Yale-NUIST Center on Atmospheric Environment
耶鲁大学-南京信息工程大学大气环境中心

Quantifying and decomposing surface temperature difference between global lakes and surrounding lands from 1991 to 2010

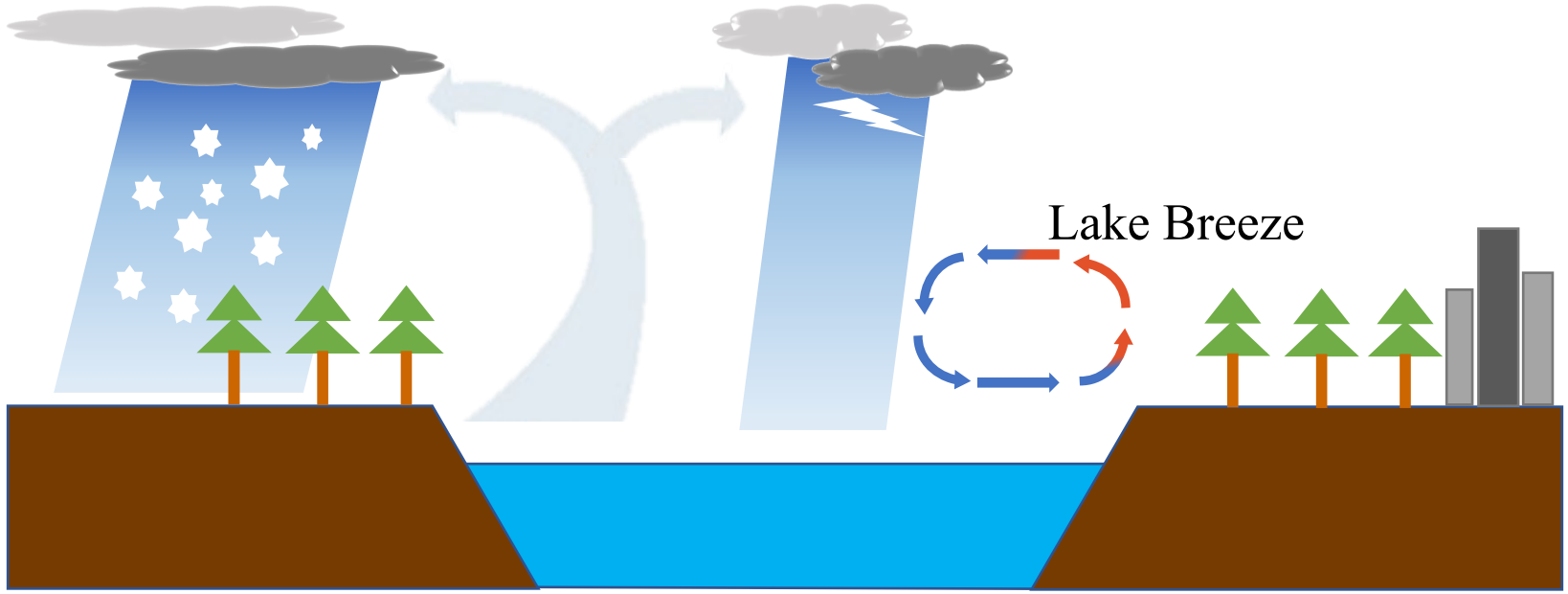
Heng Lv, 吕恒
2020.07.31

Outline

- Background
- Methods
- Results
- Discussion
- Conclusions

Background

1. The surface temperature difference between lakes and surrounding lands affect the basin weather and regional climate



Lakes versus Lands：

- Smaller albedo
- Greater heat capacity
- Smaller roughness

→ Surface temperature difference →

- Affect the regional radiation budget and energy balance
- Affect Lake-Land-Atmosphere interaction

(Subin et al., 2012)

Background

2. The observation and simulation of surface temperature difference between lakes and surrounding lands are controversial(Dutra et al., 2010; Krinner, 2003; Lofgren, 1997; Rouse et al., 2008).
3. The current researches lack the comparative study of multiple lakes in different climate zones and the decomposition of influencing factors (Diallo et al., 2018; Lv et al., 2019; Sun et al., 2015; Williams et al., 2015) .
4. As global warming, lake warming, glacier melting and human activities increase the complexity of surface temperature difference between lake and surrounding lands (Schneider and Hook, 2010; Sugiyama et al., 2018; O'Reilly et al., 2015).

Background

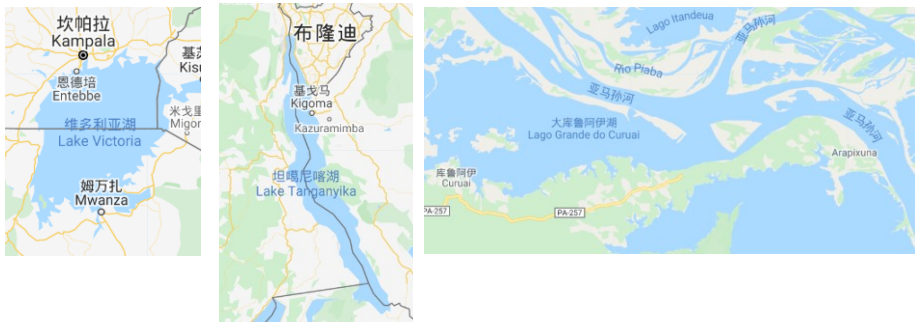
- Research Contents:
  - In this study, the meteorological conditions of global lakes and surrounding lands from 1991 to 2010 are simulated by CESM(Community Earth System Model) coupled CLM4.5(Community Land Model 4.5);
  - Based on Google Earth Engine, the MODIS surface temperature product(MOD11A2, MYD11A2) from 2003 to 2010 are obtained to verify CLM4.5 simulation results;
  - The surface temperature difference between lake and surrounding land are decomposed into four biophysical contributions using the IBPM(Intrinsic Biophysical Mechanism).
- Research Objective:
  - Quantifying and decomposing surface temperature difference between global lakes and surrounding lands.

Methods

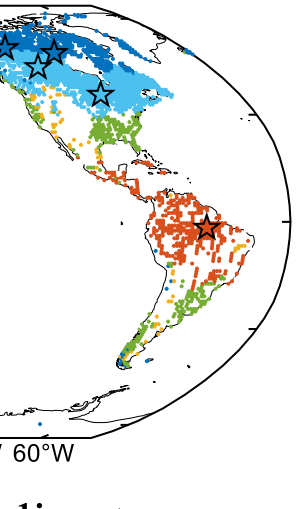
1. Study pairs of lake & surrounding land and climates distribution

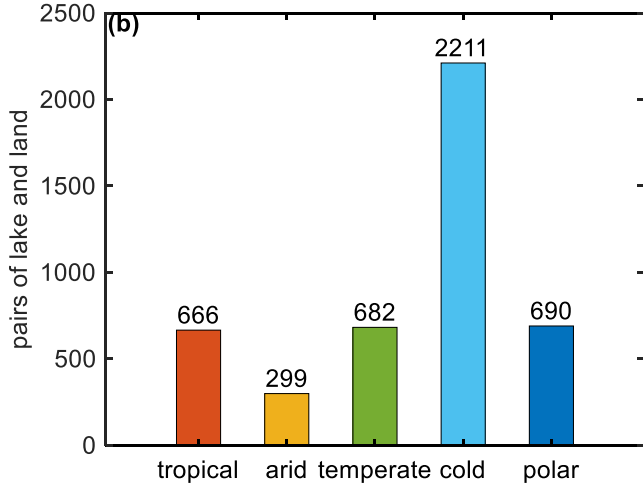
★ Cases in Polar climate:

★ Cases in Tropical climate:



★ Cases in Arid climate:





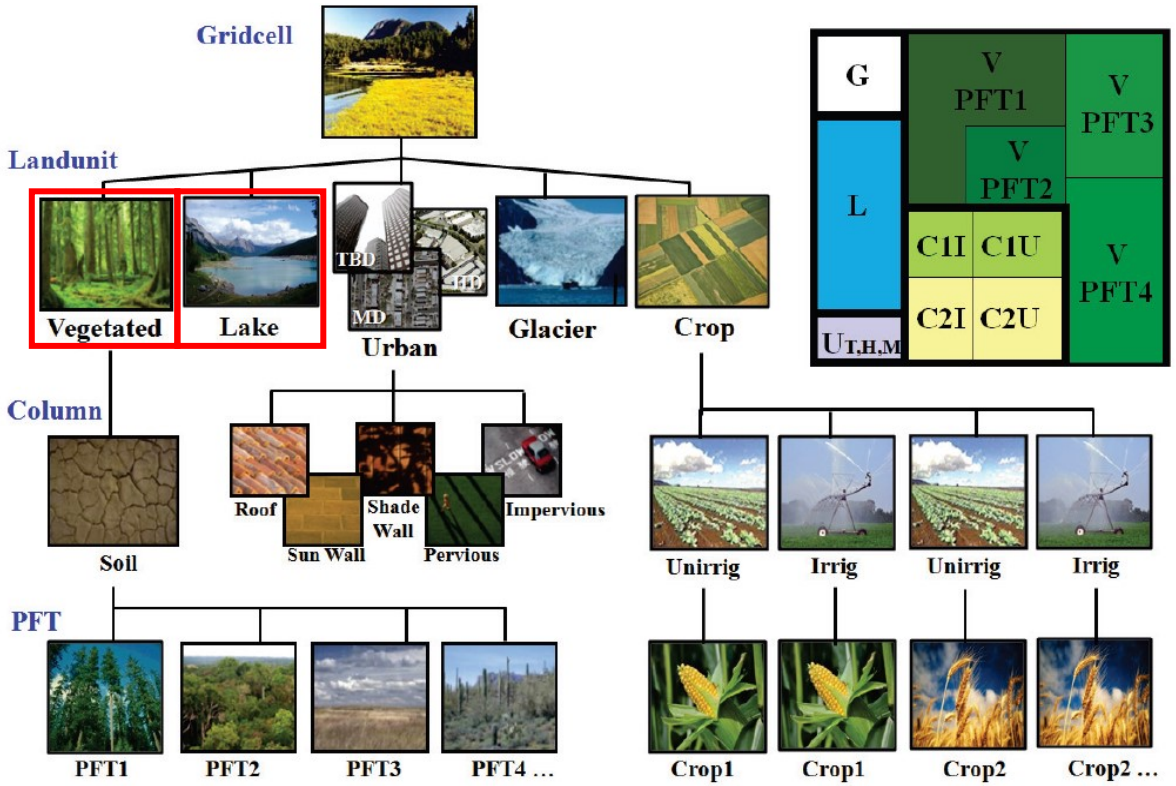
★ Cases in Temperature climate:

★ Cases in Cold climate:

☐ Climate zones according to the Köppen-Geiger classification (Peel et al., 2007);

Methods

2. The lake and surrounding land simulator, CLM4.5



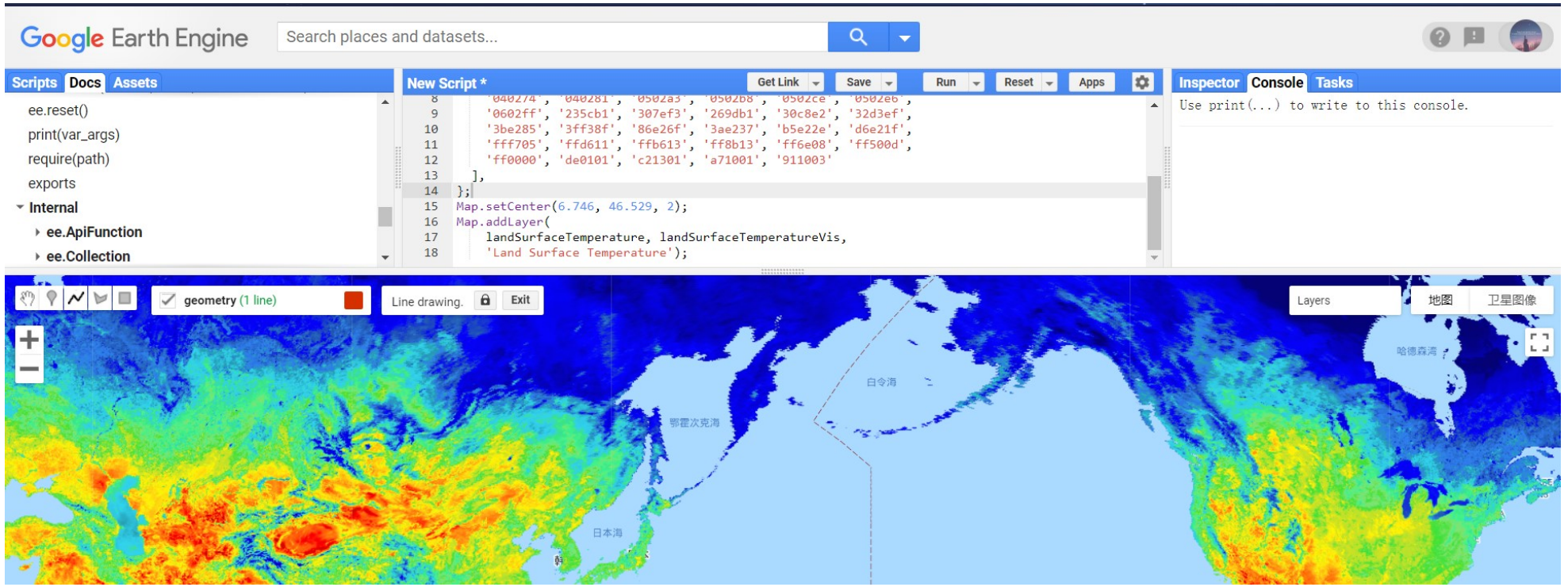
- **Nest hierarchy:** Each gridcell consists of up to five land units or tiles(glacier, urban, agricultural, vegetation and lake).
- **Atmospheric forcing data:** CRUNCEP（Climatic Research Unit - National Centers for Environmental Prediction）
- **Spatial resolution:** 0.94° lat×1.25° lon
- **Grid quantity:** 192×288
- **Temporal resolution:** Month
- **Simulation time :** 1991-2010

（Oleson et al., 2013）

Methods

3. Google Earth Engine

- Google Earth Engine is an online platform created to allow remote sensing users to easily perform big data analyses without the need for computation resources(Ermida et al., 2020).



(https://code.earthengine.google.com/)

Methods

3. Google Earth Engine

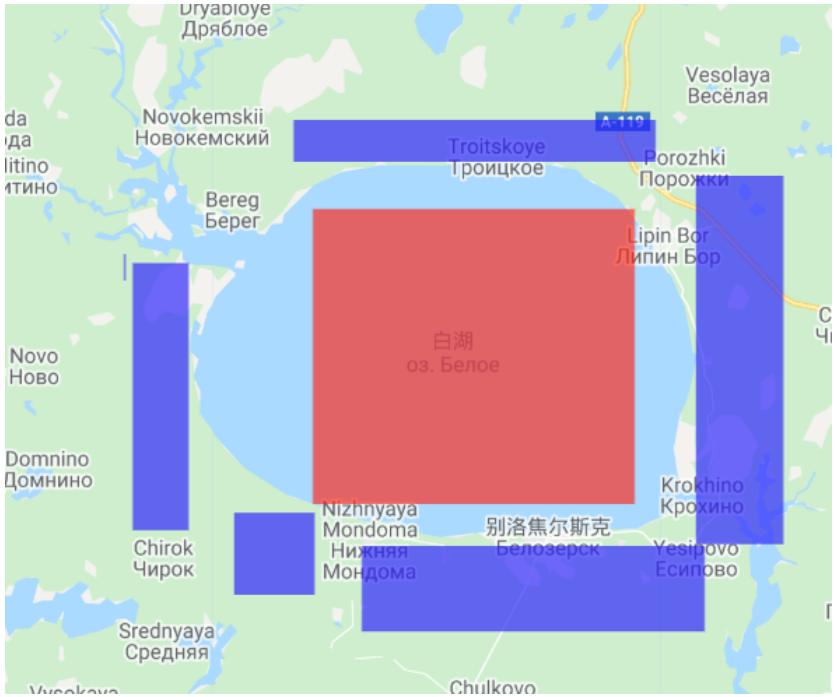
- MOD11A2 & MYD11A2

Variable	Spatial resolution	Temporal resolution	Study Period	Study areas
Day land surface temperature	1 km	8 day	2003-01-01T00:00:00 – 2010-12-27T00:00:00	15 lakes and surrounding lands in different climate zones
Night land surface temperature				

- Based on day and night land surface temperature, calculating the monthly average of lakes and surrounding lands surface temperature.

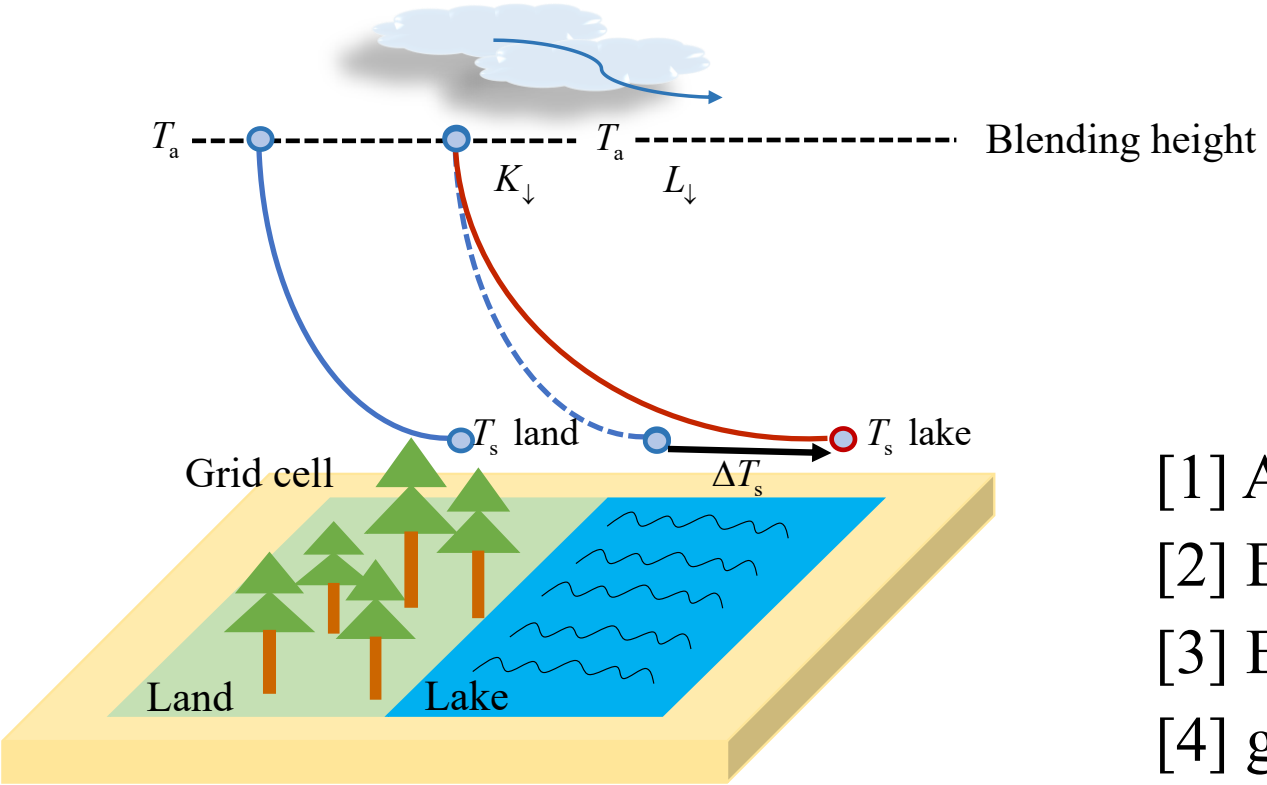
（https://ladsweb.modaps.eosdis.nasa.gov/）

- A lake or land consists of multiple points or polygons in Google Earth Engine



Methods

5. The intrinsic biophysical mechanism——IBPM（Lee et al., 2011）
   - Online ΔT_s: The surface temperature difference between lake and surrounding lands simulated in CLM4.5, as T_s lake - T_s land;
   - Offline ΔT_s: The summation of all terms([1]~[4]) in IBPM theory, using the variables saved from the online CLM4.5 calculation.



$$\Delta T_s \approx \underbrace{\frac{-\lambda_0}{1+f} K_\downarrow \Delta\alpha}_{[1]} + \underbrace{\frac{-\lambda_0}{(1+f)^2}\left(R_n^* - G\right)\Delta f_1}_{[2]} + \underbrace{\frac{-\lambda_0}{(1+f)^2}\left(R_n^* - G\right)\Delta f_2}_{[3]} + \underbrace{\frac{-\lambda_0}{1+f}\Delta G}_{[4]}$$

[1] Albedo change

[2] Energy redistribution due to roughness change

[3] Energy redistribution due to Bowen ratio change

[4] ground heat flux change

The diagnostic calculation of *total resistance to sensible heat diffusion* r_t

$$r_t = \rho C_p \frac{T_s - T_a}{H}$$

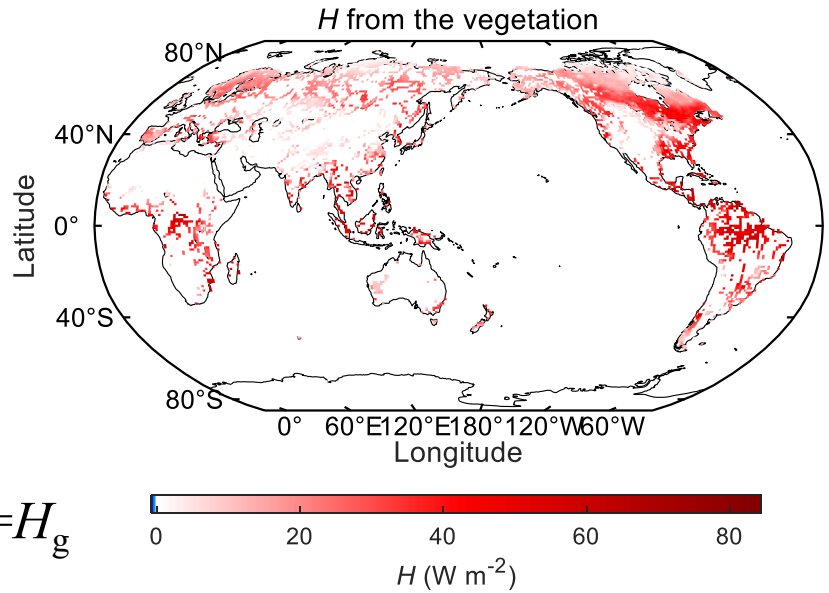
$$H = H_v + H_g$$

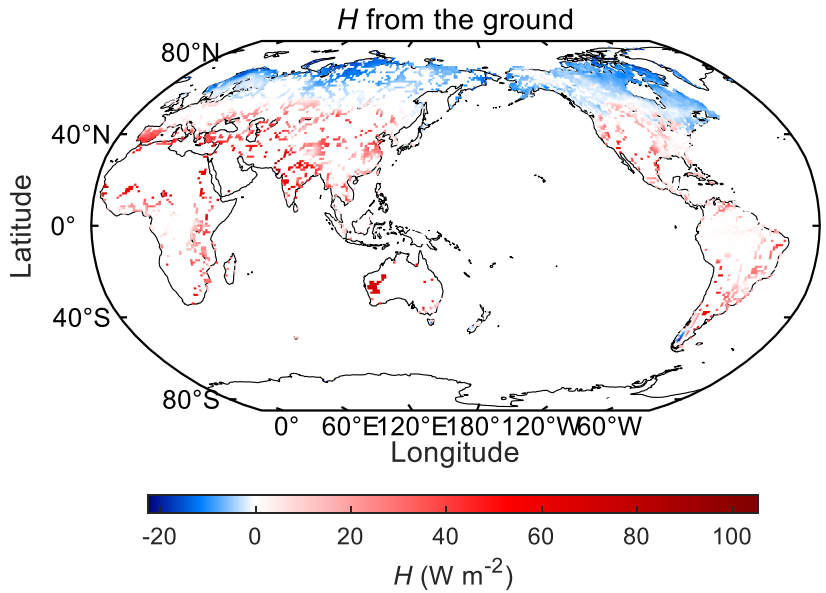
Lands in cold and polar climates: $H=H_g$

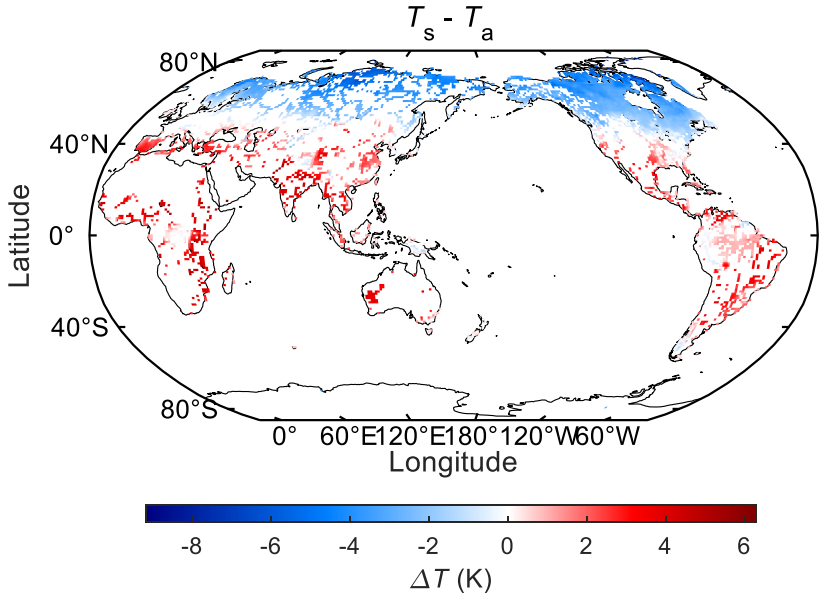
$$f = \frac{-\rho C_p \lambda_0}{r_t}\left(1+\frac{1}{\beta}\right)$$

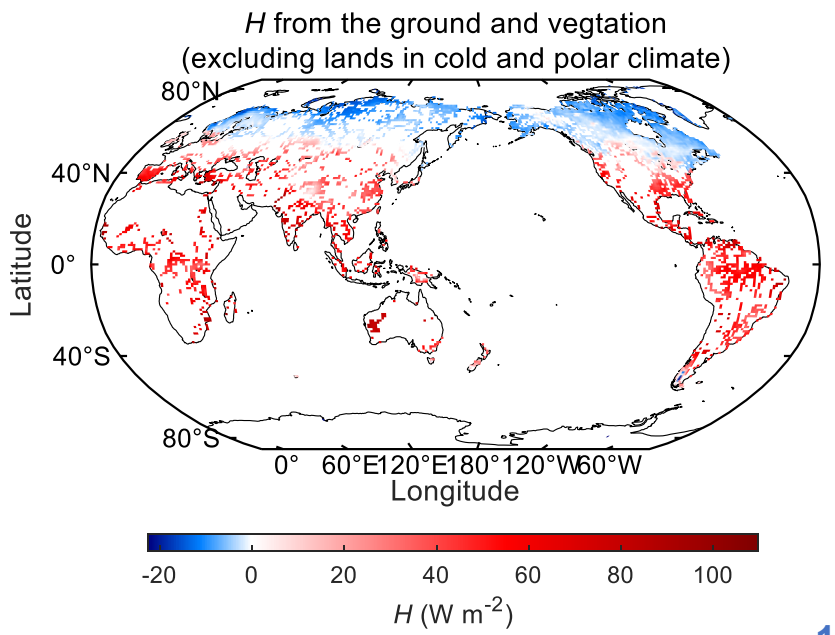
$$\Delta f_1 = \frac{-\rho C_p \lambda_0}{r_t}\left(1+\frac{1}{\beta}\right)\frac{\Delta r_t}{r_t}$$

$$\Delta f_2 = \frac{-\rho C_p \lambda_0}{r_t}\left(\frac{\Delta\beta}{\beta^2}\right)$$









Outline

- Background
- Methods
- Results
  - Model Evaluation
  - Online versus Offline Surface Temperature Difference between lakes and surrounding lands
  - Contributions of Surface Temperature Difference
- Discussion
- Conclusions

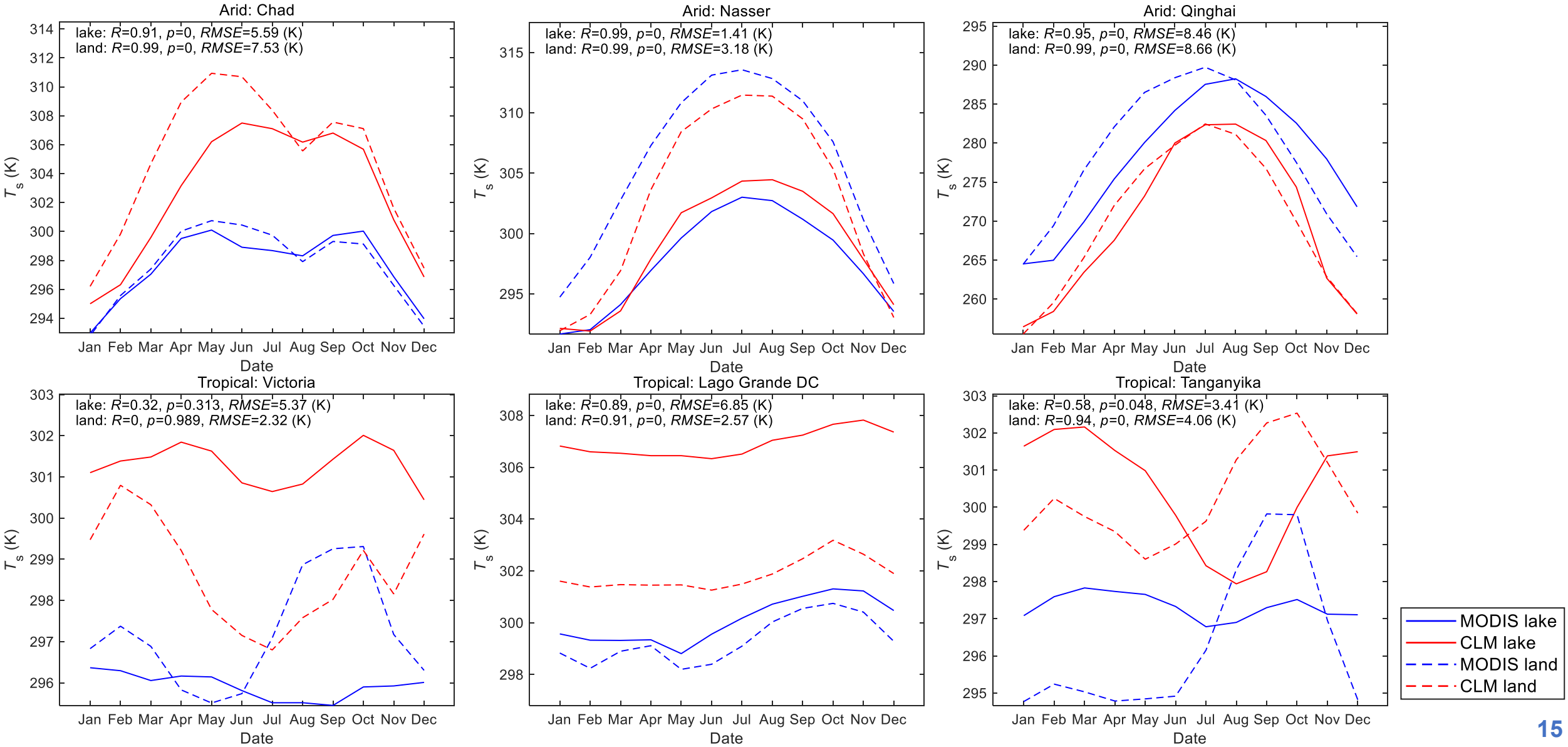
Results

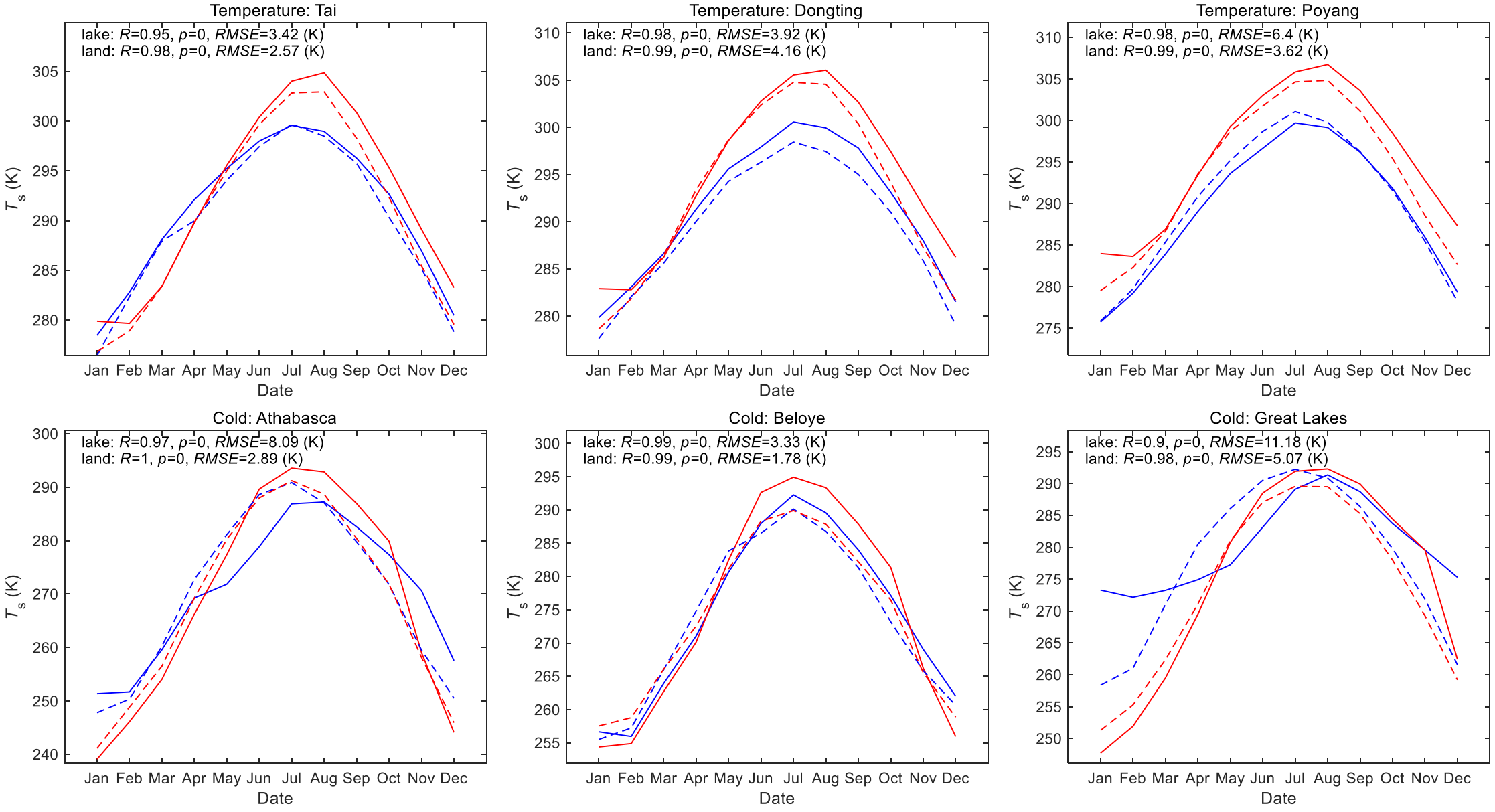
1. Model Evaluation

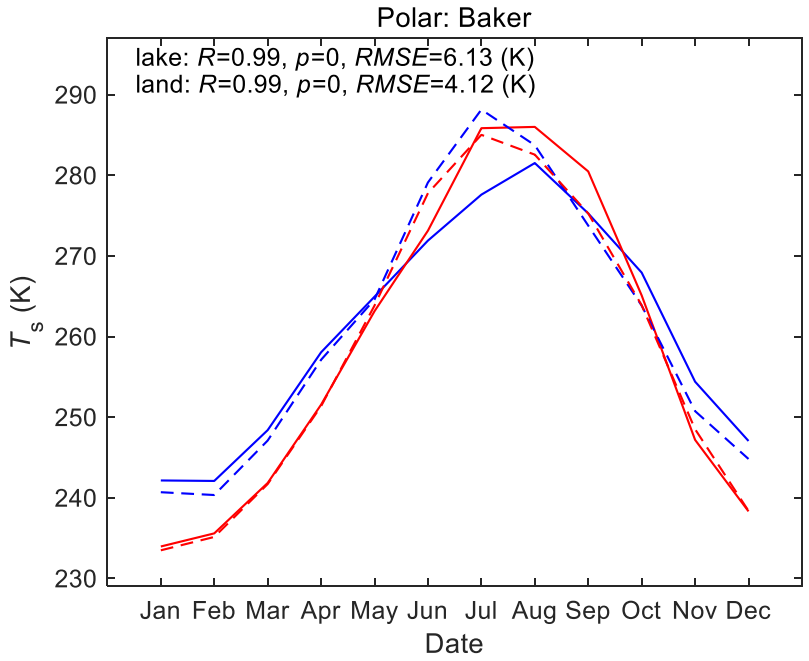
- On month scale:
  - Seasonal variations in the *lakes and surrounding lands* T_s
  - Relationship between ΔT_s (MODIS) and ΔT_s (CLM), using monthly mean
- On annual scale:
  - Annual variations in the *lakes and surrounding lands* T_s
  - Relationship between ΔT_s (MODIS) and ΔT_s (CLM), using annually mean

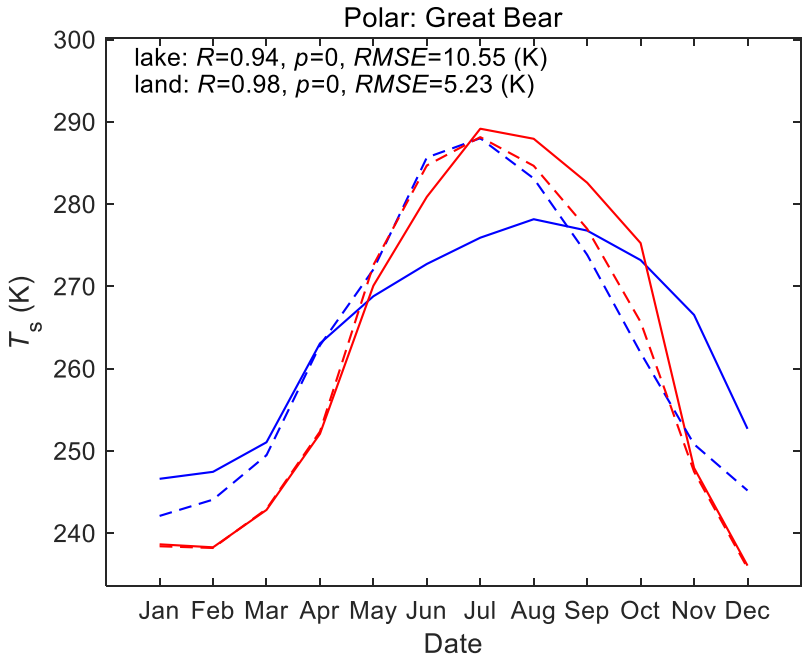
Results

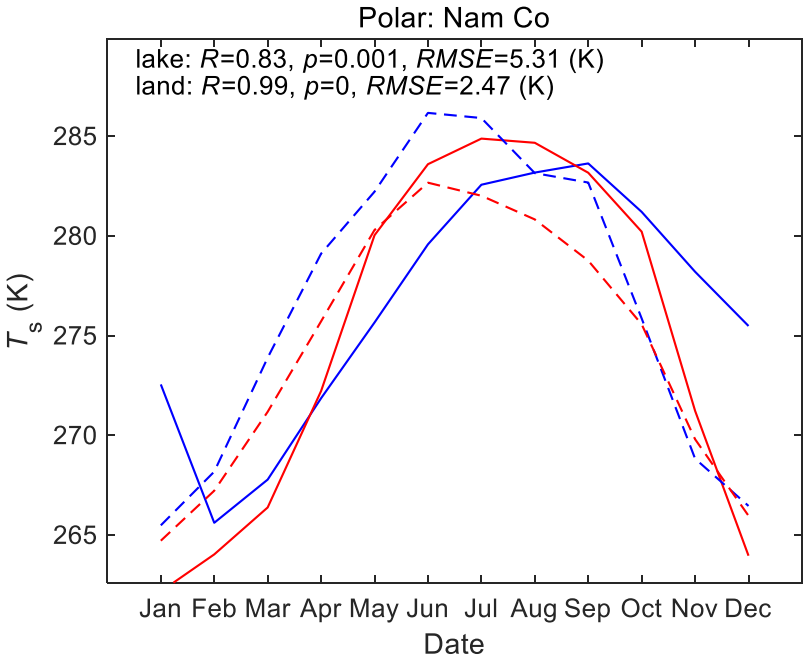
- On month scale: Seasonal variations in the *lakes and surrounding lands* T_s

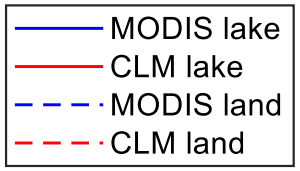



Temperature: Tai
lake: R=0.95, p=0, RMSE=3.42 (K)
land: R=0.98, p=0, RMSE=2.57 (K)
Temperature: Dongting
lake: R=0.98, p=0, RMSE=3.92 (K)
land: R=0.99, p=0, RMSE=4.16 (K)
Temperature: Poyang
lake: R=0.98, p=0, RMSE=6.4 (K)
land: R=0.99, p=0, RMSE=3.62 (K)
Cold: Athabasca
lake: R=0.97, p=0, RMSE=8.09 (K)
land: R=1, p=0, RMSE=2.89 (K)
Cold: Beloye
lake: R=0.99, p=0, RMSE=3.33 (K)
land: R=0.99, p=0, RMSE=1.78 (K)
Cold: Great Lakes
lake: R=0.9, p=0, RMSE=11.18 (K)
land: R=0.98, p=0, RMSE=5.07 (K)
T_s (K)
Date
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
MODIS lake
CLM lake
MODIS land
CLM land

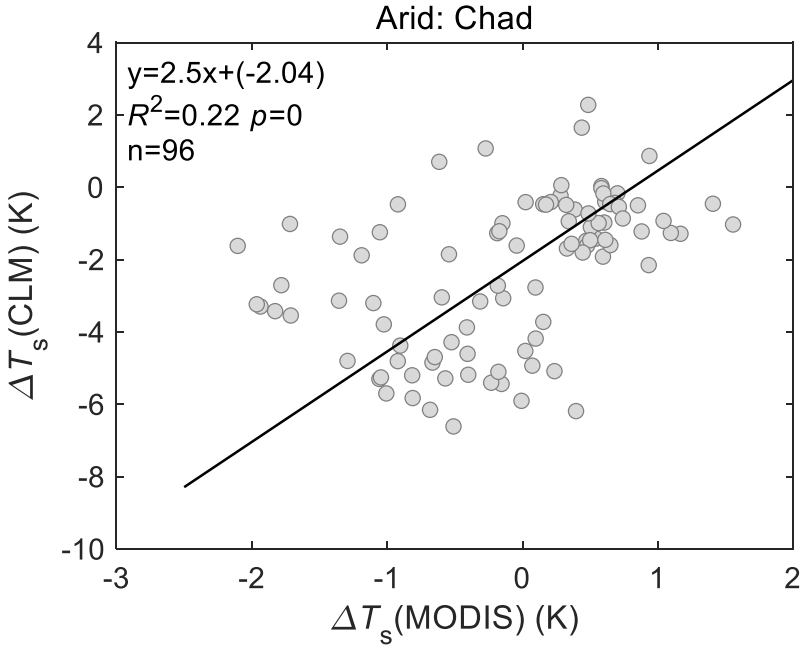

Polar: Baker
lake: R=0.99, p=0, RMSE=6.13 (K)
land: R=0.99, p=0, RMSE=4.12 (K)
290
280
270
260
250
240
230
T_s (K)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Date

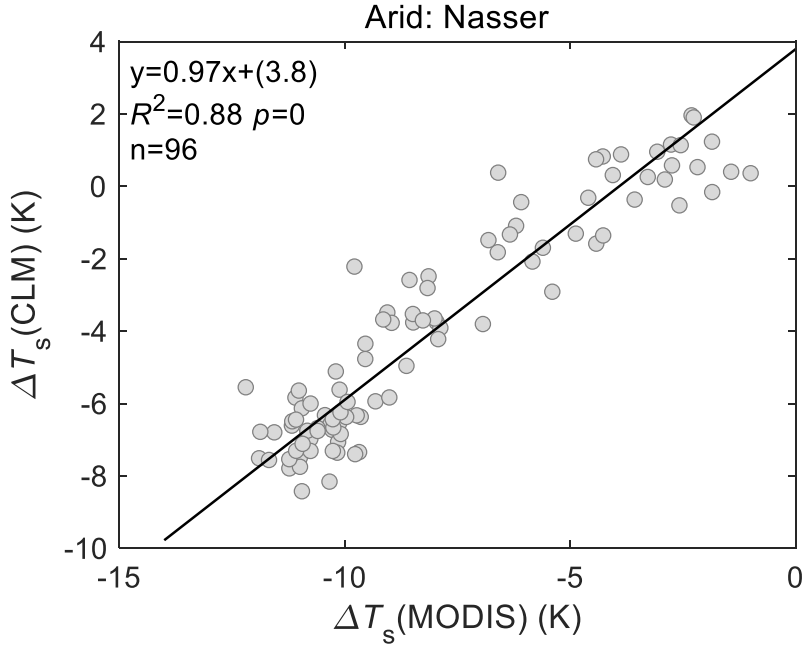

Polar: Great Bear
lake: R=0.94, p=0, RMSE=10.55 (K)
land: R=0.98, p=0, RMSE=5.23 (K)
300
290
280
270
260
250
240
T_s (K)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Date

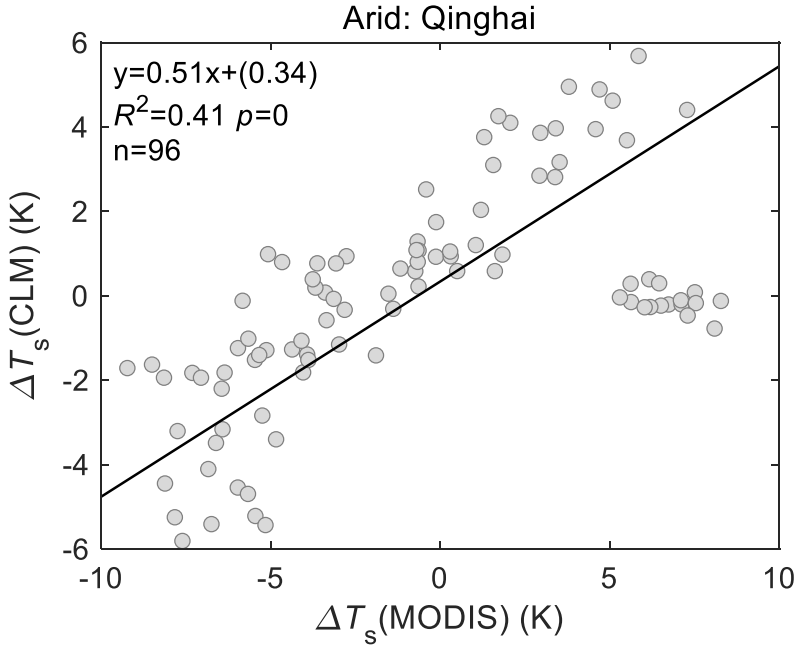

Polar: Nam Co
lake: R=0.83, p=0.001, RMSE=5.31 (K)
land: R=0.99, p=0, RMSE=2.47 (K)
285
280
275
270
265
T_s (K)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Date

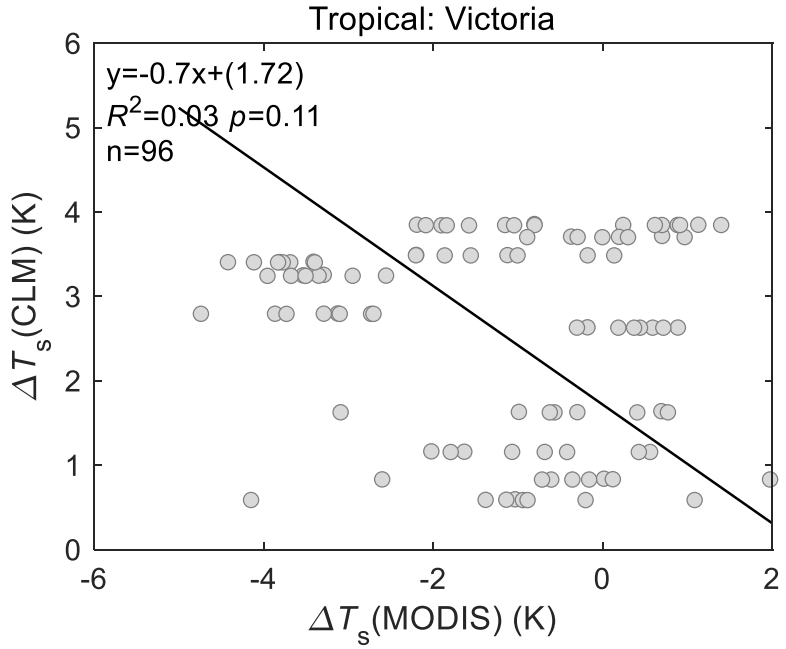

MODIS lake
CLM lake
MODIS land
CLM land

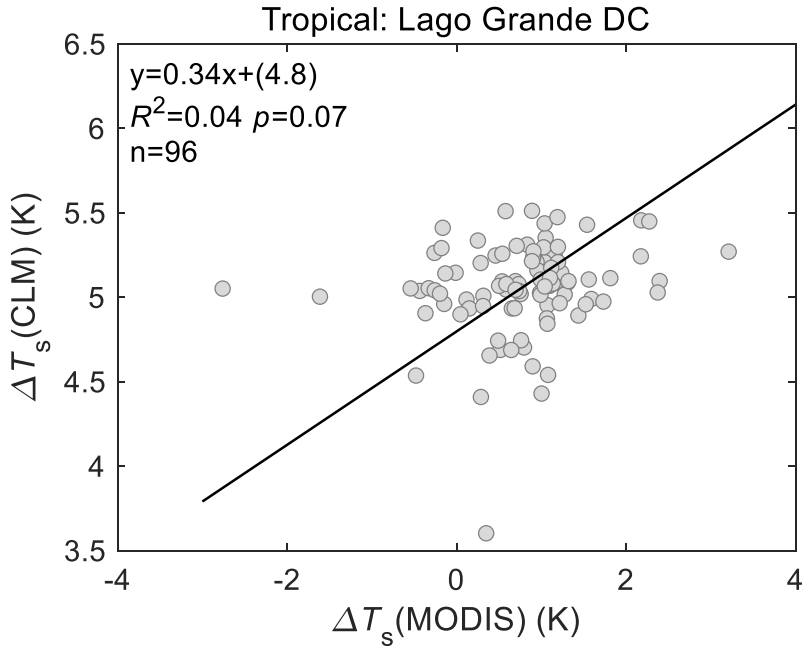
On month scale: Relationship between ΔT_s (MODIS) and ΔT_s (CLM), using monthly mean

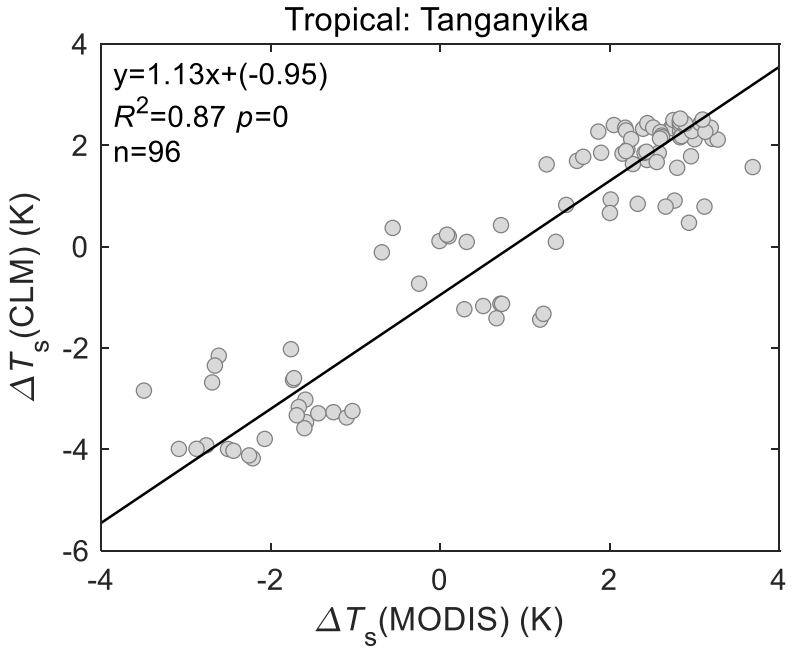


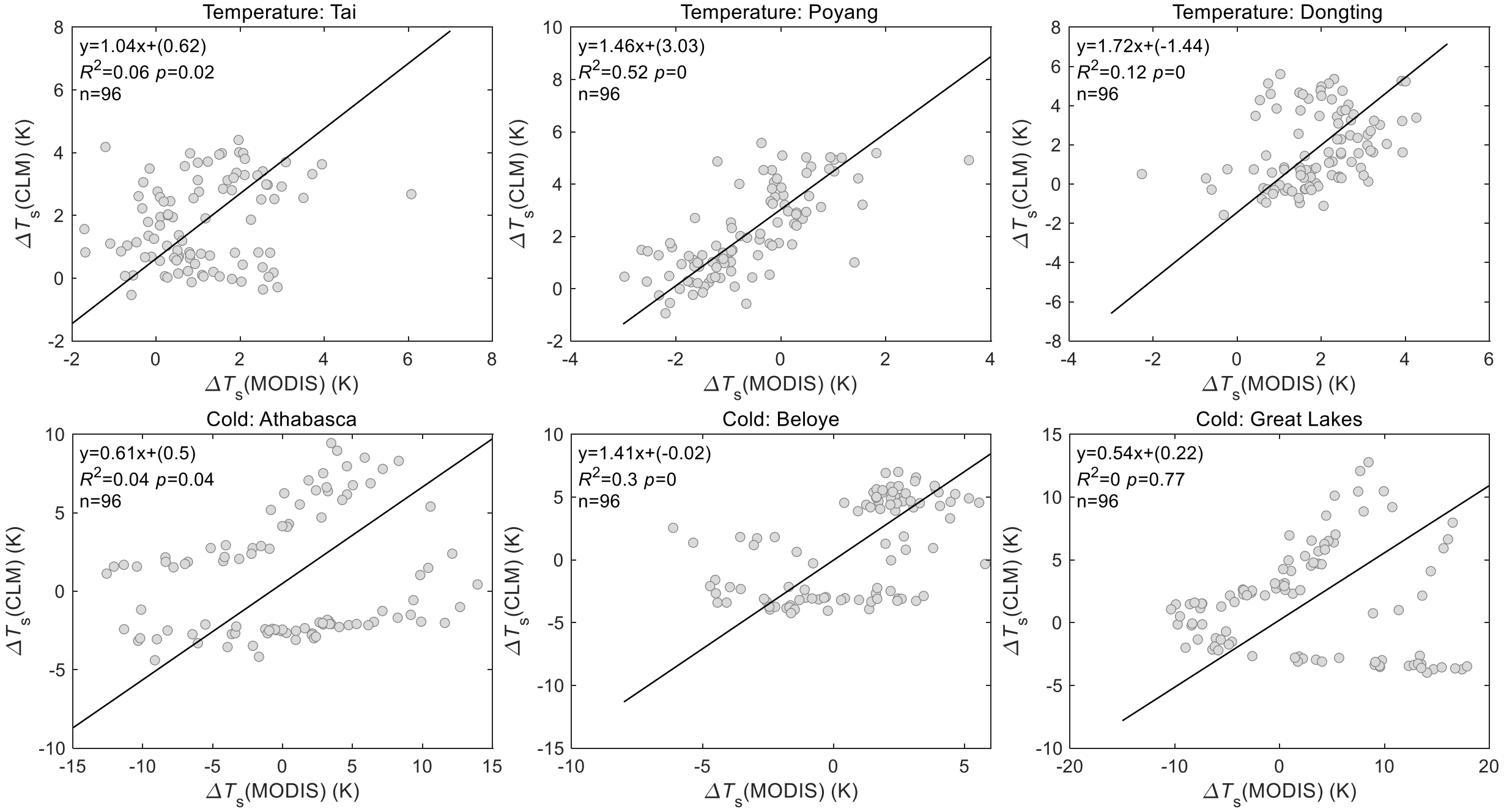


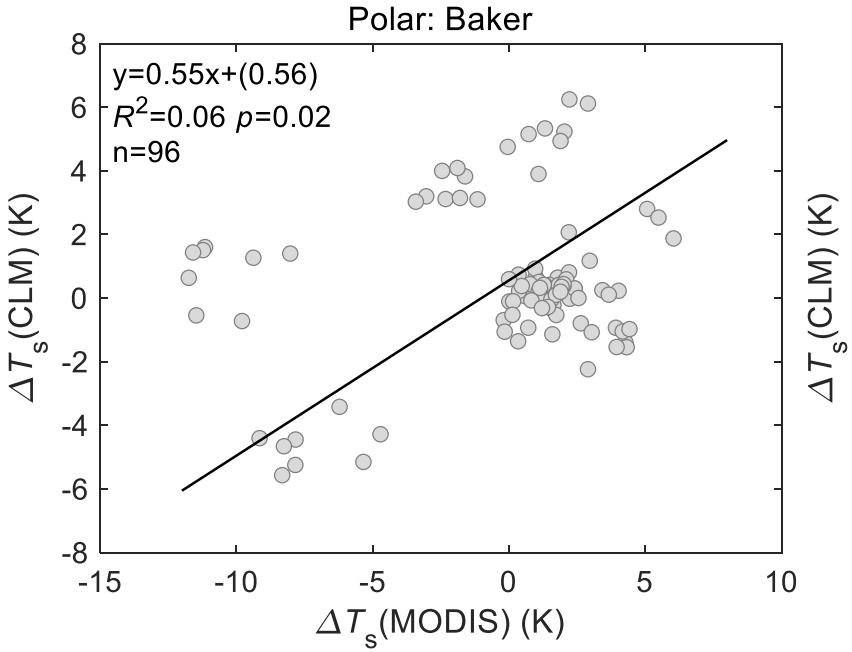


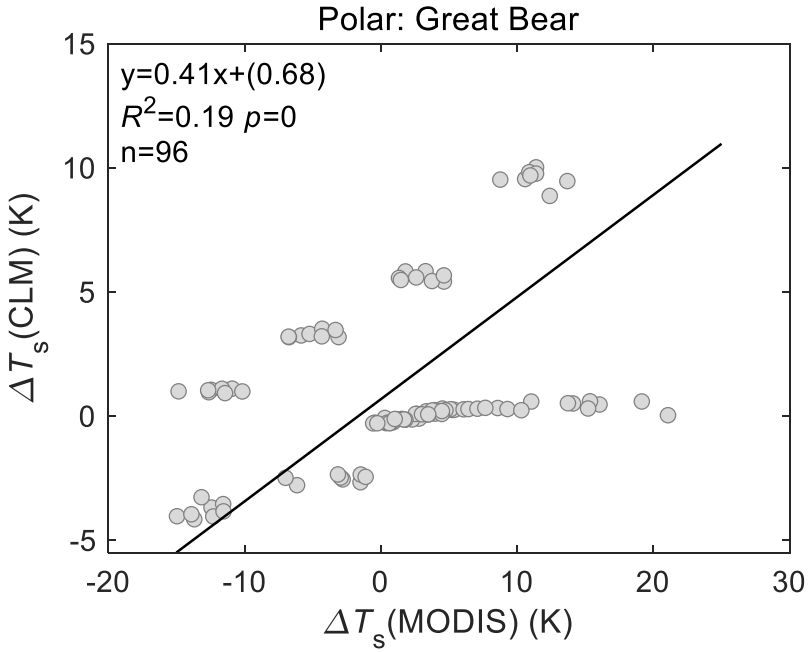


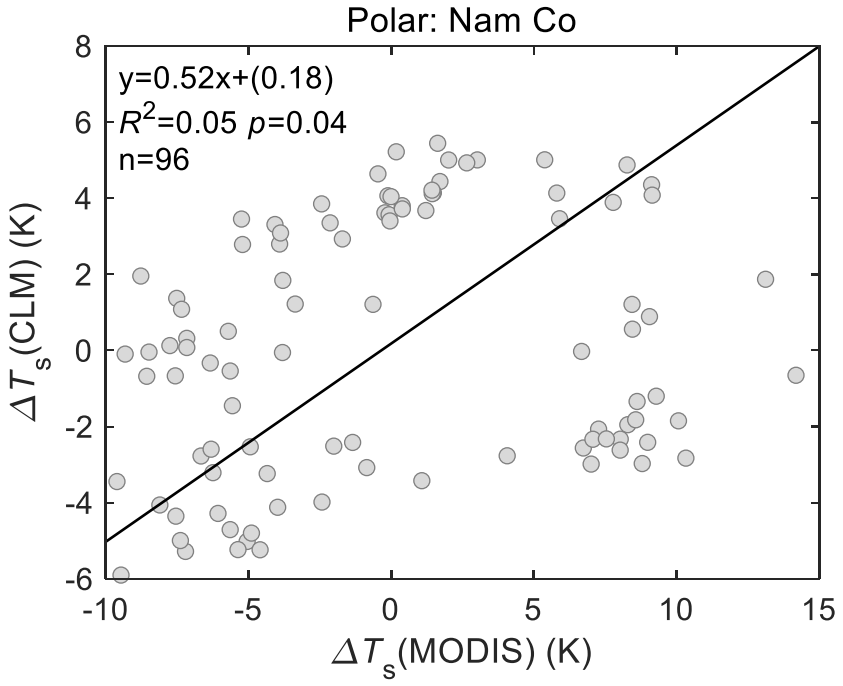





Temperature: Tai
y=1.04x+(0.62)
R^2=0.06 p=0.02
n=96
ΔT_s(CLM) (K)
ΔT_s(MODIS) (K)
Temperature: Poyang
y=1.46x+(3.03)
R^2=0.52 p=0
n=96
ΔT_s(CLM) (K)
ΔT_s(MODIS) (K)
Temperature: Dongting
y=1.72x+(-1.44)
R^2=0.12 p=0
n=96
ΔT_s(CLM) (K)
ΔT_s(MODIS) (K)
Cold: Athabasca
y=0.61x+(0.5)
R^2=0.04 p=0.04
n=96
ΔT_s(CLM) (K)
ΔT_s(MODIS) (K)
Cold: Beloye
y=1.41x+(-0.02)
R^2=0.3 p=0
n=96
ΔT_s(CLM) (K)
ΔT_s(MODIS) (K)
Cold: Great Lakes
y=0.54x+(0.22)
R^2=0 p=0.77
n=96
ΔT_s(CLM) (K)
ΔT_s(MODIS) (K)

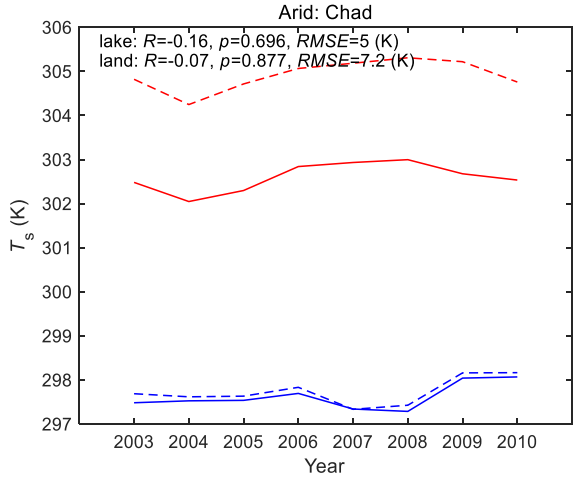

Polar: Baker
y=0.55x+(0.56)
R^2=0.06 p=0.02
n=96
ΔT_s(CLM) (K)
ΔT_s(MODIS) (K)

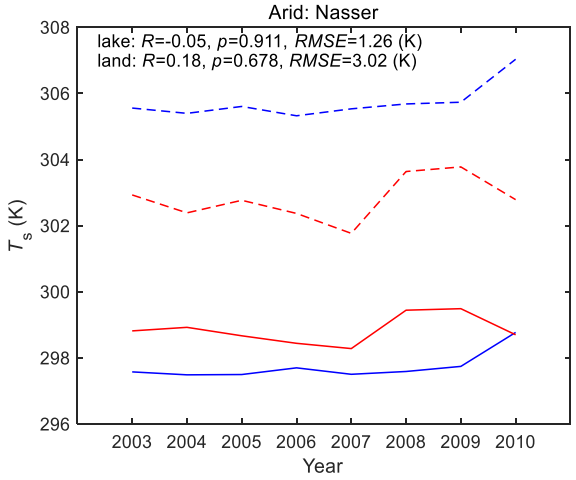

Polar: Great Bear
y=0.41x+(0.68)
R^2=0.19 p=0
n=96
ΔT_s(CLM) (K)
ΔT_s(MODIS) (K)

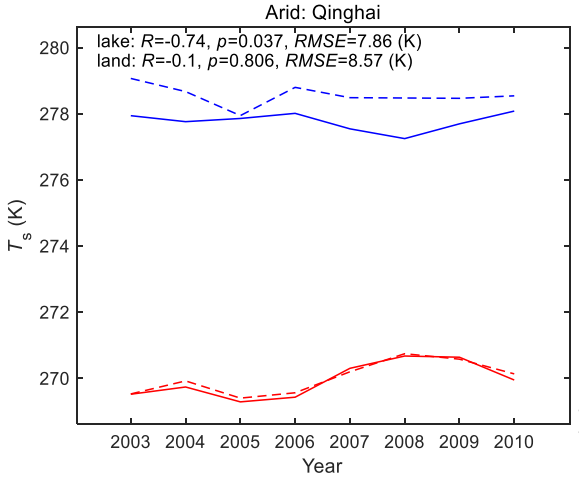

Polar: Nam Co
y=0.52x+(0.18)
R^2=0.05 p=0.04
n=96
ΔT_s(CLM) (K)
ΔT_s(MODIS) (K)

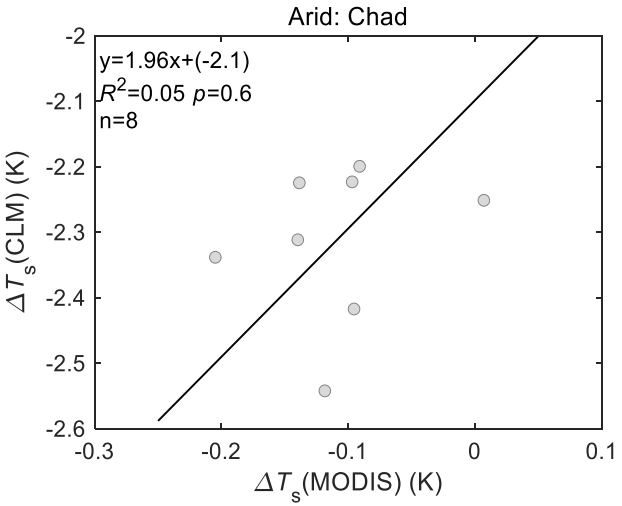
On annual scale: Annual variations in the *lakes and surrounding lands* T_s

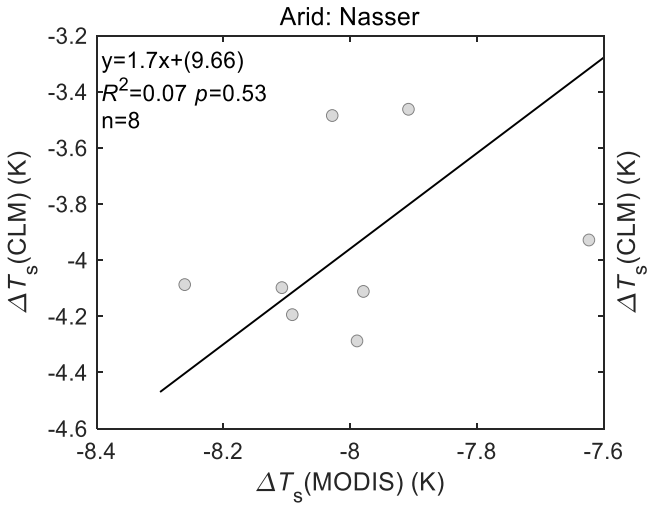
Relationship between ΔT_s (MODIS) and ΔT_s (CLM), using annually mean

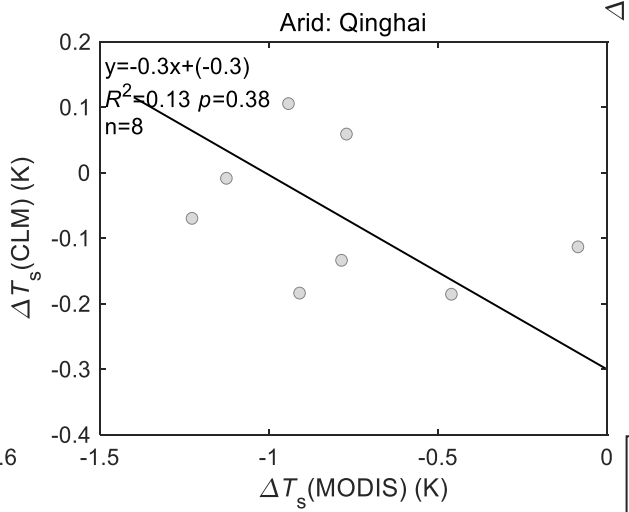


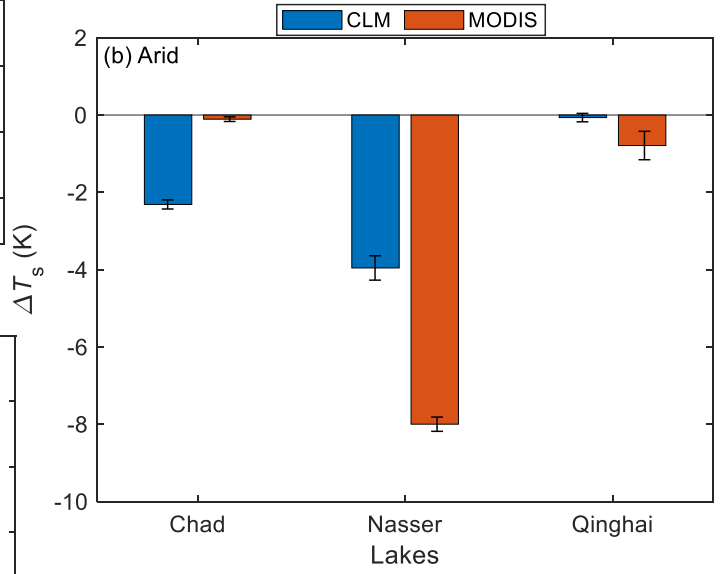


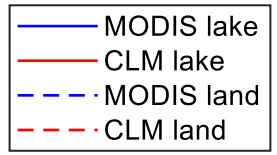


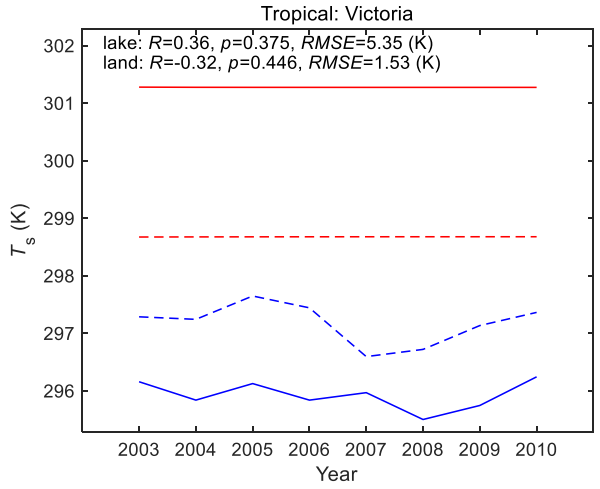


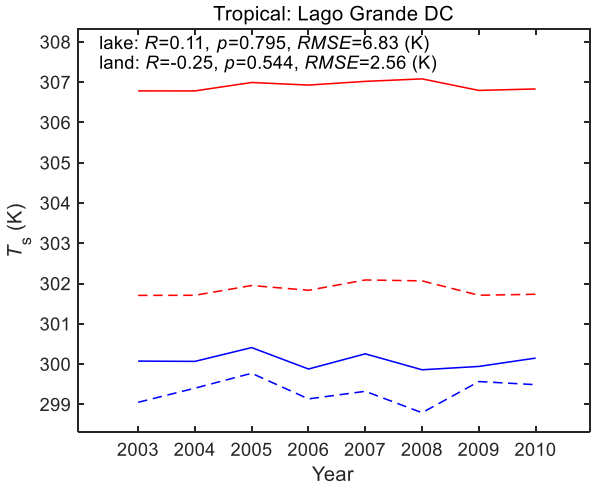


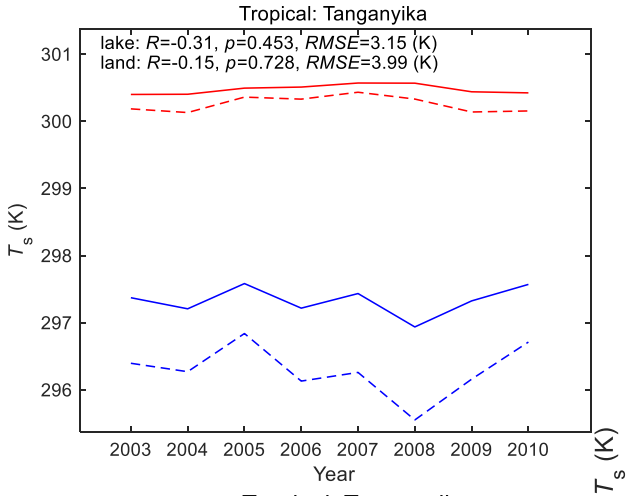


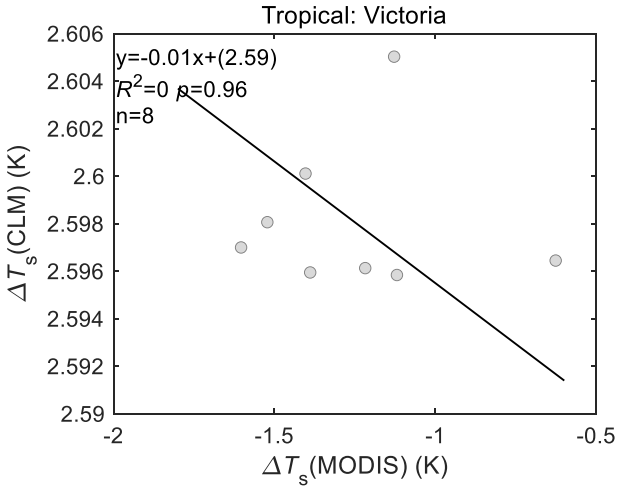


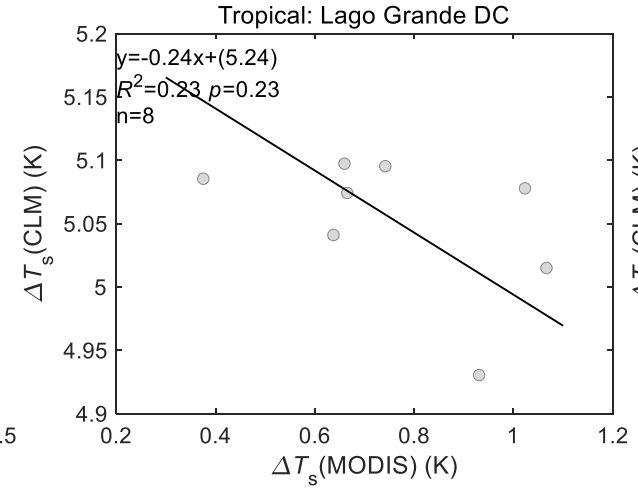


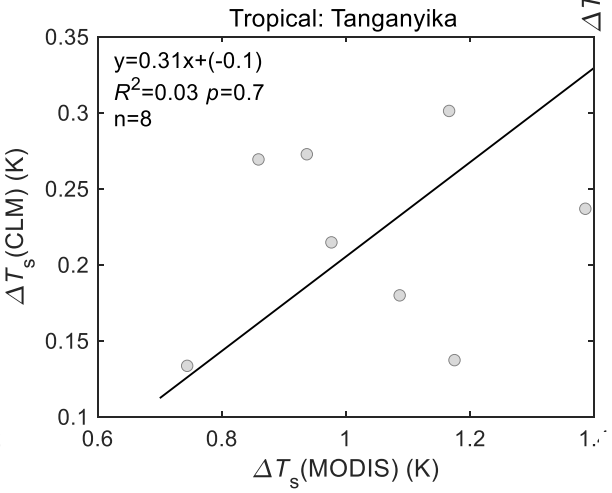

Tropical: Victoria
lake: R=0.36, p=0.375, RMSE=5.35 (K)
land: R=-0.32, p=0.446, RMSE=1.53 (K)
T_s (K)
Year

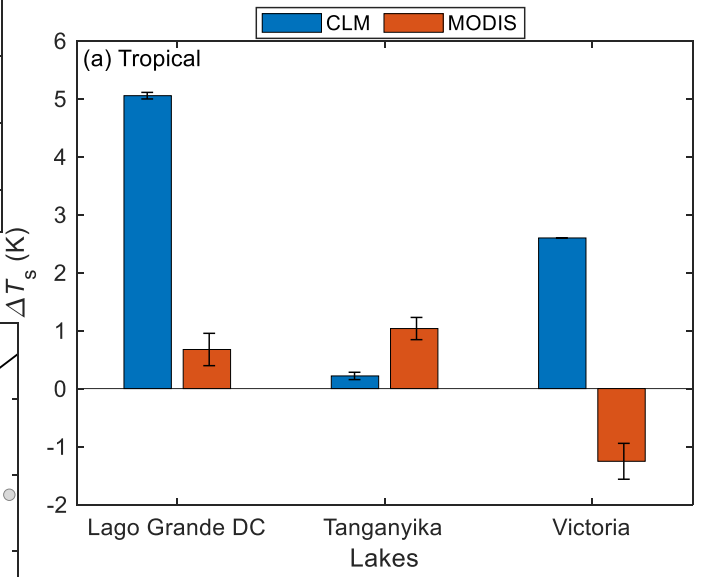

Tropical: Lago Grande DC
lake: R=0.11, p=0.795, RMSE=6.83 (K)
land: R=-0.25, p=0.544, RMSE=2.56 (K)
T_s (K)
Year

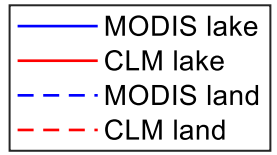

Tropical: Tanganyika
lake: R=-0.31, p=0.453, RMSE=3.15 (K)
land: R=-0.15, p=0.728, RMSE=3.99 (K)
T_s (K)
Year

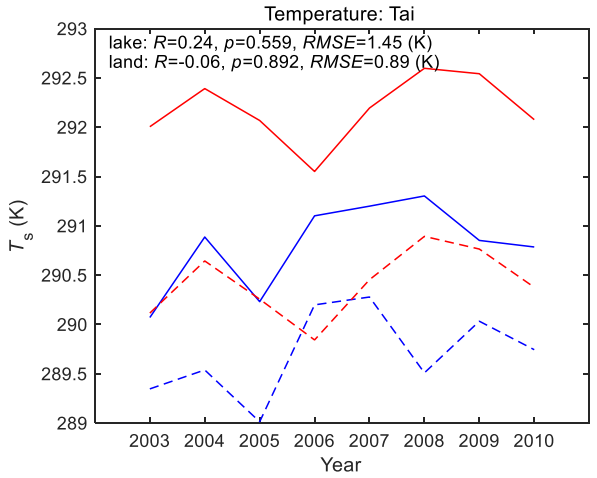

Tropical: Victoria
y=-0.01x+(2.59)
R²=0 p=0.96
n=8
ΔT_s(CLM) (K)
ΔT_s(MODIS) (K)

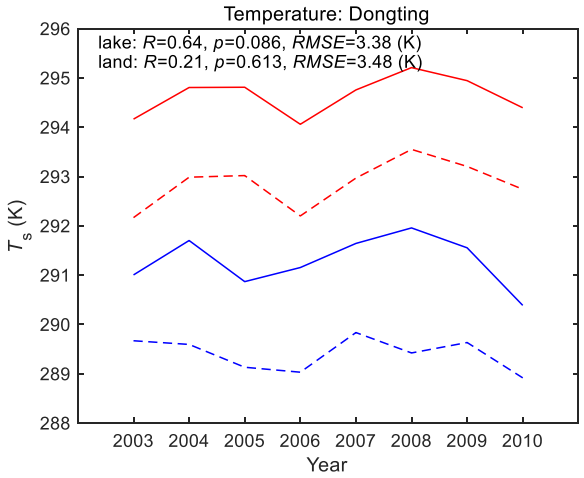

Tropical: Lago Grande DC
y=-0.24x+(5.24)
R²=0.23 p=0.23
n=8
ΔT_s(CLM) (K)
ΔT_s(MODIS) (K)

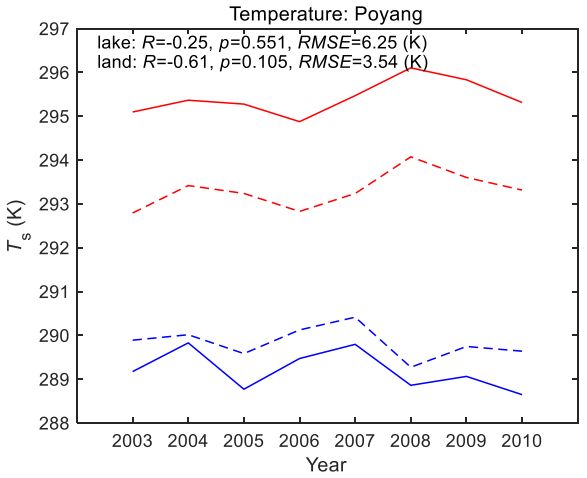

Tropical: Tanganyika
y=0.31x+(-0.1)
R²=0.03 p=0.7
n=8
ΔT_s(CLM) (K)
ΔT_s(MODIS) (K)

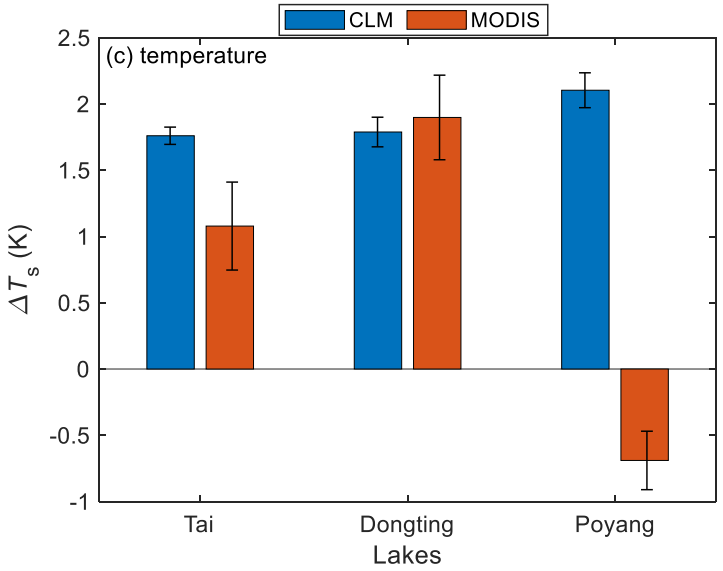

CLM
MODIS
(a) Tropical
ΔT_s (K)
Lago Grande DC
Tanganyika
Victoria
Lakes

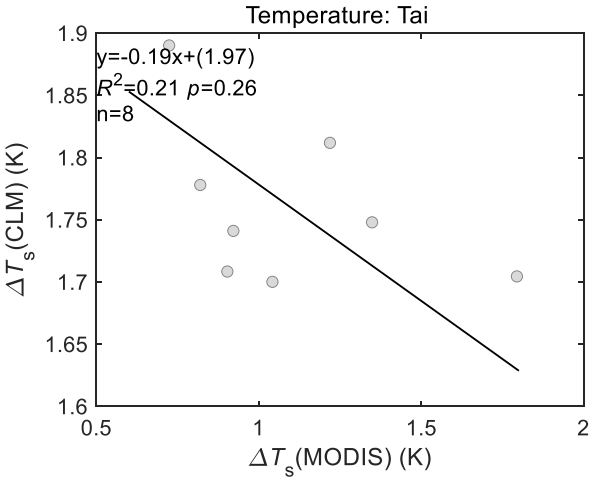

MODIS lake
CLM lake
MODIS land
CLM land

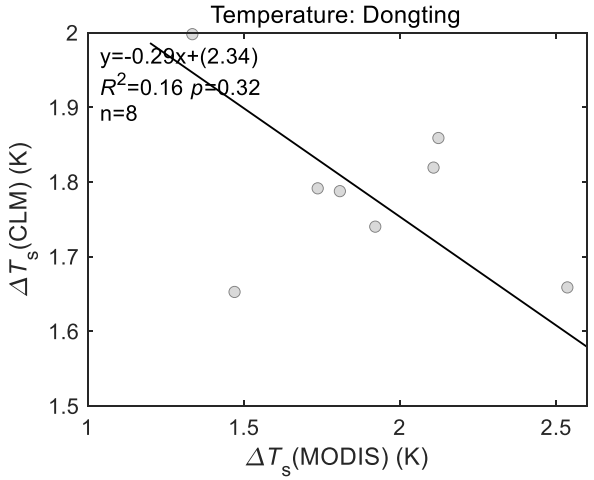

Temperature: Tai
lake: R=0.24, p=0.559, RMSE=1.45 (K)
land: R=-0.06, p=0.892, RMSE=0.89 (K)
T_s (K)
Year

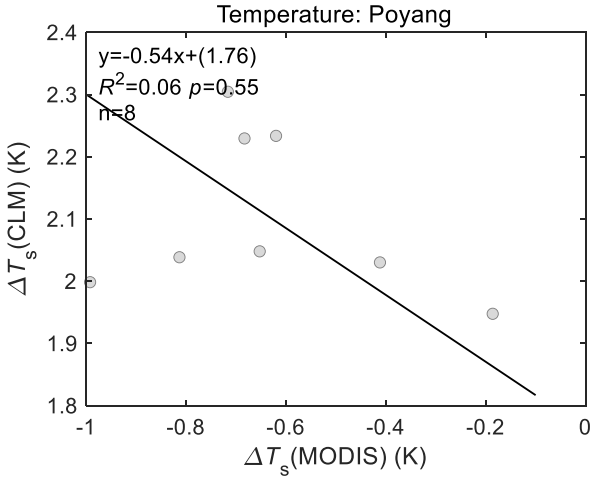

Temperature: Dongting
lake: R=0.64, p=0.086, RMSE=3.38 (K)
land: R=0.21, p=0.613, RMSE=3.48 (K)
T_s (K)
Year

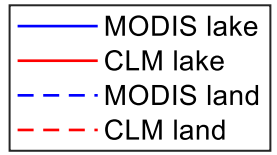

Temperature: Poyang
lake: R=-0.25, p=0.551, RMSE=6.25 (K)
land: R=-0.61, p=0.105, RMSE=3.54 (K)
T_s (K)
Year

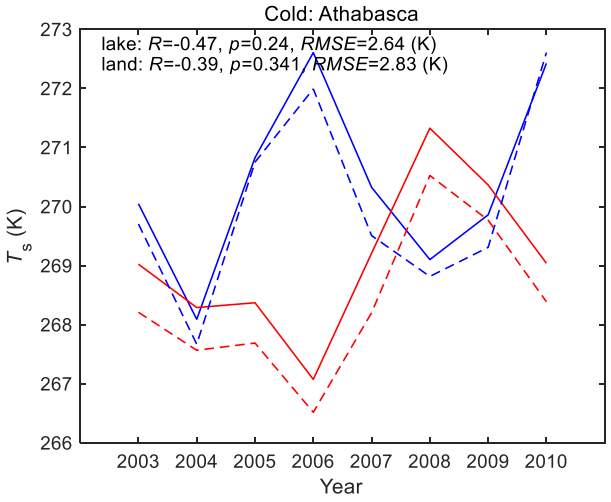

CLM
MODIS
(c) temperature
ΔT_s (K)
Tai
Dongting
Poyang
Lakes

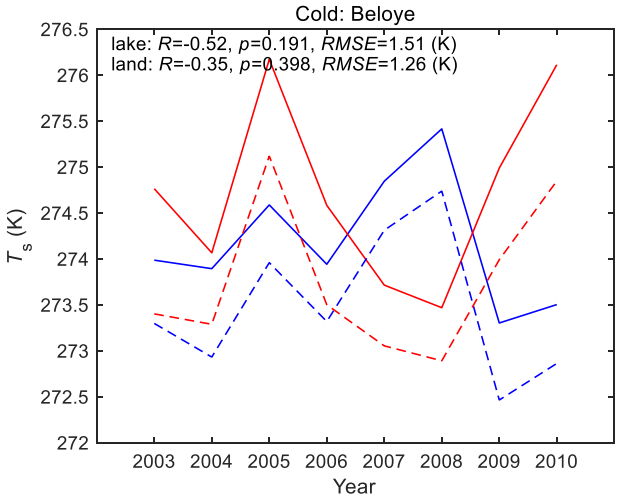

Temperature: Tai
y=-0.19x+(1.97)
R²=0.21 p=0.26
n=8
ΔT_s(CLM) (K)
ΔT_s(MODIS) (K)

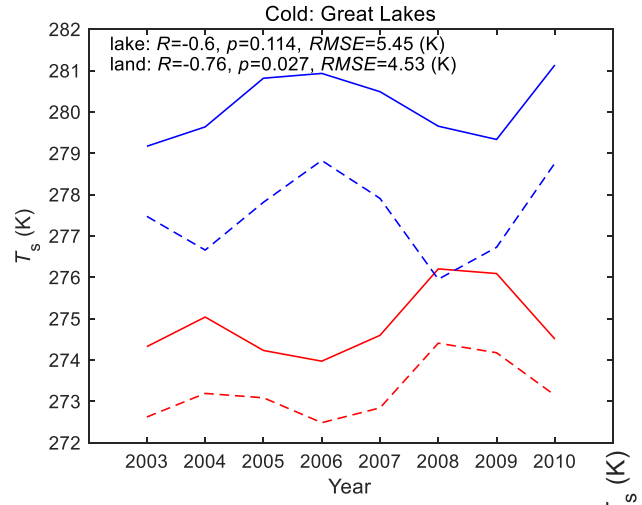

Temperature: Dongting
y=-0.29x+(2.34)
R²=0.16 p=0.32
n=8
ΔT_s(CLM) (K)
ΔT_s(MODIS) (K)

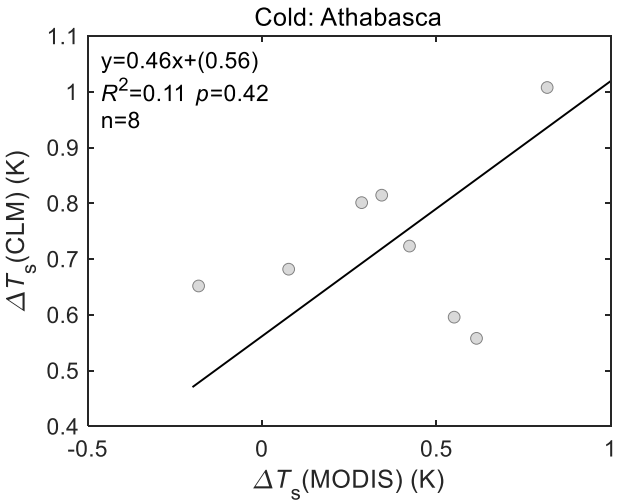

Temperature: Poyang
y=-0.54x+(1.76)
R²=0.06 p=0.55
n=8
ΔT_s(CLM) (K)
ΔT_s(MODIS) (K)

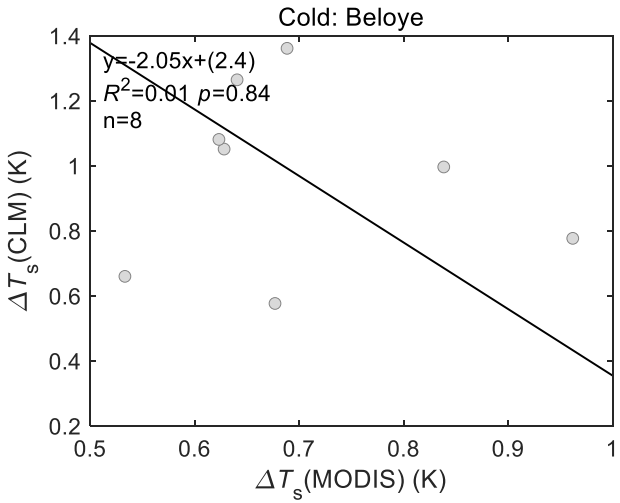

MODIS lake
CLM lake
MODIS land
CLM land

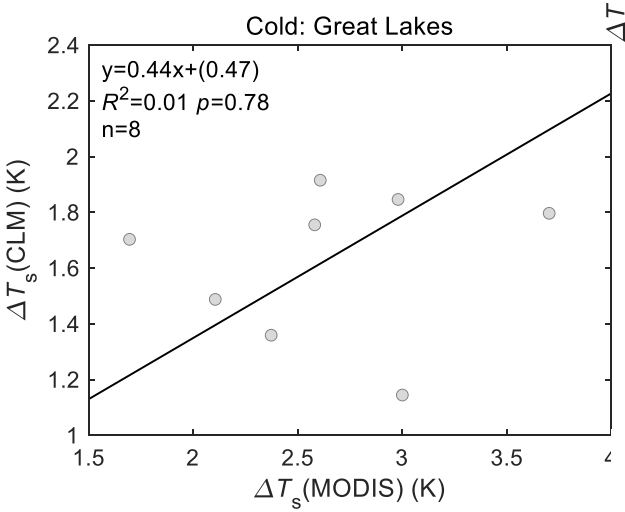

Cold: Athabasca
lake: R=-0.47, p=0.24, RMSE=2.64 (K)
land: R=-0.39, p=0.341, RMSE=2.83 (K)
T_s (K)
Year

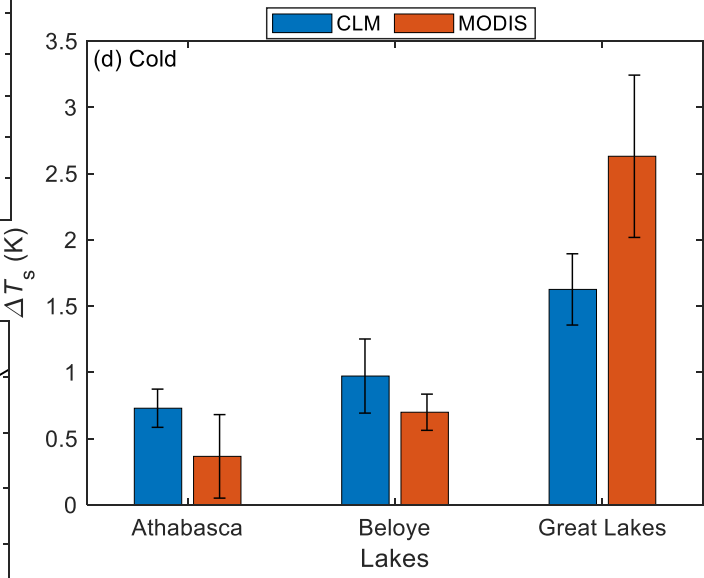

Cold: Beloye
lake: R=-0.52, p=0.191, RMSE=1.51 (K)
land: R=-0.35, p=0.398, RMSE=1.26 (K)
T_s (K)
Year

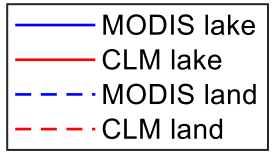

Cold: Great Lakes
lake: R=-0.6, p=0.114, RMSE=5.45 (K)
land: R=-0.76, p=0.027, RMSE=4.53 (K)
T_s (K)
Year

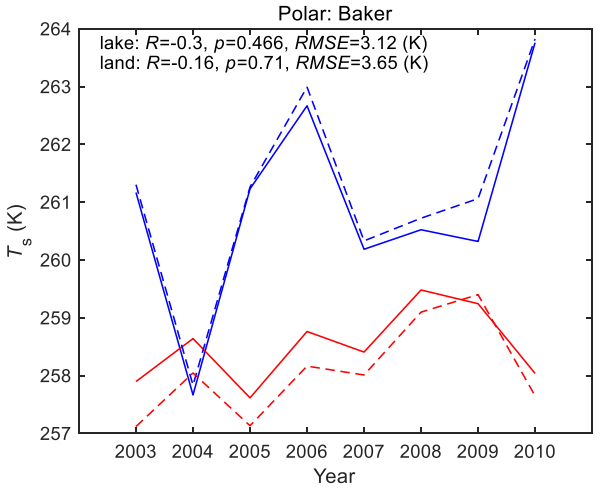

Cold: Athabasca
y=0.46x+(0.56)
R²=0.11 p=0.42
n=8
ΔT_s(CLM) (K)
ΔT_s(MODIS) (K)

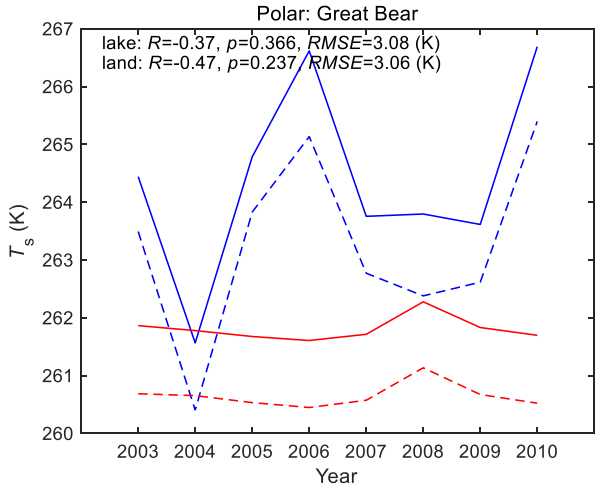

Cold: Beloye
y=-2.05x+(2.4)
R²=0.01 p=0.84
n=8
ΔT_s(CLM) (K)
ΔT_s(MODIS) (K)

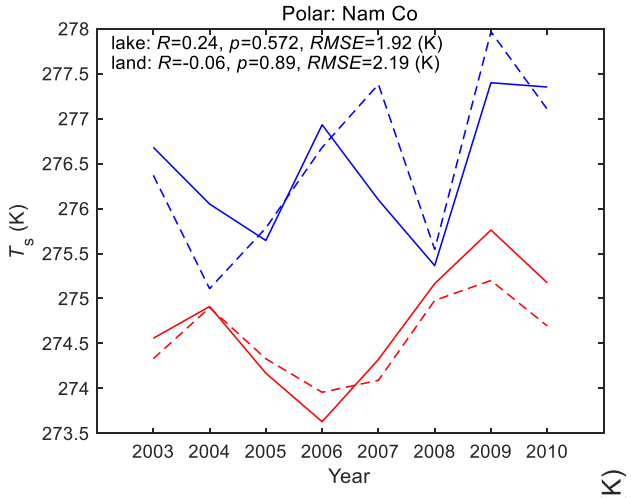

Cold: Great Lakes
y=0.44x+(0.47)
R²=0.01 p=0.78
n=8
ΔT_s(CLM) (K)
ΔT_s(MODIS) (K)

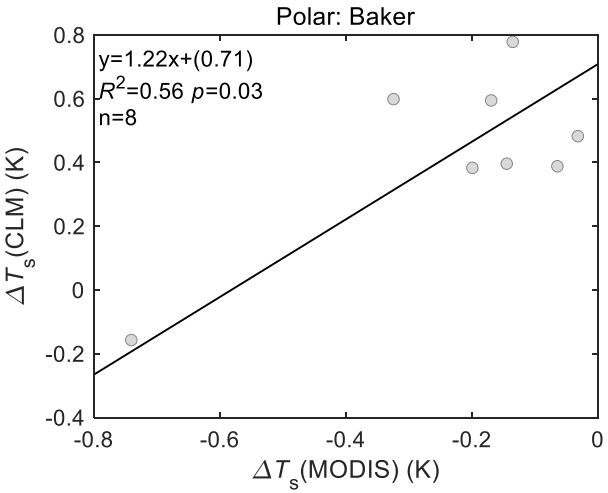

CLM
MODIS
(d) Cold
ΔT_s (K)
Athabasca
Beloye Lakes
Great Lakes

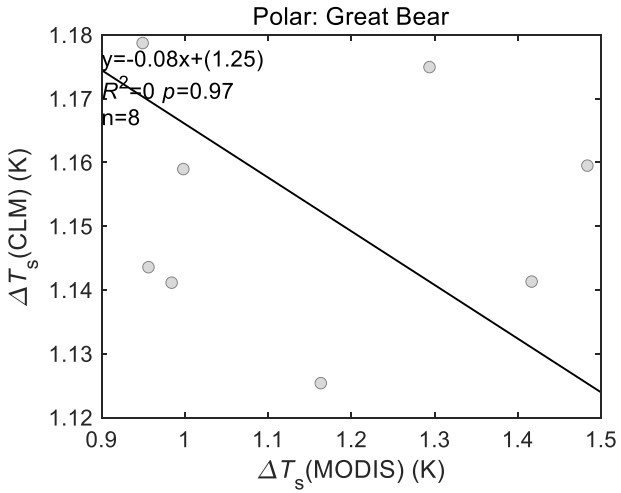

MODIS lake
CLM lake
MODIS land
CLM land

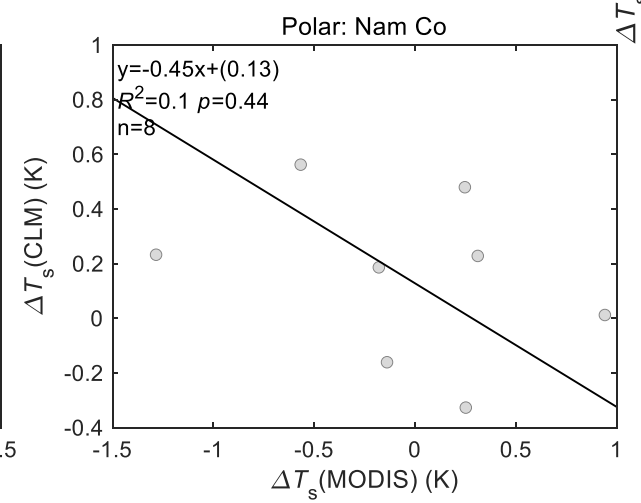

Polar: Baker
lake: R=-0.3, p=0.466, RMSE=3.12 (K)
land: R=-0.16, p=0.71, RMSE=3.65 (K)
T_s (K)
Year

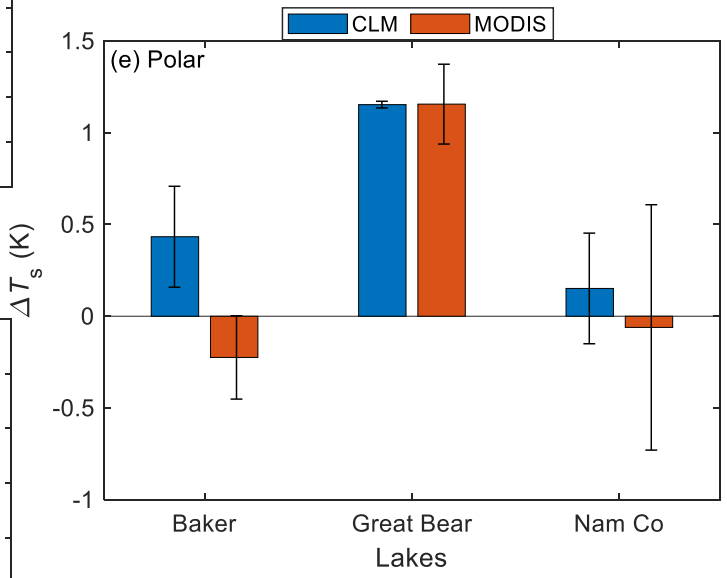

Polar: Great Bear
lake: R=-0.37, p=0.366, RMSE=3.08 (K)
land: R=-0.47, p=0.237, RMSE=3.06 (K)
T_s (K)
Year

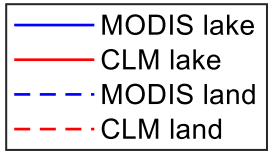

Polar: Nam Co
lake: R=0.24, p=0.572, RMSE=1.92 (K)
land: R=-0.06, p=0.89, RMSE=2.19 (K)
T_s (K)
Year


Polar: Baker
y=1.22x+(0.71)
R²=0.56 p=0.03
n=8
ΔT_s(CLM) (K)
ΔT_s(MODIS) (K)


Polar: Great Bear
y=-0.08x+(1.25)
R²=0 p=0.97
n=8
ΔT_s(CLM) (K)
ΔT_s(MODIS) (K)


Polar: Nam Co
y=-0.45x+(0.13)
R²=0.1 p=0.44
n=8
ΔT_s(CLM) (K)
ΔT_s(MODIS) (K)

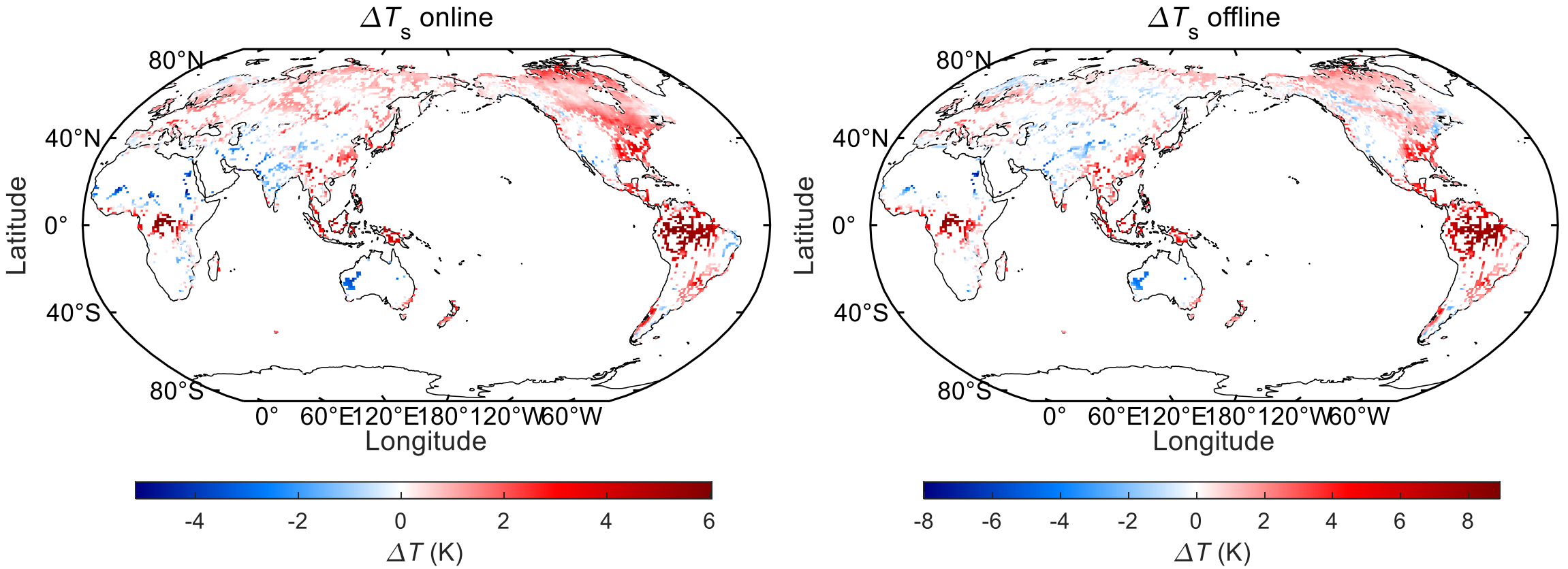

CLM
MODIS
(e) Polar
ΔT_s (K)
Baker
Great Bear
Nam Co
Lakes


MODIS lake
CLM lake
MODIS land
CLM land

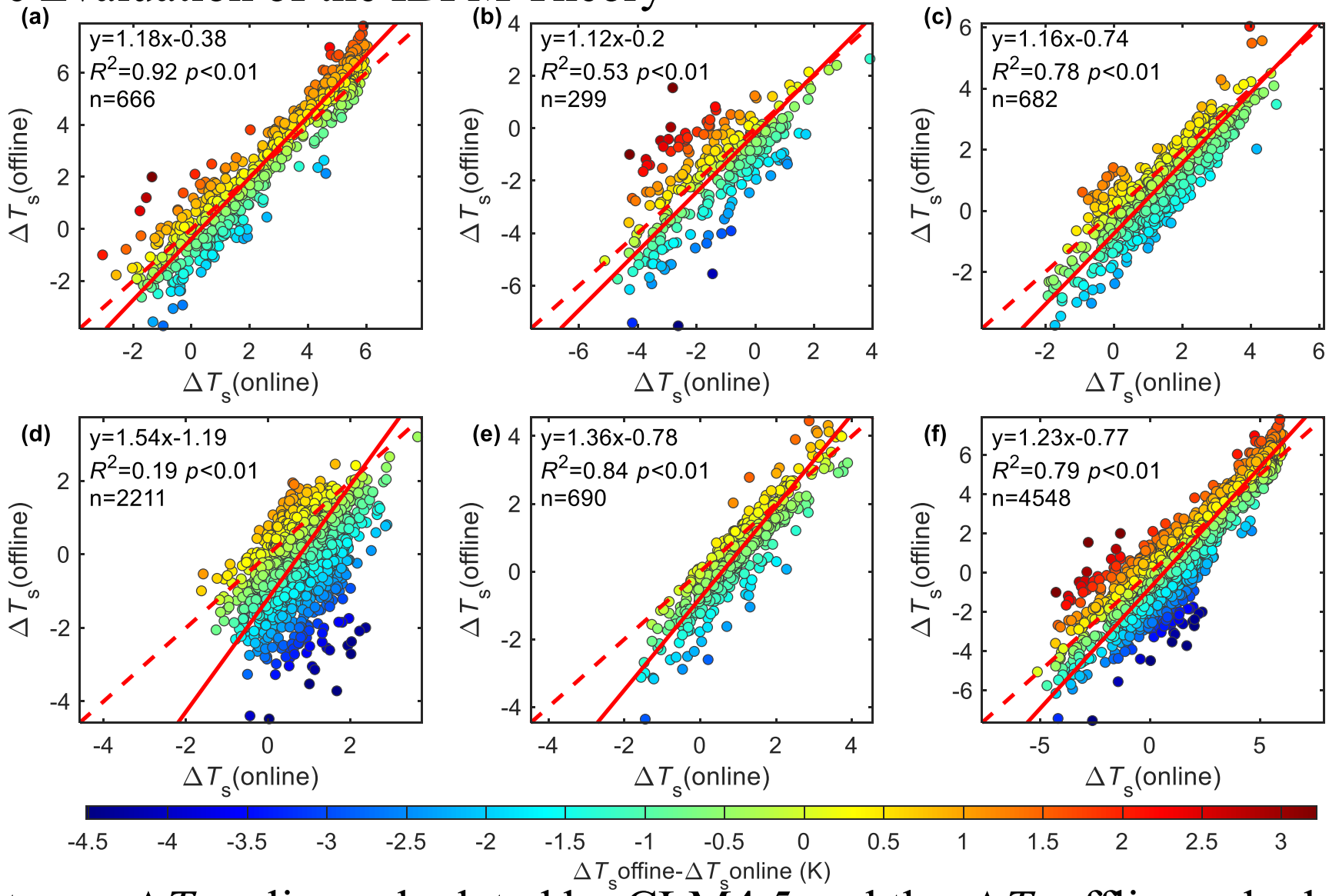
Results

2. Online versus Offline ΔT_s between lakes and surrounding lands

- Spatial Distribution of ΔT_s (1991-2010 mean)



Performance Evaluation of the IBPM Theory

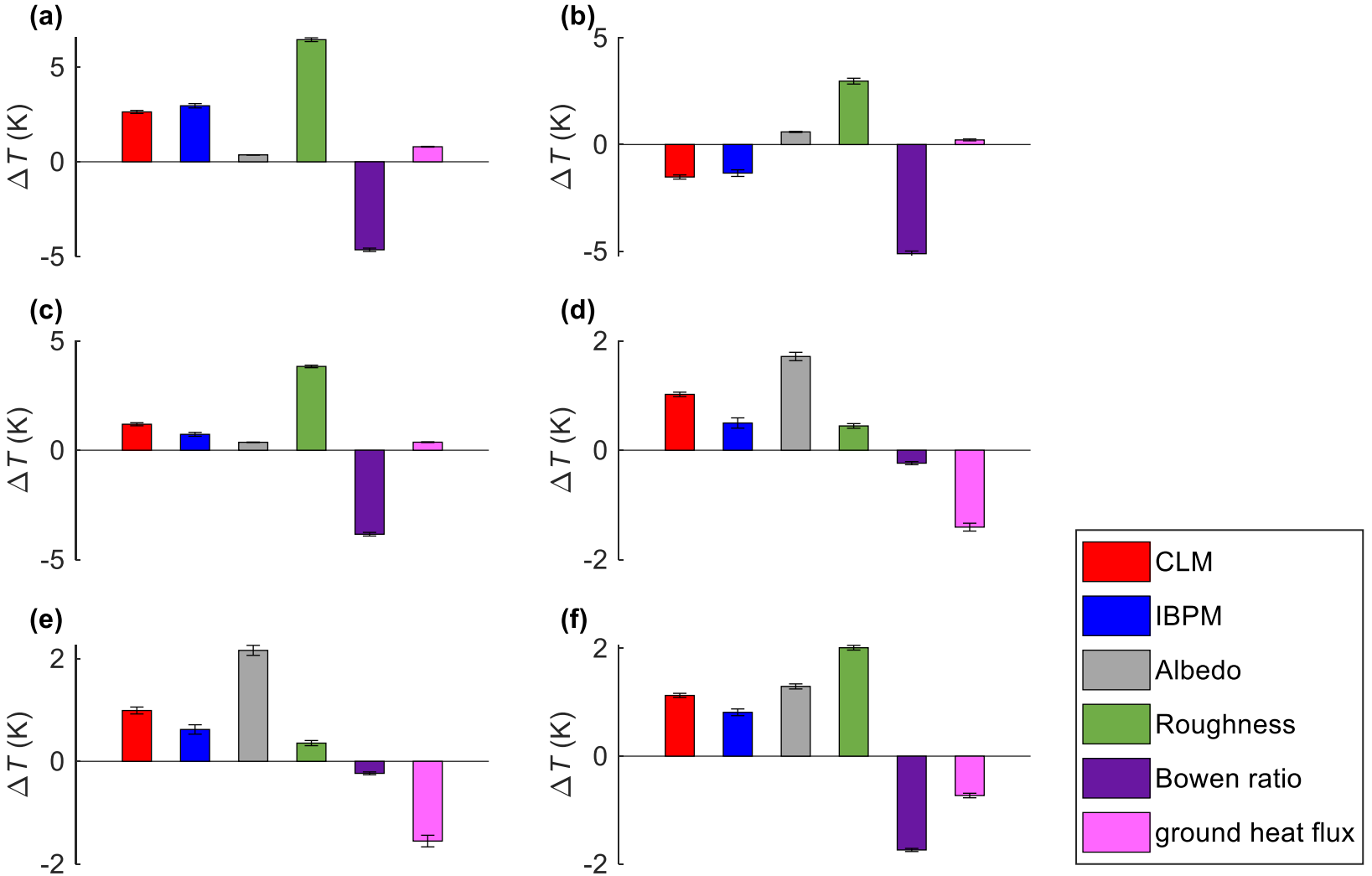


Relationship between ΔT_s online calculated by CLM4.5 and the ΔT_s offline calculated with the IBPM theory (1991-2010 mean), pairs of lake and surrounding land in tropical(a), arid(b), temperature(c), cold(d), polar(e) climates and global(f).

Results

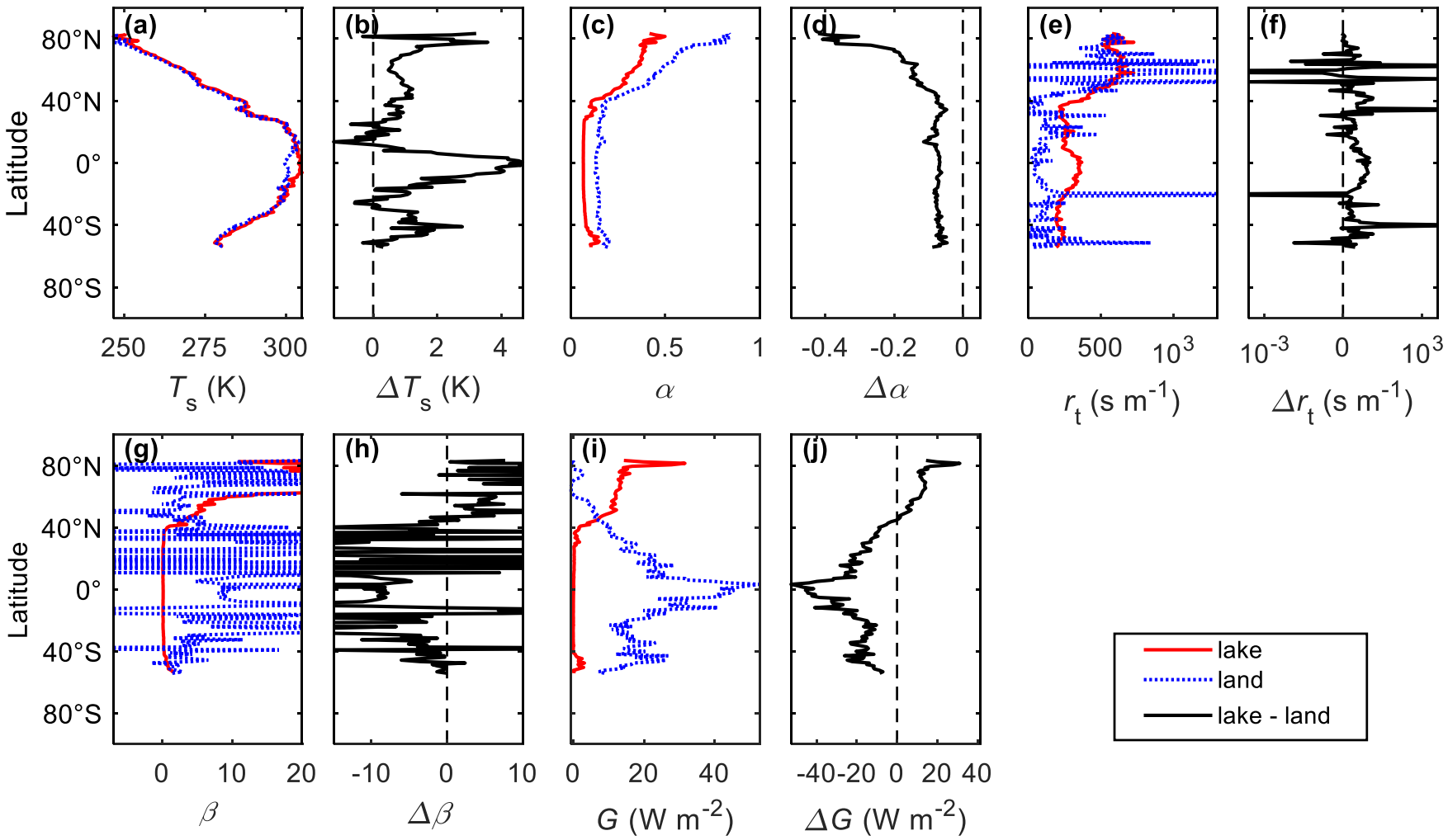
3. Contributions of Surface Temperature Difference

- Comparison of the biophysical effect partition in different climates according to the IBPM theory



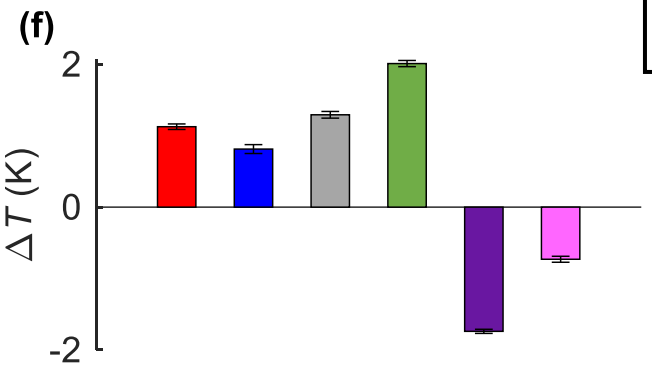
1991-2010 mean, tropical(a), arid(b), temperature(c), cold(d), polar(e) climates and global(f).

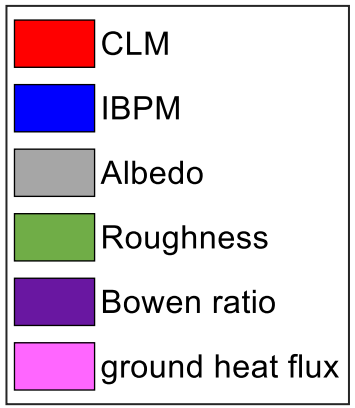
Formation of Surface Temperature Difference between lake and surrounding land



Zonal Mean of biophysical factors and differences between lake and surrounding land

For global($\Delta T_s = 1.1 \pm 0.0$ K):





Smaller Albedo ⇒ Net shortwave radiation $(1-\alpha)K_{\downarrow}\uparrow$ ⇒ $T_s\uparrow$ **(1.3 ± 0.0 K)**

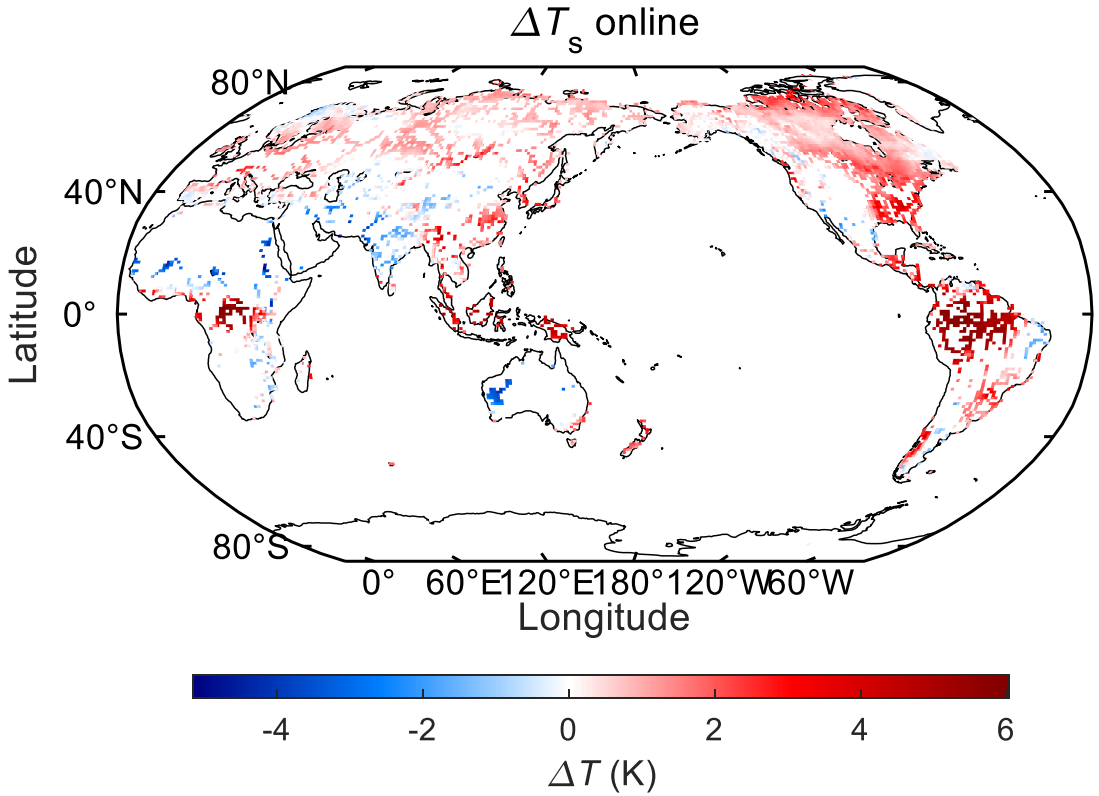
Smaller Roughness ⇒ Total resistance to sensible heat diffusion $r_t\uparrow$ ⇒ Efficiency of energy dissipation by convective motion↓ ⇒ $T_s\uparrow$ **(2.0 ± 0.0 K)**

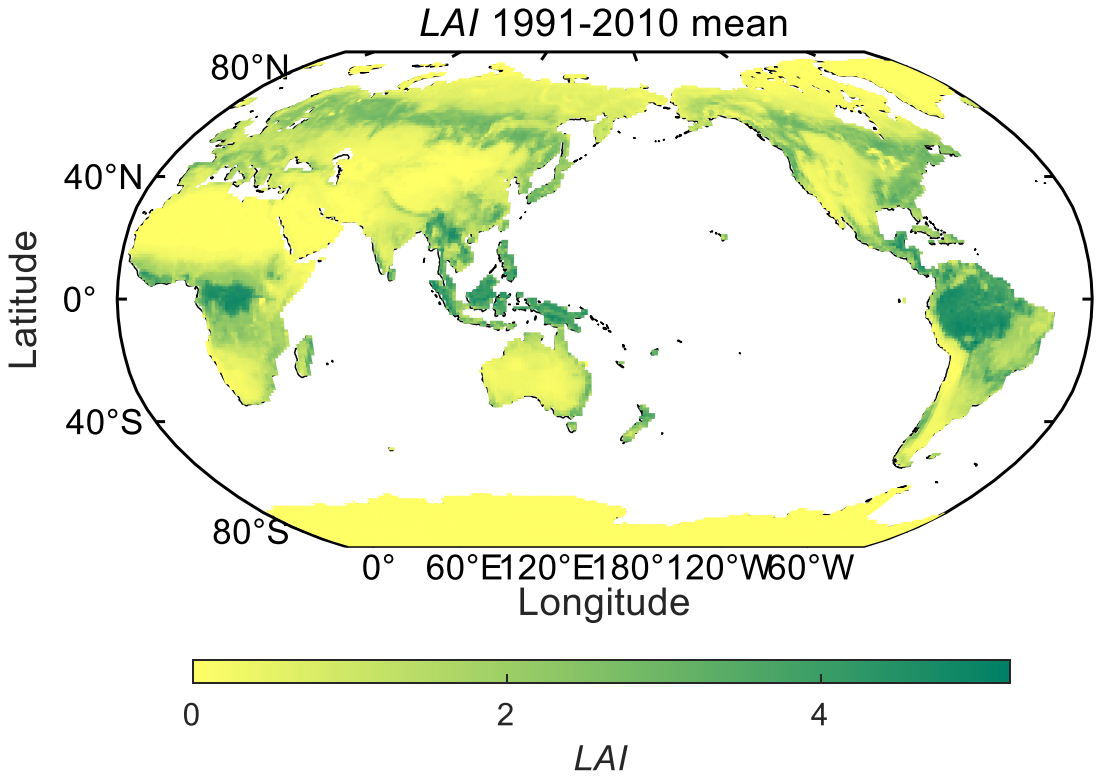
Smaller Bowen ratio ⇒ Latent heat flux $\lambda E\uparrow$ ⇒ $T_s\downarrow$ **(-1.7 ± 0.0 K)**

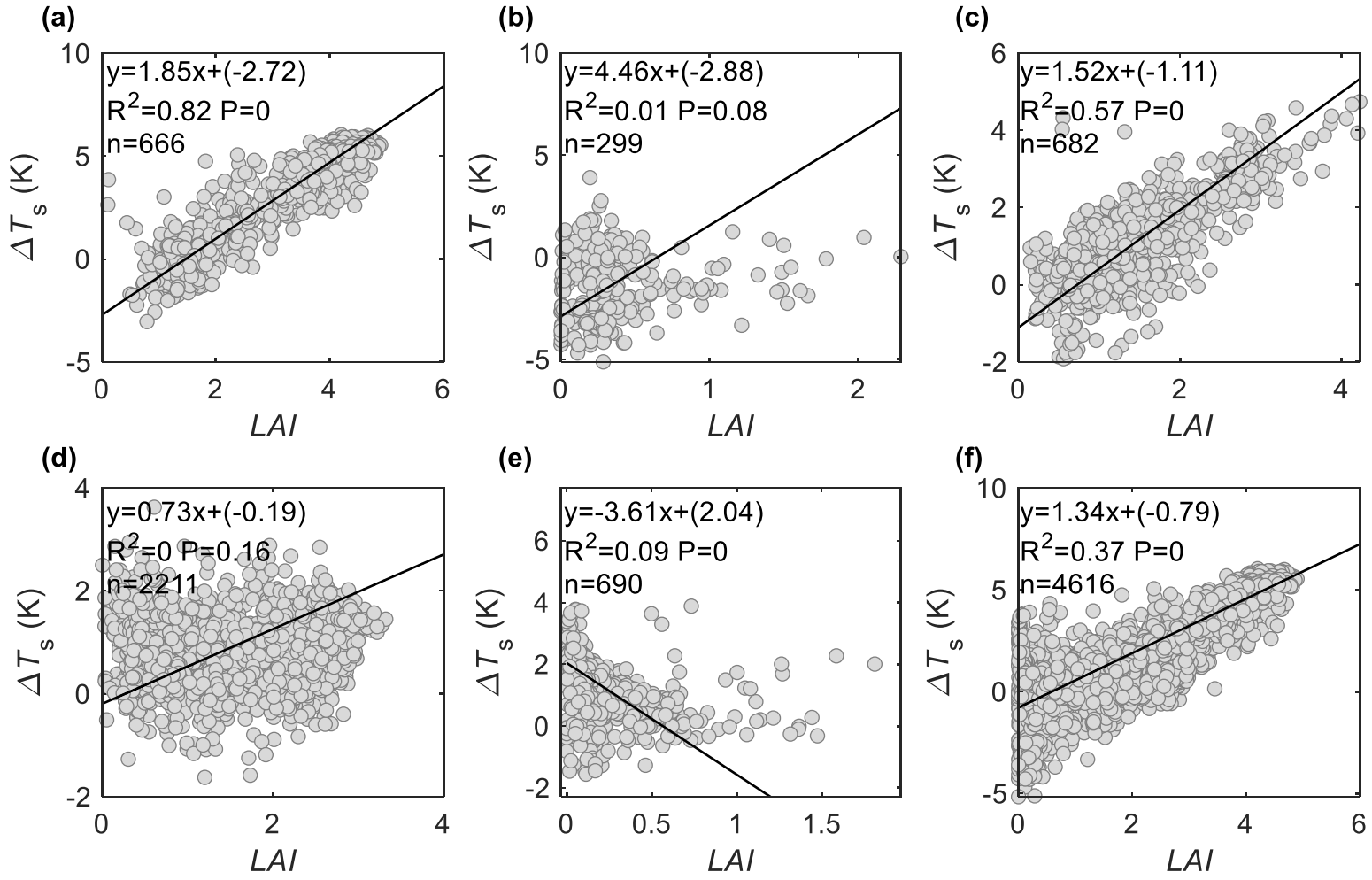
Greater Ground heat flux G ⇒ Available energy to warm surface ↓ ⇒ $T_s\downarrow$ **(-0.7 ± 0.0 K)**

Discussion

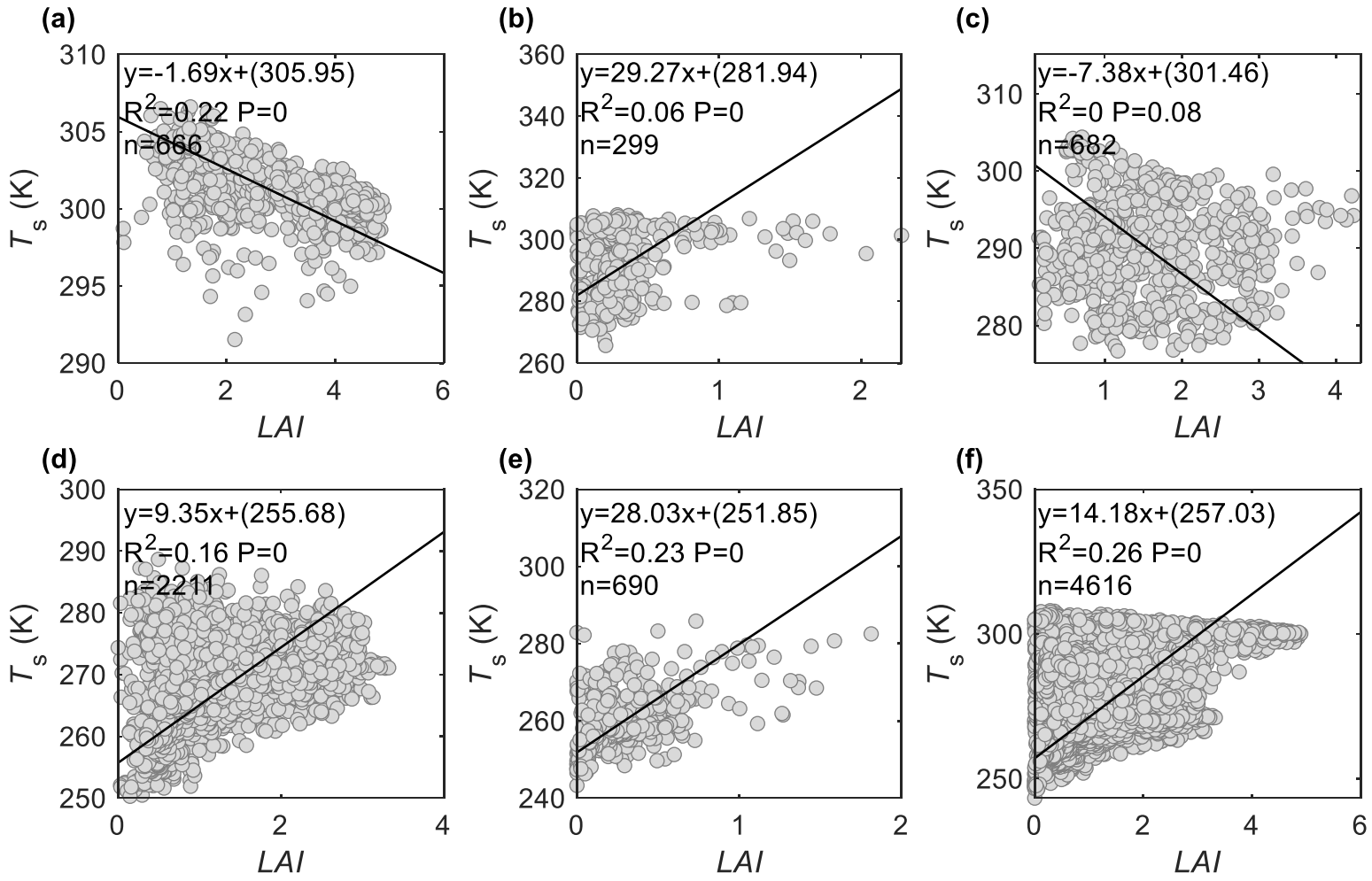
1. Relationship between Leaf Area Index(LAI) and Surface Temperature Difference







tropical(a), arid(b), temperature(c), cold(d), polar(e) climates and global(f).



tropical(a), arid(b), temperature(c), cold(d), polar(e) climates and global(f).

Conclusions

- On the annual scale, lakes in arid regions show cooling effect (-1.5 ± 0.1 K). Global lakes show warming effect (1.1 ± 0.0 K), as well as tropical (2.6 ± 0.1K), temperate (1.2 ± 0.1K), and cold (1.0 ± 0.0 K) and polar (0.9 ± 0.1 K) lakes.
- On global scale, the small albedo, small roughness are the main reasons for lake warming effect, which contribute 159% and 247% to the temperature effect, respectively. The small Bowen ratio is the main reasons for lake cooling effect, which contributes -215% to the temperature effect. The warming or cooling effects resulted from ground heat flux change depends on its climate conditions.

Thanks for your attention!