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

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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

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

(Subin et al., 2012)
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 Temperature climate:

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

★ Cases in Arid climate:

★ Cases in Cold climate:
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

<table>
<thead>
<tr>
<th>Variable</th>
<th>Spatial resolution</th>
<th>Temporal resolution</th>
<th>Study Period</th>
<th>Study areas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Day land surface temperature</td>
<td>1 km</td>
<td>8 day</td>
<td>2003-01-01T00:00:00 – 2010-12-27T00:00:00</td>
<td>15 lakes and surrounding lands in different climate zones</td>
</tr>
<tr>
<td>Night land surface temperature</td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

- 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/](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 $\Delta T_s$: The surface temperature difference between lake and surrounding lands simulated in CLM4.5, as $T_s$ lake - $T_s$ land;
- Offline $\Delta T_s$: The summation of all terms([1]~[4]) in IBPM theory, using the variables saved from the online CLM4.5 calculation.

\[
\Delta T_s \approx \frac{-\lambda_0}{1+f} \Delta \alpha \left( T_a \right) + \frac{-\lambda_0}{(1+f)^2} \left( R^* - G \right) \Delta f_1 + \frac{-\lambda_0}{(1+f)^2} \left( R^* - G \right) \Delta f_2 \\
+ \frac{-\lambda_0}{1+f} \Delta G
\]

[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

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  ➢ 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 $\Delta T_s$ (MODIS) and $\Delta T_s$ (CLM), using monthly mean

- On annual scale:
  - Annual variations in the *lakes and surrounding lands* $T_s$
  - Relationship between $\Delta T_s$ (MODIS) and $\Delta T_s$ (CLM), using annually mean
Results

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

Relationship between $\Delta T_s$ (MODIS) and $\Delta T_s$ (CLM), using annually mean

![Graphs showing the relationship between $\Delta T_s$ (MODIS) and $\Delta T_s$ (CLM) for different regions.](image-url)
Results

2. Online versus Offline $\Delta T_s$ between lakes and surrounding lands

- Spatial Distribution of $\Delta T_s$ (1991-2010 mean)
Performance Evaluation of the IBPM Theory

Relationship between $\Delta T_s$ online calculated by CLM4.5 and the $\Delta T_s$ 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).
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 $\rightarrow$ Net shortwave radiation $(1 - \alpha)K_s$ $\uparrow$ $\rightarrow$ $T_s$ $\uparrow (1.3 \pm 0.0$ K)
- Smaller Roughness $\rightarrow$ Total resistance to sensible heat diffusion $r_t$ $\uparrow$ $\rightarrow$ Efficiency of energy dissipation by convective motion $\downarrow$
  - $T_s$ $\uparrow (2.0 \pm 0.0$ K)
- Smaller Bowen ratio $\rightarrow$ Latent heat flux $\lambda E$ $\uparrow$ $\rightarrow$ $T_s$ $\downarrow (-1.7 \pm 0.0$ K)
- Greater Ground heat flux $G$ $\rightarrow$ Available energy to warm surface $\downarrow$ $\rightarrow$ $T_s$ $\downarrow (-0.7 \pm 0.0$ K)
1. Relationship between Leaf Area Index (LAI) and Surface Temperature Difference
tropical, arid, temperature, cold, polar climates and global.
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!