Monitoring Urban Heat Islands from Space: Challenges and Applications

Presented by:
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The Urban Heat Island Effect

Cities are hotter than surroundings; leads to heat stress, higher energy use, secondary air pollution, etc.
Spatial Inconsistencies in UHI quantification

- Administrative boundaries as units of calculation
- Identical buffer width as rural reference
- Inconsistent rural references

Beijing

Tokyo

Non-urban

Urban

Monitoring Urban Heat Islands from Space
Study overview

### Problem

- Existing multi-city studies focus on larger cities
- Inconsistencies in UHI quantification
- UHI intensity across climate zones not characterized
- Temporal trends at a global scale unknown
## Study overview

### Problem
- Existing multi-city studies focus on larger cities
- Inconsistencies in UHI quantification
- UHI intensity across climate zones not characterized
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### Objectives of study
- Create new algorithm to quantify surface UHI
- Investigate seasonal and temporal trend of surface UHI intensity at global scale
- Determine effect of background climate
- Create interactive web portal of surface UHI intensity
Google Earth Engine platform

Saved scripts, documentation, and asset manager

Console output, task manager, and map inspector

Code editor

Map output and visualization

Monitoring Urban Heat Islands from Space
Google Earth Engine platform

- Cloud-based platform for planetary scale geospatial analysis
- Uses Google's computational resources to reduce processing time
- Massive archive of remote sensing data

- 200 public datasets
- > 4000 new images every day
- > 5 million images
- > 5 petabytes of data

Source: Google Earth Engine User summit
Simplified Urban-Extent (SUE) algorithm

1. Subset MODIS LU/LC data based on urban extents.
2. Remove water pixels.
3. Subset urban pixels.
4. Subset non-urban pixels.
5. Calculate mean of LST over urban subset.
6. Calculate mean of LST over non-urban subset.
7. Subtract non-urban LST from urban LST to get UHI.
Simplified Urban-Extent (SUE) algorithm

Data used:
Global dataset of urban shapefiles [Schneider et al. 2009]
MCD12Q1: MODIS 500 m Land Cover product
MOD11A1 and MYD11A1: MODIS 1 km Land Surface Temperature
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Urban cluster boundary
MODIS LU/LC data clipped to shapefile
Mask from urban pixels
Simplified Urban-Extent (SUE) algorithm

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Urban cluster boundary → MODIS LU/LC data clipped to shapefile → Mask from urban pixels → Mask from non-urban pixels
SUB algorithm evaluation

Comparing the latitudinal trends with results from Peng et al. (2012) for 419 largest urban clusters.
## SUB algorithm evaluation

### Monitoring Urban Heat Islands from Space

Comparing global trends with the results from Clinton and Gong (2013) for 2010

<table>
<thead>
<tr>
<th>Local time</th>
<th>Present study (SUE)</th>
<th>Clinton and Gong (5 km buffer)</th>
<th>Clinton and Gong (10 km buffer)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0130 LT</td>
<td>0.51 ± 0.47</td>
<td>0.60 ± 0.90</td>
<td>0.70 ± 1.00</td>
</tr>
<tr>
<td>1030 LT</td>
<td>0.73 ± 0.86</td>
<td>0.70 ± 1.40</td>
<td>1.00 ± 1.60</td>
</tr>
<tr>
<td>1330 LT</td>
<td>1.00 ± 1.08</td>
<td>0.90 ± 1.60</td>
<td>1.10 ± 1.80</td>
</tr>
<tr>
<td>2230 LT</td>
<td>0.60 ± 0.47</td>
<td>0.60 ± 0.90</td>
<td>0.80 ± 1.00</td>
</tr>
</tbody>
</table>
Global Daytime surface UHI intensity

Daytime surface UHI (global mean value = 0.85 °C)
Global Nighttime surface UHI intensity

Nighttime surface UHI (global mean value = 0.55 °C)
Arid zones have been previously shown to have lower UHI intensity; sometimes cool islands

Control of background climate on UHI has been modeled for a subset of US cities
Background climate and annual surface UHI

- Highest daytime UHI for tropical urban; lowest for arid
- Opposite diurnal trend seen for arid and other climate classes
Seasonal trends in surface UHI

- Very little seasonality in daytime UHI intensity and opposite seasonality in Nighttime UHI for arid and tropical urban areas
Long-term trends in surface UHI

- Increase in daytime UHI intensity for warm temperate and snow climate (and globally)
- Nighttime values only increased in arid zone
Vegetation differential and UHI intensity

- Vegetation differential between urban and reference areas strongly controls spatial variability of UHI for arid and tropical climate
- Seasonal trend in temperate and snow climate also modulated by vegetation differentials
The Global Surface UHI Explorer

Link to Global Surface UHI Explorer web app: https://yceo.users.earthengine.app/view/uhimap
Research summary and more information about the app: https://yceo.yale.edu/research/global-surface-uhi-explorer

Chakraborty and Lee, 2019
Updates to the SUE algorithm

- The European Space Agency Climate Change Initiative (ESA CCI) land cover data are used instead of the MODIS land use/land cover data.
- 15-year means (for monthly, annual, summer and winter) are calculated based on the UHI estimates for each year taking into account the land cover data for the corresponding year.
- Instead of filtering out urban clusters where the mean elevation difference between the urban and non-urban, non-water pixels are greater than 50 m, the rural reference to calculate the UHI was modified by masking out the pixels that have an elevation difference of more than 50 m with the median of the elevation of the urban pixels, significantly increases our sample size (from 7374 to 10136).
Applications: UESI

Tracking the performance of cities at a global scale combining environmental variables with social inclusion

https://datadrivenlab.org/urban/
Intra-city variation in surface UHI

Other than coastal cities, intra-urban vegetation distribution controls UHI distribution.
In 72% of the cities considered, surface UHI intensity is higher for poorer neighborhoods [Chakraborty et al. 2019]
Significant increase in urban area from 1992 to 2015, particularly in tropical countries
Urban growth needs to be considered...[2/4]
Vectorizing Global Urban Rasters

-Capabilities of Google Earth Engine (GEE) and ArcGIS combined to create temporally consistent urban boundaries

-Initial vectorization is done using GEE, with cleaning and final merging automated using ArcPy

Example of an urban area sprawling over a national boundary

Select urban land cover from ESA CCI data

Class number 190

Create bounding polygons from urban pixels

Separate for each country to avoid computational limitations

Create 1 m buffer around each polygon

To emulate overlap for the next step

Dissolve polygons based on overlap on a geodesic surface

Combines urban areas crossing country borders and diagonal pixels

Extract all single-part features

Separates all urban clusters into individual clusters

Create -1 m buffer for each polygon

To account for the initial buffer created

Final collection of urban clusters

One for each year; from 1992 to 2015

El Paso across the US-Mexican border
Urban growth needs to be considered...[3/4]
Urban growth needs to be considered...

Countries with the highest number of urban clusters

Values in count; Data source: ESA CCI Landcover data

- United States: 60,131
- China: 52,069
- Russia: 22,366
- Germany: 22,411
- Ukraine: 22,286
- France: 13,733
- Brazil: 11,883
- Italy: 10,176
- Romania: 8,977
- India: 6,432

1992
Creating area-normalized rural references

- For the iteration, a step-size of 300 m is used to be consistent with the resolution of the ESA CCI data
- Produced rural references are roughly twice the area of the corresponding urban clusters

Examples of urban clusters, along with their area-normalized rural references, for Los Angeles (above) and around Shanghai (right)
Dynamic urban-rural delineations and UHI

- World: Change=0.957°C, 0.927°C, and -0.030°C per decade for rural LST, urban LST, and UHI, respectively
- Tropical: Change=0.127°C, 0.135°C, and 0.008°C per decade for rural LST, urban LST, and UHI, respectively
- Arid: Change=-0.221°C, -0.227°C, and -0.006°C per decade for rural LST, urban LST, and UHI, respectively
- Temperate: Change=0.811°C, 0.800°C, and -0.011°C per decade for rural LST, urban LST, and UHI, respectively
- Boreal: Change=0.840°C, 0.796°C, and -0.045°C per decade for rural LST, urban LST, and UHI, respectively
- Polar: Change=1.337°C, 1.261°C, and -0.076°C per decade for rural LST, urban LST, and UHI, respectively
Static urban-rural delineations and UHI

- World: Change=0.292°C, 0.490°C, and 0.198°C per decade for rural LST, urban LST, and UHI, respectively
- Tropical: Change=0.313°C, 0.412°C, and 0.099°C per decade for rural LST, urban LST, and UHI, respectively
- Arid: Change=0.506°C, 0.590°C, and 0.084°C per decade for rural LST, urban LST, and UHI, respectively
- Temperate: Change=0.335°C, 0.483°C, and 0.147°C per decade for rural LST, urban LST, and UHI, respectively
- Boreal: Change=0.477°C, 0.478°C, and 0.001°C per decade for rural LST, urban LST, and UHI, respectively
- Polar: Change=0.367°C, 0.745°C, and 0.378°C per decade for rural LST, urban LST, and UHI, respectively
Why the difference?

<table>
<thead>
<tr>
<th>Year</th>
<th>Static</th>
<th>Dynamic</th>
</tr>
</thead>
<tbody>
<tr>
<td>2001</td>
<td>21.25 °C</td>
<td>25 °C</td>
</tr>
<tr>
<td>2018</td>
<td>23.75 °C</td>
<td>23.75 °C</td>
</tr>
</tbody>
</table>

2001
- Urban LST = 21.25 °C
- Rural LST = 20 °C
- UHI = 1.25 °C

2018
- Urban LST = 23.75 °C
- Rural LST = 20 °C
- UHI = 3.75 °C
Conclusions

- Relative consistency in regional spatial distribution of UHI using multiple methods
- Dynamic urban-rural delineations suggest UHI intensity has not changed significantly over time (except slightly for tropical regions)
- Static buffer-based UHI calculations may overestimate long-term trends
- A need to standardize both urban and rural definitions for estimating urban heat island trends
Thank you!

Questions?