Attribution of Urban Heat Island for Cities in China

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Chang Cao
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Outline

• Background
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Background

- More than half of the world’s population reside in urban area which consists of 2% of global land area.
- Urbanization gives rise to Urban Heat Island (UHI) which has impact on local climate and human health.
- Community Earth System Model (CESM) climate model has incorporated urban canopy model to study urban climatic response under atmospheric condition in the future.
- Study on UHI for cities in North American showed that convection efficiency is the main driver of UHI variation across climatic zones.
Motivation

• What is the UHI spatial pattern across different climatic zones in China?
• What is the driver of UHI variation for cities in China?
• What is the contribution of each biophysical process to UHI?
Method

• 39 cities in China
• Exclude elevation and latitude difference between urban and rural area more than 100 meters and 1°
• Exclude water pixels
• Avoid ‘oasis effect’ for semi-arid cities (Hotan)
Other data

• Precipitation data: National Climate Center
• Air temperature data: National Climate Center
• Normalized Difference Vegetation Index data: MODIS MYD13Q1 250m 16-day
• White Sky Albedo data: MODIS MCD43A3 500m 16-day
Observational land surface temperature

• 2003-2013
• MODIS Land Surface Temperature (LST)
  MYD11A2 1km 8-day
  daytime 13:30
  nighttime 1:30
Model simulation

• Community Land Model 4.0 - CLMU
• 1972-2004, 0.23° longitude × 0.31° latitude
• Offline, Qian et al forcing data
• Extract data at 1:00 and 13:00 (local time) and for clear-sky condition
Figure 1 | Schematic overview of urban land unit in CLM

Result

Spatial variation
Figure 2 | Vegetation of China
Source: Zhou, Zhao, Liu et al. (2014) Sci of Tol
Env 488: 136-145

Figure 3 | Spatial variation of MODIS-derived annual-mean daytime (a) and night-time (b) UHI.
## Cropland pixel fraction of rural area

*(MODIS land cover)*

<table>
<thead>
<tr>
<th></th>
<th>Humid</th>
<th>Semi-humid</th>
<th>Semi-arid</th>
<th>Averaged</th>
</tr>
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<tbody>
<tr>
<td><strong>China</strong></td>
<td>0.53</td>
<td>0.80</td>
<td>0.29</td>
<td>0.51</td>
</tr>
<tr>
<td><strong>North American</strong></td>
<td>0.20</td>
<td>0.44</td>
<td>0.23</td>
<td>0.30</td>
</tr>
</tbody>
</table>
Figure 4 | Precipitation influence on annual daytime UHI. a, All 39 cites in. b, Without cities whose rural area has cropland pixel fraction bigger than 0.5. c and d are the same as a and b but for North American cities.
Relationship between UHI and variables

Figure 5 | The square of linear correlation coefficients ($R^2$) (a) and stepwise multiple linear regression derived explanation (b) of each variable for cities in China.
Figure 5 | The square of linear correlation coefficients ($R^2$) (c) and stepwise multiple linear regression derived explanation (d) of each variable for cities in North American.
Figure 6 | Modelled albedo influence on modelled annual mean (a), winter (b) and summer (c) night-time UHI intensity
Attribution to model-predicted UHI

\[
(1-\alpha)K \downarrow + L \downarrow - \sigma T^4_s = H + LE + Q_s - Q_{AH}
\]

(1)

\[
\sigma T^4_s = \sigma T^4_a + 4 \sigma T^3_a (T_s - T_a)
\]

\[
H = \rho C_p \frac{T_s - T_a}{r_a}
\]

\[
LE = \frac{H}{\beta}
\]

\[
\lambda_0 = \frac{1}{4 \epsilon \sigma T^3}
\]

\[
f = \frac{\lambda_0 \rho C_p}{r_a} \left(1 + \frac{1}{\beta}\right)
\]

\[
\Delta T = \frac{\lambda_0}{1+f} (R^*_n - Q_s + Q_{AH})
\]

(2)

\[
\Delta T \approx \frac{\lambda_0}{1+f} \Delta R^*_n + \frac{-\lambda_0}{(1+f)^2} (R^*_n - Q_s + Q_{AH}) \Delta f_1
\]

\[+ \frac{-\lambda_0}{(1+f)^2} (R^*_n - Q_s + Q_{AH}) \Delta f_2 + \frac{-\lambda_0}{1+f} \Delta Q_s
\]

\[
+ \frac{\lambda_0}{1+f} \Delta Q_{AH}
\]

(3)

\[
R^*_n = (1-\alpha)K \downarrow + L \downarrow - (1-\epsilon) L \downarrow - \epsilon \sigma T^4_a
\]

\[
\Delta f_1 = \frac{-\lambda_0 \rho C_p}{r_a} \left(1 + \frac{1}{\beta}\right) \frac{\Delta r_a}{r_a}
\]

\[
\Delta f_2 = \frac{-\lambda_0 \rho C_p}{r_a} \frac{\Delta \beta}{\beta^2}
\]
Model UHI

\[ L_\downarrow - (1 - \varepsilon)L_\downarrow - \varepsilon \sigma T_s^4 = L_{\text{net}} \]  \hspace{1cm} (4)

\[ T_s = \sqrt[4]{L_\downarrow + \left( \frac{L_{\text{net}}}{\varepsilon} \right) / \sigma} \]  \hspace{1cm} (5)
Validation

Figure 7 | Model-predicted $\Delta T$ vs calculated $\Delta T$. a, Annual-mean daytime. b, Annual-mean night-time. c, Summer mean daytime. d, Summer mean night-time. e, Winter mean daytime. f, Winter mean night-time.
Tuning emissivity

• North American: 0.88 (urban area)  
  0.96 (rural area)

• Chinese cities (combined with CLM and MODIS emissivity, H/W ratio)

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<th>Humid</th>
<th>Semi-humid</th>
<th>Semi-arid</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban</td>
<td>0.914</td>
<td>0.960</td>
<td>0.969</td>
</tr>
<tr>
<td>Rural</td>
<td>0.927</td>
<td>0.980</td>
<td>0.973</td>
</tr>
</tbody>
</table>
Figure 8 | Attribution of UHI intensity in three climate zones in annual-mean (a), summer (b) and winter (c) daytime.
Figure 9 | Attribution of UHI intensity in three climate zones in annual-mean (a), summer (b) and winter (c) night-time.
Covariance analysis

\[ \Delta T = C_R + C_H + C_{LE} + C_s + C_{AH} + e \]  \hspace{1cm} (6)

\[ \text{Cov}(\Delta T, P) = \text{Cov}(C_R, P) + \text{Cov}(C_H, P) + \text{Cov}(C_{LE}, P) + \text{Cov}(C_s, P) + \text{Cov}(C_{AH}, P) + \text{Cov}(e, P) \]  \hspace{1cm} (7)
Daytime

Figure 10 | Relationship between model-predicted daytime $\Delta T$ and precipitation among the cities in China. a (up), Correlation of $\Delta T$ and the biophysical components with annual-mean precipitation. a (bottom), $\Delta T$-precipitation covariance explained by different biophysical factors. b and c are the same as a but for summer and winter.
Temporal sensitivity
Figure 11 | Temporal sensitivity of UHI intensity to precipitation. a, c, Map of the temporal sensitivities according to MODIS (a) and climate model (c). b, d, Dependence of MODIS (b) and model-predicted (d) temporal sensitivity on annual mean precipitation.
Conclusion

• UHI pattern for cities in China are mainly depend on annual precipitation but high cropland fraction in rural area can weaken this relationship.

• Convection efficiency and storage heat is the dominant contributor to UHI at day time and night time respectively. Evaporation can be a significant factor for cities in drier region in summer daytime.
Future work

• Finding solutions to the underestimation of nighttime UHI
• Can soil moisture be an important factor?
• Investigating relationship between UHI and biochemical factors (aerosol..)
Thank you