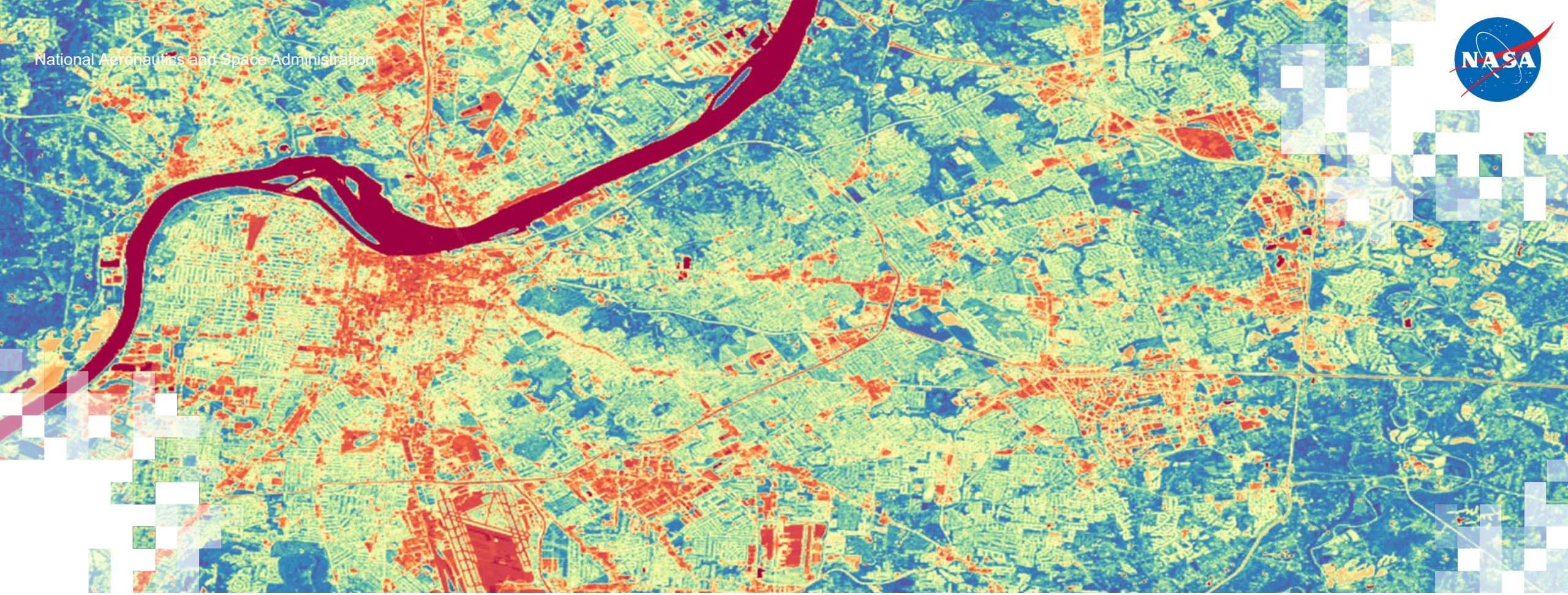


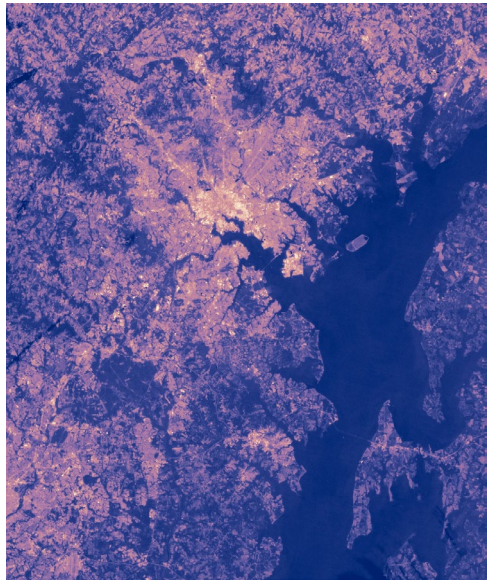
Satellite Remote Sensing for Measuring Urban Heat Islands and Constructing Heat Vulnerability Indices

Part 4: Using High-Resolution, Satellite Derived Hot-Humid Heat Estimates and Gridded Population Data to Map Extreme Heat Exposure Worldwide

Cascade Tuholske, PhD – August 11, 2022

Training Outline

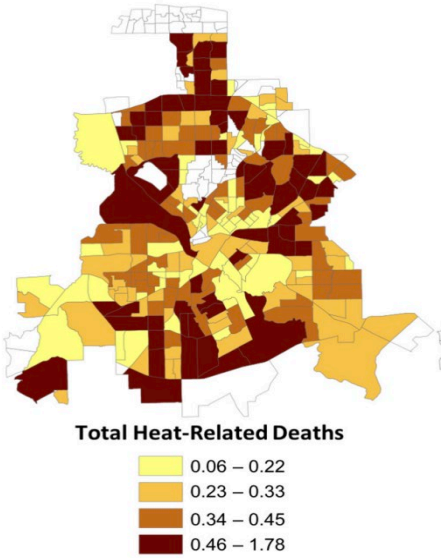
2 August 2022



Credit: NASA

Land Surface Temperature-based Urban Heat Island Mapping

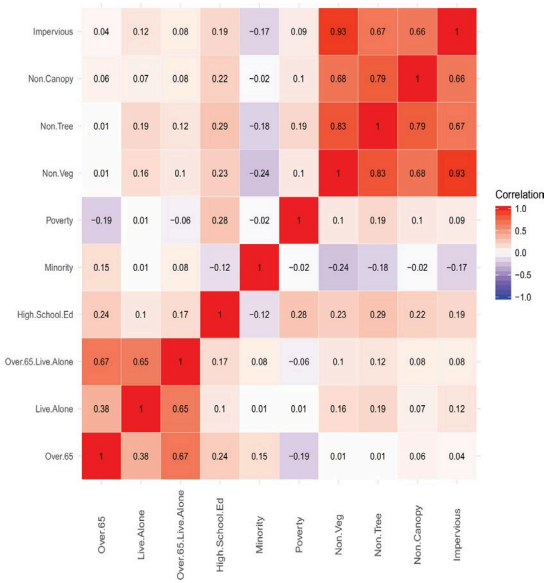
4 August 2022



Credit: Mallen et al., 2019

Integrating Socioeconomic Data with Satellite Imagery for Constructing Heat Vulnerability Indices - Session 1

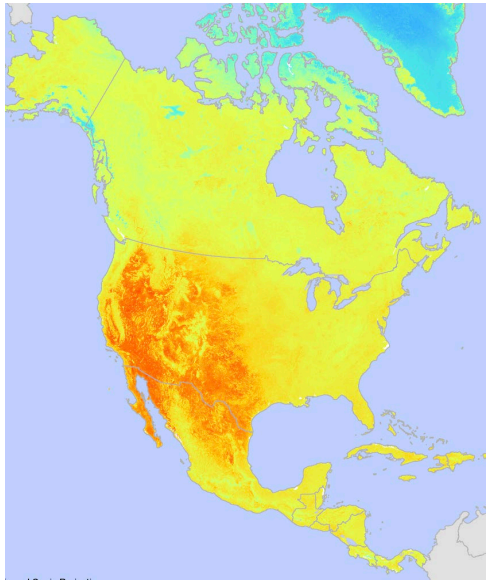
9 August 2022



Credit: Conlon et al., 2020

Integrating Socioeconomic Data with Satellite Imagery for Constructing Heat Vulnerability Indices - Session 2

11 August 2022



Credit: CIESIN

Using High-Resolution, Satellite Derived Hot-Humid Heat Estimates and Gridded Population Data to Map Extreme Heat Exposure Worldwide

Course Structure and Materials

- Webinar recordings, presentations, and the homework assignment can be accessed from the training page:
  - https://appliedsciences.nasa.gov/join-mission/training/english/arset-satellite-remote-sensing-measuring-urban-heat-islands-and

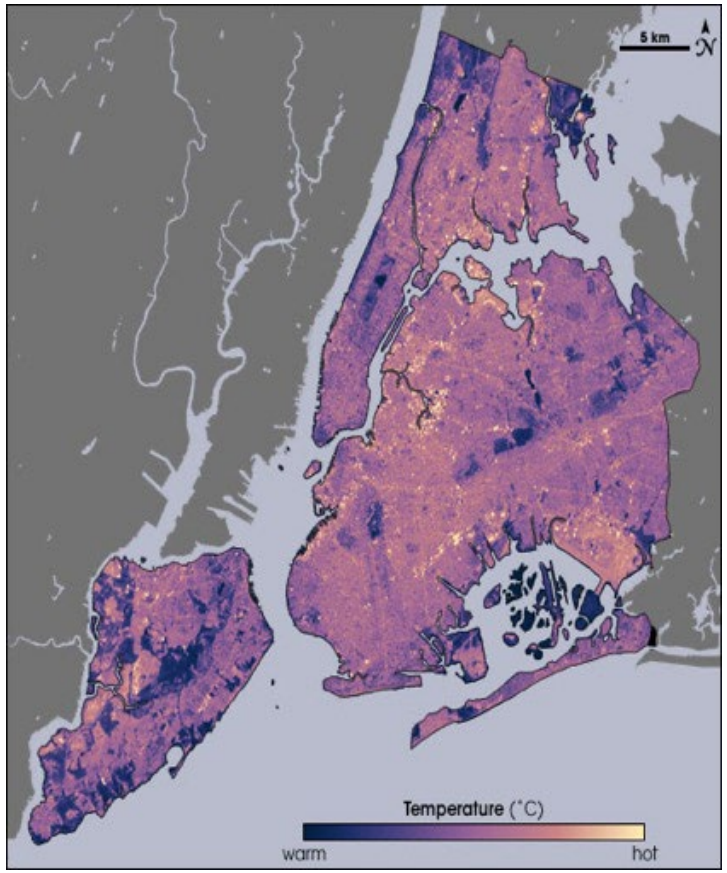
Homework and Certificate

- Homework Assignment:
  - There will be one homework assignment for this webinar series.
  - Answers must be submitted via instructions found on the training page
  - Due date: August 25, 2022
- A certificate of completion will be awarded to those who:
  - Attend all live webinars
  - Complete the homework assignment by the deadline
  - You will receive a certificate approximately two months after the completion of the course from marines.martins@ssaihq.com

Learning Objectives

After participating in today's training, attendees will be able to:

- Define the Wet Bulb Globe Temperature and how it is a measure of heat stress
- Discuss the Global High Resolution Daily Extreme Urban Heat Exposure dataset and how it is used with socioeconomic data for understanding exposure
- Demonstrate the use of a Python Jupyter Notebook for assessing extreme urban heat exposure



Credit: NASA Earth Observatory

Presenter Bio

I am a human-environment geographer at CIESIN, a center at the new Columbia Climate School and an in-coming Assistant Professor at Montana State University.

My research focuses on the intersection of extreme heat exposure, climate change, and food security.

My goal is to inform adaptation strategies that reduce the harmful and inequitable impacts of extreme heat events.

I received my PhD in Geography from UC Santa Barbara in 2020.

COLUMBIA CLIMATE SCHOOL
CENTER FOR INTERNATIONAL EARTH SCIENCE INFORMATION NETWORK

MONTANA STATE UNIVERSITY

Cascade Tuholske, PhD
Postdoctoral Research Scientist
Center for International
Earth Science Information Network
Columbia Climate School

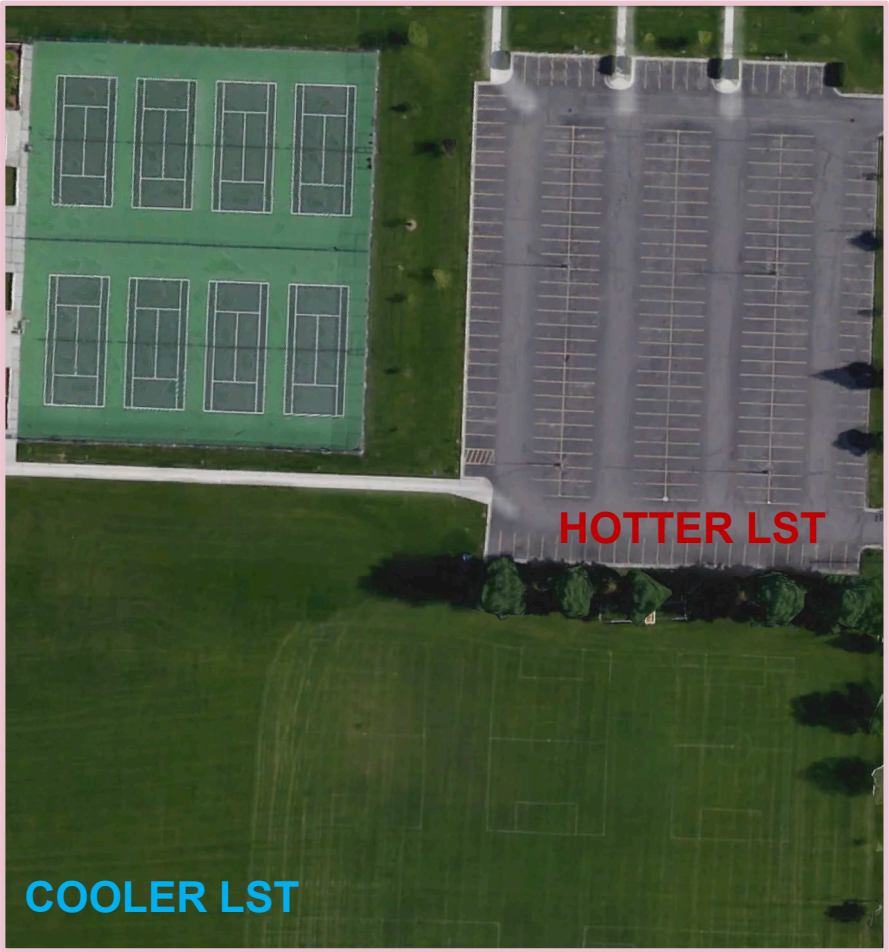
Assistant Professor (Fall '22)
Montana State University

Part 4: Using High-Resolution, Satellite Derived Hot-Humid Heat Estimates and Gridded Population Data to Map Extreme Heat Exposure Worldwide

- Introduction to Wet Bulb Globe Temperature
- Overview of Global High Resolution Daily Extreme Urban Heat Exposure (UHE-Daily), v1 (1983–2016)
- Overview of Annual Global High-Resolution Extreme Heat Estimates, v1
- Jupyter Notebook Demonstration
- Questions and Answer Session

The Urban Heat Island & Human Health + Wellbeing

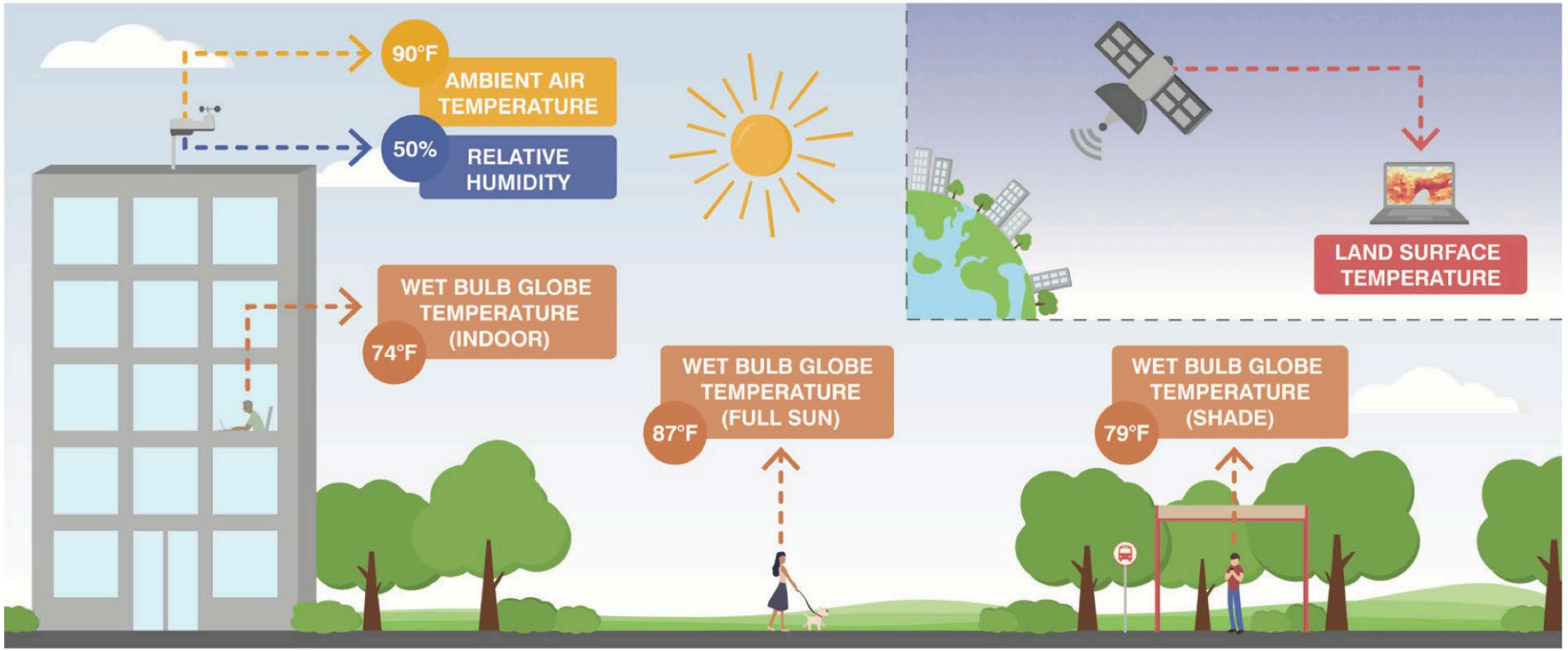
- Many satellite-borne Earth observation derived temperature datasets (e.g., MODIS, Landsat) measure land surface temperature (LST).
- But humans don't live on the ground, we live ~2 meters above.
- LST temperature is the radiated heat from a given surface.
- LST can vary greatly over very short distances and time span.
- Example: Grass football field next to an asphalt parking lot.



(Google Earth)

The Urban Heat Island & Human Health + Wellbeing

Figure 2.9. A multitude of measures exist for heat, including remote sensing of land surface temperatures, ambient air temperatures, and wet bulb globe temperature readings (Ladd Keith and Sara Meerow)



(Keith & Meerow, 2022)

- LST, or radiated heat, can amplify heat impacts to human health + wellbeing.
- But observing LST alone is not sufficient.

Wet Bulb Globe Temperature (WBGT) Overview

- **Wet Bulb Globe Temperature (WBGT)** accounts for ambient (2 meter) air temperatures, relative humidity, radiated heat (LST), and wind speeds (air flows).
- WBGT is usually measured with a field instrument called a WBGT thermometer.
- WBGT = 0.7 Twb + 0.2 Tg + 0.1 Ta
  - Twb: temp of 'natural wick' (wetted cotton exposed)
  - Tg: temp of black globe (exposed)
  - Ta: air temperature (not exposed)
- **Important**: WBGT and Wet Bulb Temperature are two different metrics.

Kestrel Instruments

Wet Bulb Globe Temperature (WBGT) Overview

- WBGT was created in the 1950s for the US Marine Corps.
- WBGT is often used for occupational health risk standards, as well by sporting leagues, to identify dangerous thresholds to human health.

Table 1. ISO 7243: WBGT reference values

Metabolic rate (Wm^{-2})	WBGT reference value	
	Acclimatized (°C)	Not acclimatized (°C)
Resting $M < 65$	33	32
$65 < M < 130$	30	29
$130 < M < 200$	28	26
$200 < M < 260$	25 (26)*	22 (23)*
$M > 260$	23 (25)*	18 (20)*

The values given have been established allowing for a maximum rectal temperature of 38°C for the persons concerned.

*: Figures in brackets refer to sensible air movement.

(Parsons 2006)

Wet Bulb Globe Temperature (WBGT) Overview

- International Standards Organization (ISO) 7243 is an often-cited criteria for WBGT dangerous thresholds.
- ISO WBGT thresholds are defined by metabolic rates and time exerting.
- ISO WBGT thresholds were designed for the "working man" (e.g., young, fit, healthy, American Marines) … e.g., not the vast majority worldwide of people who are most at risk to heat stress (Parsons 2006; Cheung et al. 2015).

Table 1. ISO 7243: WBGT reference values

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The values given have been established allowing for a maximum rectal temperature of 38°C for the persons concerned.

*: Figures in brackets refer to sensible air movement.

(Parsons 2006)

Wet Bulb Globe Temperature (WBGT) Overview

- WGBT can be estimated from meteorological data obtained from space-born Earth-observing satellites.
- WBGT can also be estimated with meteorological data from climate reanalysis products.
- Several methodologies exist for calculating WBGT with meteorological data (See Kong and Huber 2022)

Earth's Future

Research Article | Open Access

Explicit Calculations of Wet-Bulb Globe Temperature Compared With Approximations and Why It Matters for Labor Productivity

Qinqin Kong, Matthew Huber

First published: 31 January 2022 | https://doi.org/10.1029/2021EF002334

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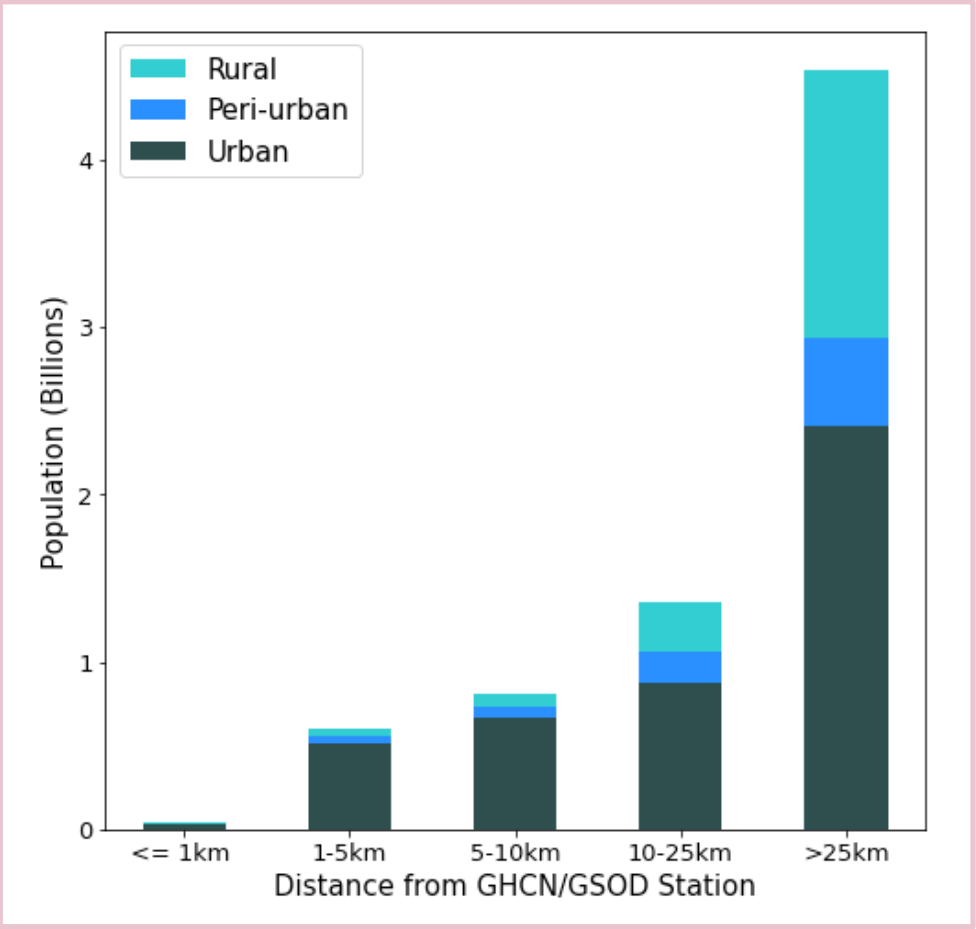
Abstract

Wet-bulb globe temperature (WBGT) is a widely applied heat stress index. However, most applications of WBGT within the heat stress impact literature that do not use WBGT at all, but use one of the ad hoc approximations, typically the simplified WBGT (sWBGT) or the environmental stress index (ESI). Surprisingly, little is known about how well these approximations work for the global climate and climate change settings that they are being applied to. Here, we assess the bias distribution as a function of temperature, humidity, wind speed, and radiative conditions of both sWBGT and ESI relative to a well-validated, explicit physical model for WBGT developed by Liljegren, within an idealized context and the more realistic setting of ERA5 reanalysis data. sWBGT greatly overestimates heat stress in hot-humid areas. ESI has much smaller biases in the range of standard climatological conditions. Over subtropical dry regions, both metrics can substantially underestimate extreme heat. We show systematic overestimation of labor loss by sWBGT over much of the world today. We recommend discontinuing the use of sWBGT. ESI may be acceptable for assessing average heat stress or integrated impact over a long period like a year, but less suitable for health applications, extreme heat stress analysis, or as an operational index for heat warning, heatwave forecasting, or guiding activity modification at the workplace. Nevertheless, Liljegren's approach should be preferred over these ad hoc approximations and we provide a fast Python implementation to encourage its widespread use.

WBGT, Urban Areas, and the Lack of Station Data

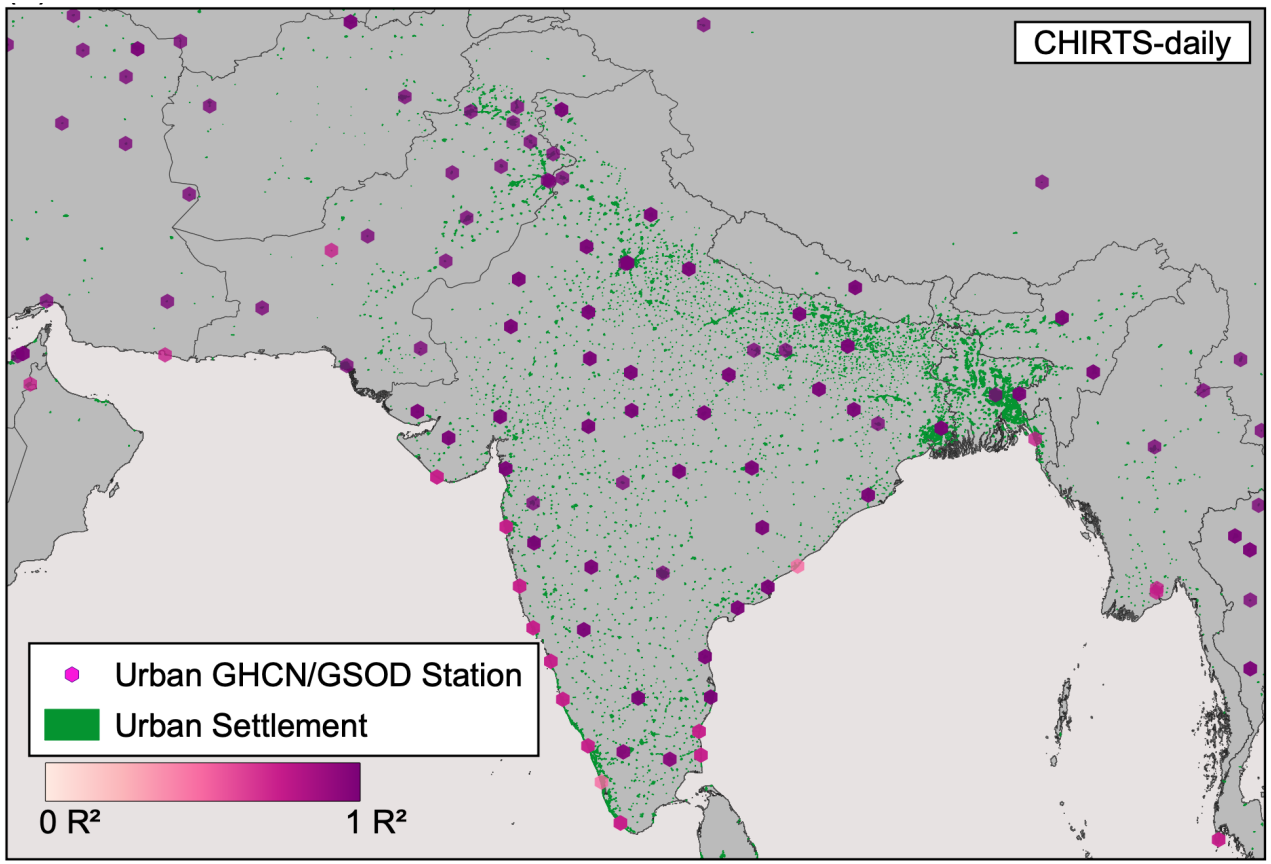
- Over **4,000,000,000** people live more than 25 km from a weather station with a robust, longitudinal reporting record.
- Half are 'urban' residents.



Zaitchik & Tuholske 2021

WBGT, Urban Areas, and the Lack of Data

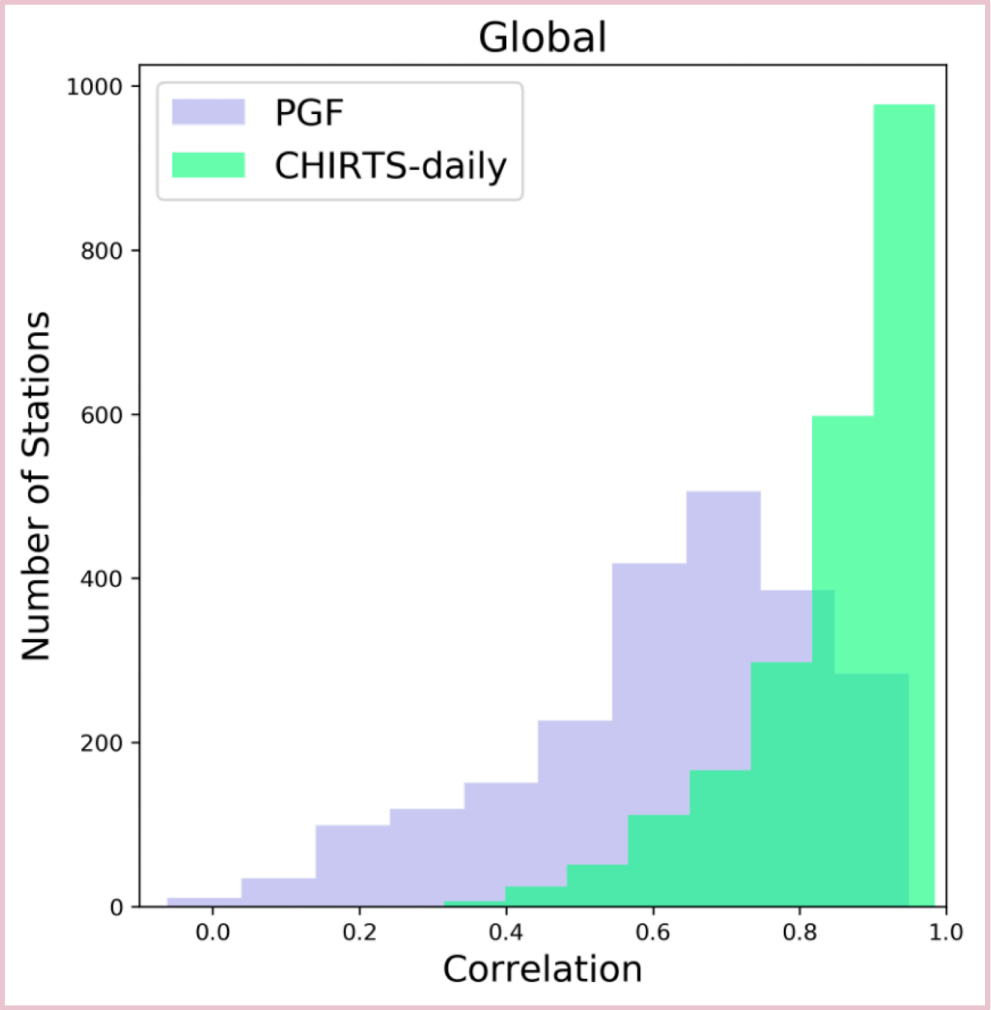
- For India, there are ~3,000 'urban' settlements but only 111 robust, longitudinal weather stations.
- **Earth observations are thus key** for assessments of historical change, current monitoring, short-term and seasonal forecasting, and future climate projections of extreme heat.



Data from Verdin et al. 2020 & Florczyk et al. 2019

WBGT, Urban Areas, and the Lack of Data

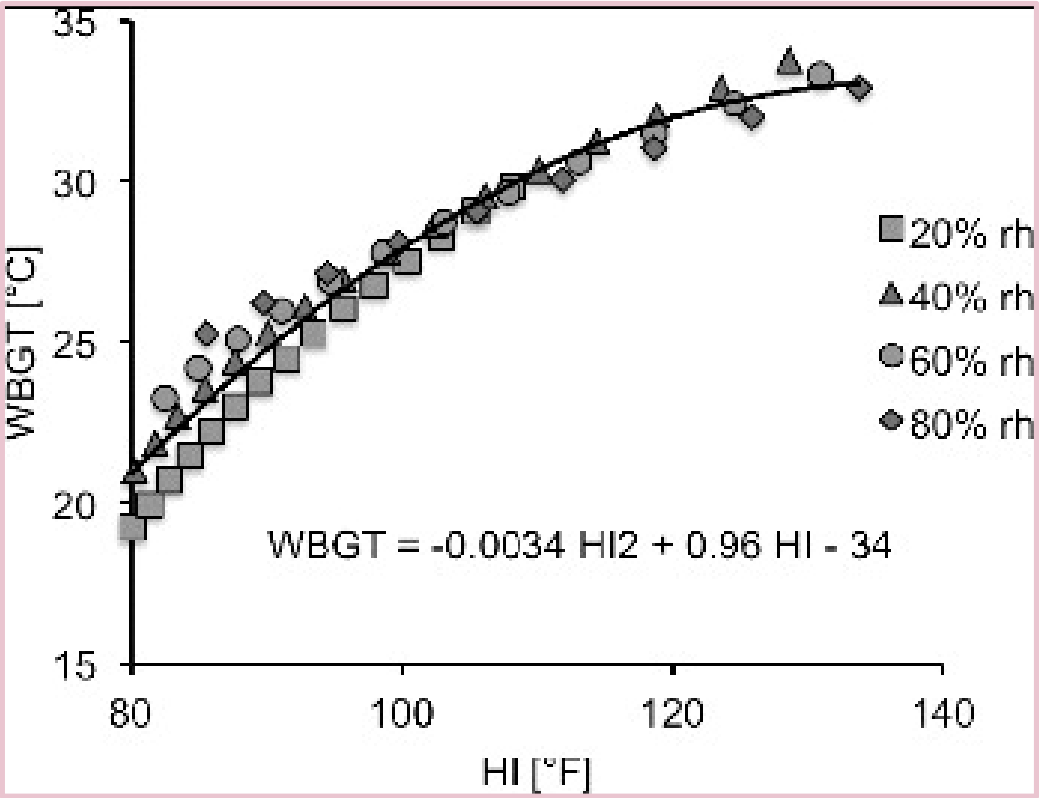
- Satellite data combined with station observations can gap-fill areas where we lack temperature data.
- CHIRTS-daily, from UC Santa Barbara Climate Hazards Center, is the most accurate and highest resolution daily (0.05°) global temperature product, available from 1983 - 2016 **(update to present forthcoming)**.
- CHIRTS-daily leverages the temporal accuracy of stations with the spatial coverage of meteorological satellites.
- DOI: https://doi.org/10.15780/G2008H



Tuholske et al. 2021

Global High Resolution Daily Extreme Urban Heat Exposure (UHE-Daily), v1 (1983–2016)

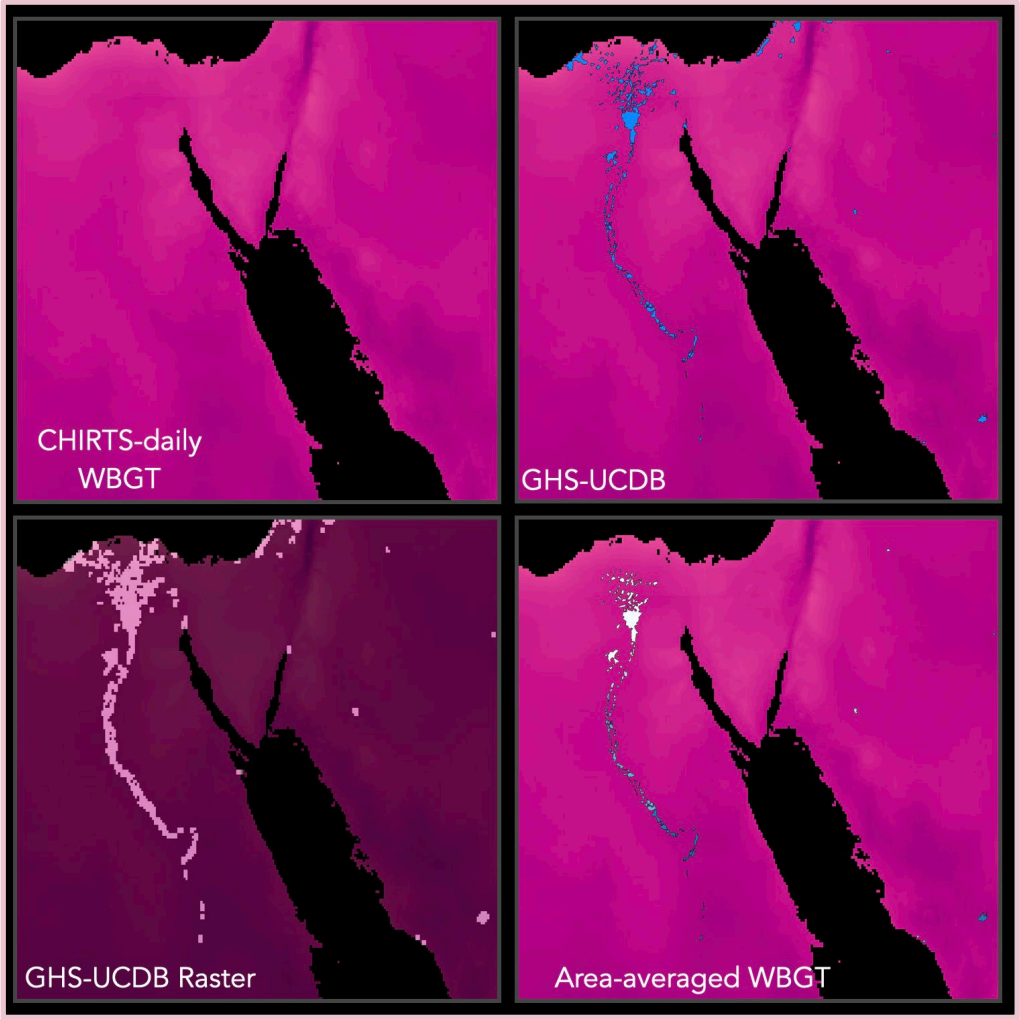
- Use CHIRTS-daily to calculate daily maximum heat index, following the US National Weather Service procedure.
  - Daily maximum air temperature
  - Daily minimum relative humidity
- Then convert HImax to WBGTmax, following Bernard & Iheanacho 2015.
- Assumes a fixed wind speed and radiation.



Bernard & Iheanacho 2015.

Global High Resolution Daily Extreme Urban Heat Exposure (UHE-Daily), v1 (1983–2016)

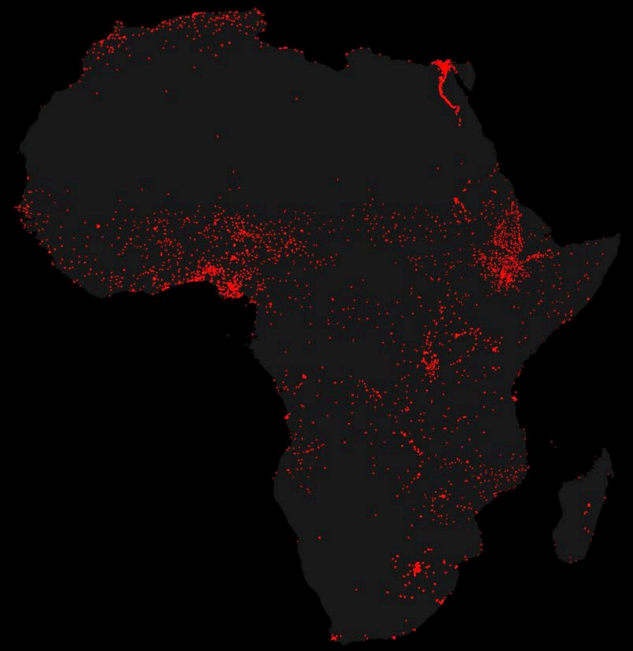
- Combine CHIRTS-daily WBGTmax record with the Global Human Settlement Layer Urban Centre Data Base (Florczyk et al. 2019)
- Create a record of WBGTmax for every urban settlement on the planet from 1983 – 2016 (150 million observations).
- Apply ISO threshold to identify dangerous hot-humid days (e.g., WBGTmax > 30°C) for each city on the planet, from 1983 – 2016 **to produce a record of all urban hot-humid heat waves**.



Global High Resolution Daily Extreme Urban Heat Exposure (UHE-Daily), v1 (1983–2016)

Exposure (Person-days) =

X

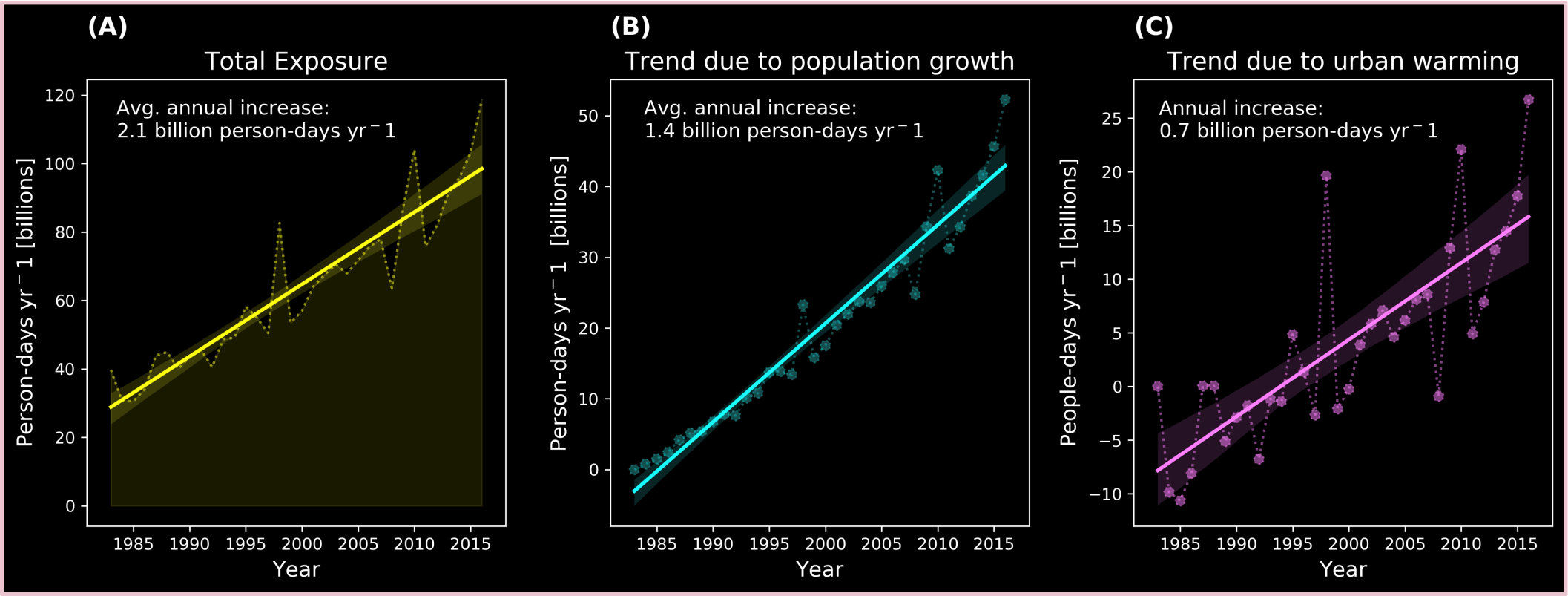


Hot Days = # Days $WBGT_{max}$ >30° C

Exp = Hot Days X Population

$Exp\ yr^{-1} = \beta_o + \beta\ Exp + \varepsilon$

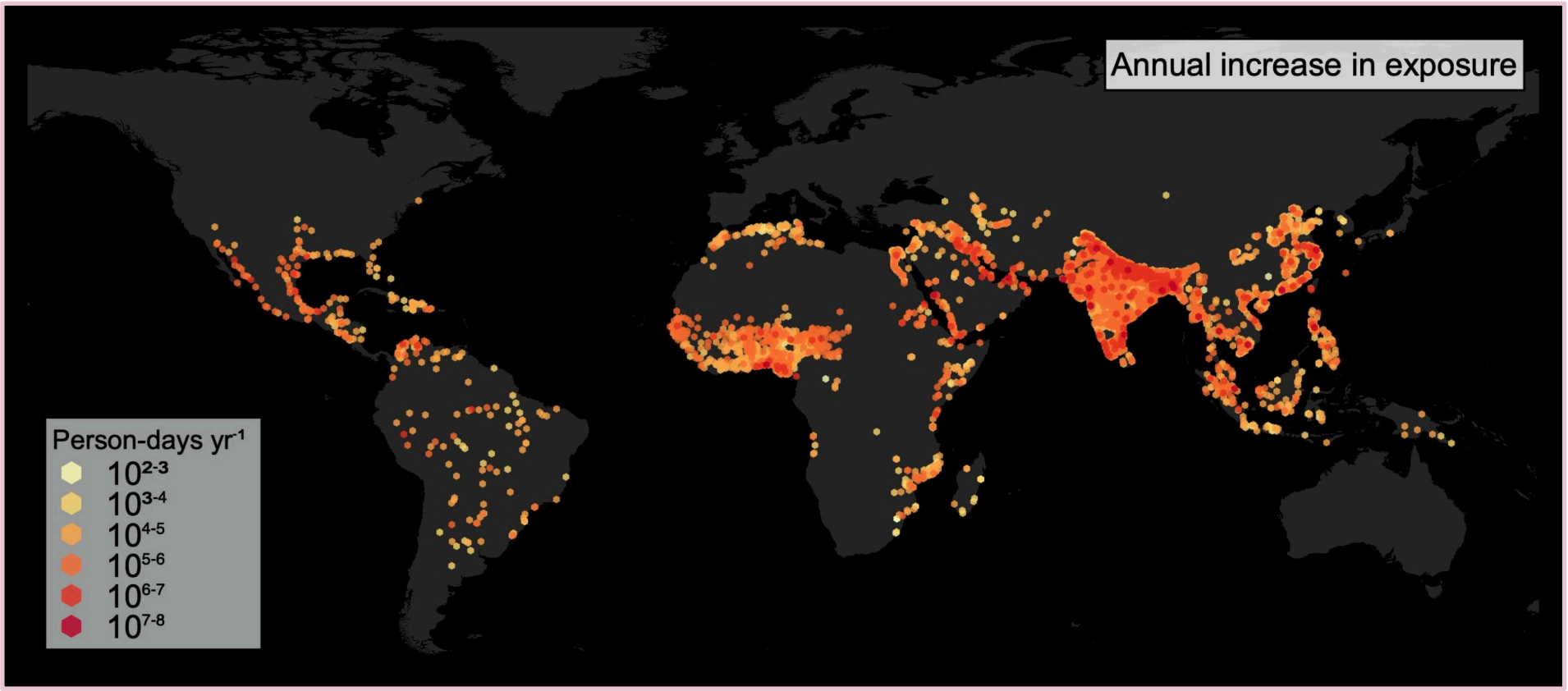
Global High Resolution Daily Extreme Urban Heat Exposure (UHE-Daily), v1 (1983–2016)



Tuholske et al. 2021

Global exposure increased 200% from 1983 – 2016. Total urban warming contributed a **third** of the annual increase in exposure.

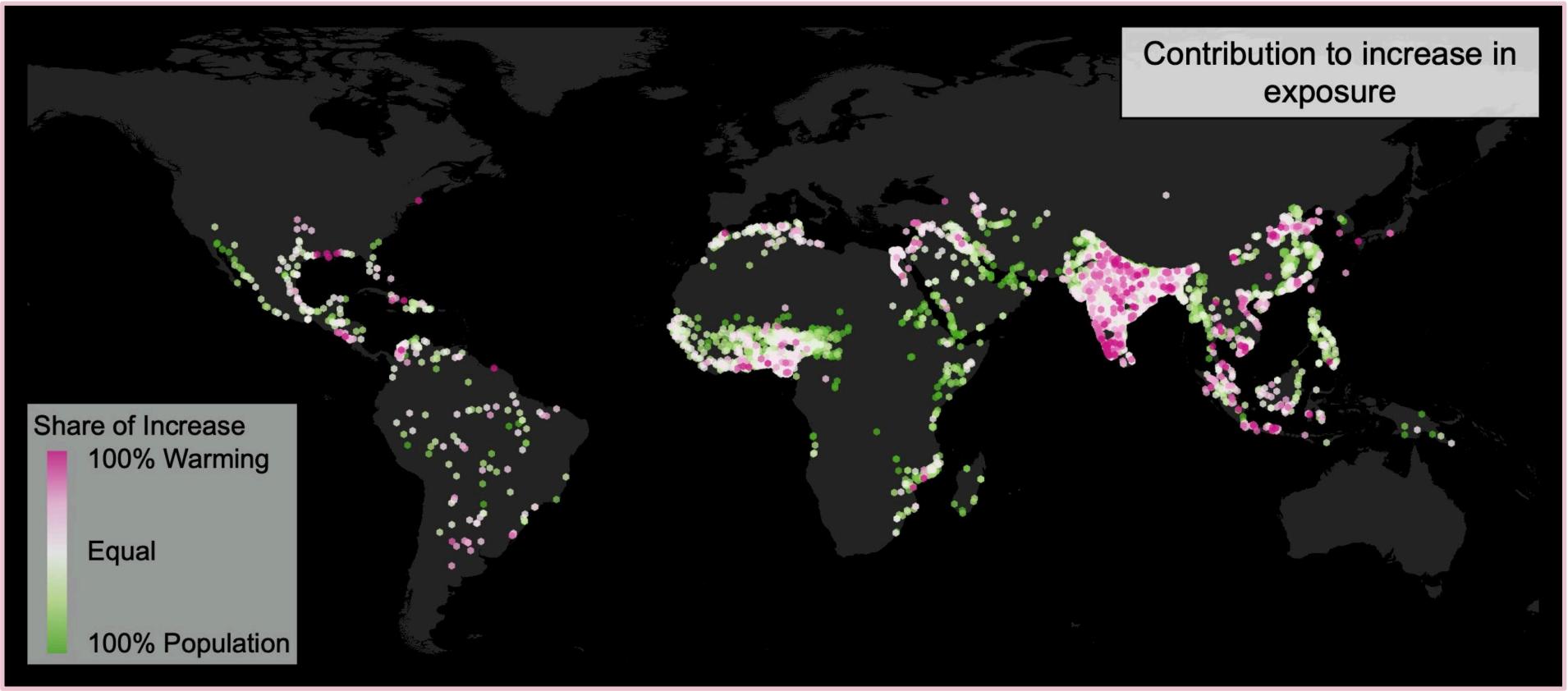
Global High Resolution Daily Extreme Urban Heat Exposure (UHE-Daily), v1 (1983–2016)



Tuholske et al. 2021

Nearly 6,000 urban settlements had an increase in exposure, which housed 1.7 billion people in 2016.

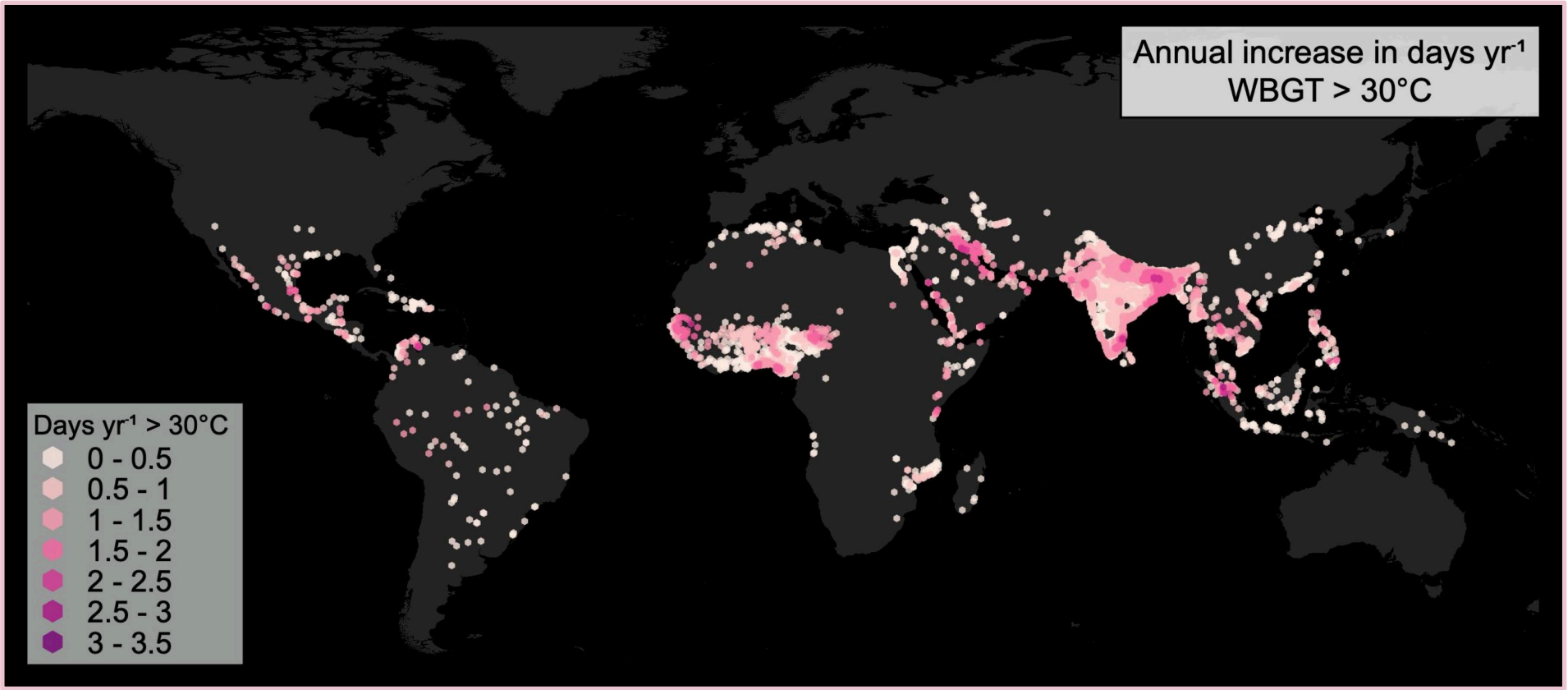
Global High Resolution Daily Extreme Urban Heat Exposure (UHE-Daily), v1 (1983–2016)



Tuholske et al. 2021

Heterogenous contribution of population growth vs. total urban warming.

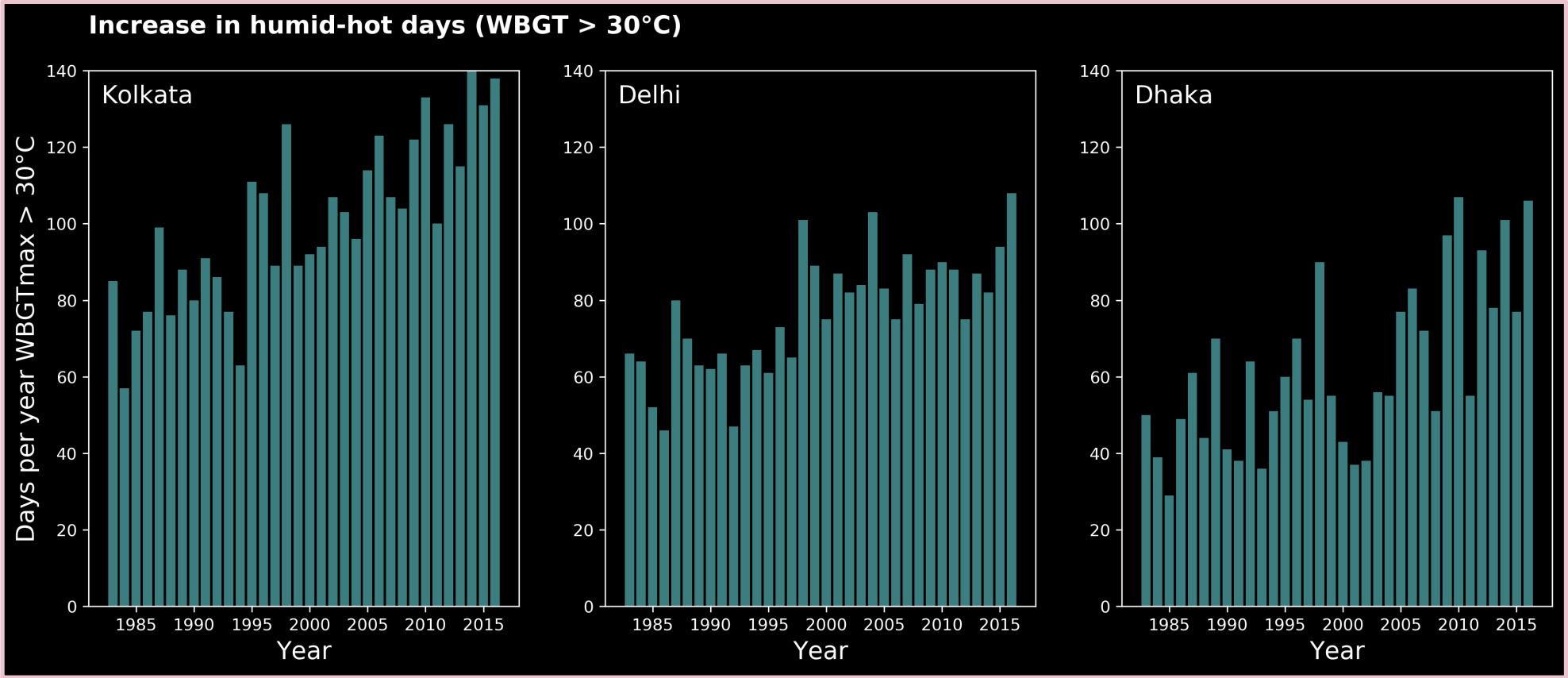
Global High Resolution Daily Extreme Urban Heat Exposure (UHE-Daily), v1 (1983–2016)



Tuholske et al. 2021

Important Note: Urban warming is both climate change and the urban heat island effect.

Global High Resolution Daily Extreme Urban Heat Exposure (UHE-Daily), v1 (1983–2016)



Tuholske et al. 2021

"Proximate" urban settlements of similar size populations and levels of economic development have much different increase in the number of dangerous hot-humid days per year.

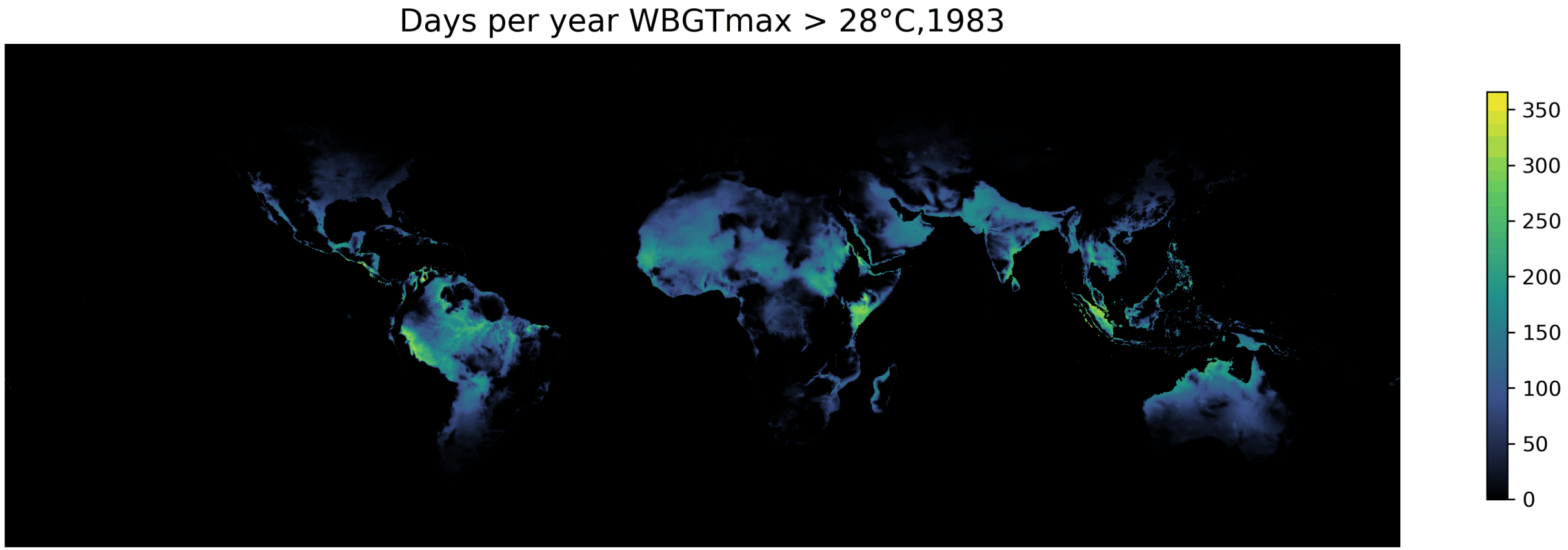
Global High Resolution Daily Extreme Urban Heat Exposure (UHE-Daily), v1 (1983–2016)

- UHE-Daily, v1 dataset is available from the NASA Socioeconomic Data and Applications Center (SEDAC).
- Record Includes:
  - Every hot-humid urban heat wave, including dates and WBGTmax estimates, from 1983 – 2016 for three ISO thresholds (WBGTmax 28°C, 30°C, & 32°C)

Global High Resolution Daily Extreme Urban Heat Exposure (UHE-Daily), v1 (1983–2016)

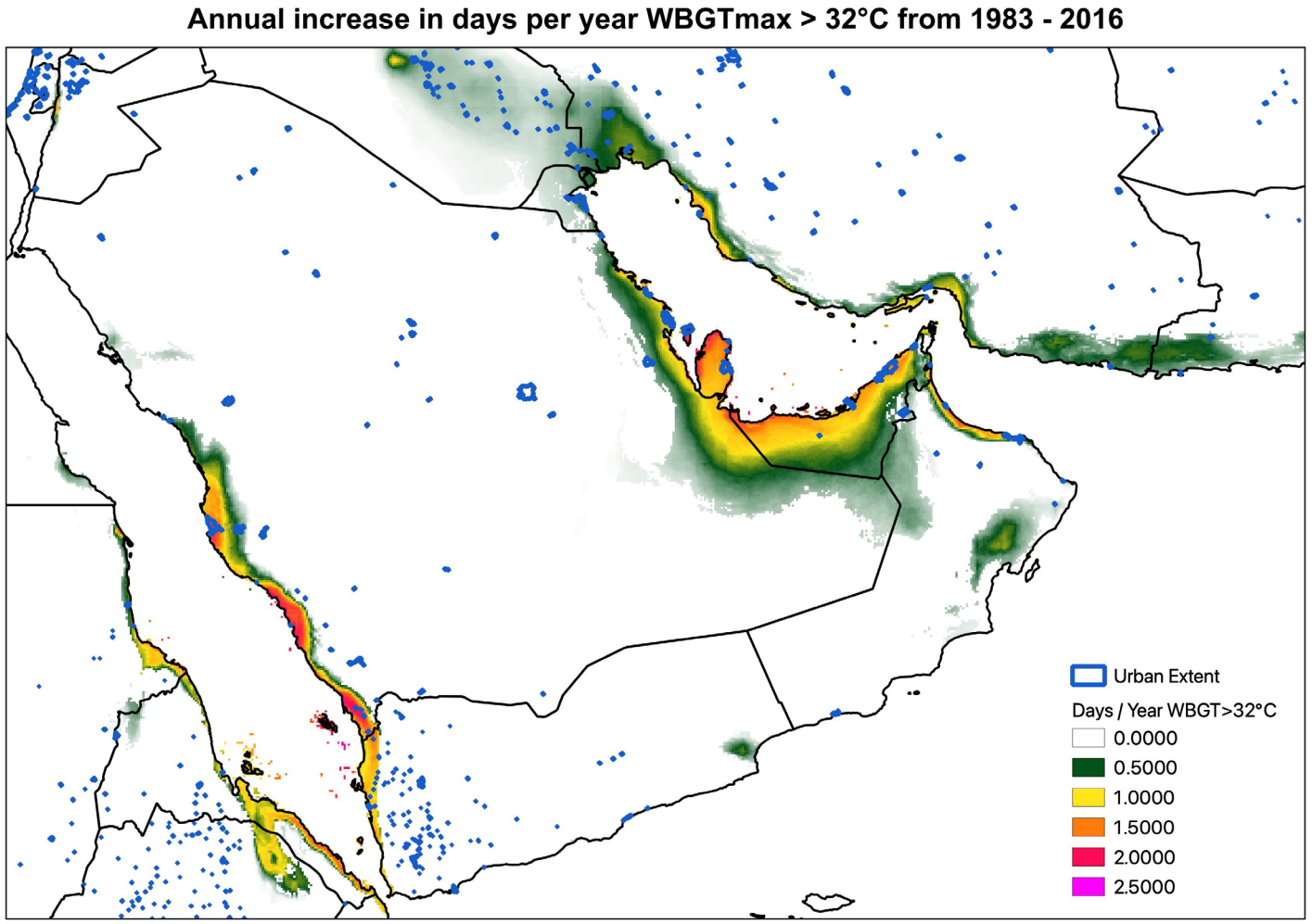
- Annual person-day estimates for each urban settlement.
- Exposure + warming trends for each urban settlement.
- Dataset available in .json, .csv. & .shp file formats.
- DOI: https://doi.org/10.7927/fq7g-ny13

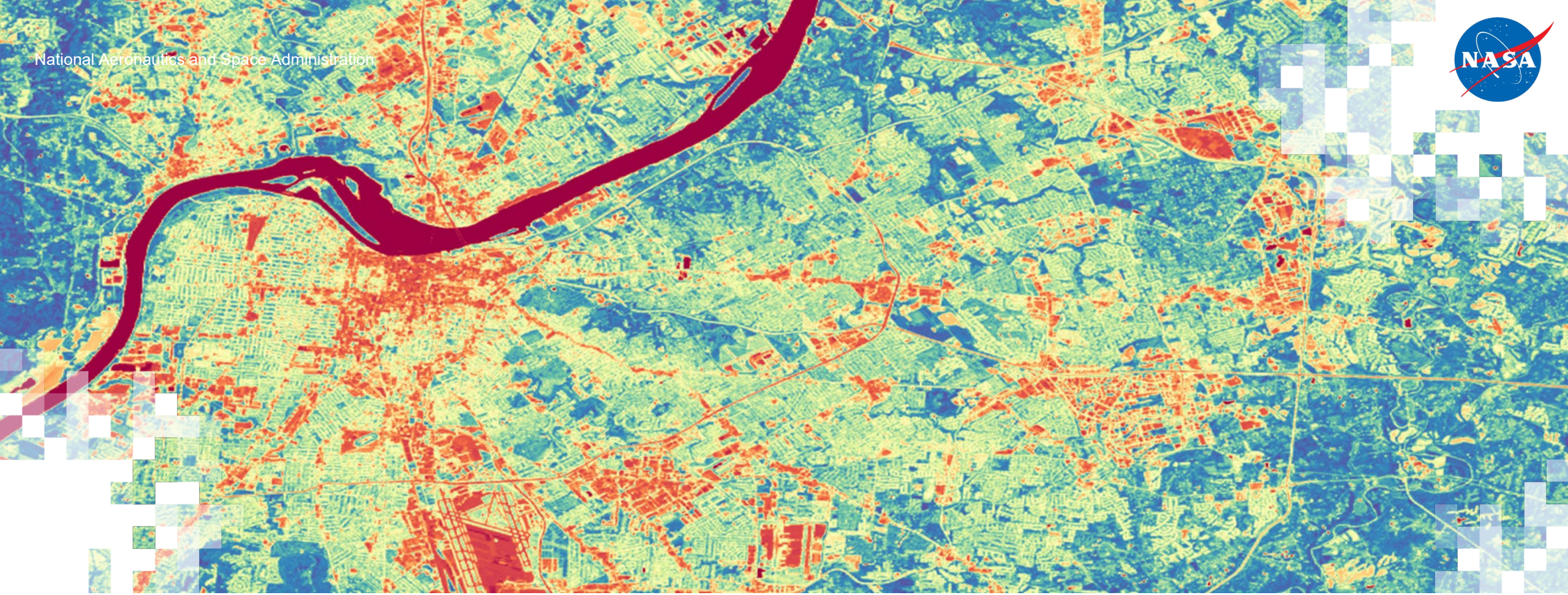
Annual Global High-Resolution Extreme Heat Estimates, v1



Annual Global High-Resolution Extreme Heat Estimates, v1

- Similar to UHE-daily, v1
- Global, annual count number of dangerous hot-humid days at 5-km spatial resolution
- ISO WBGTmax WBGTmax 28°C, 30°C, & 32°C thresholds
- Also includes annual rate of increase in days per year that exceed a given threshold
- DOI: https://doi.org/10.7927/hff0-k565





Demonstration using Python Jupyter Notebook

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- Zaitchik, B. F., & Tuholske, C. (2021). Earth observations of extreme heat events: leveraging current capabilities to enhance heat research and action. *Environmental Research Letters*, *16*(11).

Questions?

- Please enter your questions in the Q&A box. We will answer them in the order they were received.
- We will post the Q&A to the training website following the conclusion of the webinar.

Credit: NASA

Contacts

- Trainers
  - Cascade Tuholske, PhD : cascade@ciesin.columbia.edu

- Training Webpage:
  - https://appliedsciences.nasa.gov/join-mission/training/english/arset-satellite-remote-sensing-measuring-urban-heat-islands-and

- ARSET Website:
  - https://appliedsciences.nasa.gov/what-we-do/capacity-building/arset

Thank You!