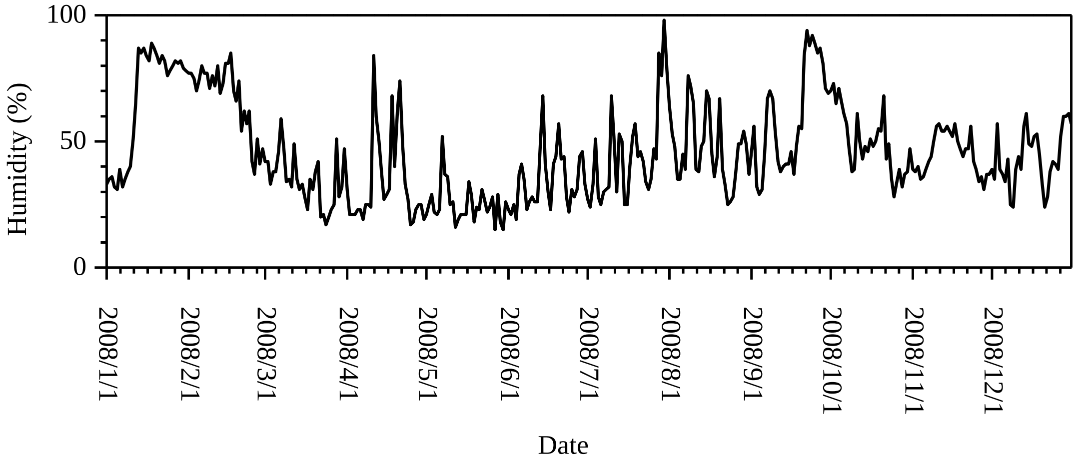


Air temperature

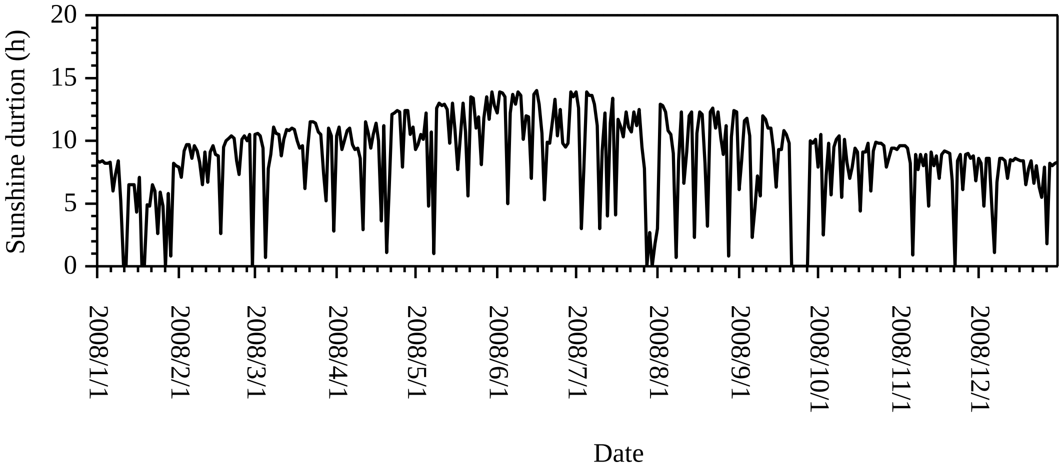


Wind speed

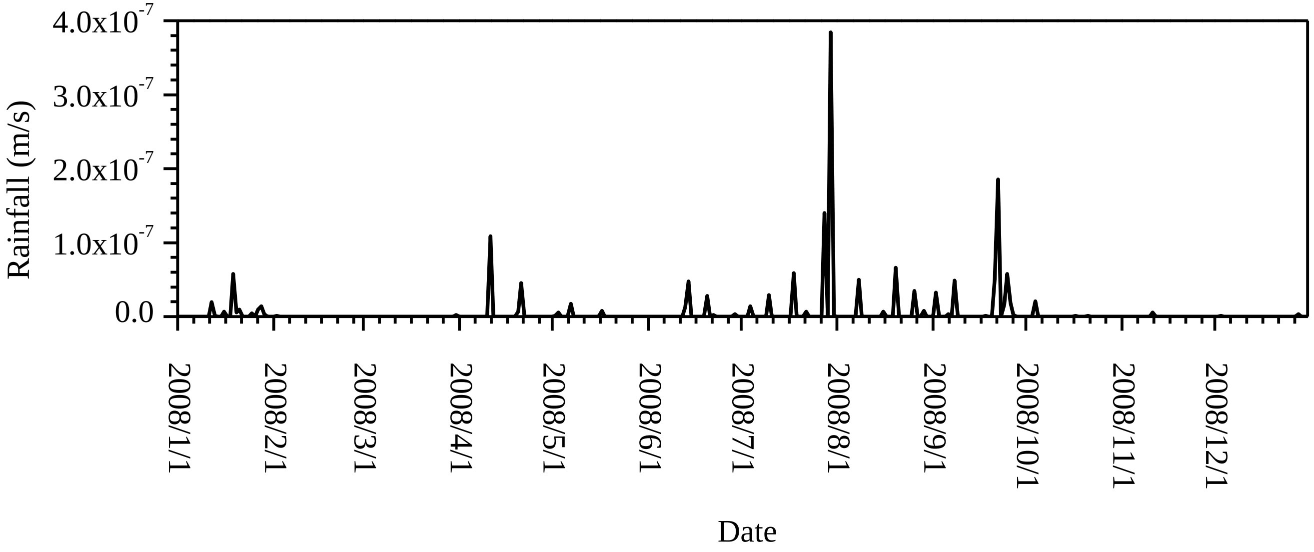
Meteorological Data – Cont'd



Humidity

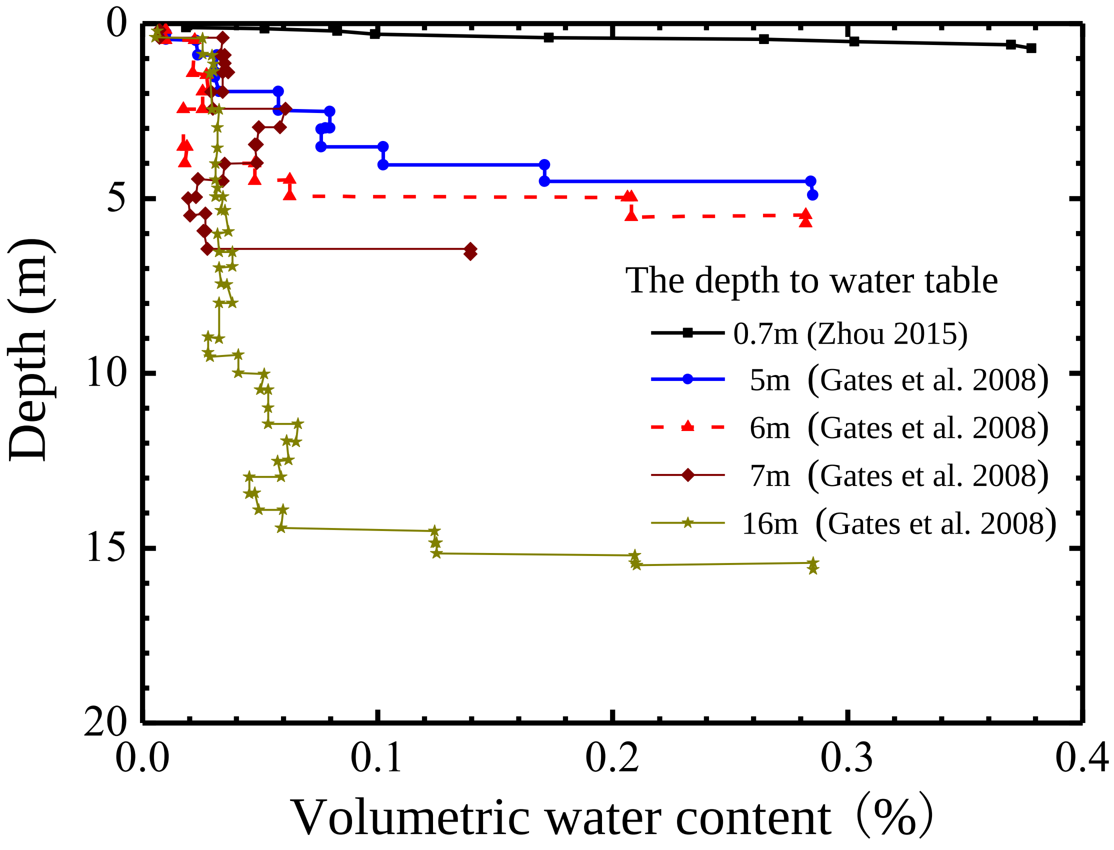


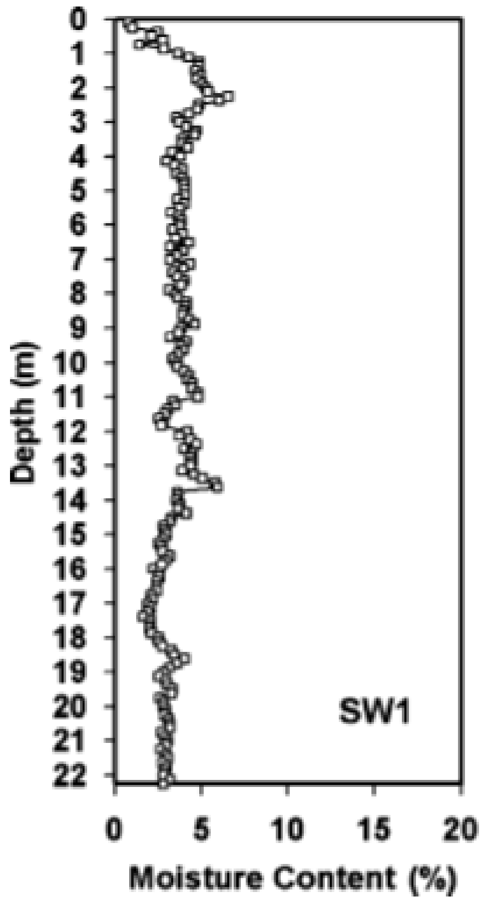
Sunshine duration

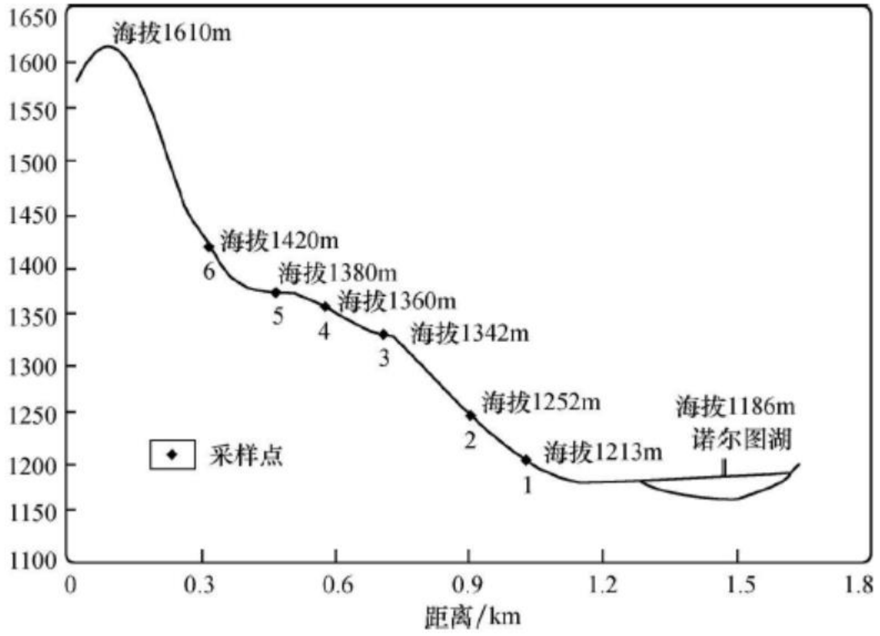


Rainfall

Volumetric water content







Surface: dry layer 35cm

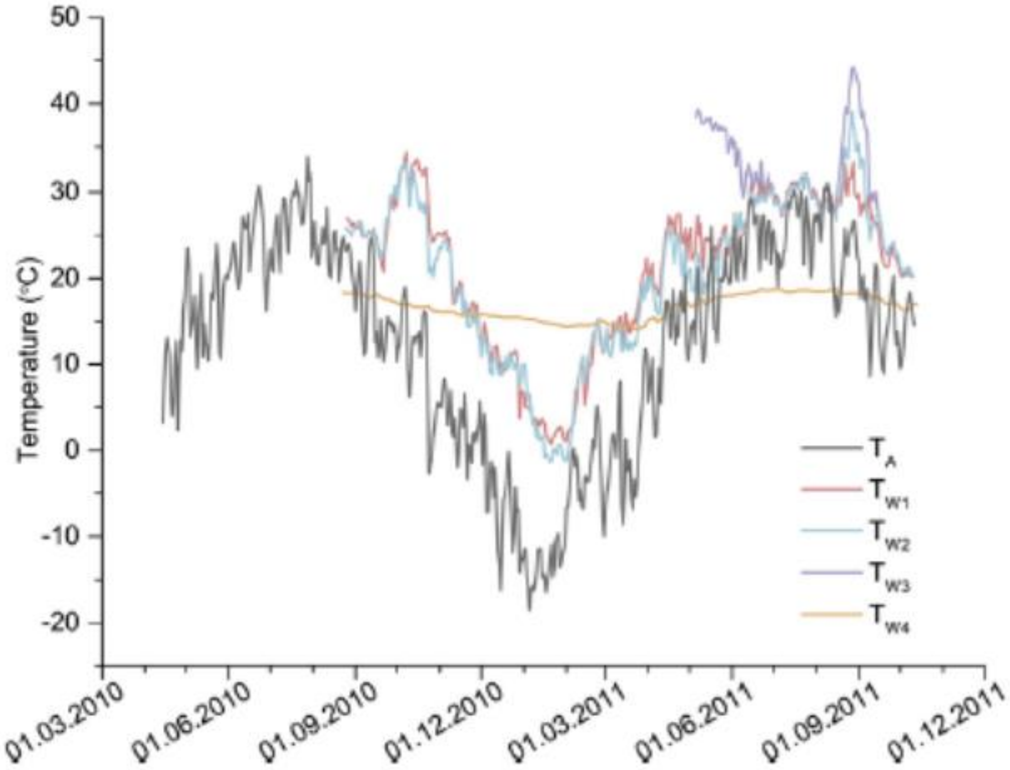
***w*<0.5%　≈0.01%**

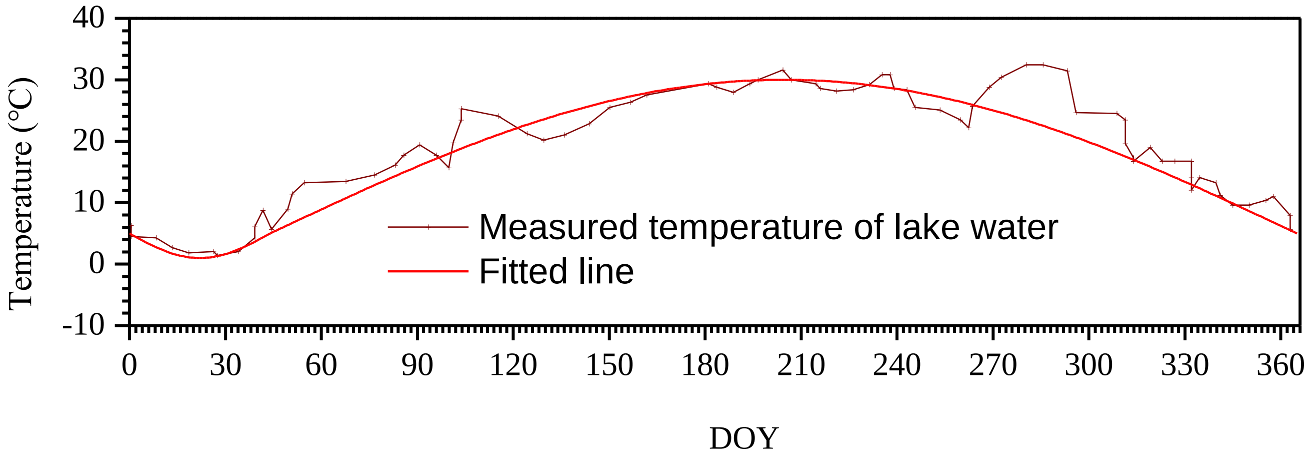
Gates et al. (2008); Zhou (2015)

Ma and Eumunds （2006）

Zhao et al.（2011）

Lake water temperature





Dong et al.（2015）

$$T=\begin{cases}5-4\times\sin(\mathrm{DOY}/44\times\pi) & \mathrm{DOY}\le 44\\ 5+25\times\sin[(\mathrm{DOY}\text{-}44)/322\times\pi) & 44<\mathrm{DOY}<366\end{cases}$$

Fully-coupled numerical method

(A1)

The fully coupled hydro-thermal method developed by Anni et al. (2017)

The governing equation of liquid and vapor water mass flow can be expressed as:

$$C_\varphi \frac{\partial \varphi}{\partial t} + C_{\varphi T} \frac{\partial T}{\partial t} = \nabla \cdot \left[K_\varphi \nabla \varphi \right] + \nabla \cdot \left[K_{\varphi T} \nabla T \right] + \rho_l \nabla K_w$$

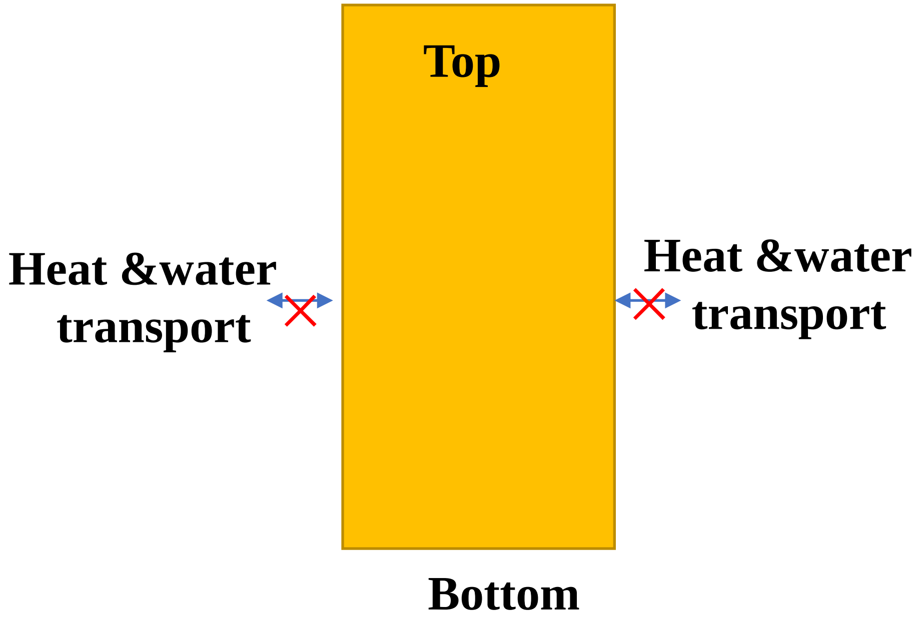
The governing equation of heat flow can be expressed as:

$$C_T \frac{\partial T}{\partial t} + C_{T\varphi} \frac{\partial \varphi}{\partial t} = \nabla \cdot \left[K_T \nabla T \right] + \nabla \cdot \left[K_{T\varphi} \nabla \varphi \right]$$

Initial and boundary conditions

(A1)

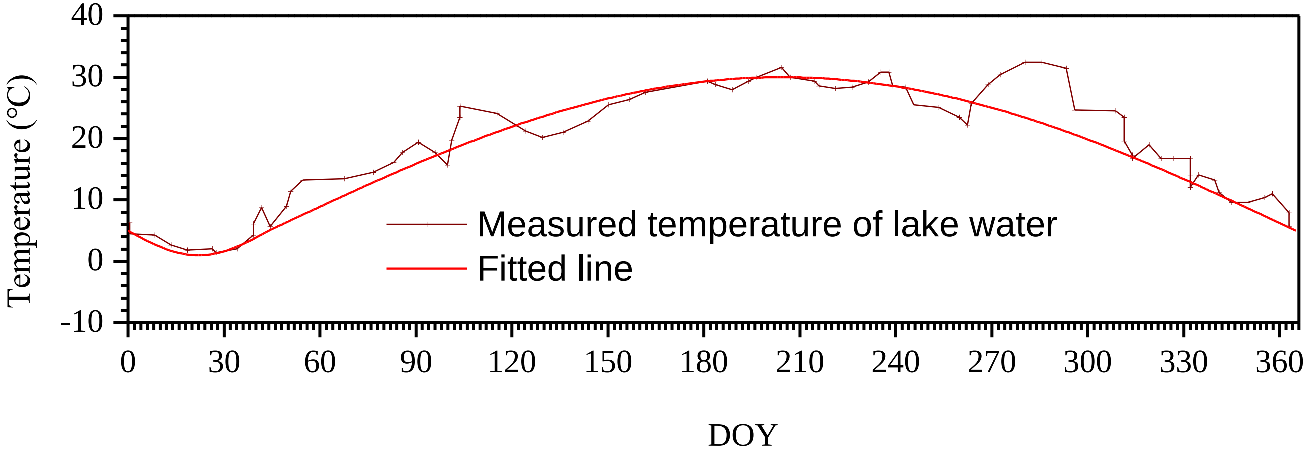
Initial temperature: 5°C Initial suction: hydrostatic equilibrium line



Bottom boundary condition:

(A1)

(1) Temperature at bottom



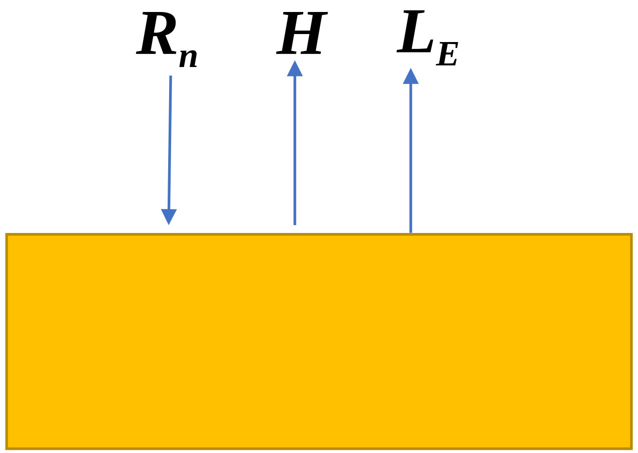
$$T = \begin{cases} 5 - 4 \times \sin(\text{DOY}/44 \times \pi) & \text{DOY} \leq 44 \\ 5 + 25 \times \sin[(\text{DOY-44})/322 \times \pi) & 44 < \text{DOY} < 366 \end{cases}$$

(2) Suction at bottom

$$\varphi = 0$$

Heat flux at the top boundary

(A1)

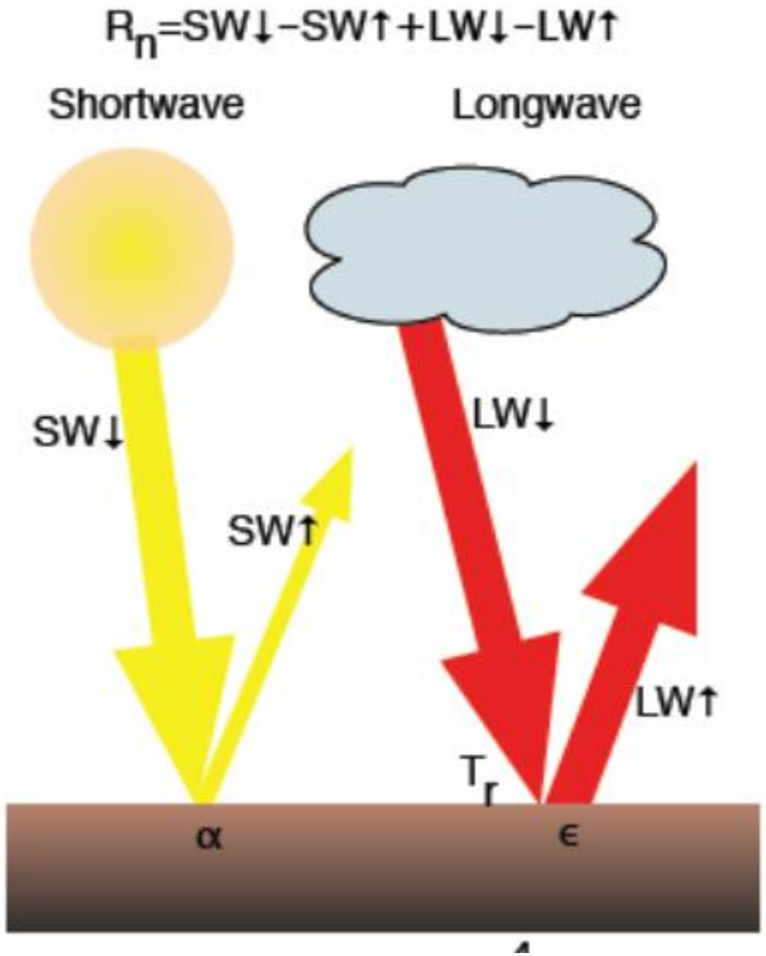


$$q_{htop} = -R_n + H + L_E$$

The net solar radiation

(A1)

The net solar radiation



$$SW\downarrow = \left(0.25 + 0.5\frac{n}{N}\right)R_{sa}$$

$$SW\uparrow = \alpha SW\downarrow$$

$$LW\downarrow = \varepsilon_a \sigma T_a{}^4$$

$$LW\uparrow = \varepsilon_s \sigma T_{surf}{}^4$$

Sensible heat and latent heat

(A1)

The sensible heat

$$H = \frac{\rho_a C_{pa} (T_s - T_a)}{r_a}$$

The latent heat

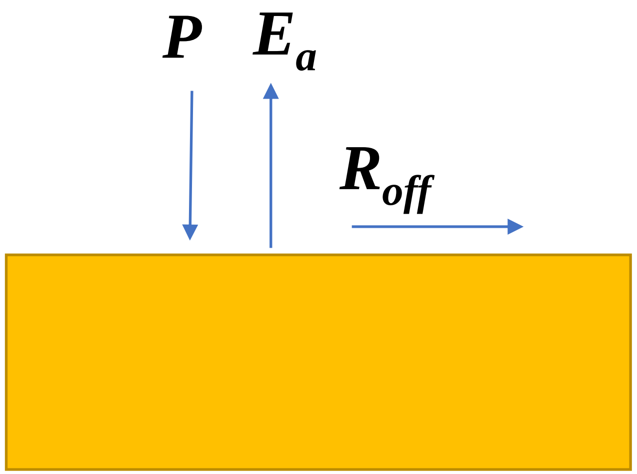
$$L_E = 1000 L_v E_a$$

$$\frac{E_a}{E_p} = \frac{e_0 - e_a}{e_s - e_a}$$

$$E_p = \frac{10^{-3}}{86400}(a + bu)(100 - h_a)$$ **Song （2015）**

Water flux at the top boundary

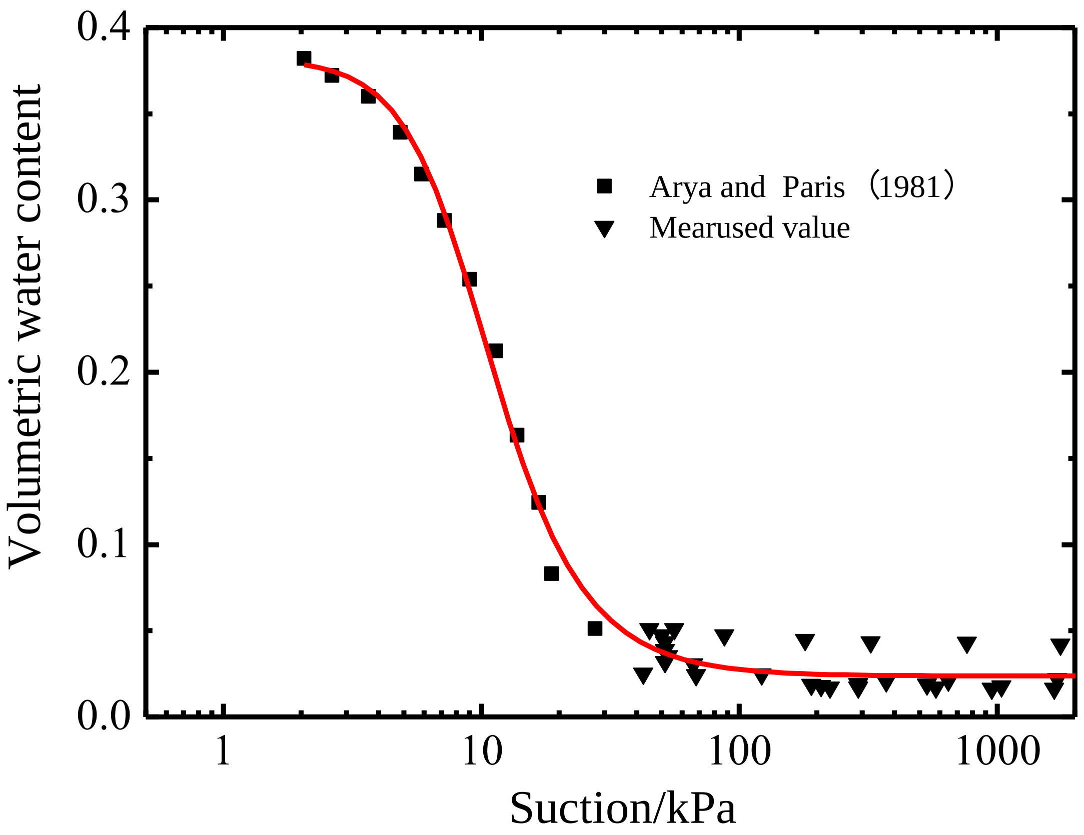
(A1)



$$q_{wtop} = E_a - (P - R_{off})$$

Hydraulic property

(A1)



Water retention curve

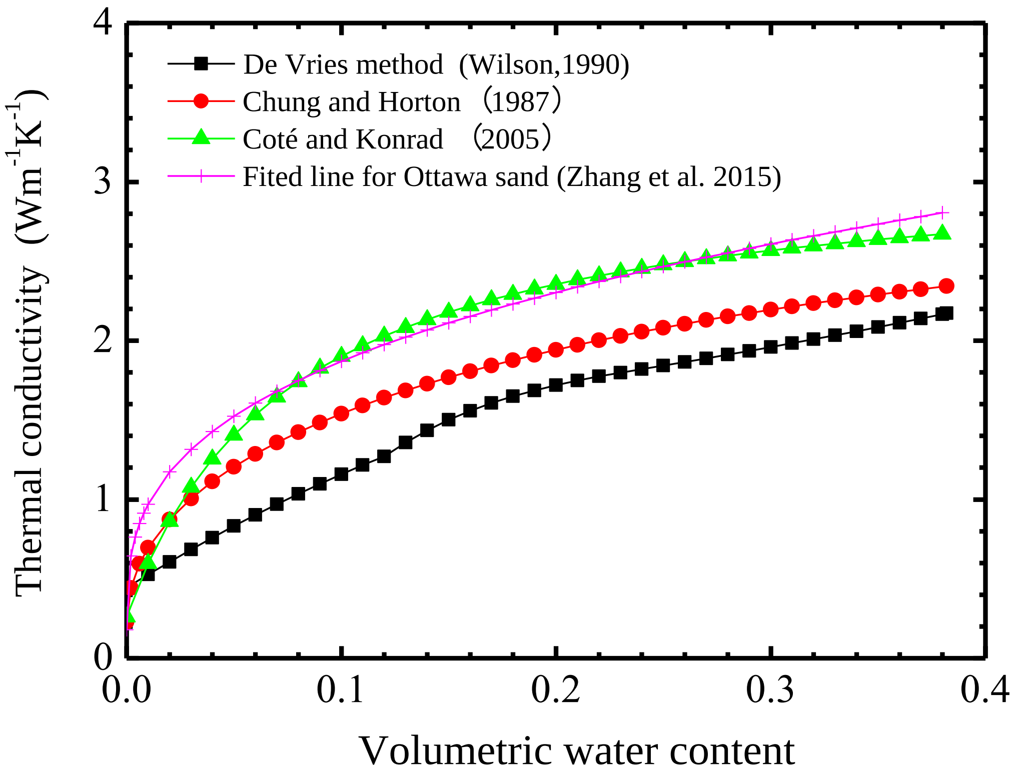
VG model

Parameter	value
a(cm)	88.3
θ_s	0.382
θ_r	0.0237
n	2.87
k_s (m/s)	1.06×10^{-4}

$$\theta=\theta_r+\frac{(\theta_s-\theta_r)}{\left(1+(\frac{\psi}{a})^n\right)^m}$$

$$k=k_s\Theta^{0.5}[1-(1-\Theta^{1/m})^m]^2$$

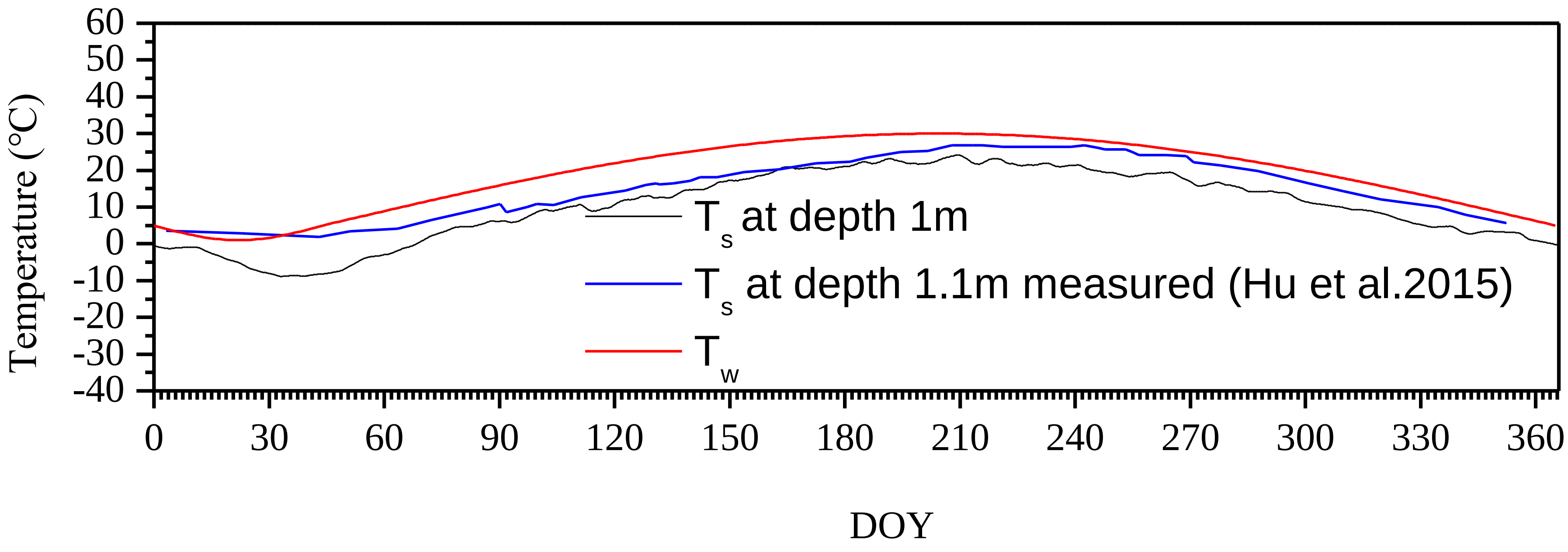
Thermal property



$$\lambda = 0.18 + 3.61\theta^{0.33}$$

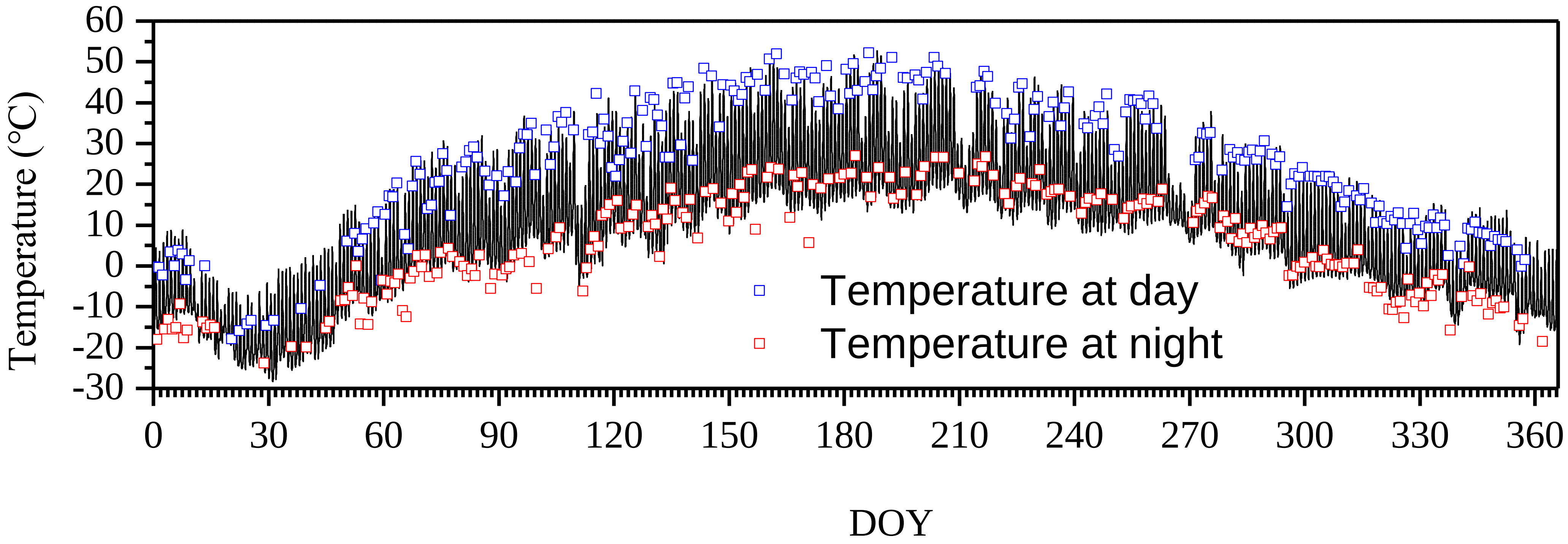
Heat conductivity

Calculation vs measurement at about 1 m depth

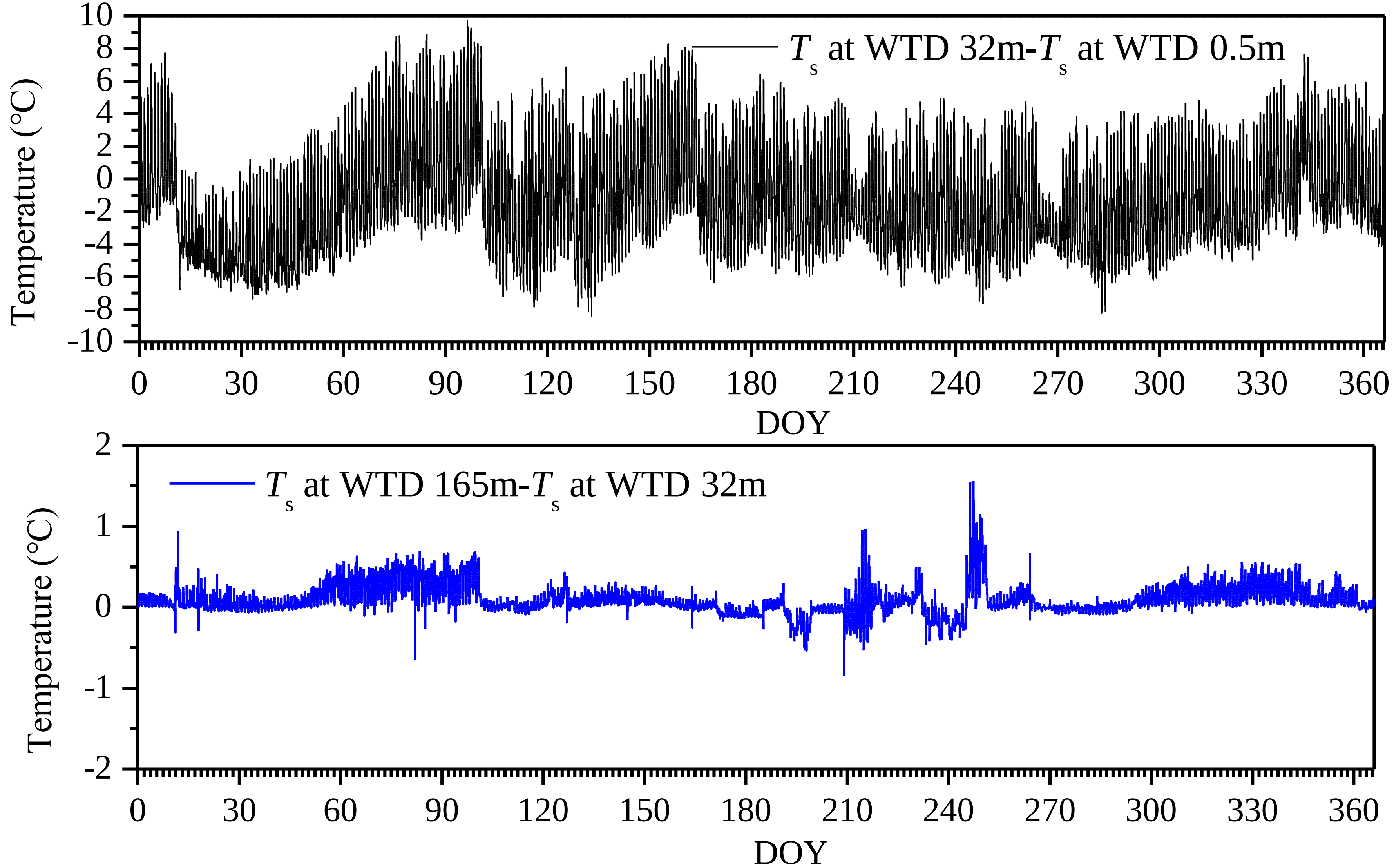


Soil temperature at about 1m depth

Calculated and measured temperatures (B1)



Surface temperature difference between different WTB depths



Surface temperature difference for different water table depth (WTD)

Conclusions

(1) The numerical approach can be used to correctly determine the soil surface temperature changes with varying water table depth.

(2) The hydraulic and thermal parameters need to be refined to increase the calculation quality.

(3) Slope direction seems to be important to be accounted for because it can greatly affect the solar radiation, wind speed etc.