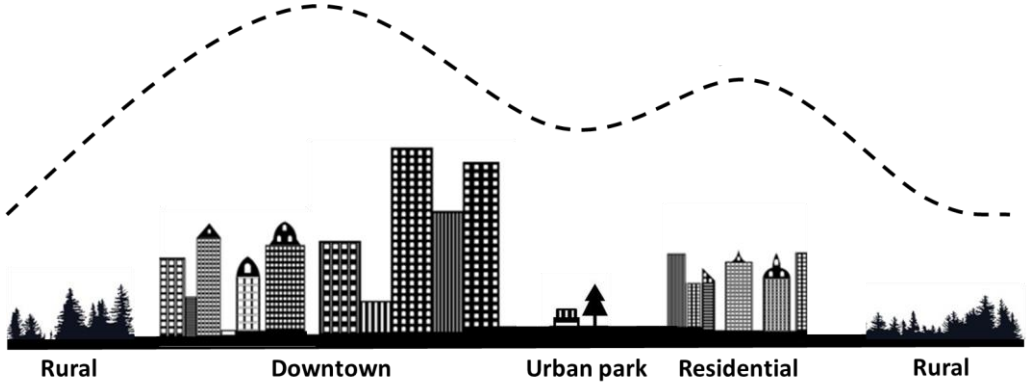
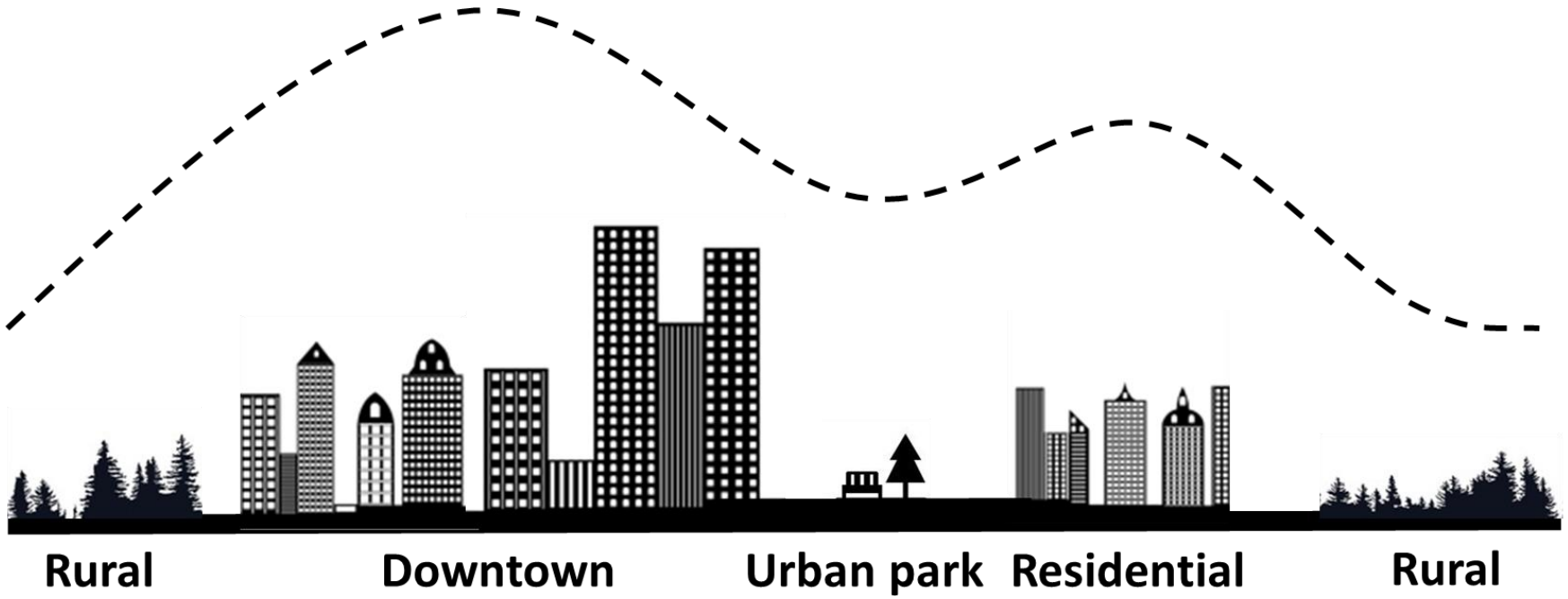
Monitoring Urban Heat Islands from Space: Challenges and Applications



Presented by:
Tirthankar Chakraborty (TC)
PhD Candidate
Yale University

The Urban Heat Island Effect

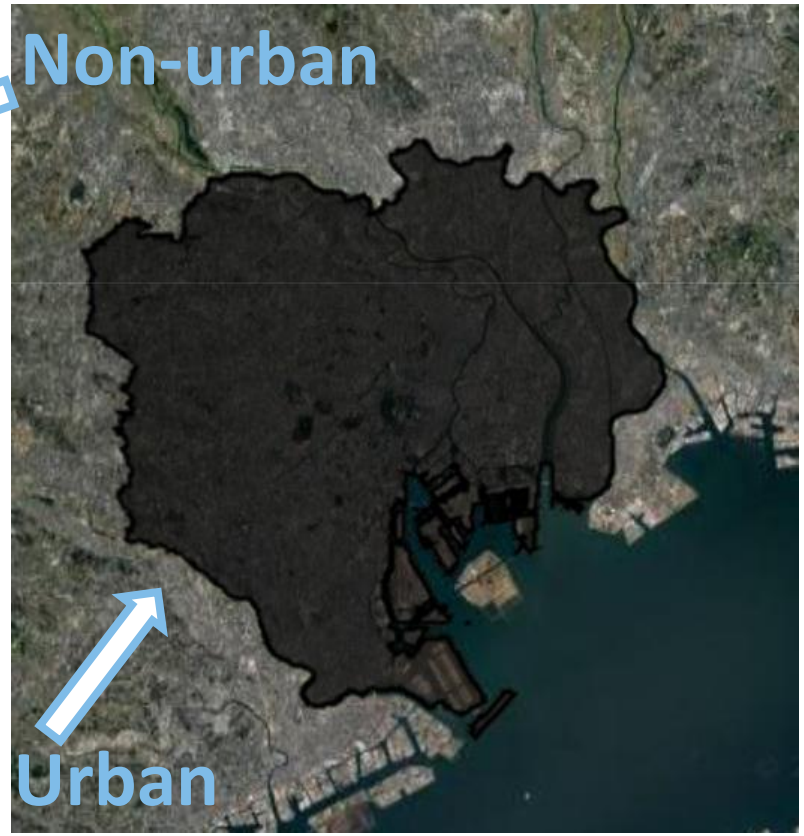


Cities are hotter than surroundings; leads to heat stress, higher energy use, secondary air pollution, etc.

Spatial Inconsistencies in UHI quantification

Beijing

Tokyo



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

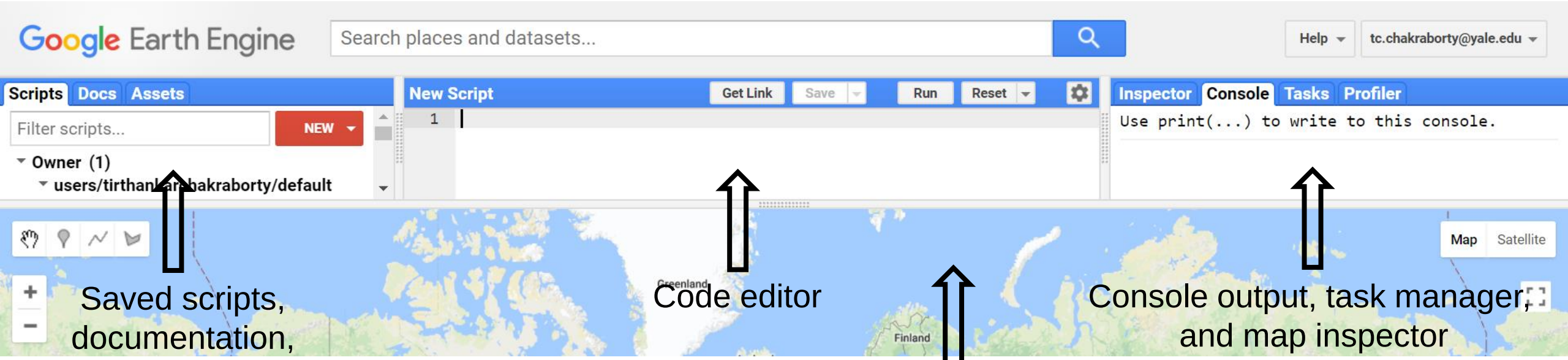
Study overview

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		Objectives of study
➢ 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	⇨	➢ 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



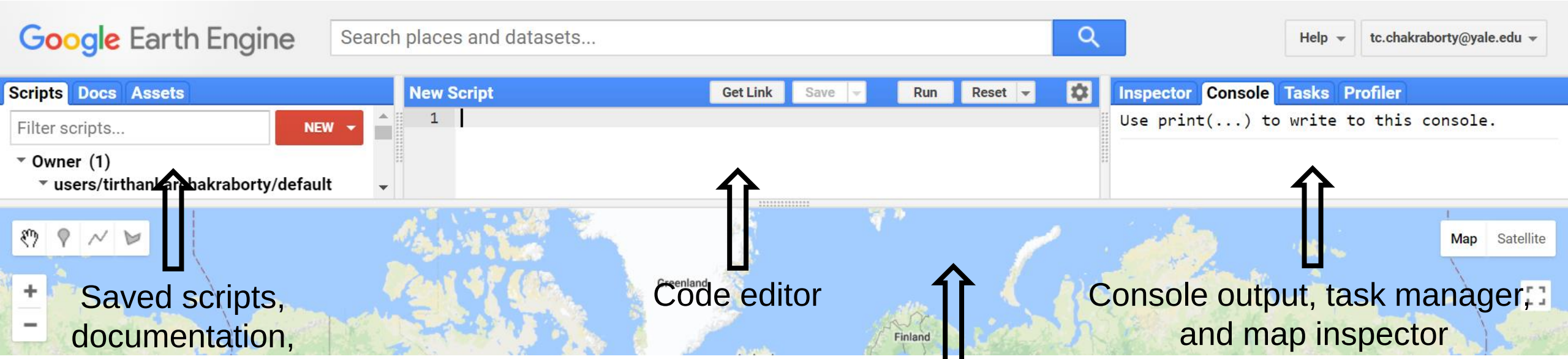
Saved scripts, documentation, and asset manager

Code editor

Console output, task manager, and map inspector

Map output and visualization

Google Earth Engine platform



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Console output, task manager, and map inspector

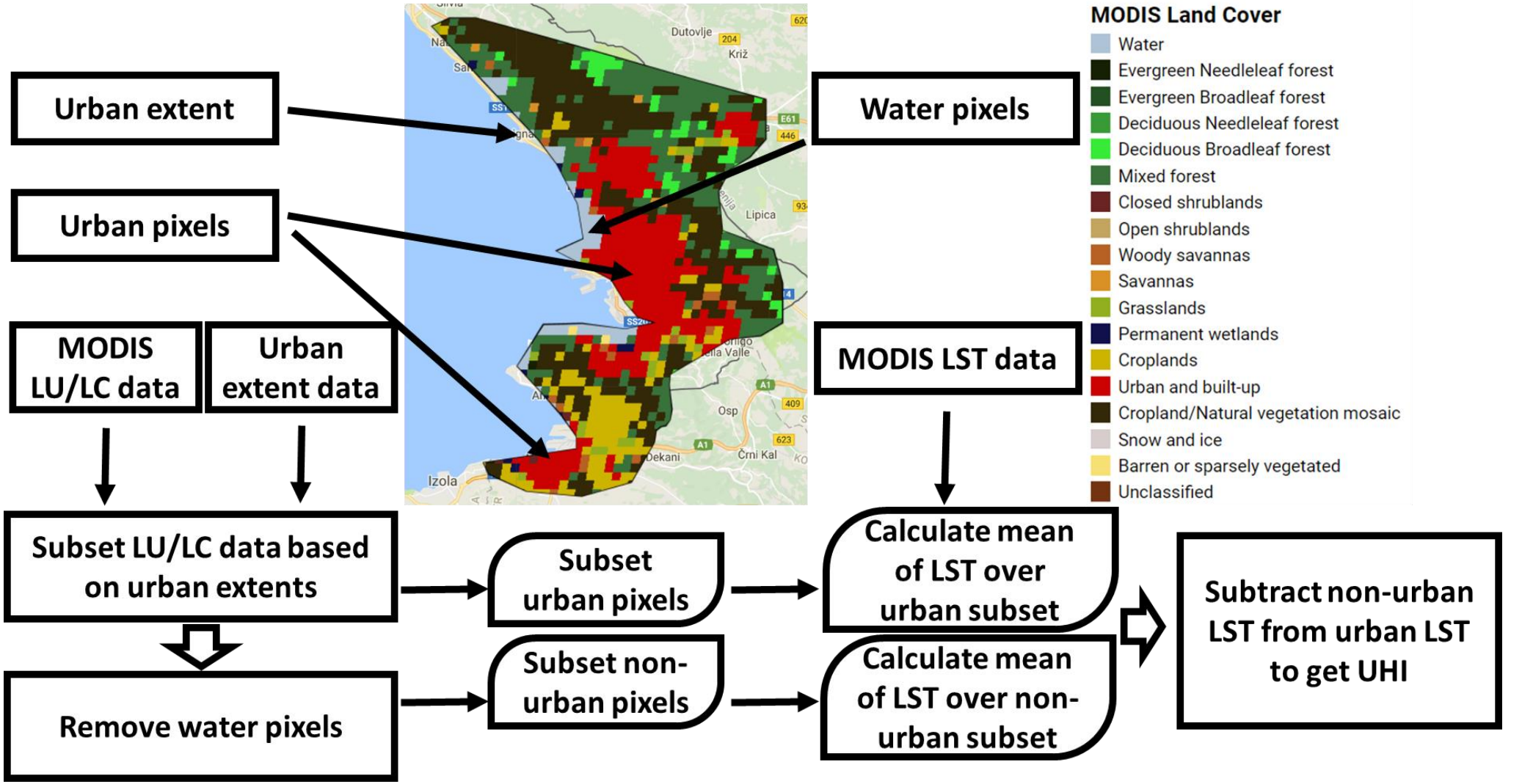
Map output and visualization

- 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



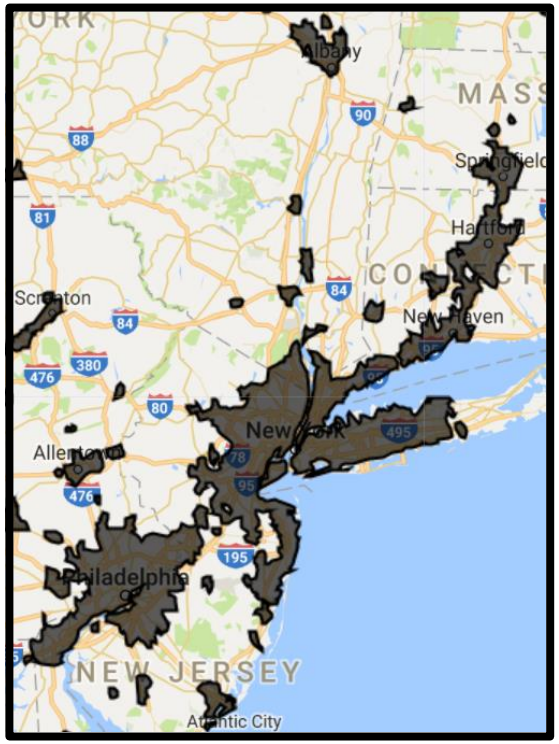
Simplified Urban-Extent (SUE) algorithm

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



Urban cluster boundary

Simplified Urban-Extent (SUE) algorithm

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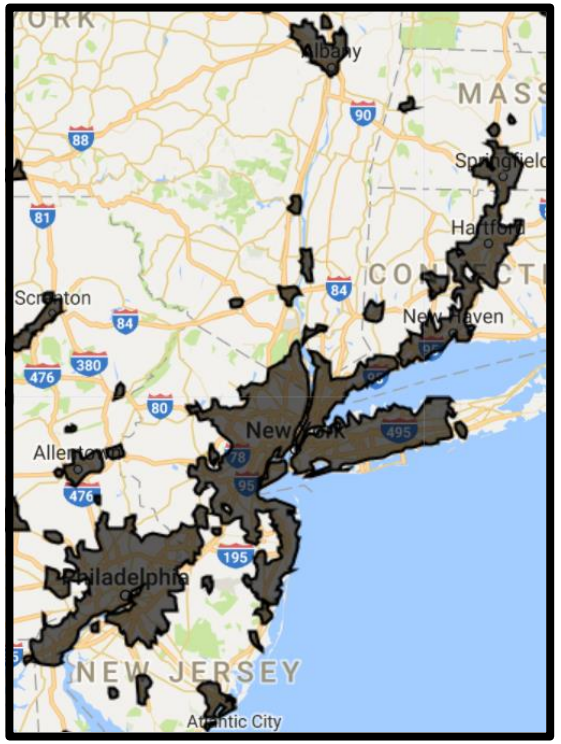
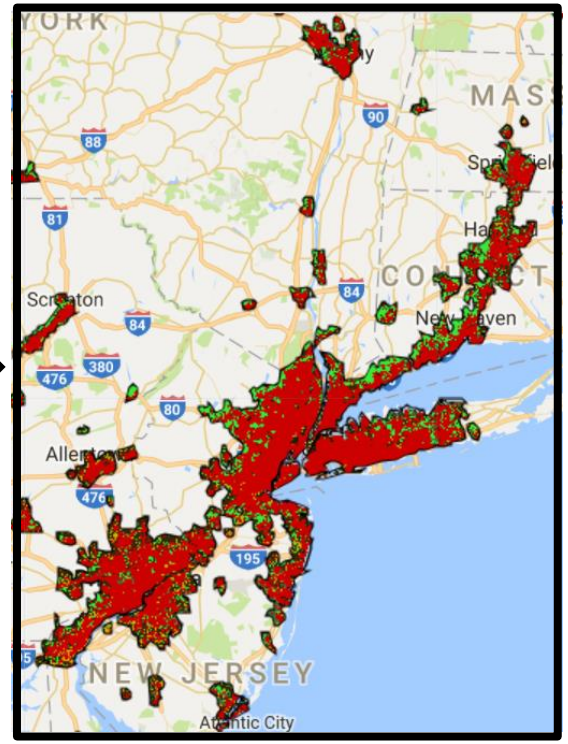


Urban cluster boundary



MODIS LU/LC data clipped to shapefile

Simplified Urban-Extent (SUE) algorithm

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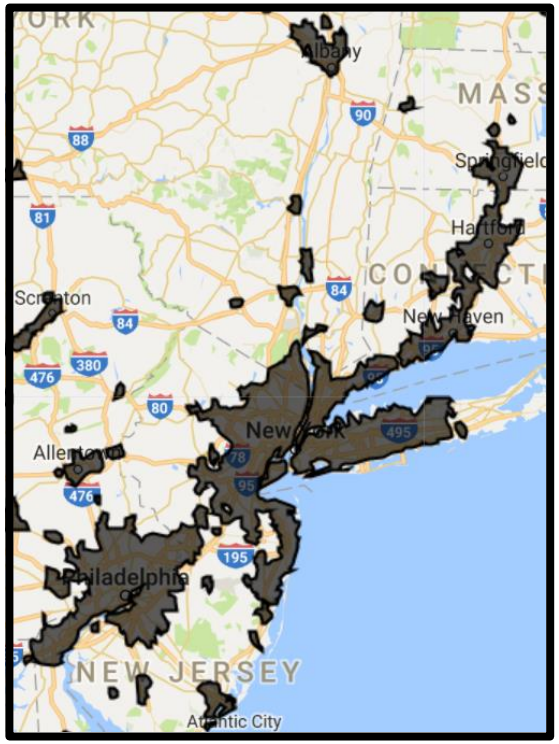

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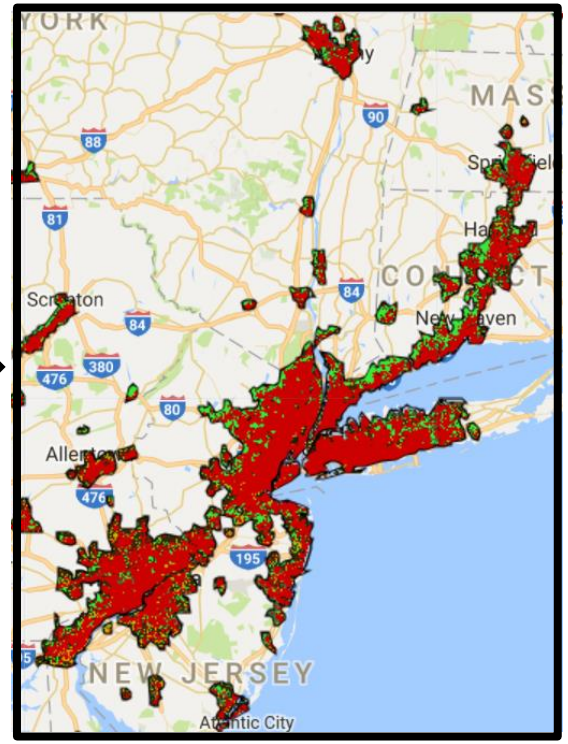
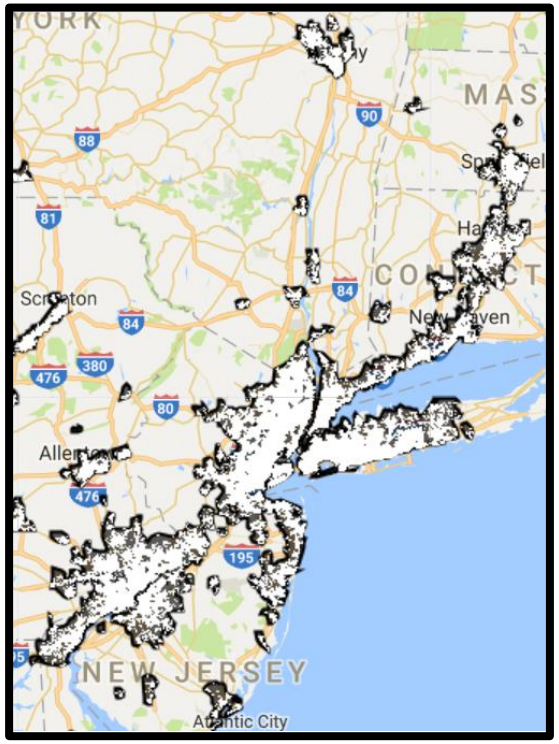


MODIS LU/LC data clipped to shapefile



Mask from urban pixels

Simplified Urban-Extent (SUE) algorithm

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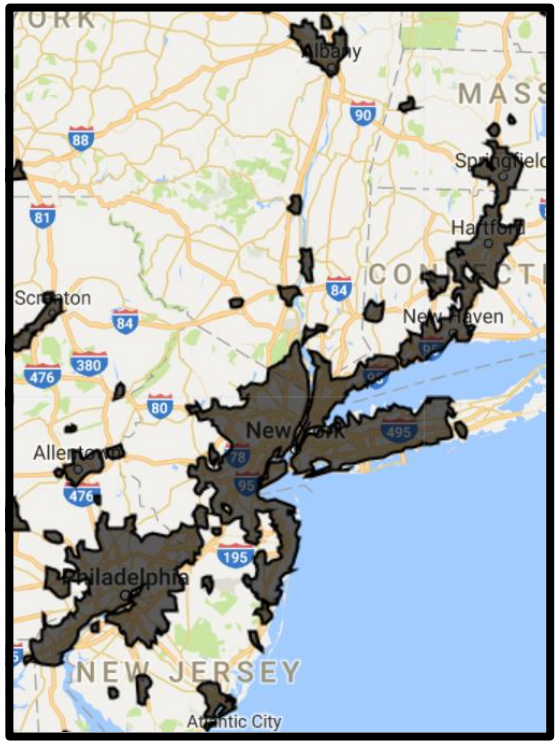
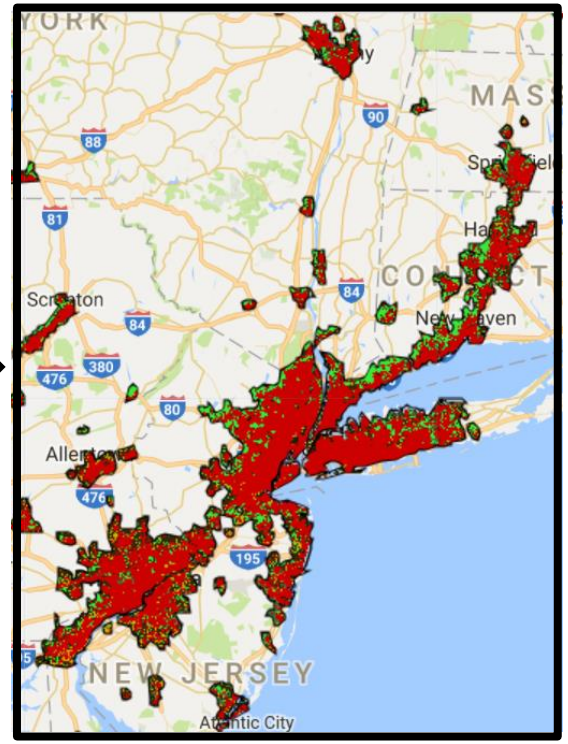
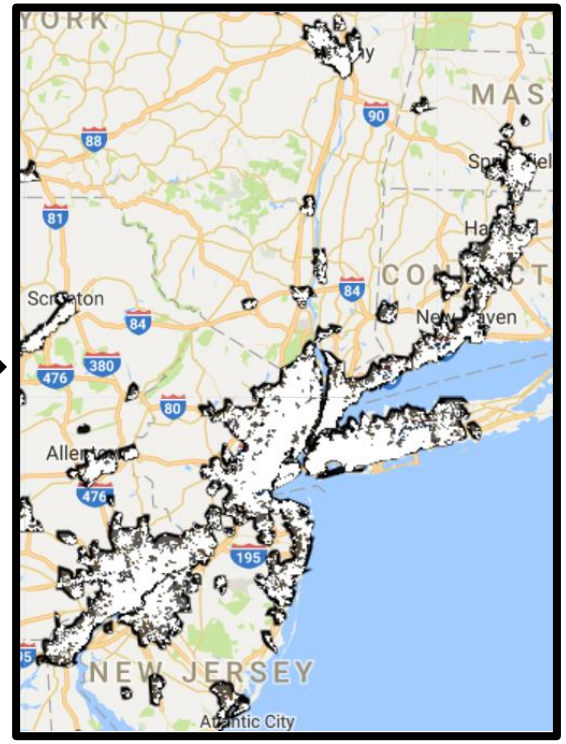


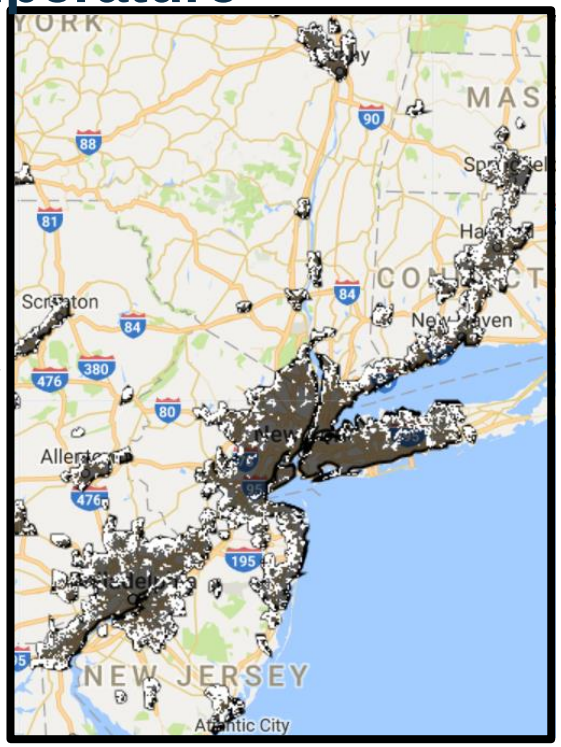
Urban cluster boundary



MODIS LU/LC data clipped to shapefile

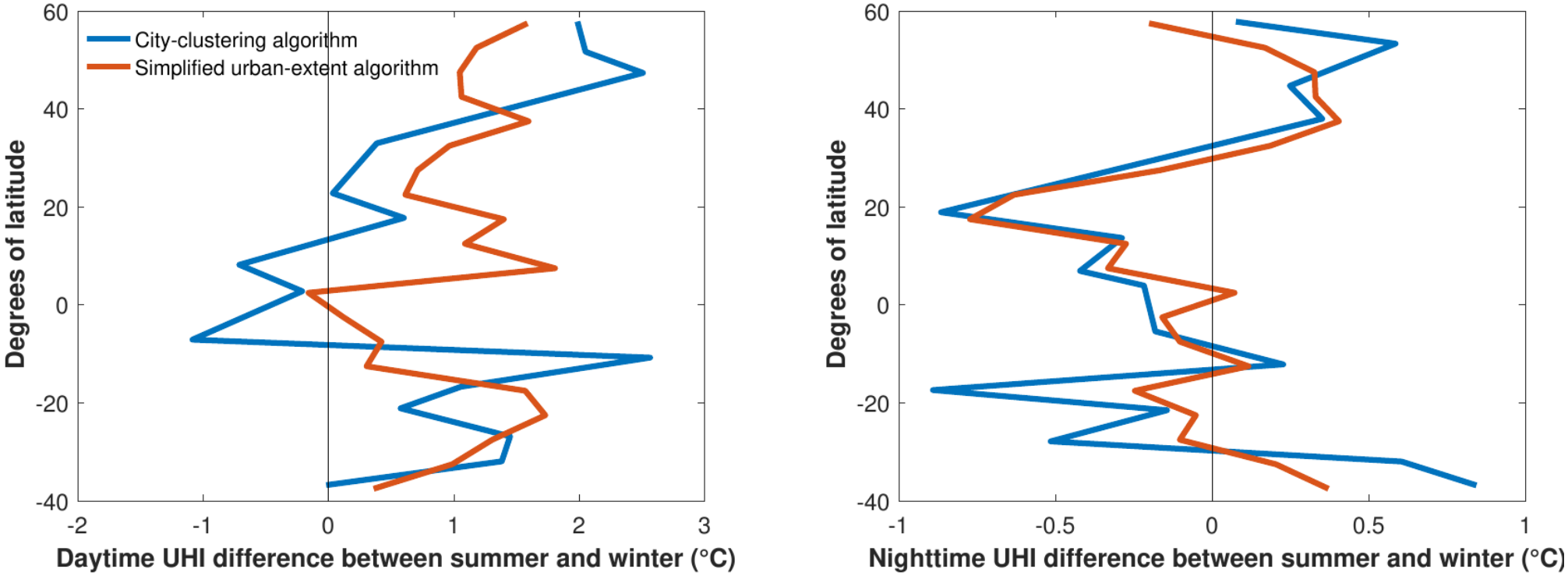


Mask from urban pixels



Mask from non-urban pixels

SUB algorithm evaluation



(a) Daytime

(b) Nighttime

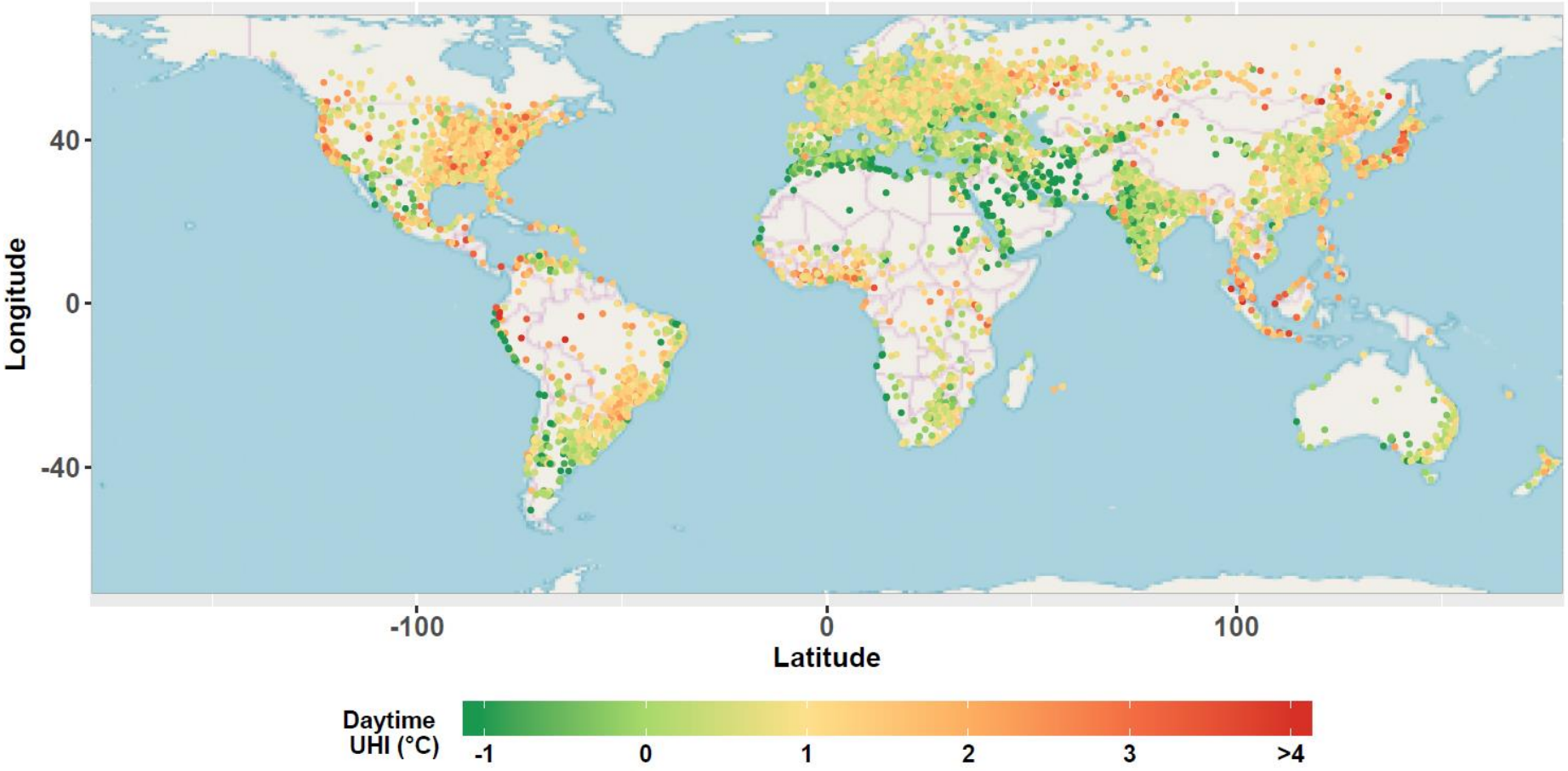
Comparing the latitudinal trends with results from Peng et al. (2012) for 419 largest urban clusters

SUB algorithm evaluation

Local time	Present study (SUE)	Clinton and Gong (5 km buffer)	Clinton and Gong (10 km buffer)
0130 LT	0.51 ± 0.47	0.60 ± 0.90	0.70 ± 1.00
1030 LT	0.73 ± 0.86	0.70 ± 1.40	1.00 ± 1.60
1330 LT	1.00 ± 1.08	0.90 ± 1.60	1.10 ± 1.80
2230 LT	0.60 ± 0.47	0.60 ± 0.90	0.80 ± 1.00

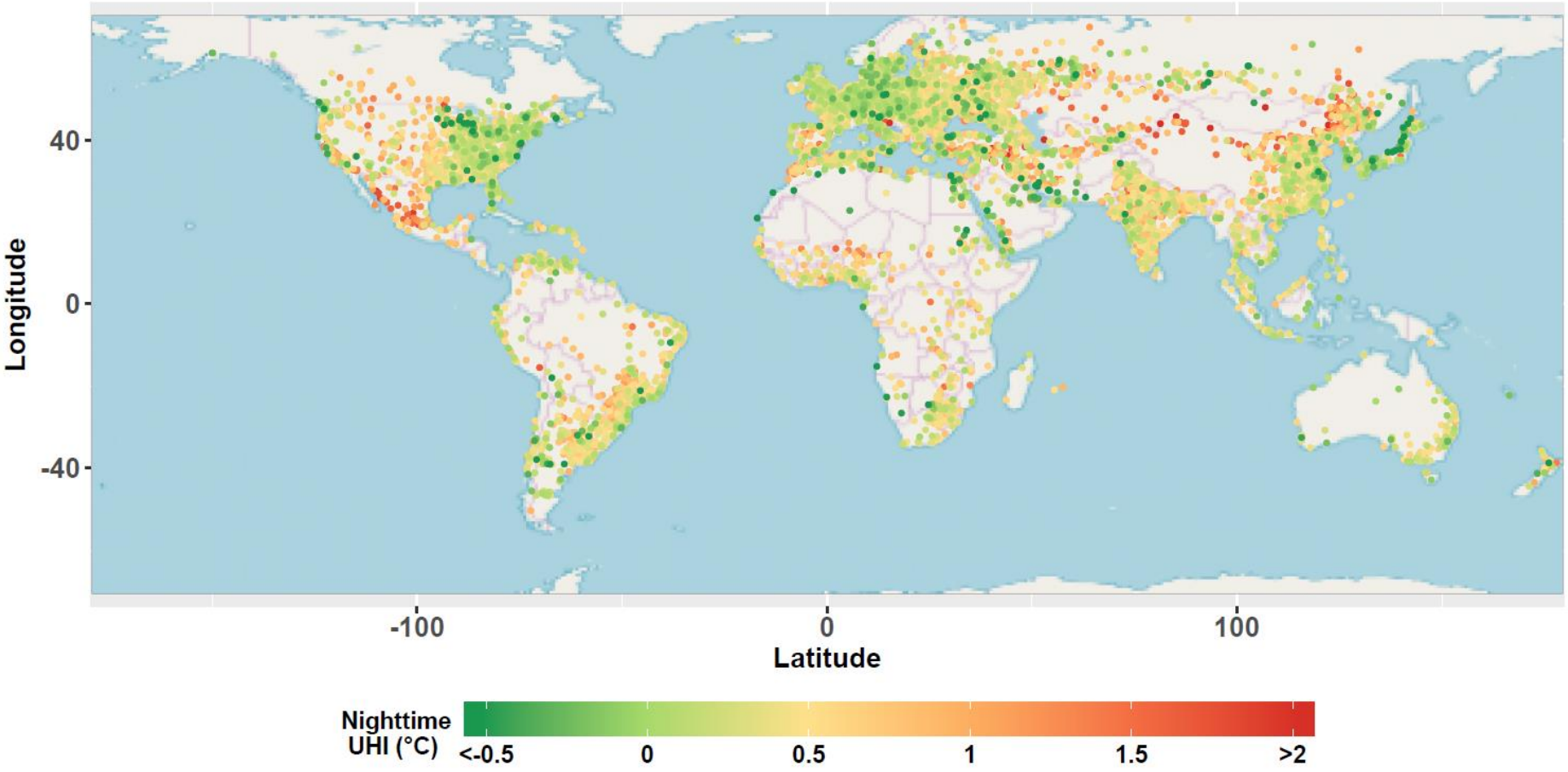
Comparing global trends with the results from Clinton and Gong (2013) for 2010

Global Daytime surface UHI intensity



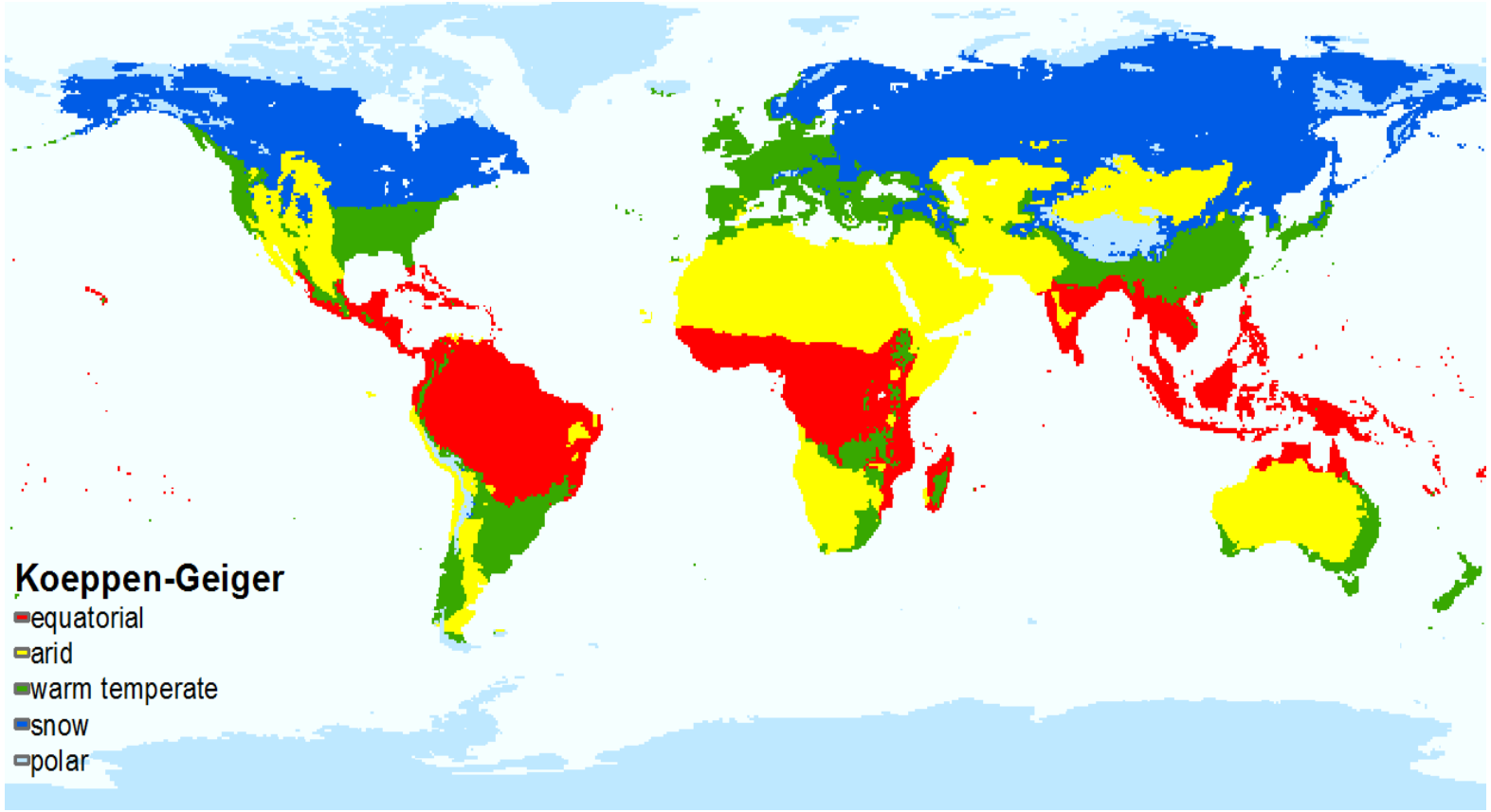
Daytime surface UHI (global mean value = 0.85 °C)

Global Nighttime surface UHI intensity



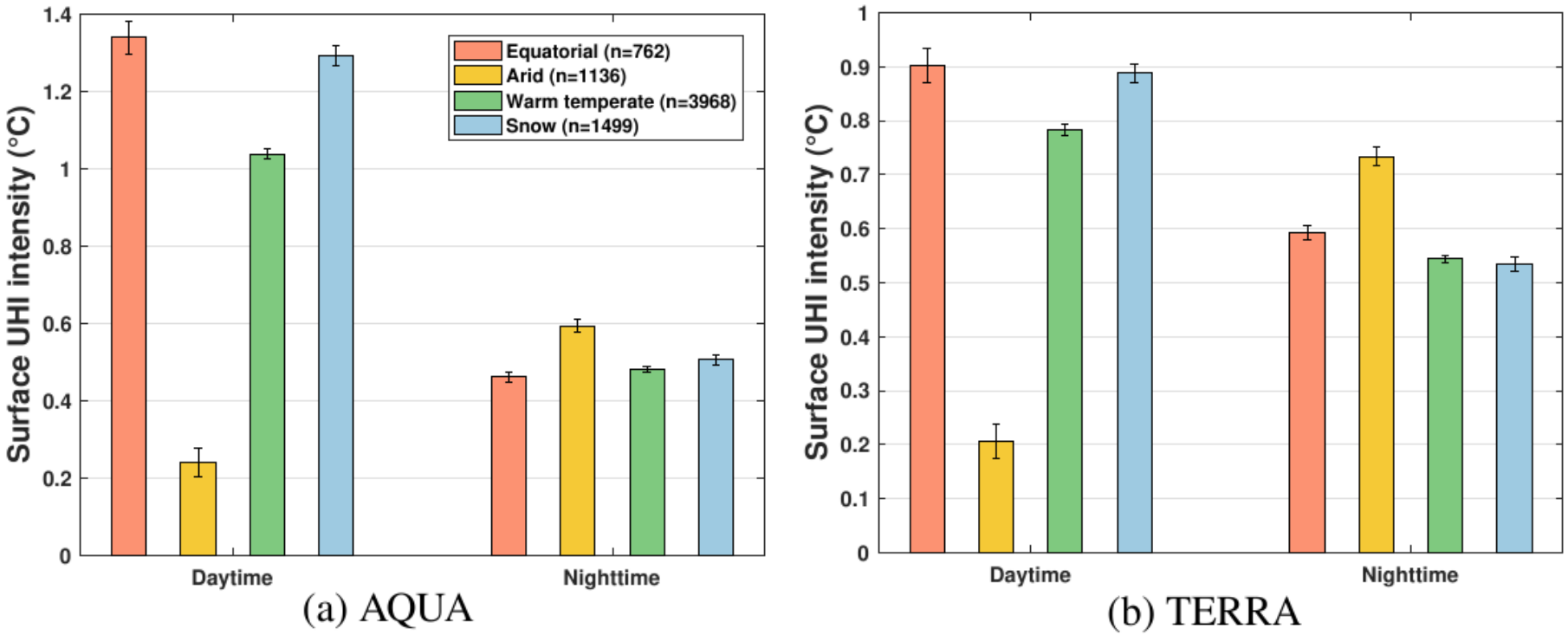
Nighttime surface UHI (global mean value = 0.55 °C)

Separating into climate zones



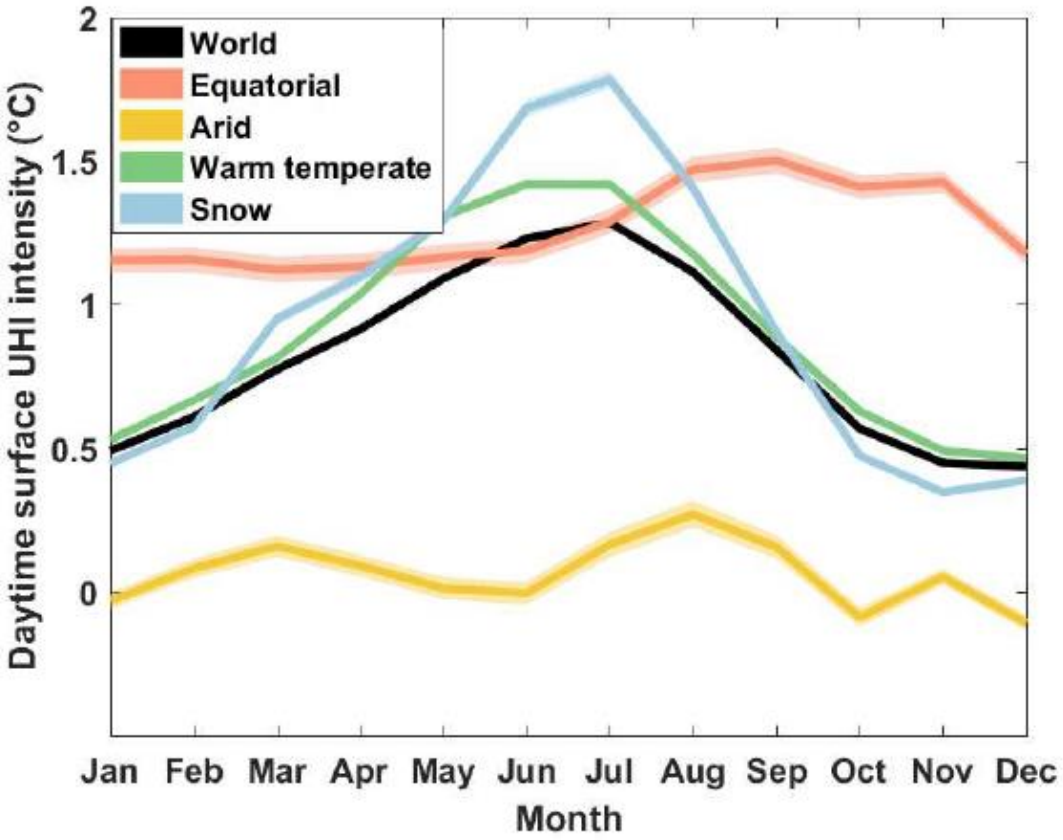
- Arid zones have been previously shown to have lower UHI intensity; sometimes cool islands
- Control of background climate on UHI has been modeled for a subset of US cities

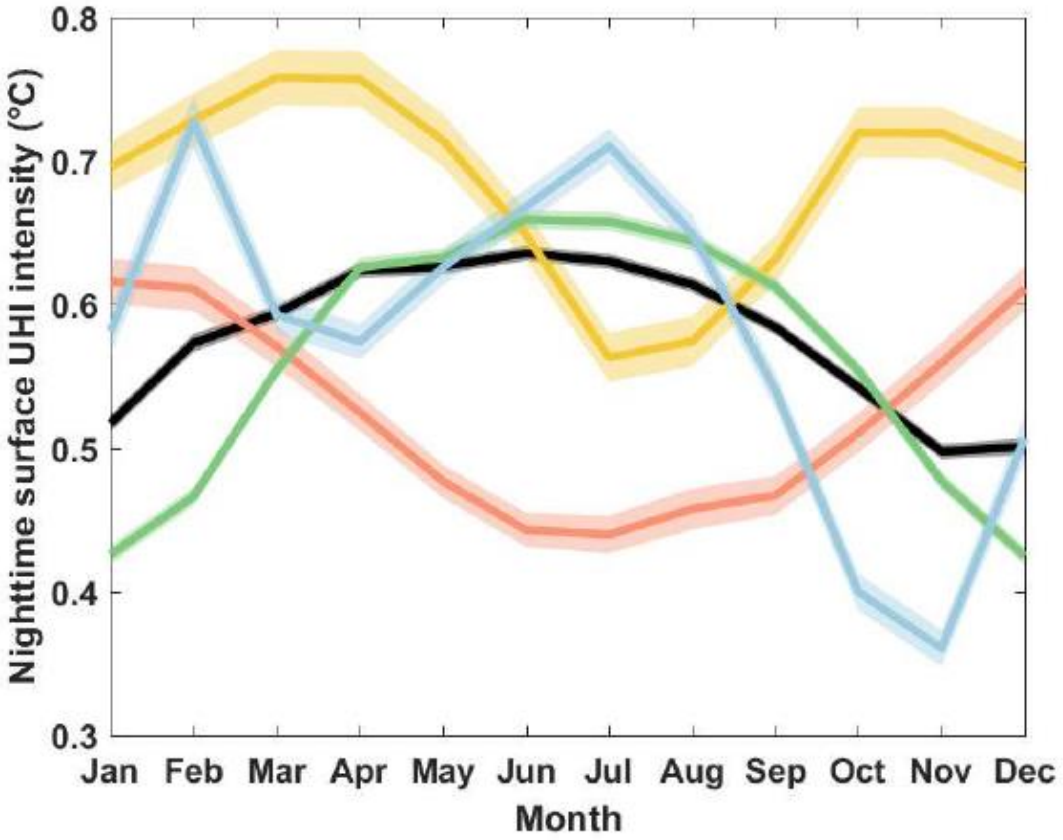
Background climate and annual surface UHI



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

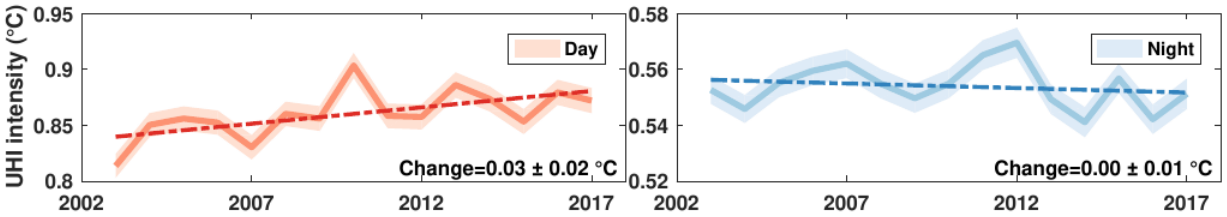
Seasonal trends in surface UHI



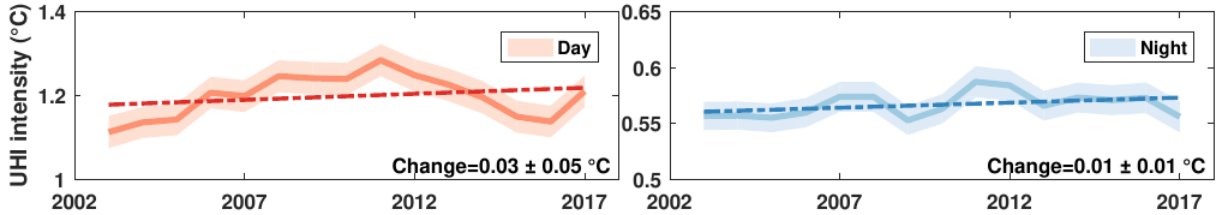


- Very little seasonality in daytime UHI intensity and opposite seasonality in Nighttime UHI for arid and tropical urban areas

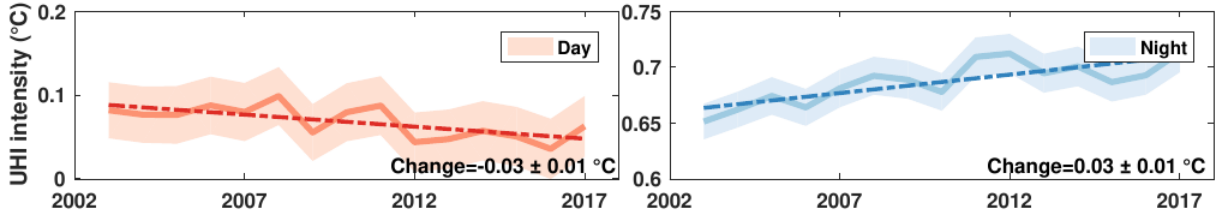
Long-term trends in surface UHI



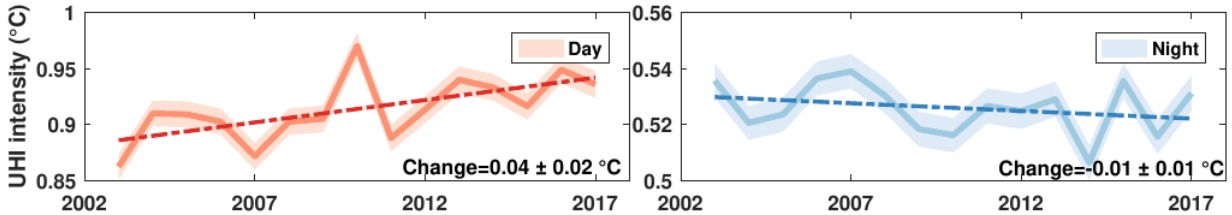
(a) World



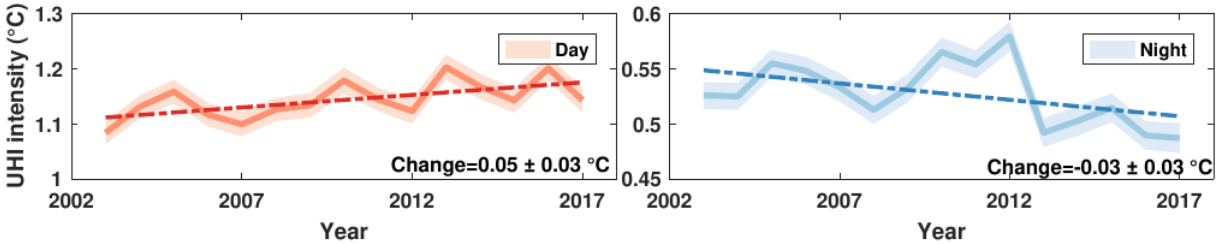
(b) Equatorial climate zone



(c) Arid climate zone



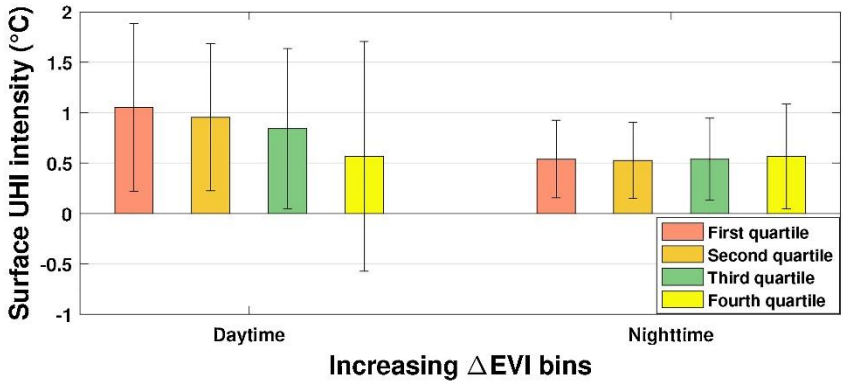
(d) Warm temperate climate zone



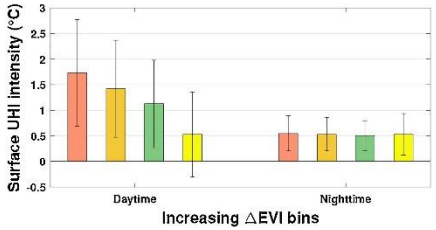
(e) Snow climate zone

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

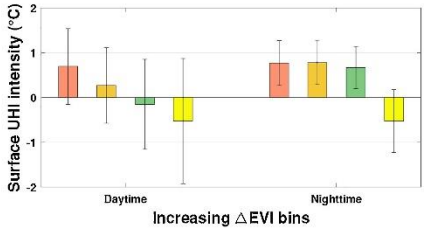
Vegetation differential and UHI intensity



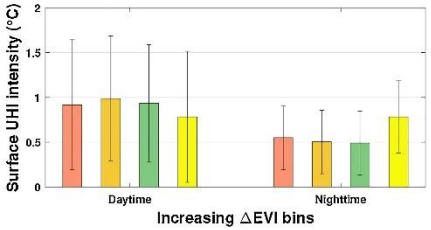
(a) World



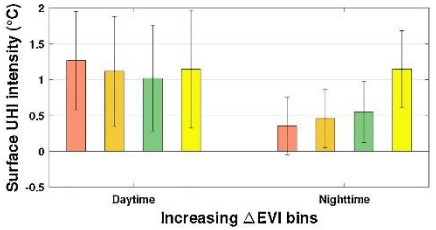
(b) Equatorial climate zone



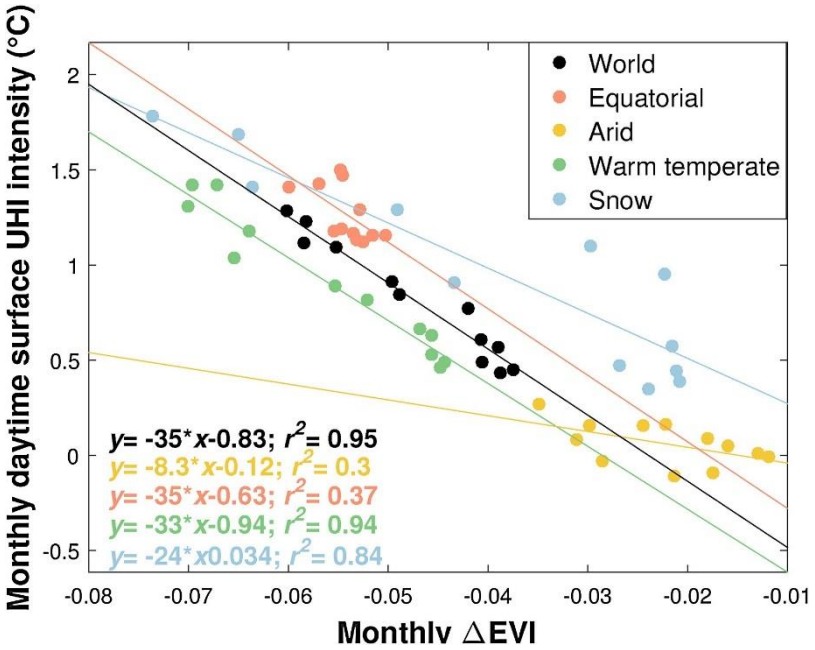
(c) Arid climate zone



(d) Warm temperate climate zone

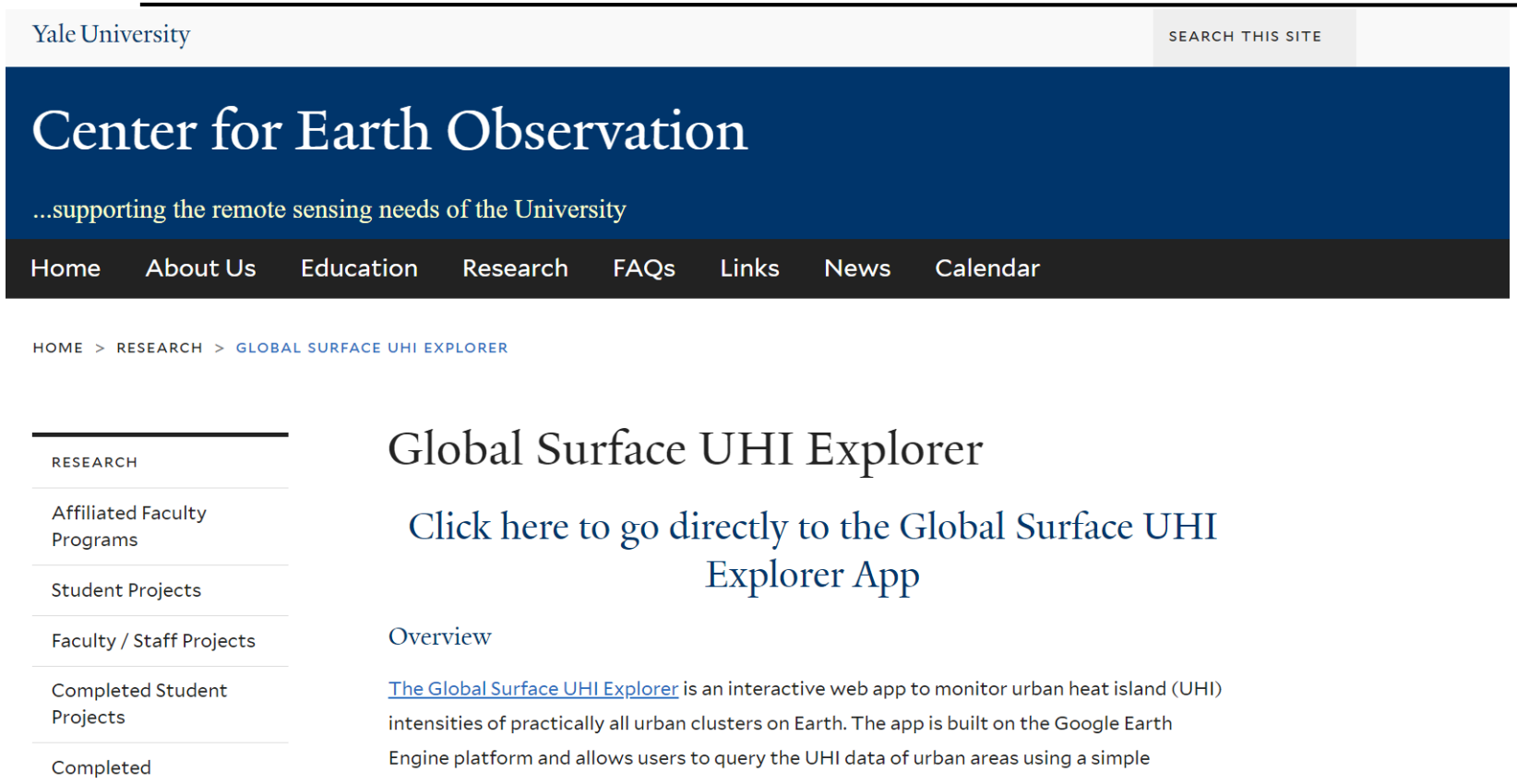


(e) Snow climate zone



- 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



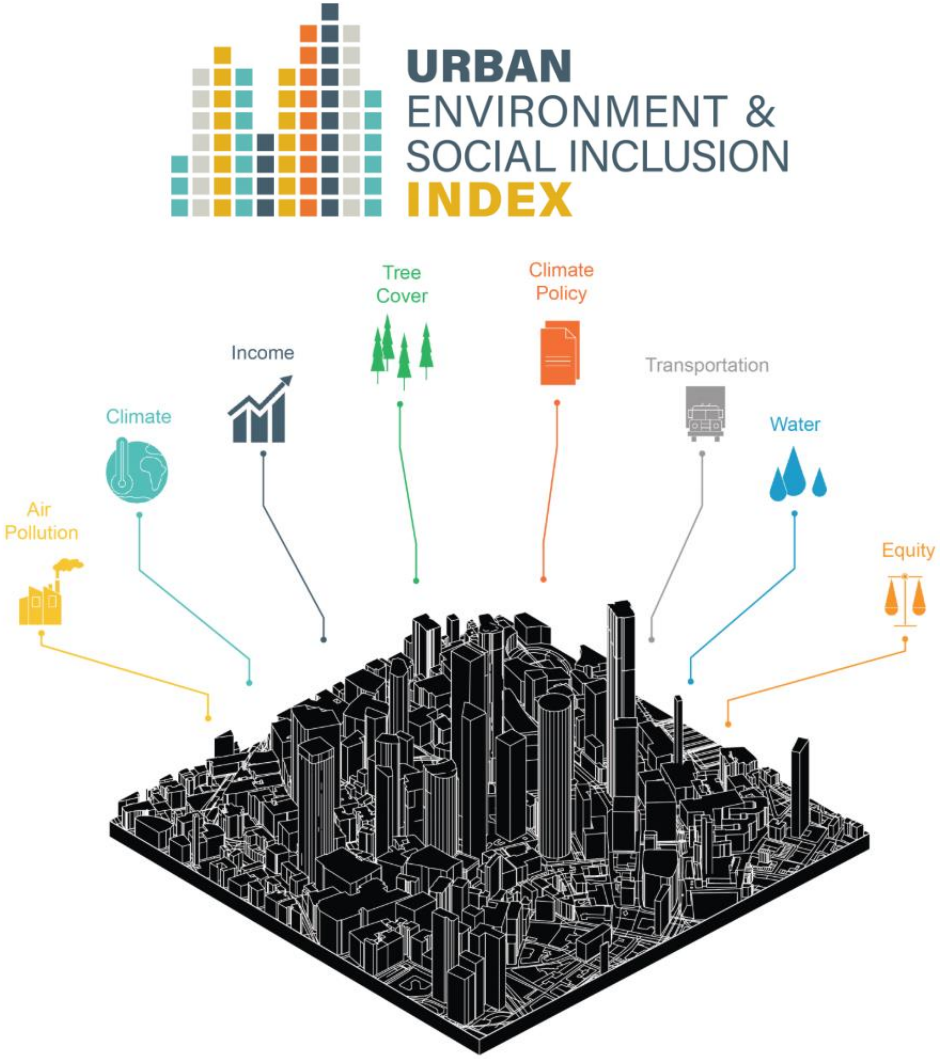
Link to Global Surface UHI Explorer web app:
https://yceo.users.earthengine.app/view/uhimap
Research summary and more information about the app:
https://yceo.yale.edu/research/global-surface-uhi-explorer

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).

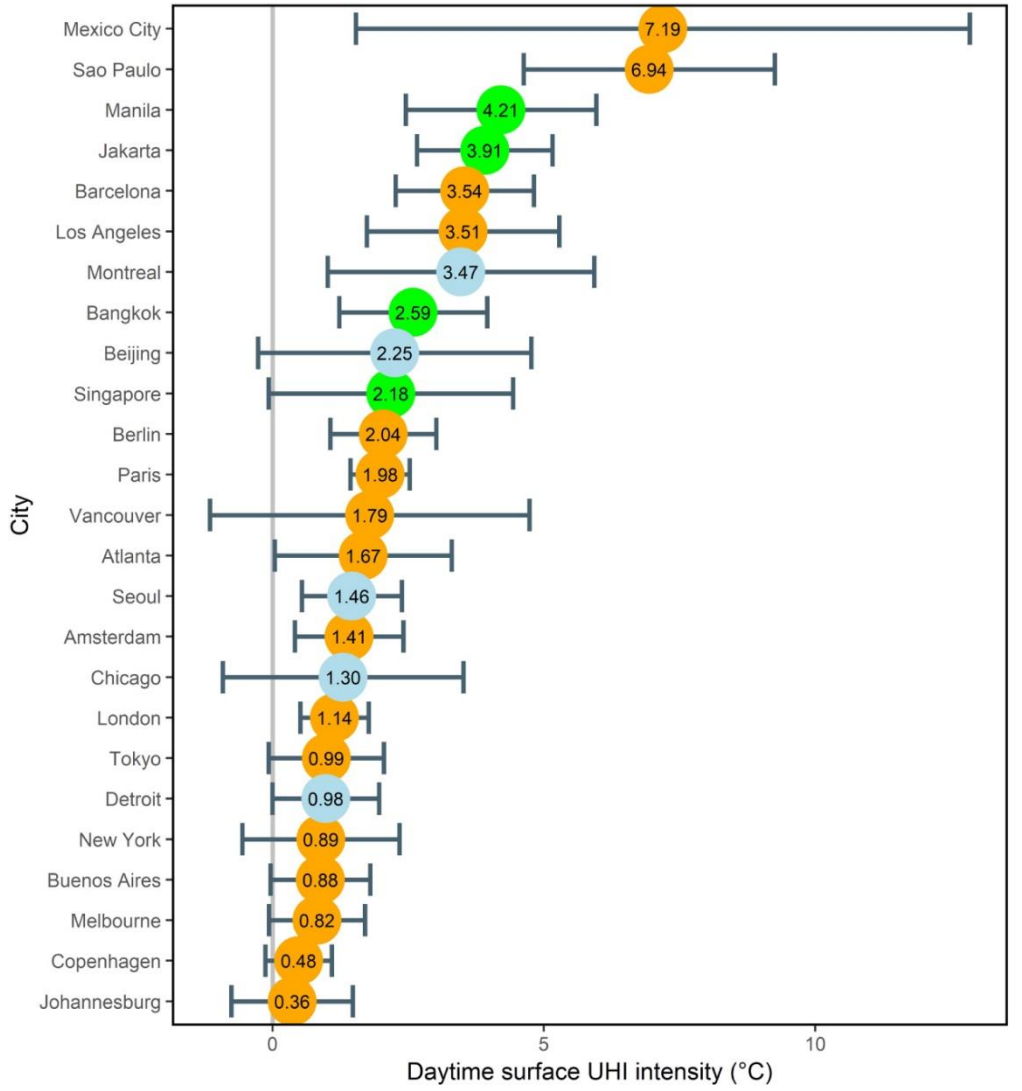
Applications: UESI

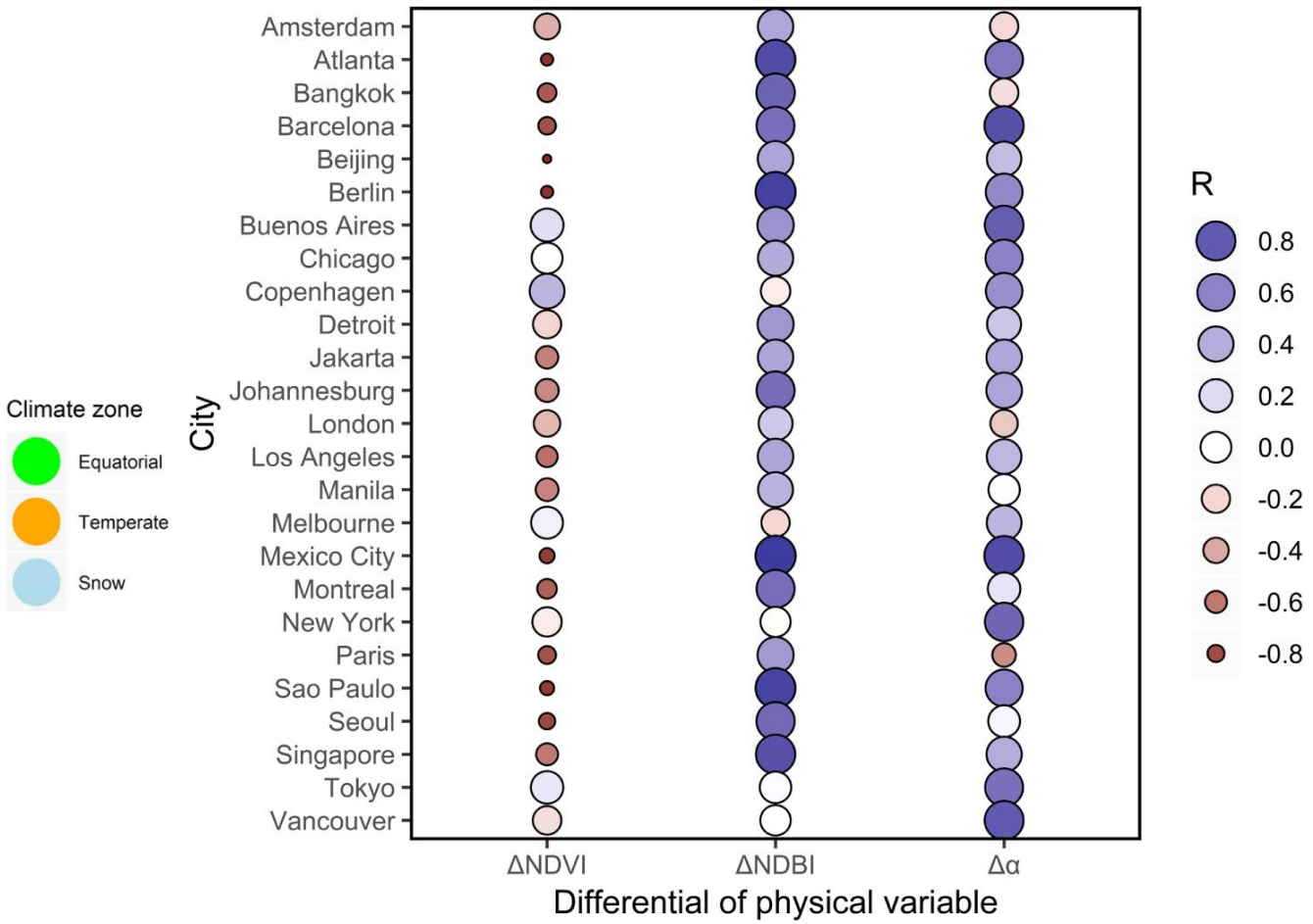


Tracking the performance of cities at a global scale combining environmental variables with social inclusion

https://datadrivenlab.org/urban/

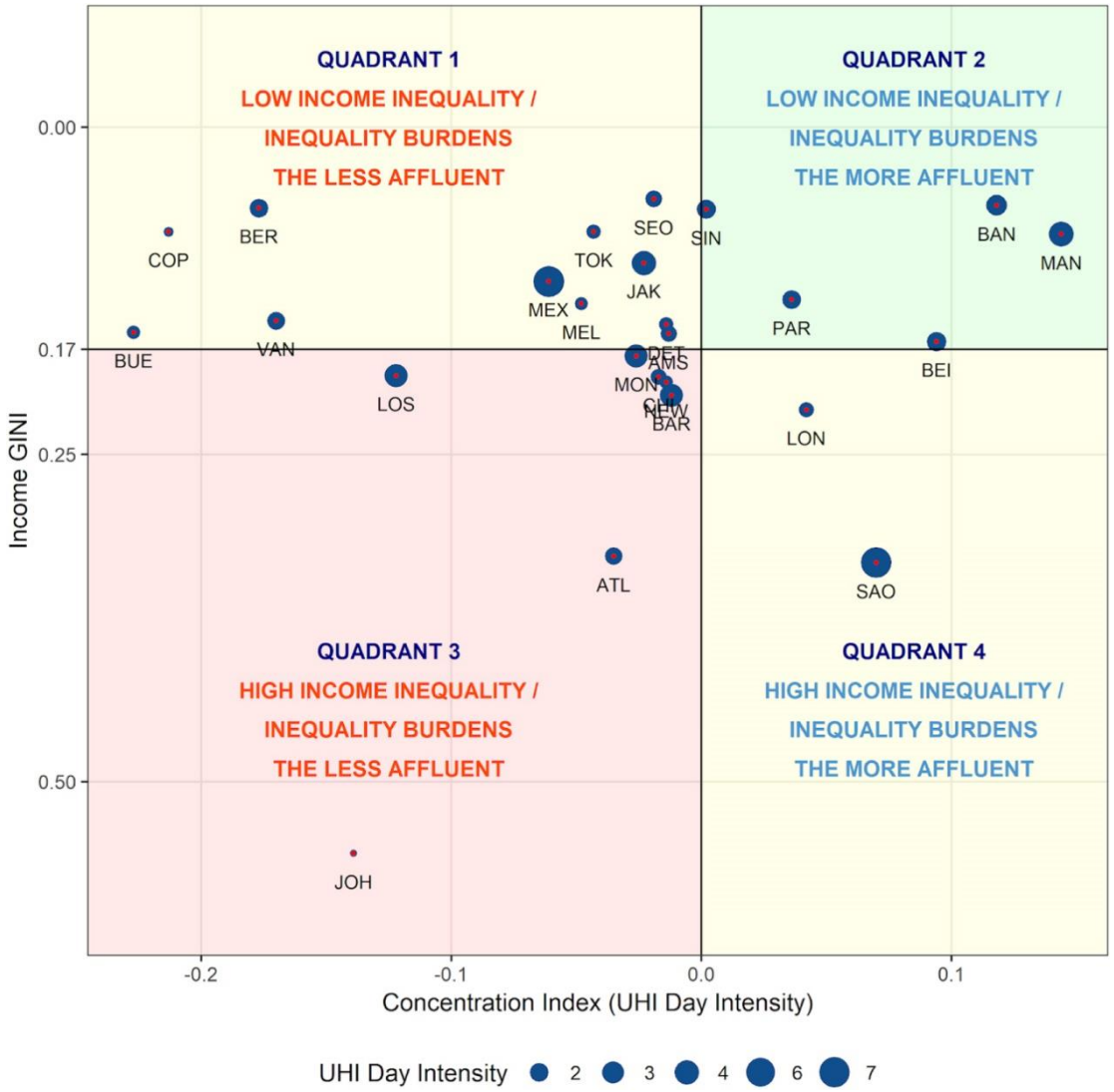
Intra-city variation in surface UHI

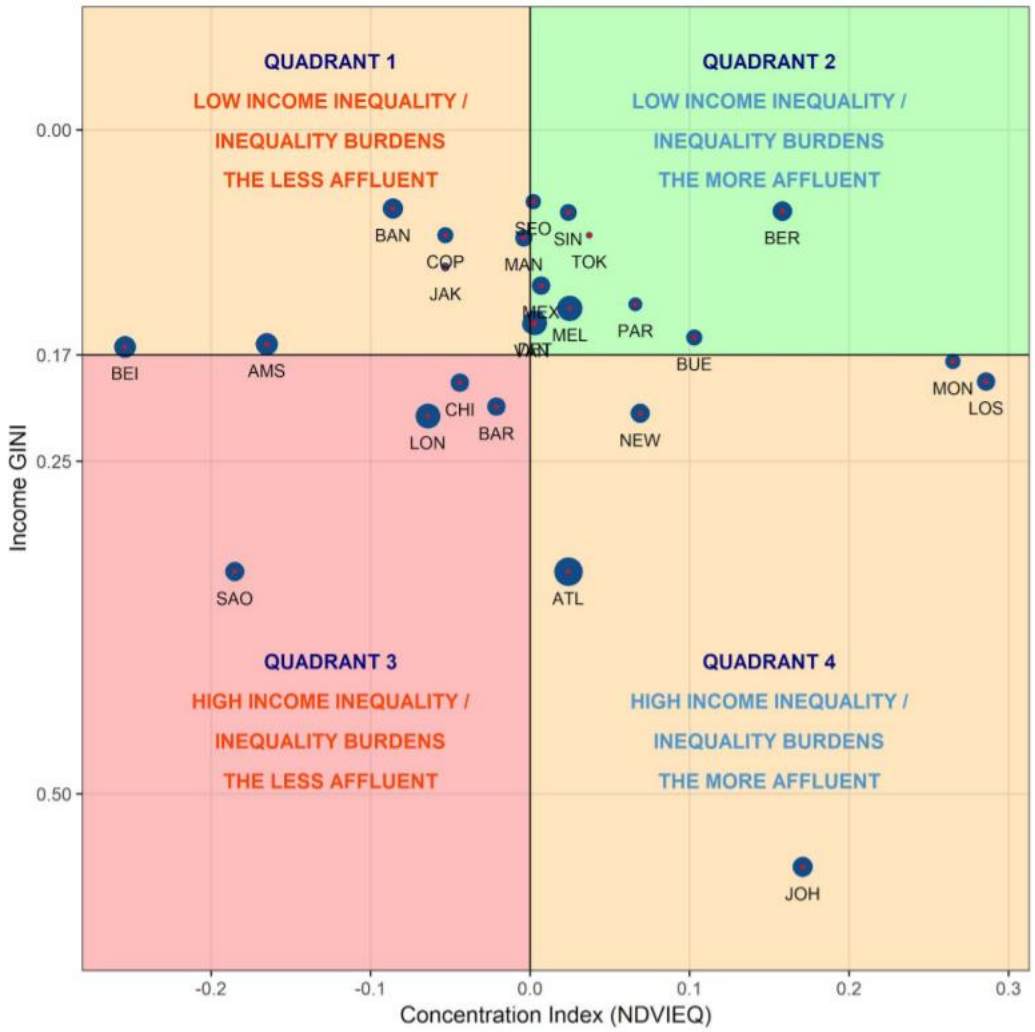




Other than coastal cities, intra-urban vegetation distribution controls UHI distribution

UHI exposure and income?

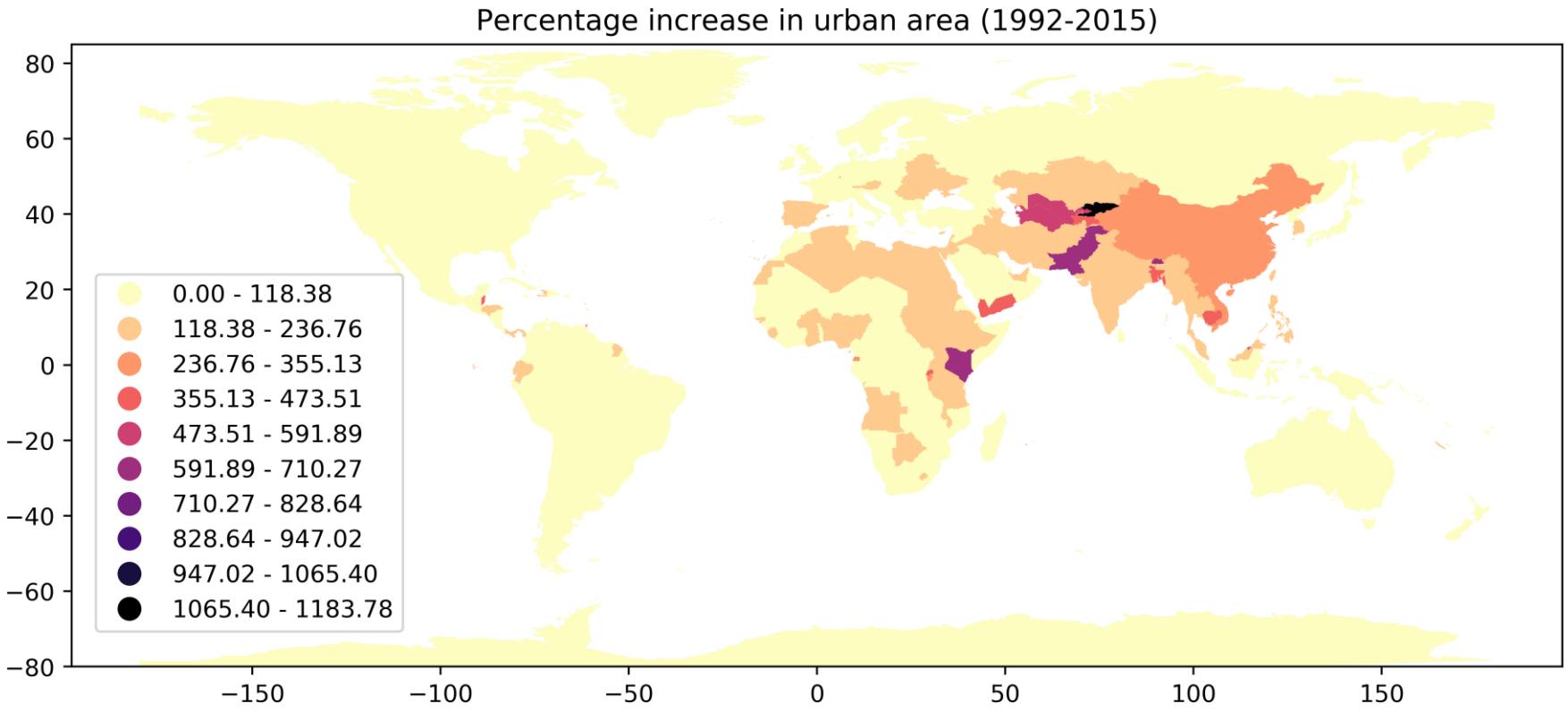




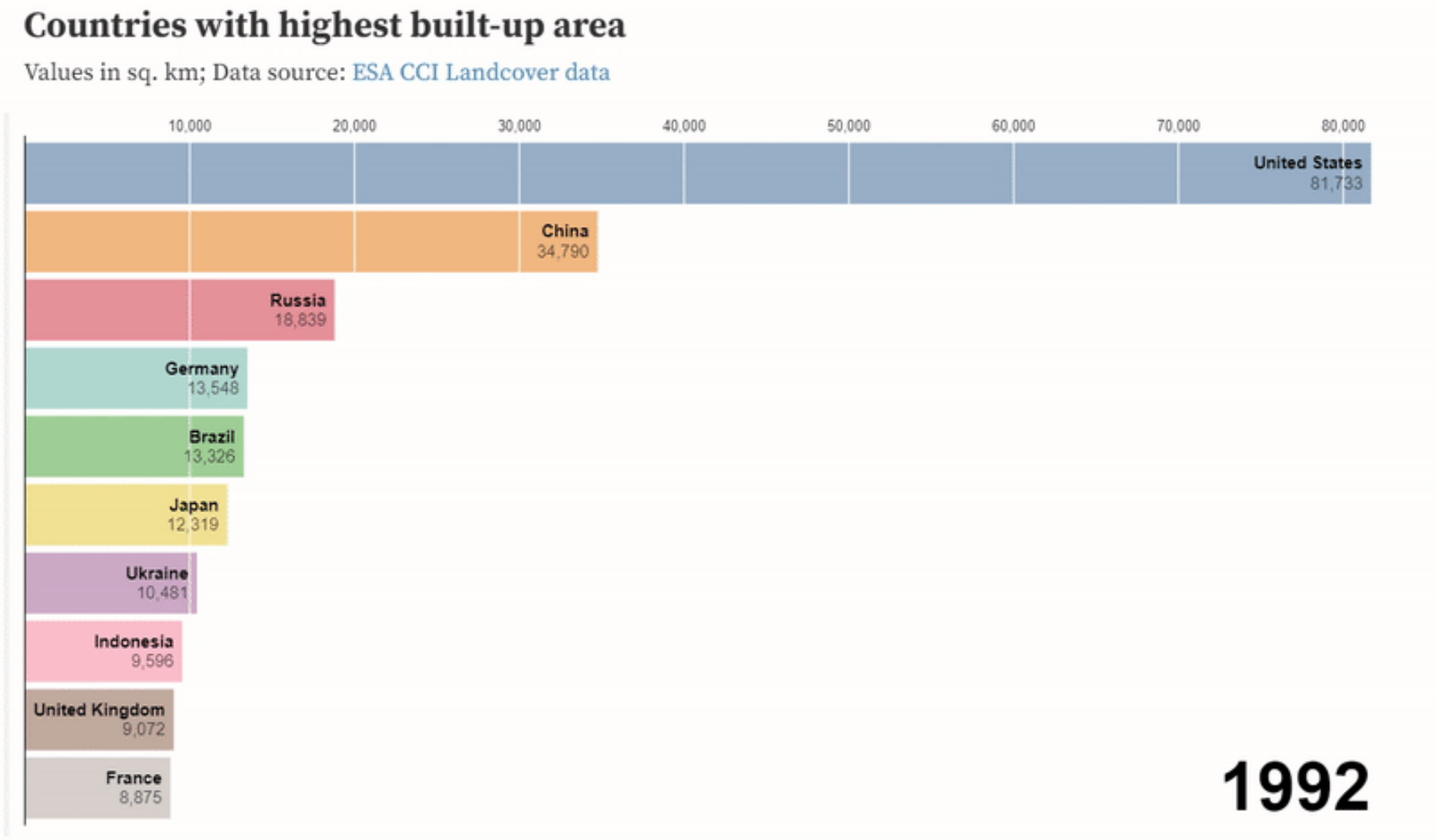
In 72% of the cities considered, surface UHI intensity is higher for poorer neighborhoods [Chakraborty et al. 2019]

Urban growth needs to be considered...[1/4]

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

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

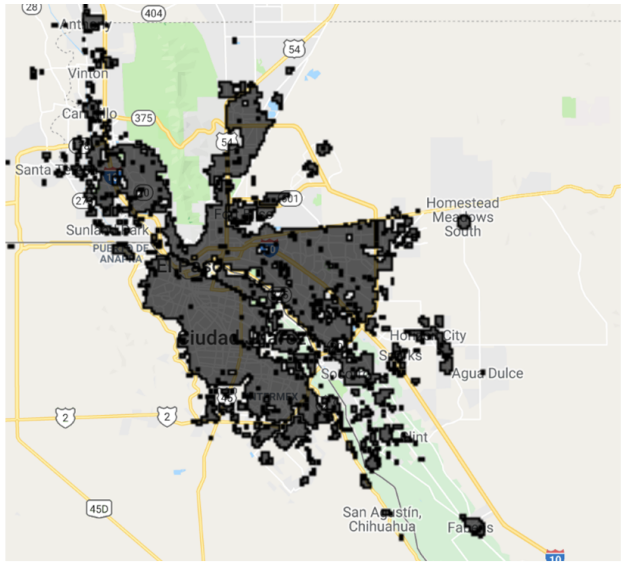
Dissolve polygons based on overlap on a geodesic surface — Combines urban areas crossing country borders and diagonal pixels

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

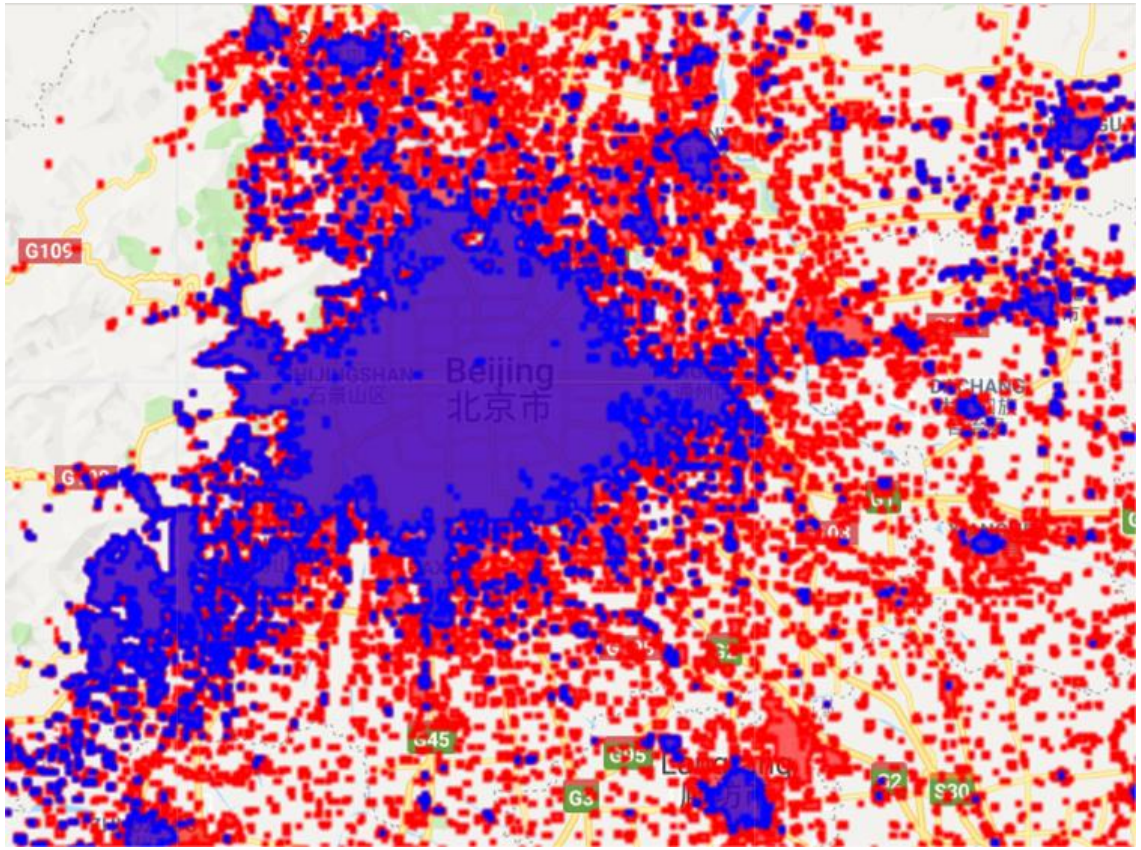
Example of an urban area sprawling over a national boundary

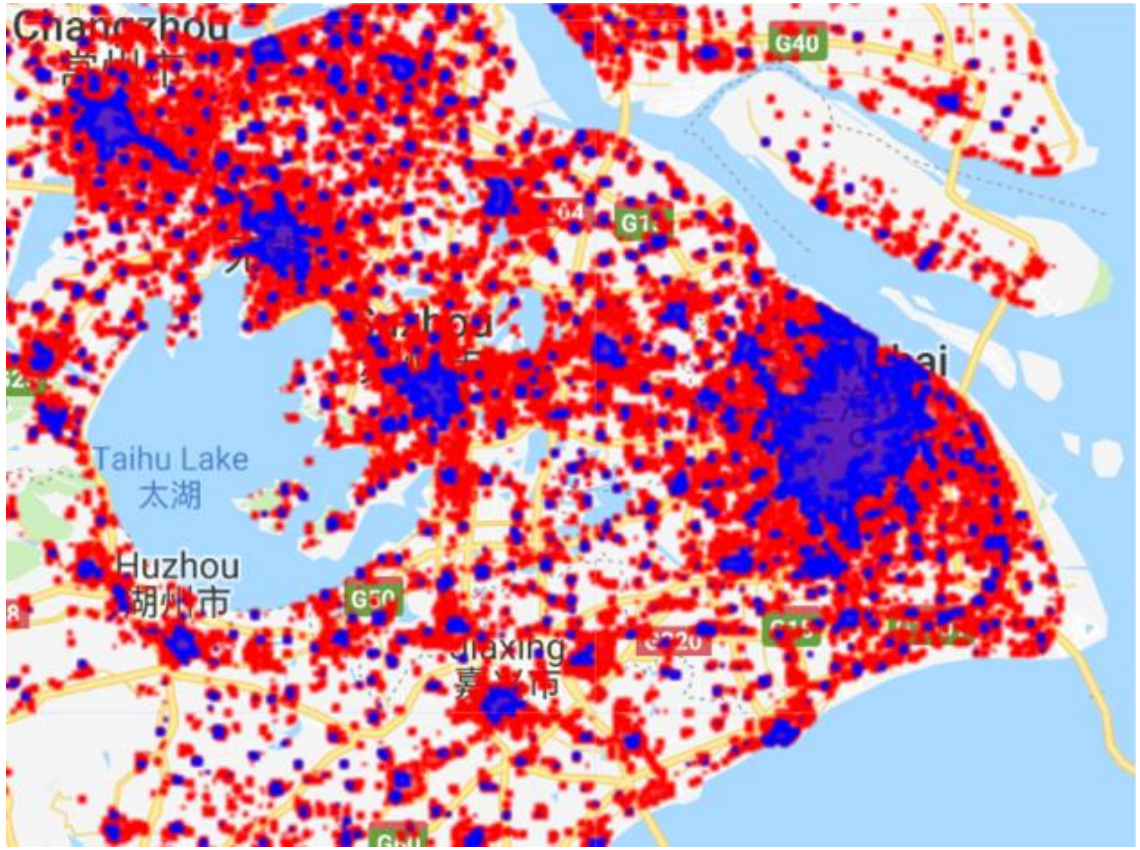


El Paso across the US-Mexican border

- 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

Urban growth needs to be considered...[3/4]

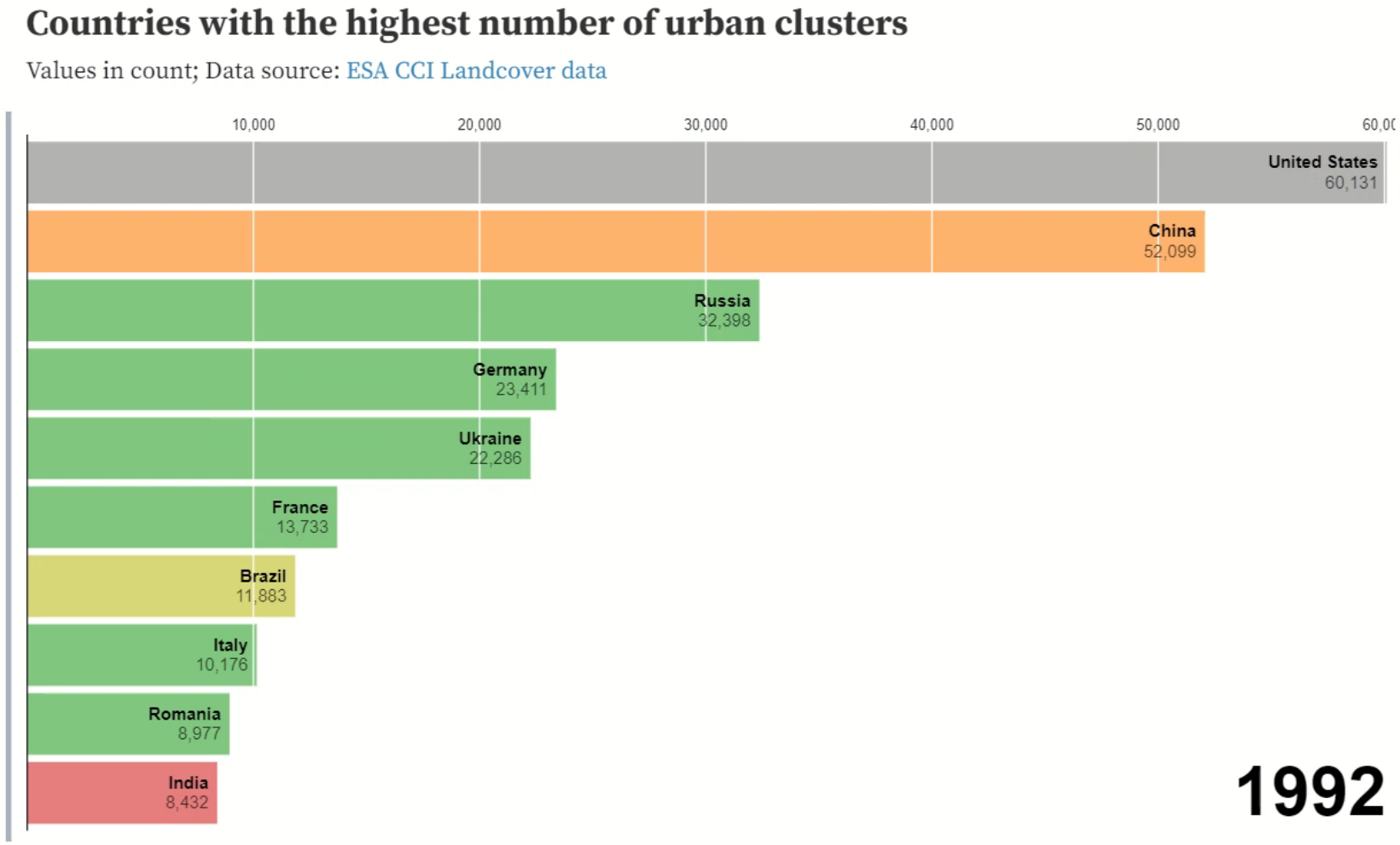




1992

2015

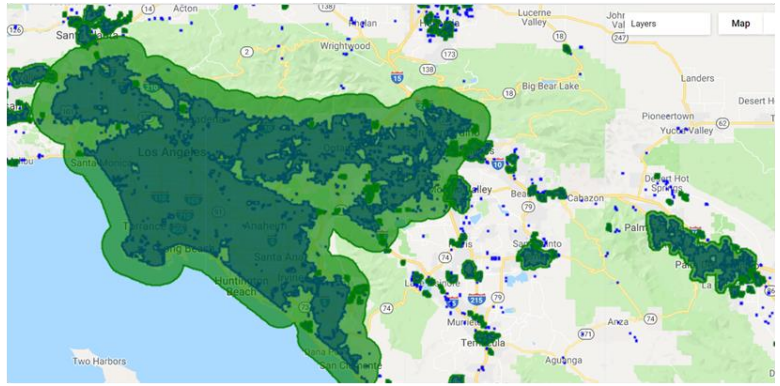
Urban growth needs to be considered...[4/4]

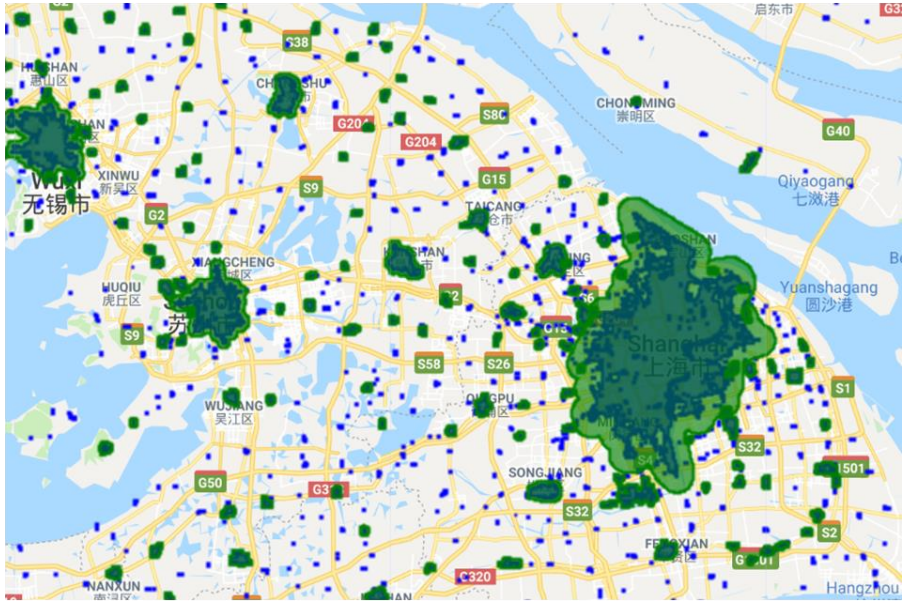


Creating area-normalized rural references

Calculate area of urban cluster → Create buffers of different widths around cluster → Calculate area of buffered cluster → Subtract buffered cluster area from thrice the area of urban cluster → Choose the buffered area with the lowest absolute difference

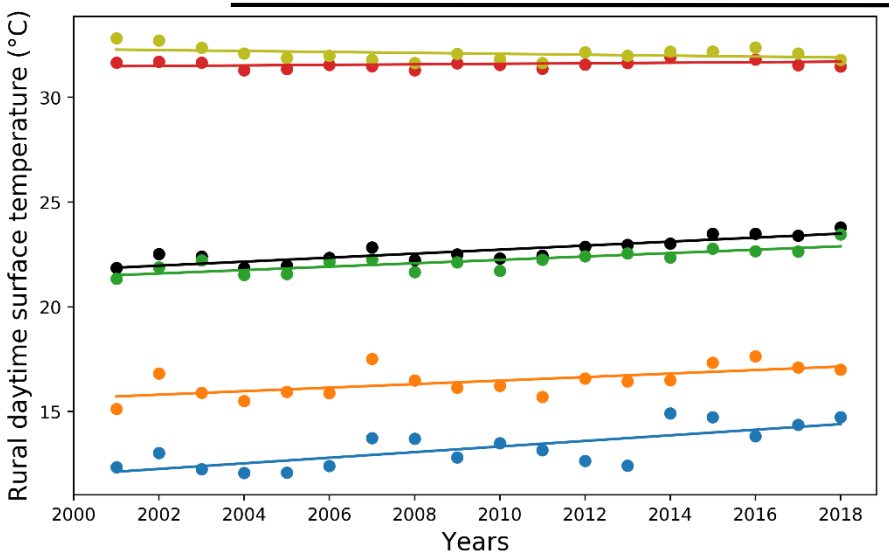
- For the iteration, a step-size of 300 m is used to be consistent with the resolution of the ESA CCI data
- Produced rural references are roughly twice the area of the corresponding urban clusters

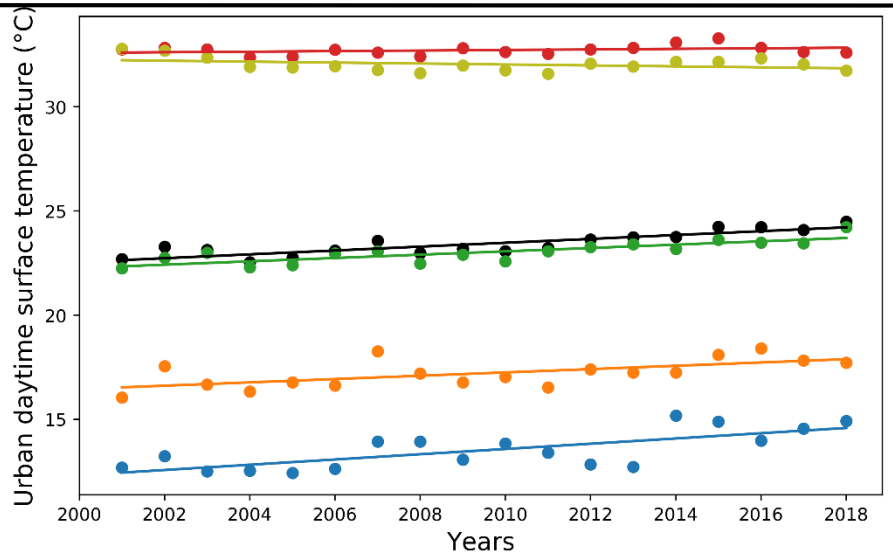




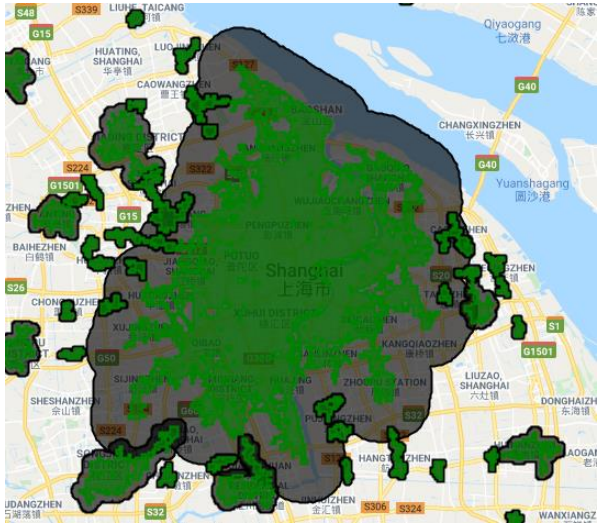
Examples of urban clusters, along with their area-normalized rural references, for Los Angeles (above) and around Shanghai (right)

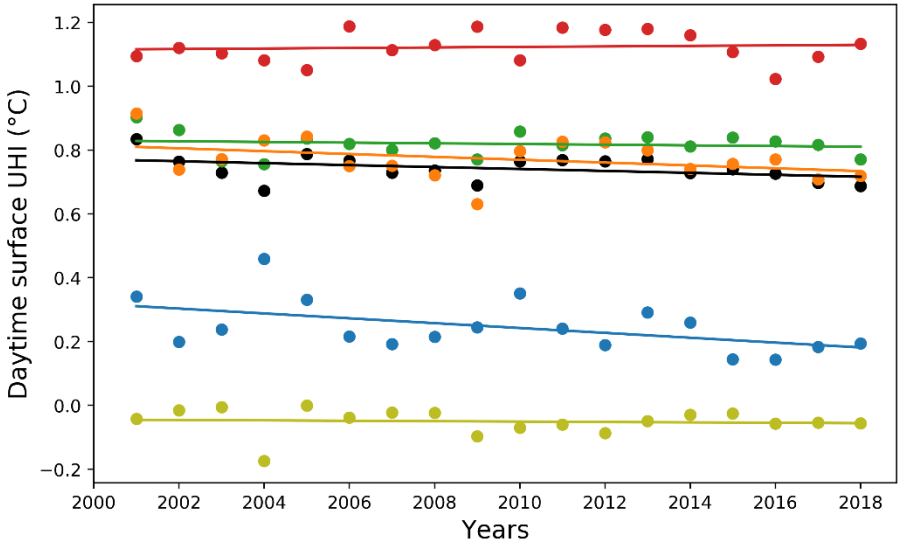
Dynamic urban-rural delineations and UHI





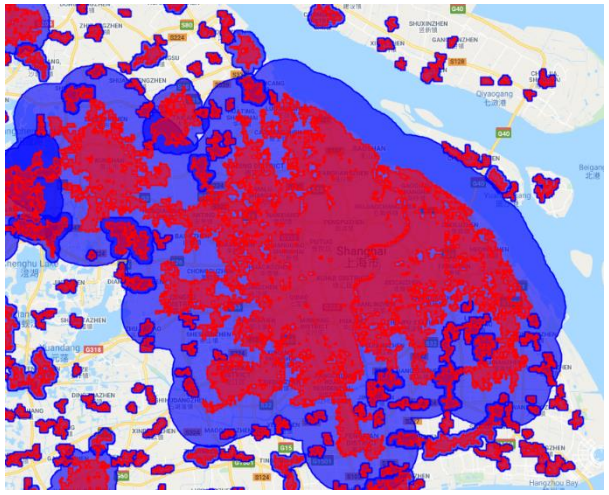
2001



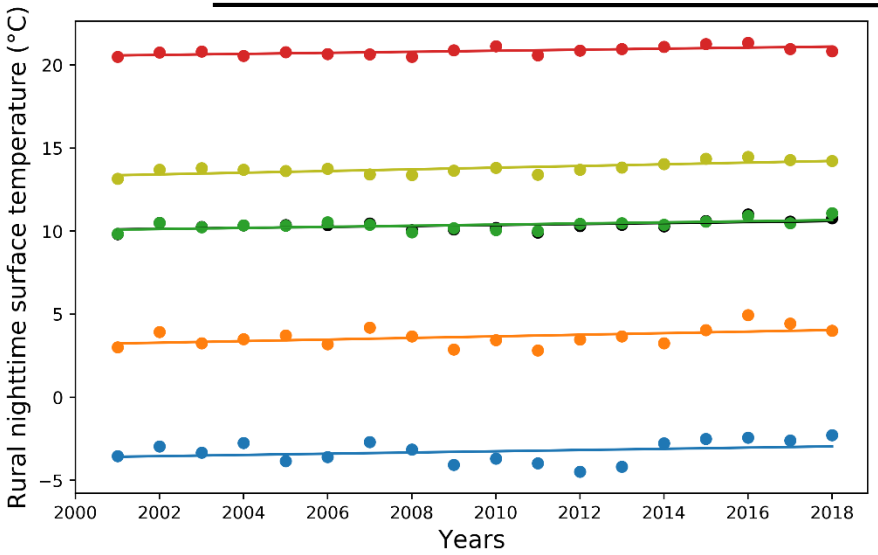


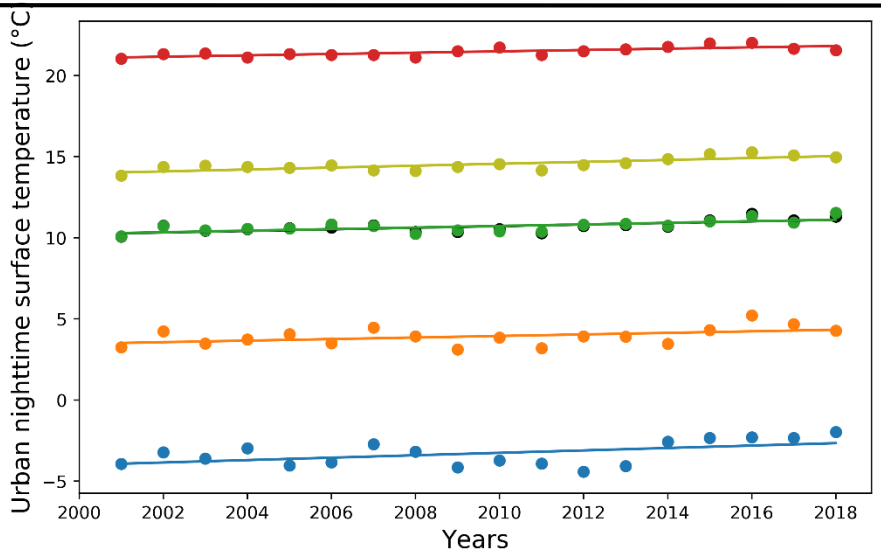
- World; Change=0.957°C, 0.927°C, and -0.030°C per decade for rural LST, urban LST, and UHI, respectively
- Tropical; Change=0.127°C, 0.135°C, and 0.008°C per decade for rural LST, urban LST, and UHI, respectively
- Arid; Change=-0.221°C, -0.227°C, and -0.006°C per decade for rural LST, urban LST, and 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

2018

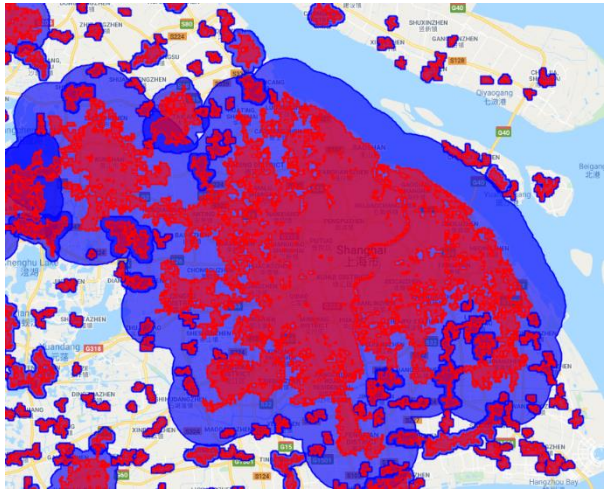


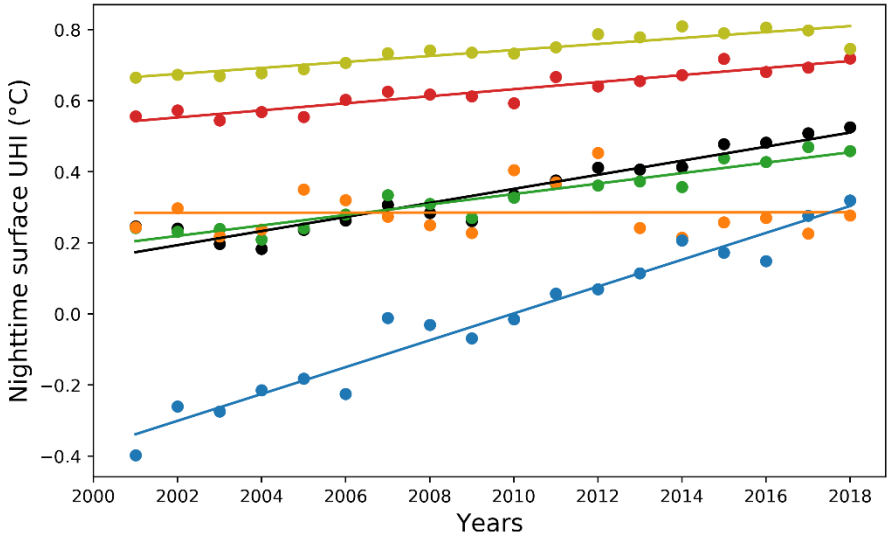
Static urban-rural delineations and UHI





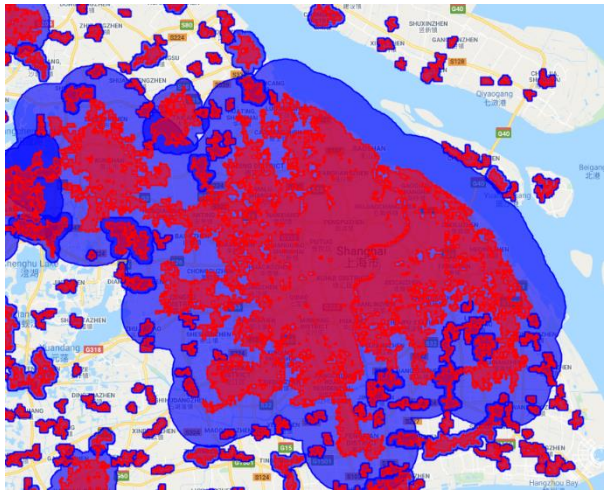
2001





- 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

2018



Why the difference?

Static

2001

20	20	20	20	20	20
20	20	20	20	20	20
20	20	25	25	20	20
20	20	25	25	20	20
20	20	20	20	20	20
20	20	20	20	20	20

2018

20	20	20	20	20	20
20	23	23	23	23	20
20	23	26	26	23	20
20	23	26	26	23	20
20	23	23	23	23	20
20	20	20	20	20	20

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

Dynamic

20	20	20	20	20	20
20	20	20	20	20	20
20	20	25	25	20	20
20	20	25	25	20	20
20	20	20	20	20	20
20	20	20	20	20	20

20	20	20	20	20	20
20	23	23	23	23	20
20	23	26	26	23	20
20	23	26	26	23	20
20	23	23	23	23	20
20	20	20	20	20	20

2001
Urban LST= 25 °C
Rural LST= 20 °C
UHI= 5 °C

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

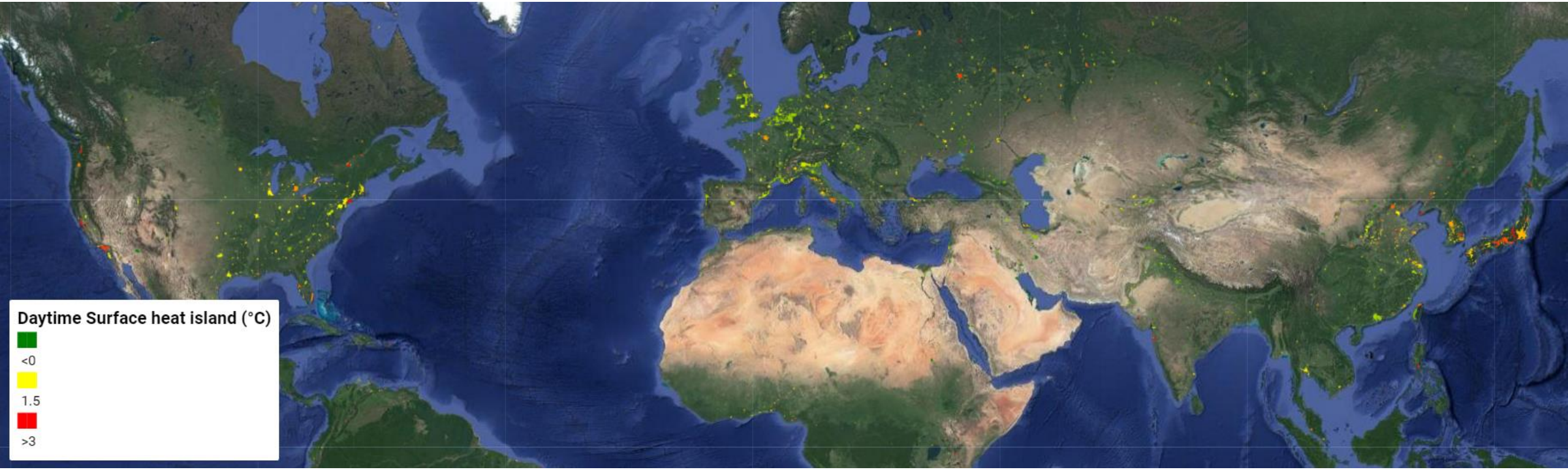
Urban boundary

Boundary+buffer

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?