Nov 2: Urban Heat Islands (UHI)

Foci of the Day

- Causes and consequences of UHI effects
- Major methods for quantifying UHI
- Strategies to reduce UHI effects

Reading: What Are Heat Islands? (https://www.epa.gov/heatislands/what-are-heat-islands)

Reference: Oke, T.R. (1973). City size and the urban heat island. *Atmospheric Environment*, 7(8), 769–779.

Urban Heat Islands (UHI)

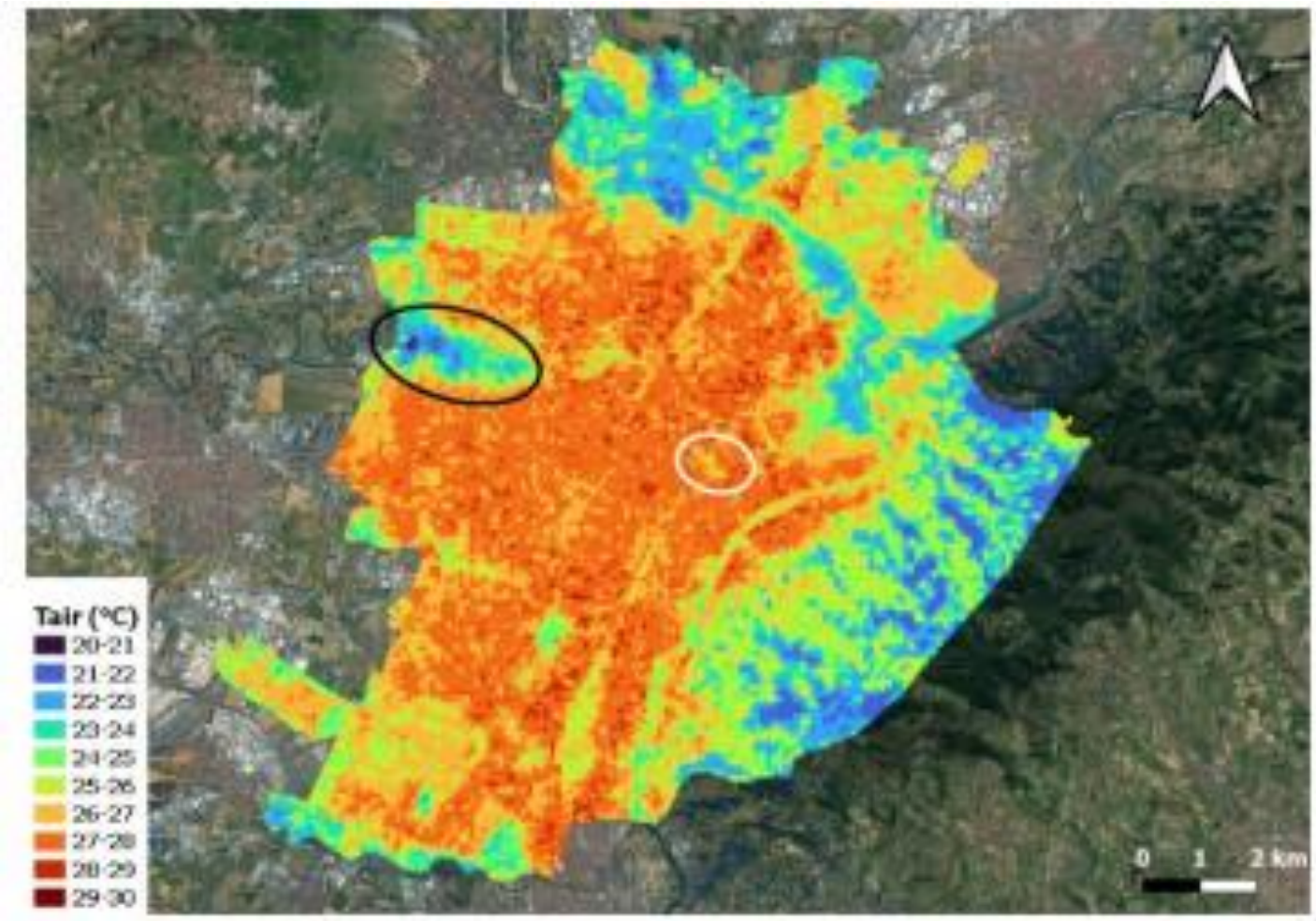
- The UHI effect is defined as a difference in temperature between the built environment and the natural (surrounding) environment.

- The UHI intensity can be measured by one of two closely coupled temperatures: (a) the **urban skin temperature** (pavements and buildings) or (b) the meteorological UHI (**air temperature**)

Phelan, P. E., Kaloush, K., Miner, M., Golden, J., Phelan, B., Silva III, H., & Taylor, R. A. (2015). Urban heat island: mechanisms, implications, and possible remedies. *Annual Review of Environment and Resources*, *40*(1), 285-307.

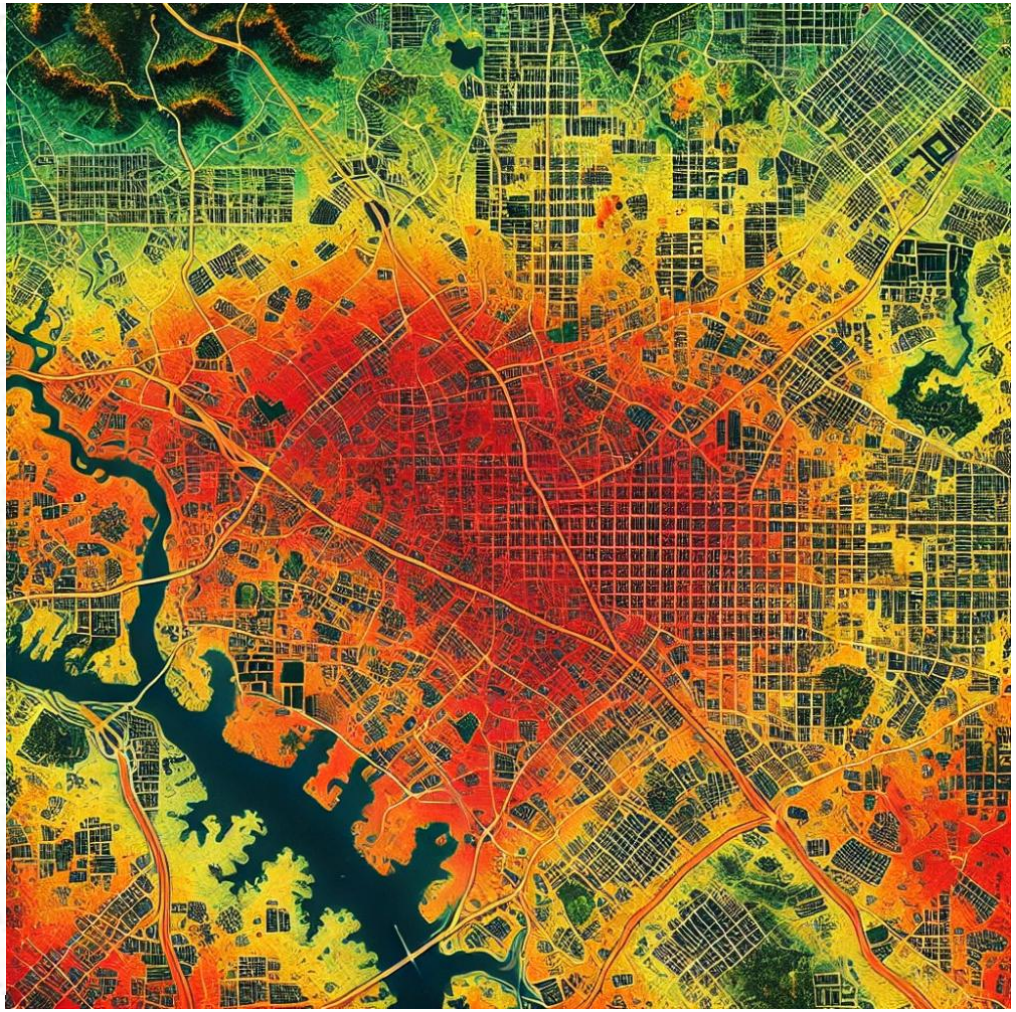
Urban Heat Islands (UHI)

Air temperature prediction in Turin for 7/10/2022



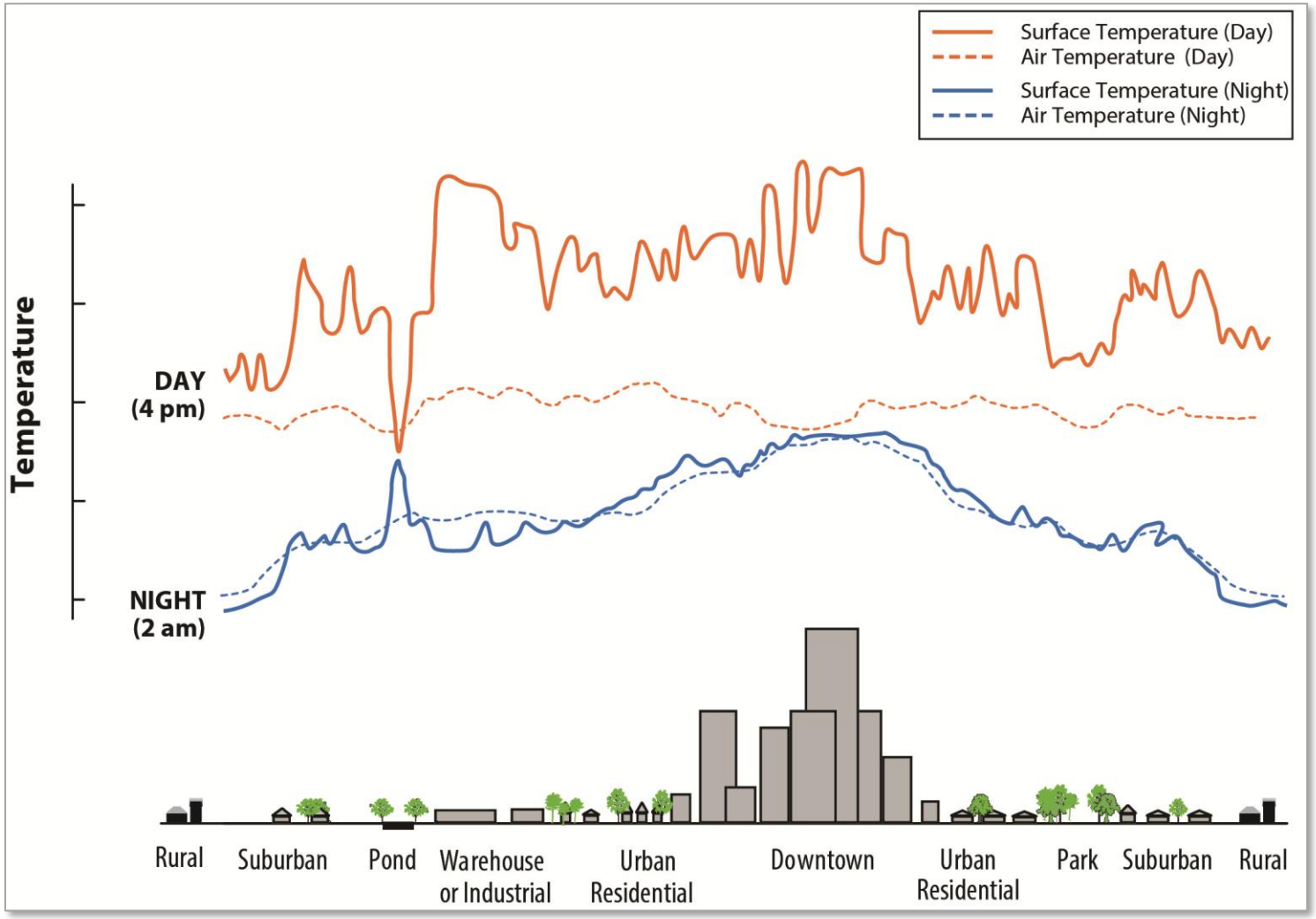
https://www.diati.polito.it/en/focus/air/urban_heat_island

A GIS-generated heat map showing temperature variations across an urban area



https://genesisray.com/blog/the-urban-heat-island-effect-and-gis-solutions/

Surface temperatures vary more than atmospheric air temperatures during the day, but they are generally similar at night. The dips and spikes in surface temperatures over the pond area show how water maintains a nearly constant temperature day and night because it does not absorb the sun's energy the same way as buildings and paved surfaces. Parks, open land, and bodies of water can create cooler areas within a city. Temperatures are typically lower at suburban-rural borders than in downtown areas.



Mileage stones

Howard, Luke (1833). *The Climate of London*. Harvey and Darton, London.

- First to systematically document how temperatures in London were higher than in surrounding rural areas.
- Concept of “urban climate” -- first quantitative evidence of URI.

AVERAGE MONTHLY MEAN TEMPERATURES, FROM 1817 TO 1823.

The Results obtained from a twenty years' series of these were made the basis, in the early part of this article, of a comparison between the London and country temperatures, which was illustrated by a set of Curves. It is proper that I should exhibit a continuation of these to the extent at which it can at present be done satisfactorily; which, for reasons already given, is only to the year 1823 inclusive. The following are the Averages in question.

	Month	In the Country	In London	Difference
1	Jan.	36.39	39.10	2.71
2	Feb.	38.38	41.31	2.93
3	Mar.	42.39	44.81	2.42
4	April	47.42	49.94	2.52
5	May	53.77	56.16	2.39
6	June	59.97	6213	2.16
7	July	62.45	63.95	1.50
8	Aug.	62.21	64.07	1.86
9	Sept.	57.35	59.77	2.42
10	Oct.	49.01	52.04	3.03
11	Nov.	44.55	47.46	2.91
12	Dec.	37.22	40.61	3.39
	Mean	49.26	51.78	2.52

Mileage stones

Oke, T.R. (1973). City size and the urban heat island. *Atmospheric Environment*, 7(8), 769–779.

- Relationship between city size and UHI intensity in Canada, North America and Europe

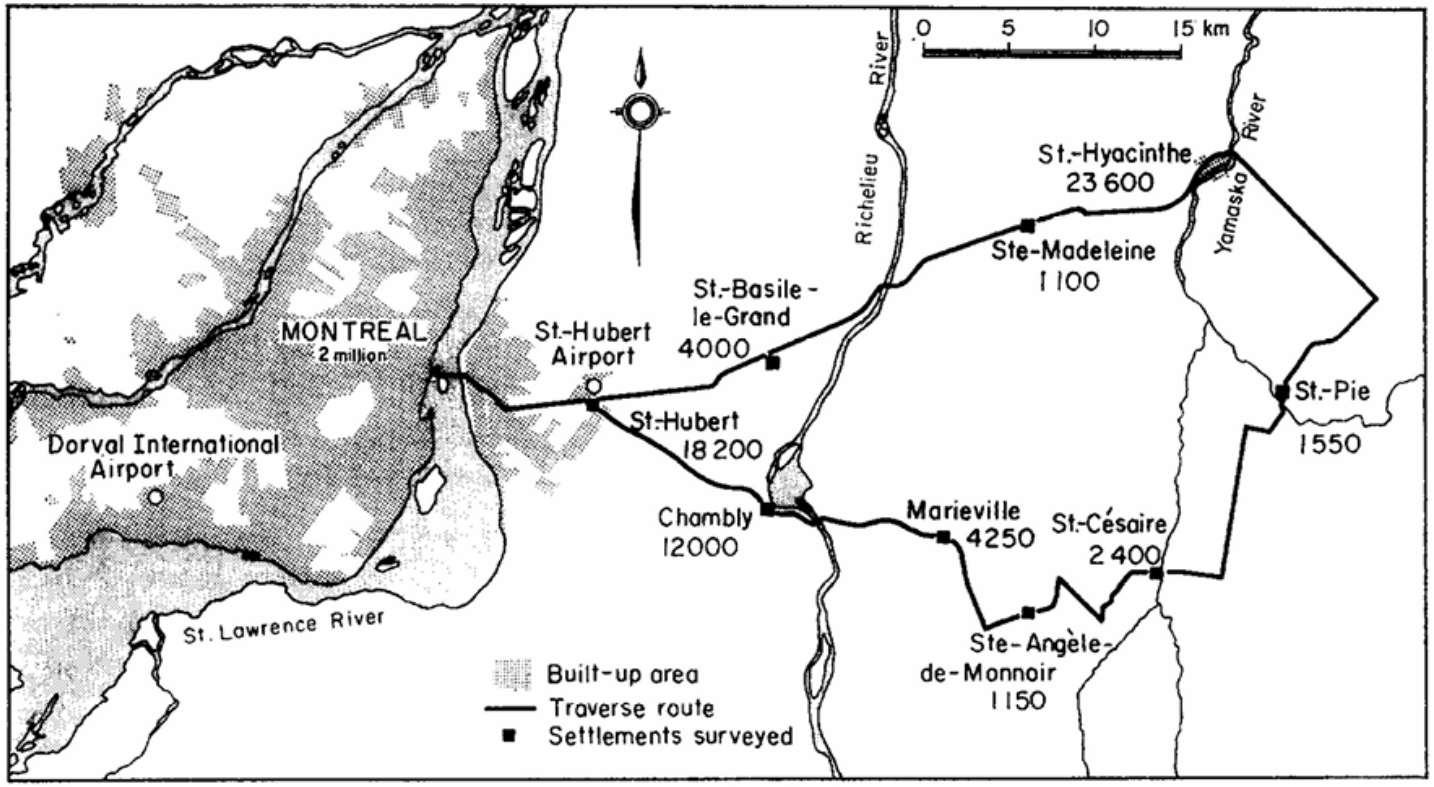


FIG. 1. Traverse route in the St. Lawrence Lowland, Quebec.

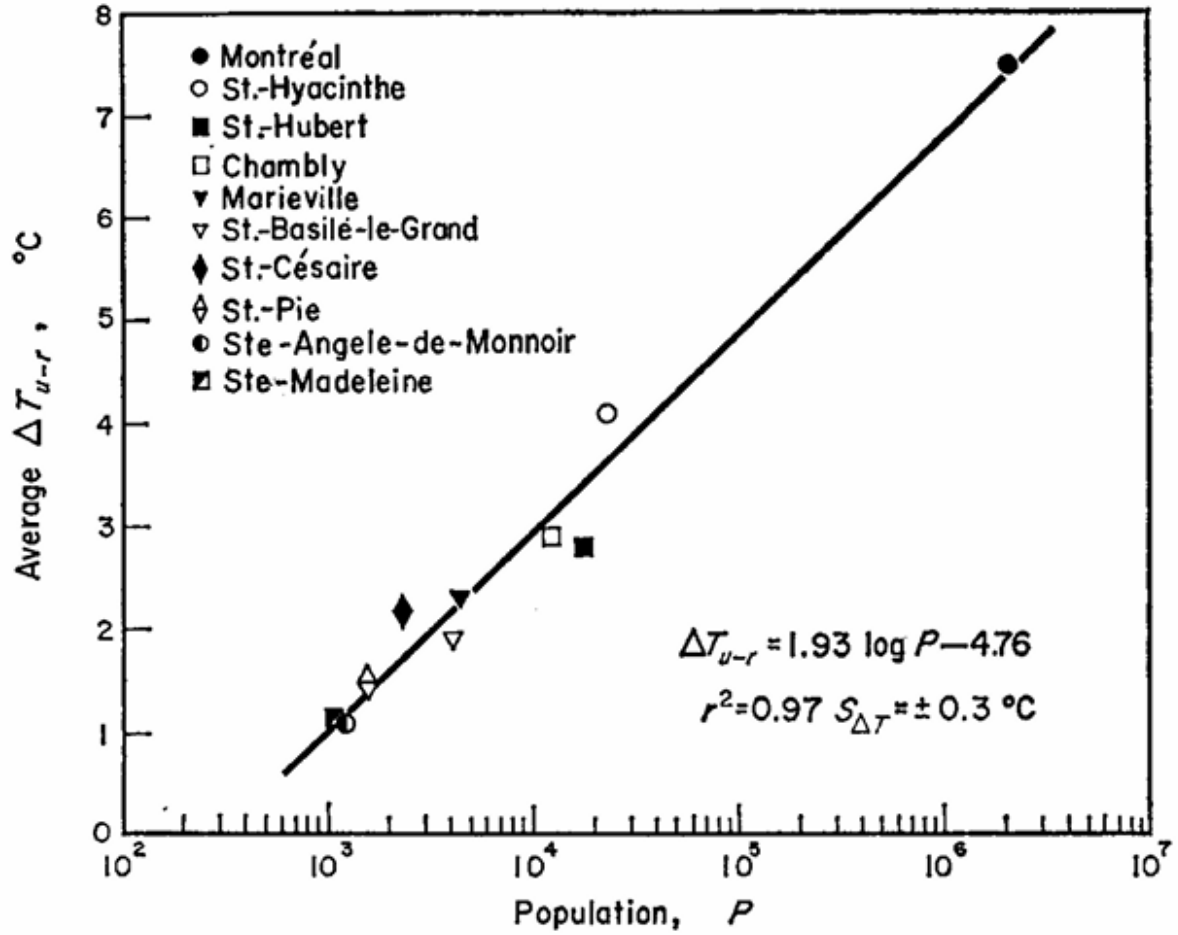


FIG. 2. Relation between the average survey ΔT_{u-r}, and city size (as given by P), for 10 settlements on the St. Lawrence Lowland. (Average windspeed 2.3 m s^{-1} and clear skies.)

Oke, T.R. (1973). City size and the urban heat island. *Atmospheric Environment*, 7(8), 769–779.

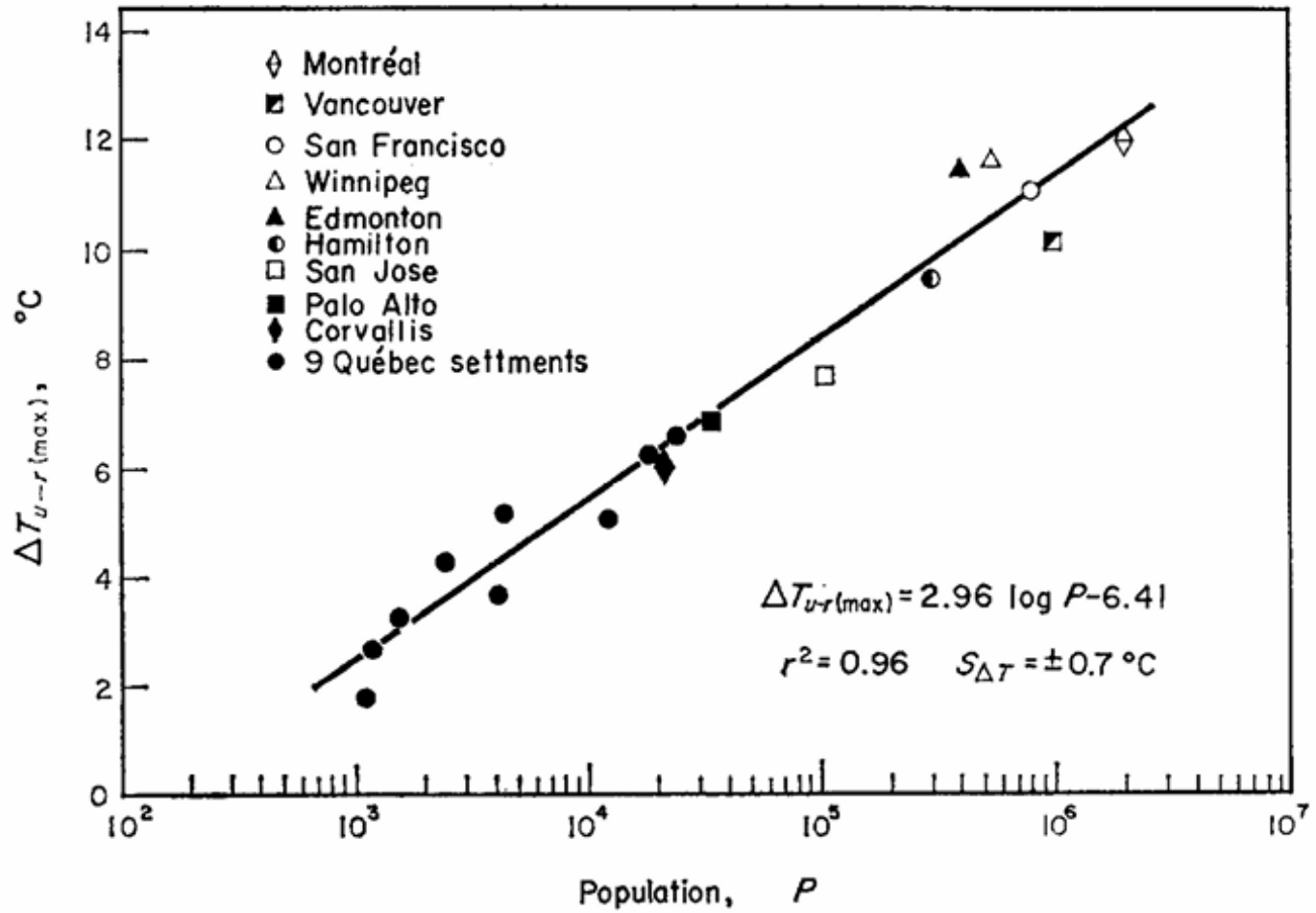


FIG. 4. Relation between $\Delta T_{u-r(max)}$ and log P for North American settlements (Source: TABLES 1 and 2).

Oke, T.R. (1973). City size and the urban heat island. *Atmospheric Environment*, 7(8), 769–779.

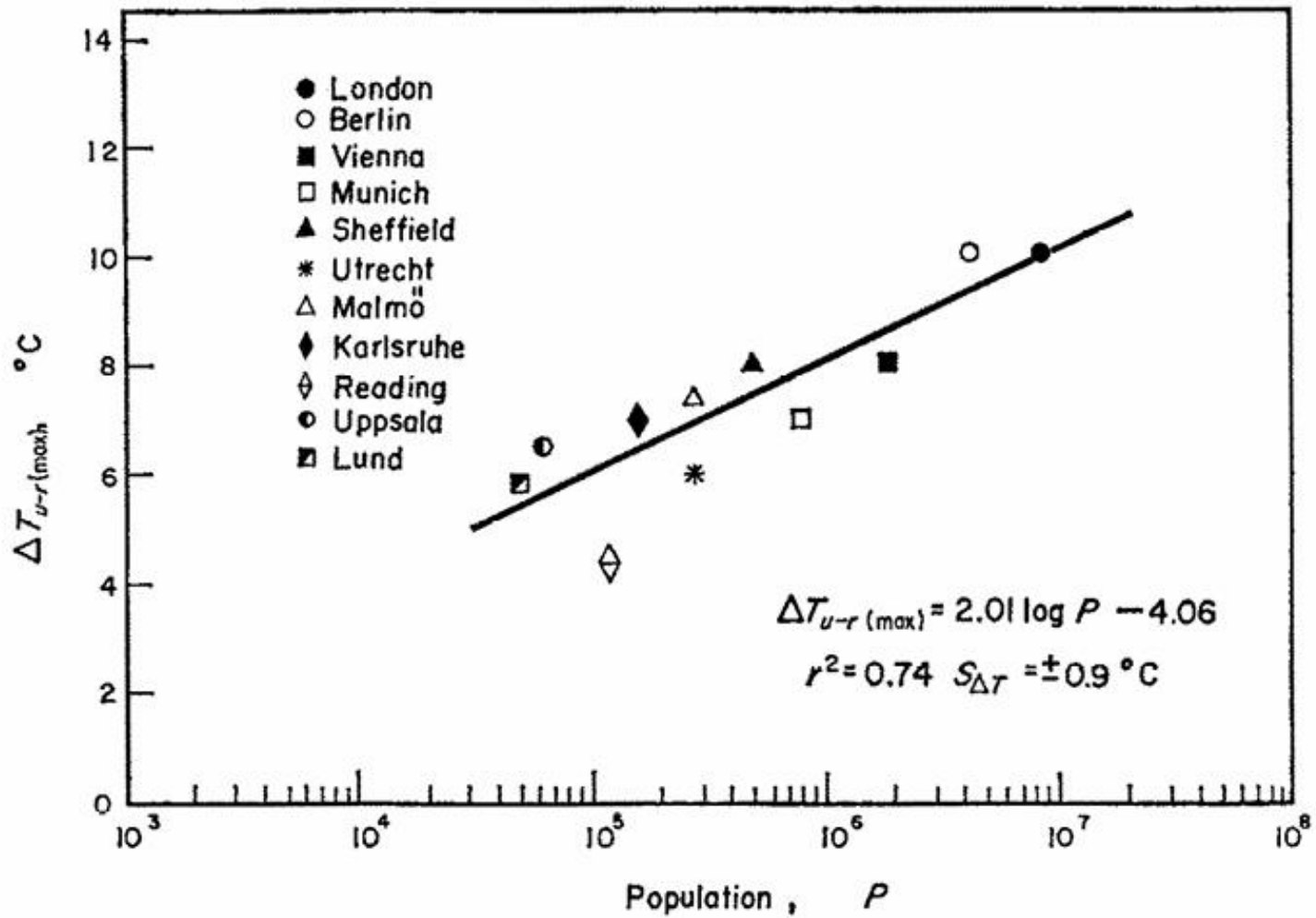


FIG. 5. Relation between $\Delta T_{u-r(max)}$ and log P for European settlements (Source: TABLE 2).

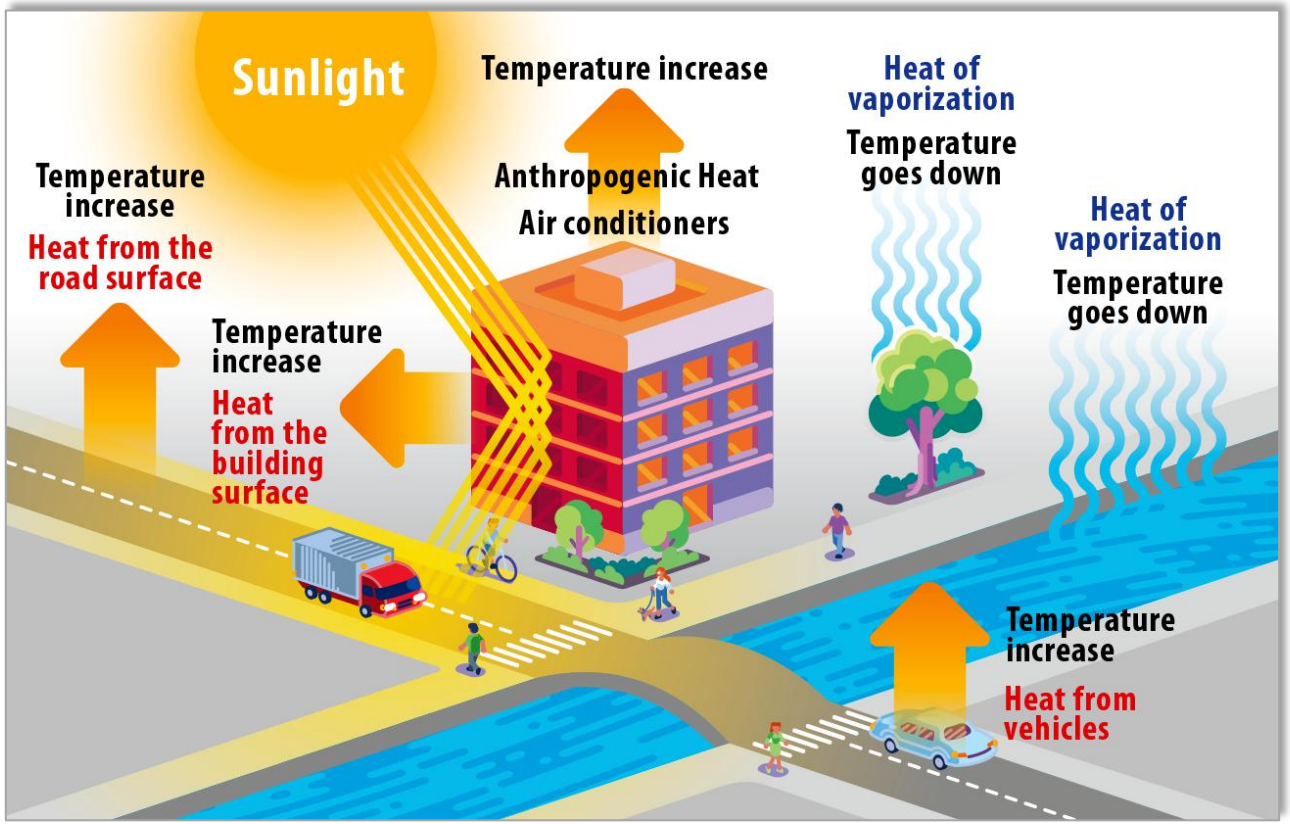
Oke, T.R. (1973). City size and the urban heat island. *Atmospheric Environment*, 7(8), 769–779.

Causes of Heat Islands

(https://www.epa.gov/heatislands/what-are-heat-islands)

Factors Contributing to UHI Effect

1) Reduced Natural Landscapes in Urban Areas.
2) Urban Material Properties.
3) Urban Geometry.
4) Heat Generated from Human Activities.
5) Weather and Geography.

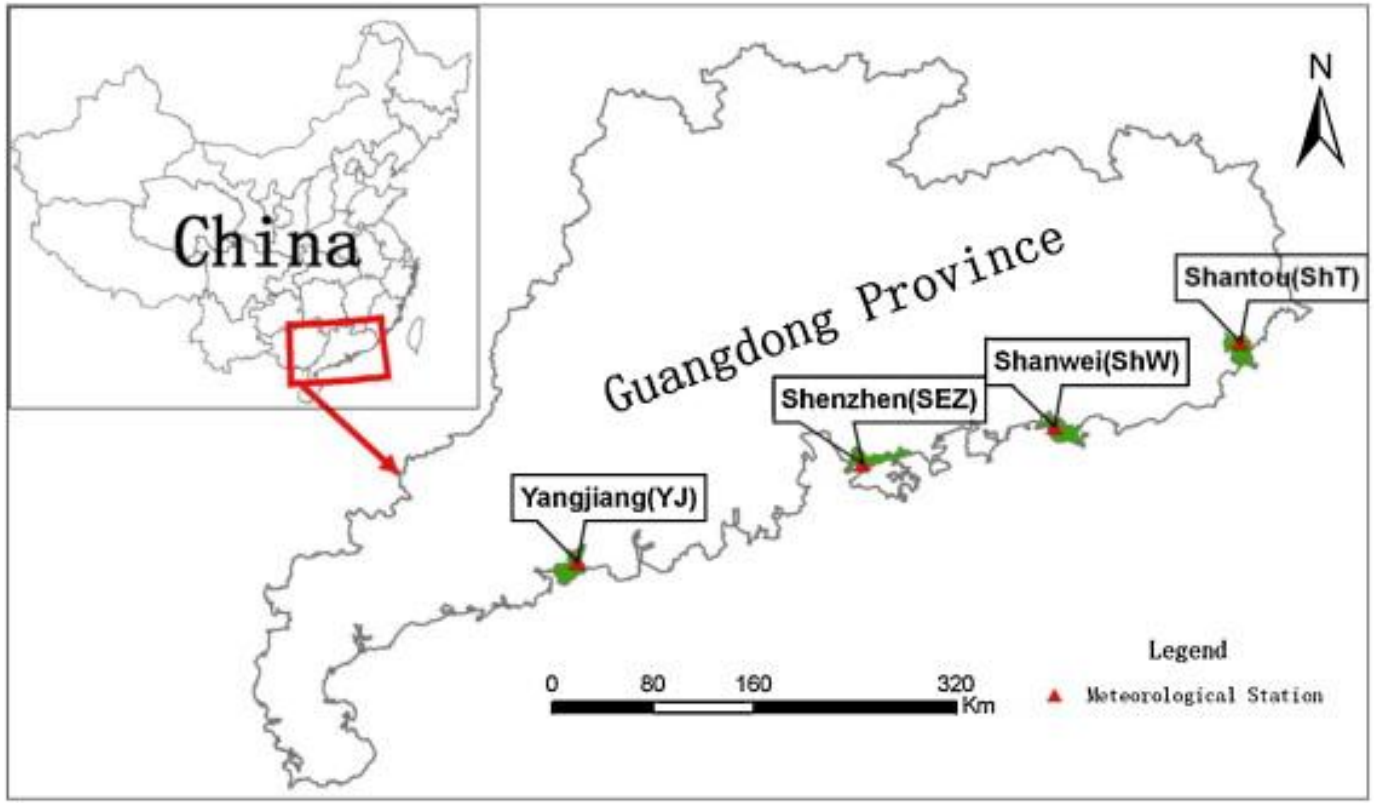


https://www.pavetechinc.com/uhi-mitigation/

How is UHI quantified?

1) Long-term climate (weather) stations
2) Remote sensing of land surface temperature (LST)
3) Modeling

Tian, L., Chen, J., & Yu, S. (2013). How has Shenzhen been heated up during the rapid urban build-up process?. *Landscape and Urban Planning*, *115*, 18-29.



Spatial locations of the four urban climatic stations used in this study in the southeast coast of PR China. The land cover was from urban fringe to a residential landscape setting in or near business areas. Shenzhen is a new city built from a small town in 1980.


12/1979
Write a description for your map.
Legend
Hong Kong Disneyland
Shenzhen
Shenzhen 深圳市
BAOAN 宝安区
NANSHAN 南山区
SHAHE RESIDENTIAL DISTRICT 沙河
CUIZHU RESIDENTIAL DISTRICT 翠竹
YANTIAN RESIDENTIAL DISTRICT 盐田
YANTIAN DISTRICT 盐田区
SHA TAU KOK 沙頭角
Mirs Bay
Qianhai Bay
前海
后海
SHEUNG SHUI 上水
Plover Cove Country Park
FANLING 粉嶺
Pat Sin Leng Country Park
SHEKOU RESIDENTIAL DISTRICT 蛇口
Mawan Port
Plover Cove Reservoir
Lam Tsuen Country Park
Chiwan Bay
TIN SHUI WAI 天水圍
YUEN LONG 元朗
TAI PO 大埔
MA ON SHAN 馬鞍山
LAM TEI 藍地
Tai Mo Shan Country Park
Ma On Shan Country Park
Sai Kung East Country Park
TUEN MUN 屯門
SAI KUNG 西貢市 西貢
SHA TIN 沙田
TSUEN WAN 荃灣
Kau Sai Chau
Tsing Yi Village
Google Earth
Image NASA
Image U.S. Geological Survey
Hong Kong 香港
Hong Kong Disneyland
Chek Lap Kok
TSEUNG KWAN O 將軍澳
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10 km


12/1990
Write a description for your map.
Legend
Hong Kong Disneyland
Shenzhen
Shenzhen 深圳市
CUIZHU RESIDENTIAL DISTRICT 翠竹
YANTIAN RESIDENTIAL DISTRICT 盐田
YANTIAN DISTRICT 盐田区
BAOAN 宝安区
NANSHAN 南山区
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LAM TEI 藍地
Tai Mo Shan Country Park
Sai Kung East Country Park
Ma On Shan Country Park
TUEN MUN 屯門
SAI KUNG 西貢市 西貢
SHA TIN 沙田
TSUEN WAN 荃灣
Kau Sai Chau
Tsing Yi Village
Hong Kong 香港
Hong Kong Disneyland
Chek Lap Kok
TSEUNG KWAN O 將軍澳
Google Earth
Image NASA
Image U.S. Geological Survey
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Legend
Hong Kong Disneyland
Shenzhen
12/2010
Write a description for your map.
Shenzhen 深圳市
BAOAN 宝安区
NANSHAN 南山区
SHAHE RESIDENTIAL DISTRICT 沙河
CUIZHU RESIDENTIAL DISTRICT 翠竹
YANTIAN DISTRICT 盐田区
YANTIAN RESIDENTIAL DISTRICT 盐田
SHA TAU KOK 沙頭角
Mirs Bay
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前海
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Kau Sai Chau
Tsing Yi Village
Hong Kong 香港
Hong Kong Disneyland
Chek Lap Kok
TSEUNG KWAN O 將軍澳
Google Earth
Image NASA
Image U.S. Geological Survey
N
10 km


12/2025
Write a description for your map.
Legend
Hong Kong Disneyland
Shenzhen
Shenzhen 深圳市
CUIZHU RESIDENTIAL DISTRICT 翠竹
YANTIAN RESIDENTIAL DISTRICT 盐田
YANTIAN DISTRICT 盐田区
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NANSHAN 南山区
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TSUEN WAN 荃灣
Kau Sai Chau
Tsing Yi Village
Hong Kong 香港
Hong Kong Disneyland
Chek Lap Kok
TSEUNG KWAN O 將軍澳
Google Earth
Image Landsat / Copernicus
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Global warming (temperature increase) vs urbanization induced UHI.

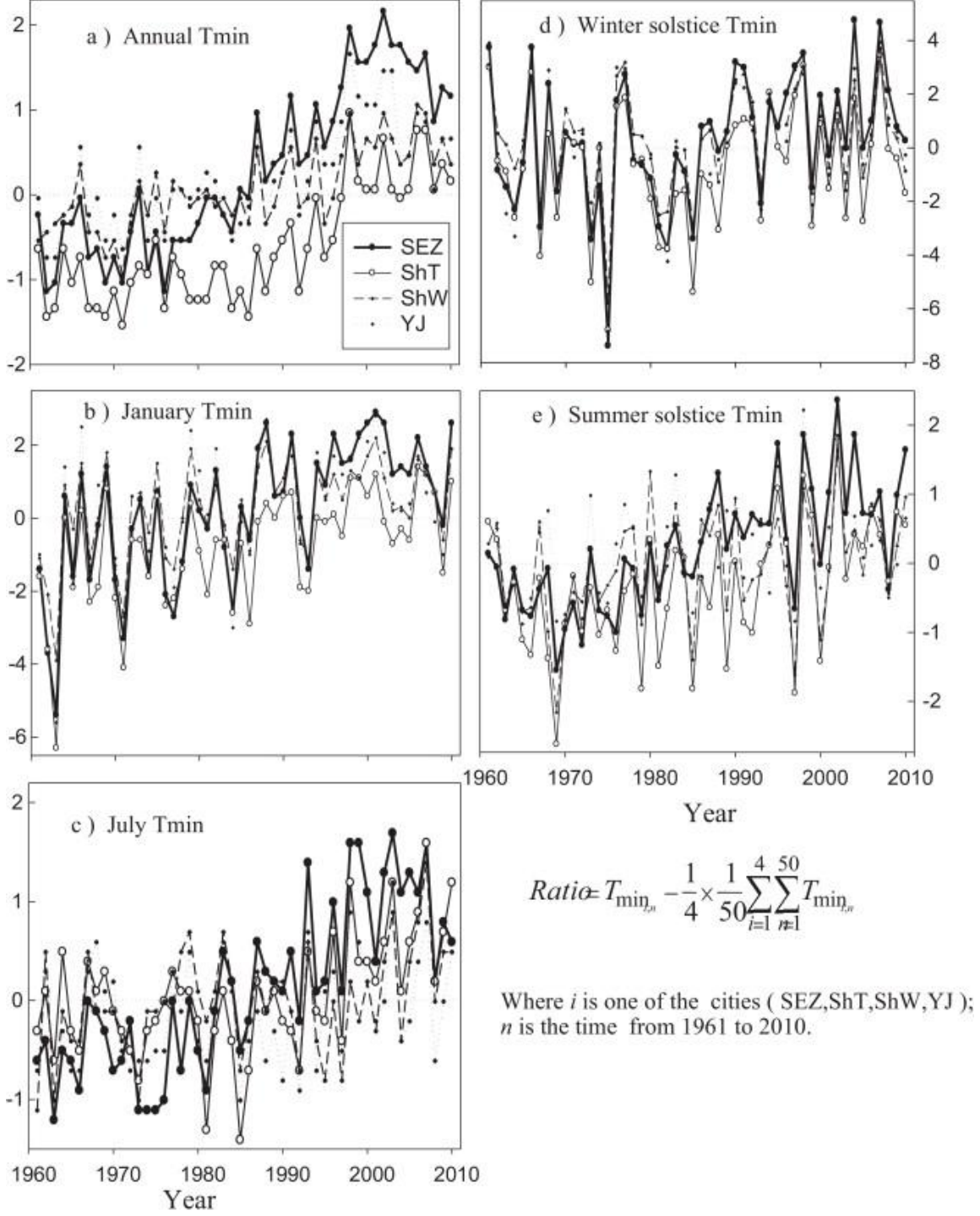
Warming trends (i.e., temperature increases) were found in all four study cities, likely due to warming trends in the region and globe

Table 2. Statistics of the absolute temperatures of four study cities before and after the SEZ was built in the mid-1980s.

		SEZ			ShT			ShW			YJ		
		1961–1985	1986–2010		1961–1985	1986–2010		1961–1985	1986–2010		1961–1985	1986–2010	
T_{ann} (°C)	Mean	22.06	23.18	1.12	21.2	22.19	0.99	22.06	22.55	0.49	22.19	22.79	0.60
	Max	26.45	26.92	0.47	24.84	25.96	1.12	25.58	26.10	0.52	26.14	26.50	0.36
	Min	18.92	20.56	1.64	18.36	19.28	0.92	19.23	19.82	0.59	19.26	20.07	0.81
T_{jan} (°C)	Mean	14.04	15.69	1.65	130	14.51	1.51	14.26	15.24	0.98	14.42	15.44	1.02
	Max	19.36	19.92	0.56	17.26	18.69	1.43	18.53	19.52	0.99	19.30	19.75	0.45
	Min	10.46	12.79	2.33	9.87	11.38	1.51	11.14	12.24	1.10	10.94	12.40	1.46
T_{jul} (°C)	Mean	28.26	28.99	0.73	28.18	28.79	0.61	28.10	28.36	0.26	28.10	28.27	0.17
	Max	32.08	32.34	0.26	31.56	32.33	0.77	30.86	31.12	0.26	31.51	31.55	0.04
	Min	25.20	26.44	1.24	25.48	26.02	0.54	25.58	25.80	0.22	25.47	25.70	0.23
T_w (°C)	Mean	15.43	16.98	1.55	14.67	15.83	1.16	15.88	16.53	0.65	15.75	16.69	0.94
	Max	20.85	21.43	0.58	19.13	20.15	1.02	20.35	21.04	0.69	20.91	21.37	0.46
	Min	11.74	13.88	2.14	11.22	12.40	1.18	12.42	13.32	0.90	11.98	13.22	1.24
T_s (°C)	Mean	27.82	28.41	0.59	27.08	27.73	0.65	27.42	27.69	0.27	27.66	28.07	0.41
	Max	31.36	31.45	0.09	30.09	30.88	0.79	29.98	30.13	0.15	30.75	30.97	0.22
	Min	24.91	26.15	1.24	24.62	25.35	0.73	25.11	25.47	0.36	25.26	25.73	0.47

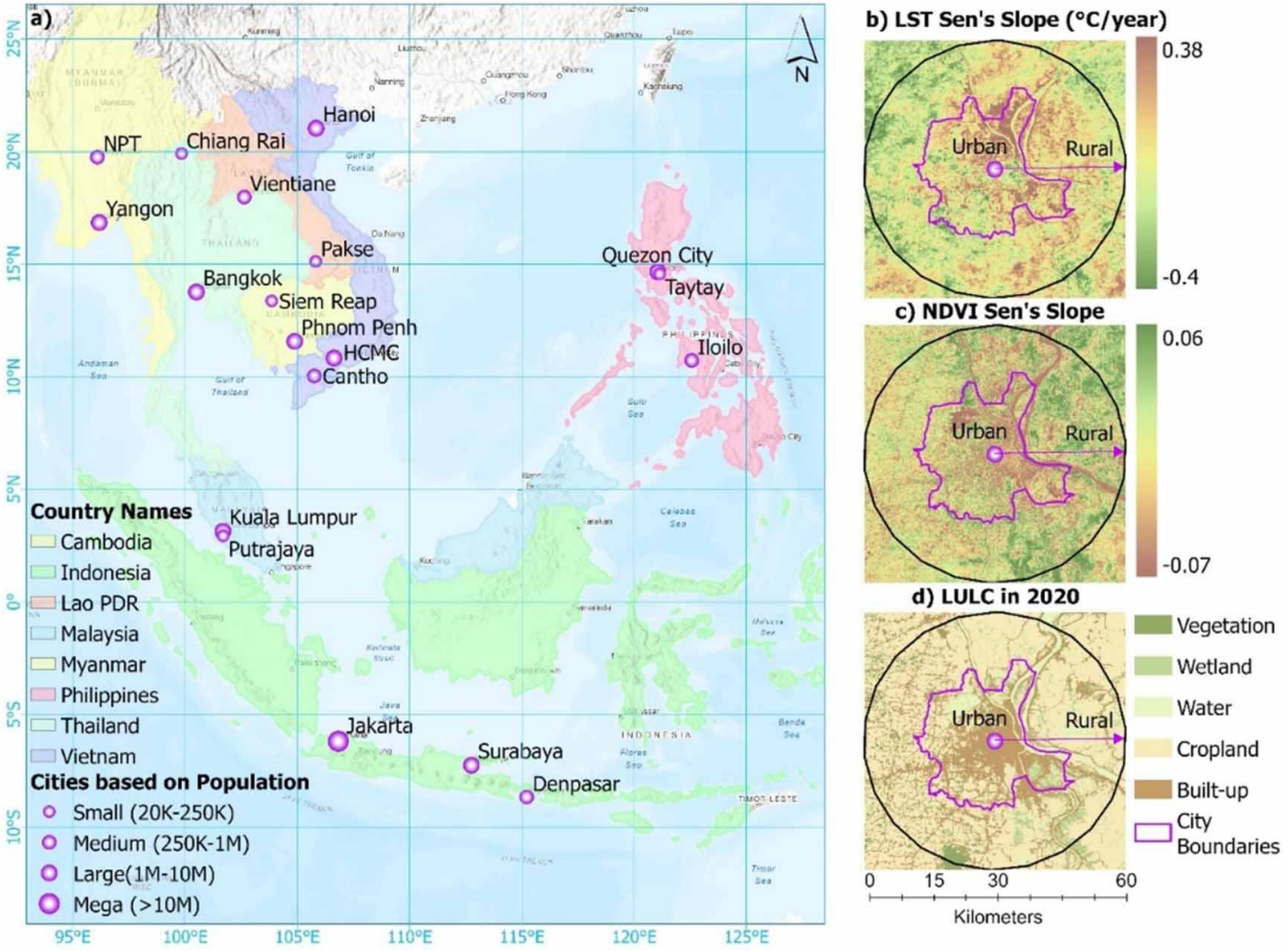
- Changes in the absolute and relative temperatures of four urban areas from 1960 to 2010. The T_{min} values of the year, January, July, and around summer/winter solstices (i.e., two weeks) were calculated based on the daily measurements.

- T_{min} appeared to be the most sensitive variable quantifying the magnitude and direction of UHI in all four cities



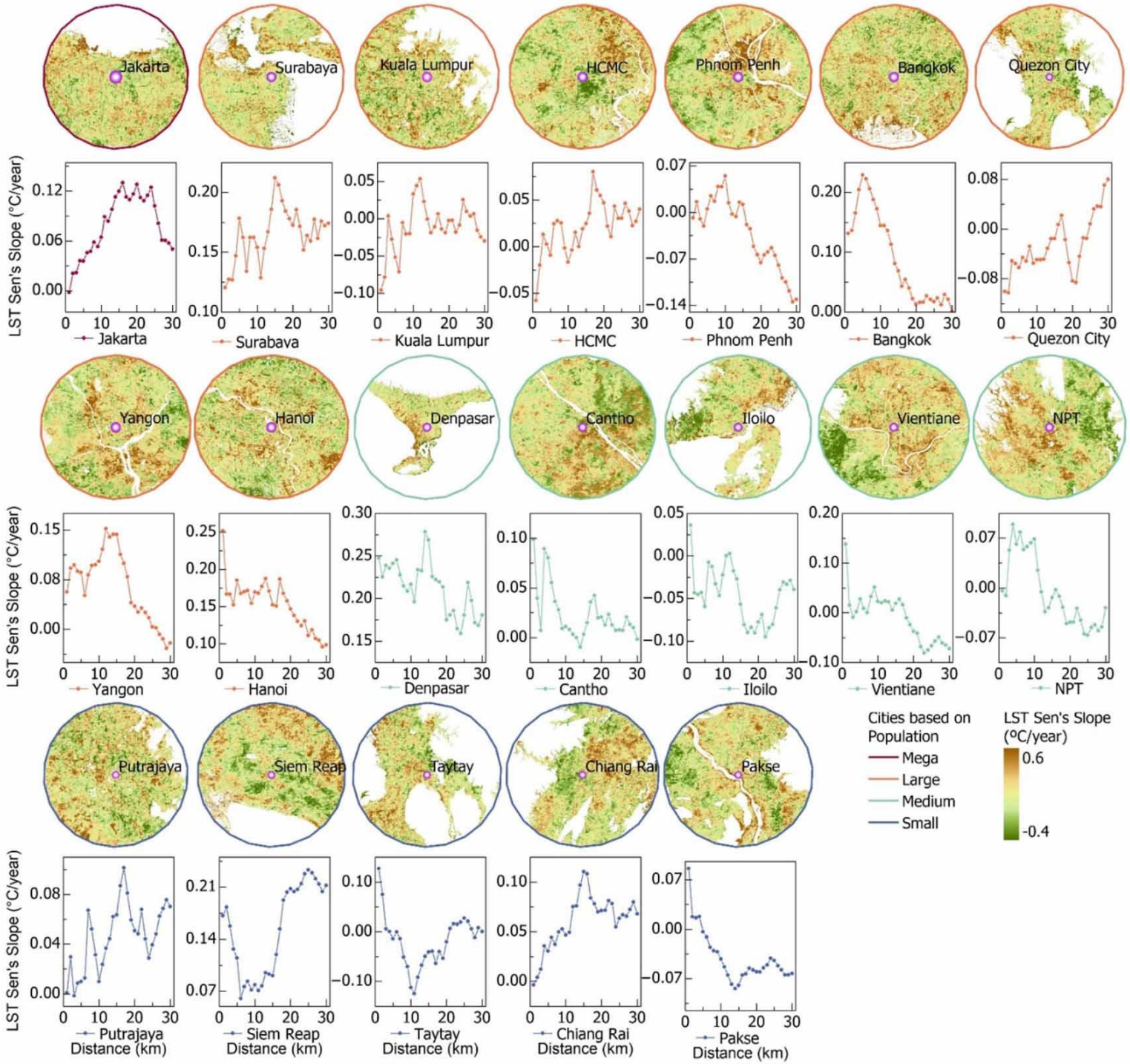
Zhu, Y., Myint, S. W., Chen, J., Fan, P., Seto, K. C., Jain, A., ... & Wang, J. (2025). Thermal changes along the urban-rural continuums in Southeast Asia. *Environmental Research Letters*, *20*(5), 054051.

- This study examines LST, LCLU, and NDVI changes across 19 SEA cities of varying urbanization levels from 2000 to 2022 using Landsat images.
- LST change rates differ by urbanization levels, with built-up lands driving urban warming.
- Larger cities exhibited more intense and widespread LST increases extending into rural areas.
- The megacities experienced significant LST growth within 5 km of city centers despite limited built-up expansion.



We used the Mann–Kendall trend analysis to calculate Sen's slope for each pixel, capturing the change rate in LST between 2000 and 2022.

The spatial patterns of LST Sen's slope and their disparities from urban to rural areas by their mean values of each ring buffer for each 1 km ring buffer within a 30 km radius.



Schlünzen, K. H., Grimmond, S., & Baklanov, A. (2023). Guidance on measuring, modelling and monitoring the canopy layer urban heat island (CL-UHI).

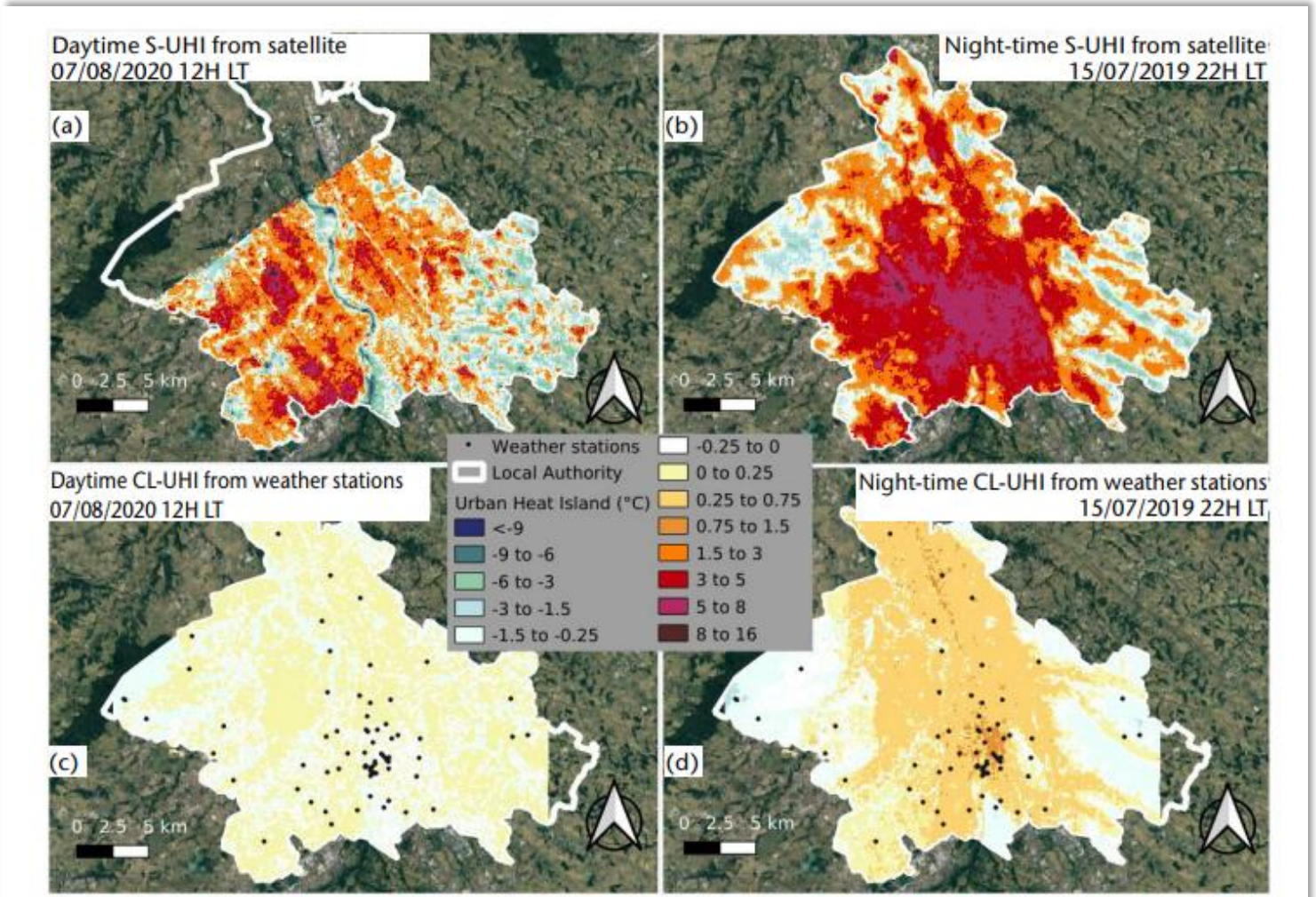


Figure A3.1. Toulouse, France (a, b) S-UHI (ECOSTRESS satellite, 70 m resolution) and (c, d) CL-UHI spatially interpolated network (dots) to 250 m using additional information on urban fraction and altitude (Touati et al., 2020). (a, c) 12:00 local time, 7 August 2020, (b, d) 22:00 local time 15 July 2019.

Heat Island Impacts

(https://www.epa.gov/heatislands/what-are-heat-islands)

1) Increased Energy Consumption.
2) Elevated Emissions of Air Pollutants and Greenhouse Gases.
3) Compromised Human Health and Comfort.
4) Impaired Water Quality.

https://www.youtube.com/watch?v=Y-bVwPRy_no&t=20s

Heat Island Reduction Solutions

(https://www.epa.gov/heatislands/what-are-heat-islands)



Increase Trees and Vegetation

Learn simple and effective ways plants can cool the environment.

Find Trees and Vegetation Solutions



Create Green Roofs

Explore green roofs as a proven method to reduce heat islands and achieve cost-effective benefits.

Explore Green Roof Solutions



Install Cool Roofs

Find what cool roofs are, how they work to reduce heat islands, and other benefits.

Learn About Cool Roofs

Heat Island Reduction Solutions

(https://www.epa.gov/heatislands/what-are-heat-islands)



Use Cool Pavement

Learn how cities are using cool pavements and emerging technologies as heat island reduction measures.

Access Cool Pavement Information



Adapt to Heat

Find ways communities can effectively plan and adapt to heat.

Assess Ways to Adapt to Heat



Follow Smart Growth Principles

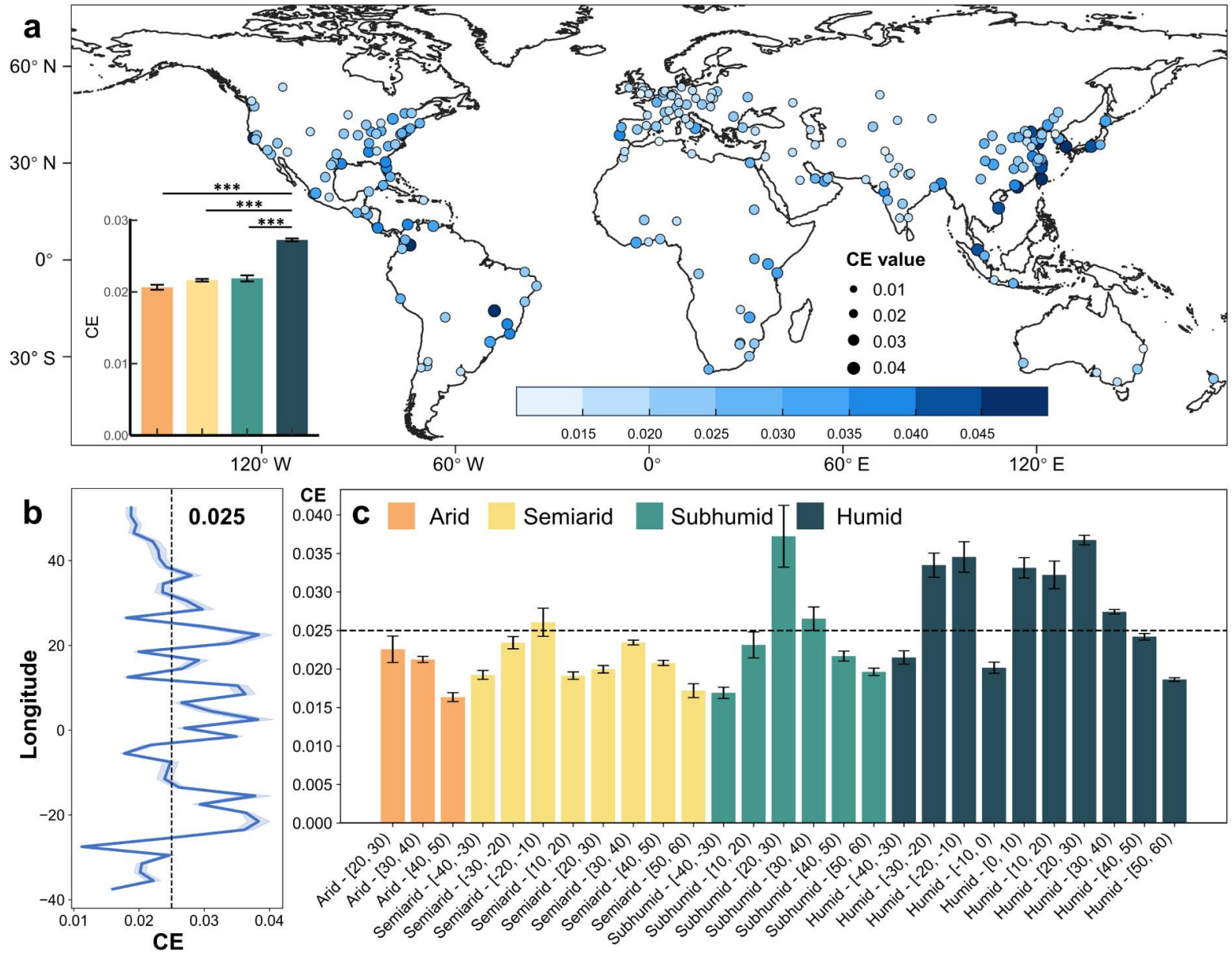
Learn the principles to make communities more attractive, livable, and economically vibrant.

Apply Smart Growth Principles

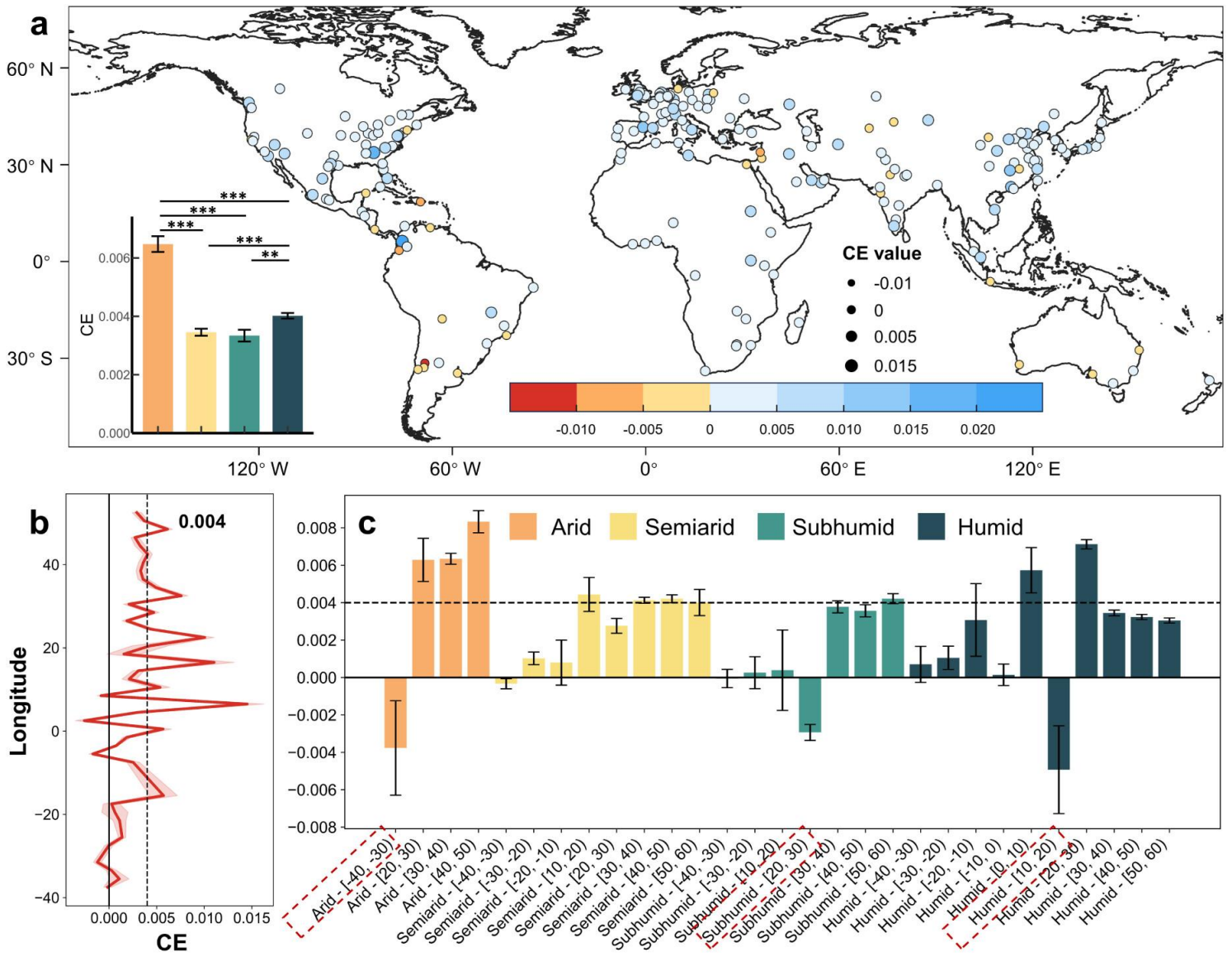
Yu, Z., Li, S., Yang, W., Chen, J., Rahman, M. A., Wang, C., ... & Zhou, W. (2025). Enhancing Climate-Driven Urban Tree Cooling with Targeted Nonclimatic Interventions. *Environmental Science & Technology*, *59*(18), 9082-9092.

- We quantify the diel CE of 229 cities across four climatic zones and employ a machine-learning model to assess the influence of variables on CE.
- We found that for every 10% increase in tree cover, surface temperatures are reduced by 0.25 °C during the day and 0.04 °C at night.
- Trees in humid regions exhibit the highest daytime CE, while those in arid zones demonstrate the greatest cooling effect at night.

Global patterns of daytime cooling efficiency (CE) of urban trees



Global patterns of nighttime cooling efficiency (CE) of urban trees



Take-home-messages

Five major causes of UHI

1) Reduced natural landscapes in urban areas.
2) Urban material properties.
3) Urban geometry.
4) Heat generated from human activities.
5) Weather and geography.

Three major approaches to quantify UHI

1) Long-term climate (weather) stations.
2) Remote sensing of land surface temperature.
3) Modeling.

Four major consequences

1) Increased energy consumption.
2) Elevated emissions of air pollutants and GHG.
3) Compromised human health and comfort.
4) Impaired water quality.

Six strategies to reduce UHI effects

1) Increase Trees and Vegetation
2) Create Green Roofs
3) Install Cool Roofs
4) Use Cool Pavement
5) Adapt to Heat
6) Follow Smart Growth Principles

Use less energy

i.e., similar to carbon footprint!

Nov. 4: Coral Bleaching: Causes, Mechanisms, and Ecological Consequences



Reading:

Van Woesik et al. (2022). Coral-bleaching responses to climate change across biological scales. GCB, 28(14), 4229-4250.
UNEP, The world's corals are bleaching. Here's why and what it means for the ocean's future; https://www.unep.org/new s-and-stories/story/worlds- corals-are-bleaching- heres-why-and-what-it- means-oceans-future