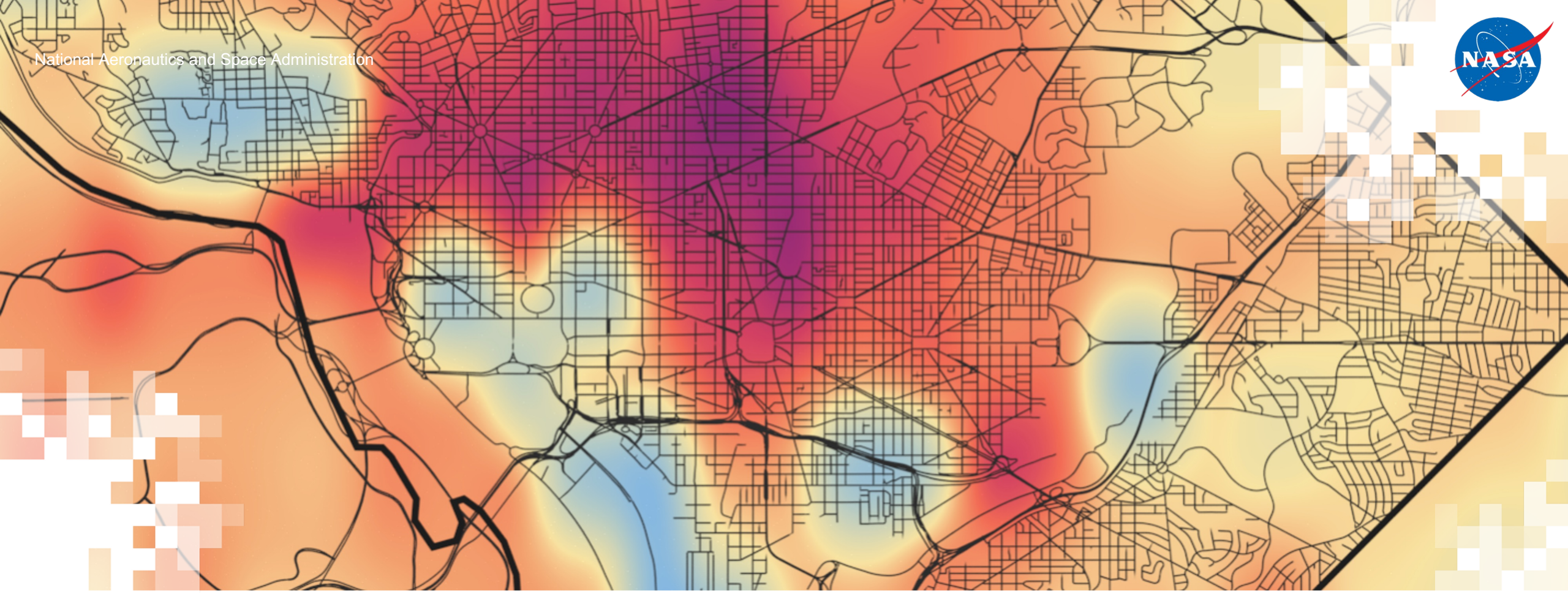
National Aeronautics and Space Administration

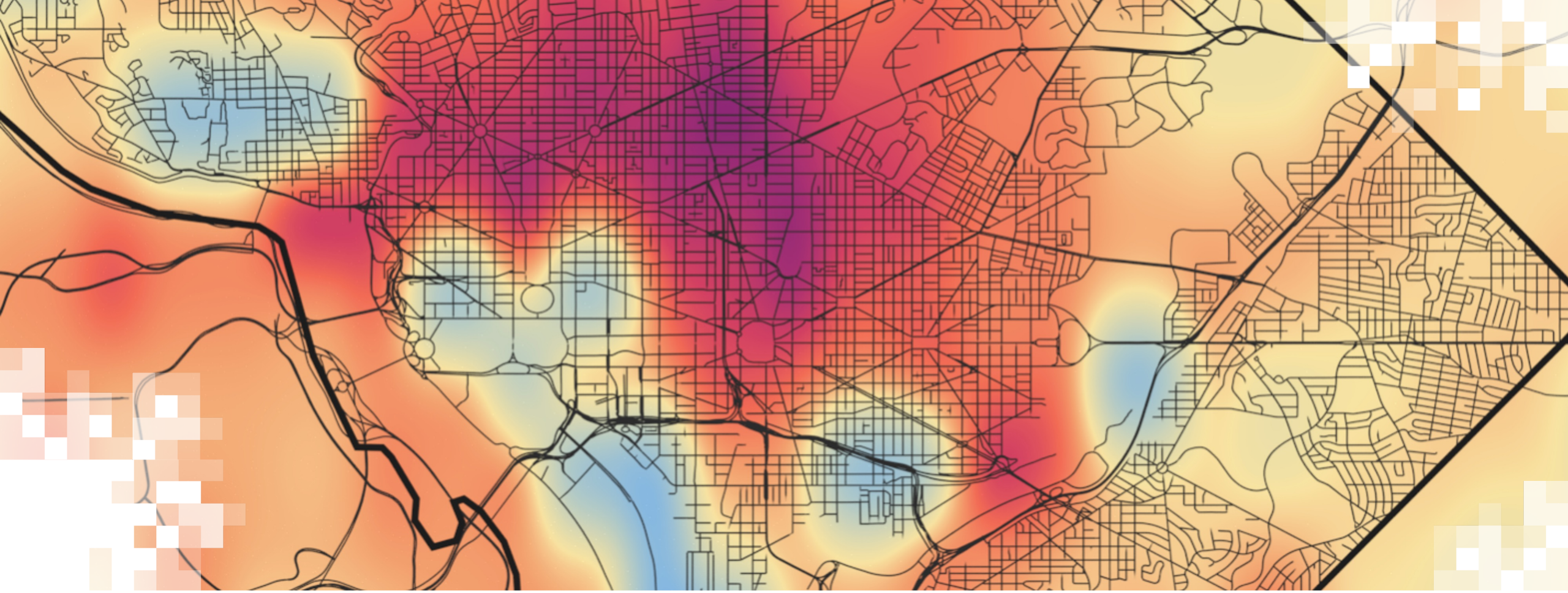


Satellite Data for Air Quality Environmental Justice and Equity Applications

Part 1: Use of Satellite Data in Environmental Justice Applications

Susan Anenberg (GWU), Gaige Kerr (GWU), Qian Xiao (University of Texas), Ufuoma Ovienmhada (MIT), Danielle Wood (MIT), Mitra Kashani (CDC), Tanya Kreutzer Sayyed (UMBC), Daniel Carrion (Yale), Shobhana Gupta (NASA EEJ), Melanie Follette-Cook (NASA), and Carl Malings (MSU, NASA)

August 23, 2023



About ARSET

About ARSET

- **ARSET provides accessible, relevant, and cost-free training on remote sensing satellites, sensors, methods, and tools.**

- Trainings include a variety of applications of satellite data and are tailored to audiences with a variety of experience levels.

AGRICULTURE

CLIMATE & RESILIENCE

DISASTERS

ECOLOGICAL CONSERVATION

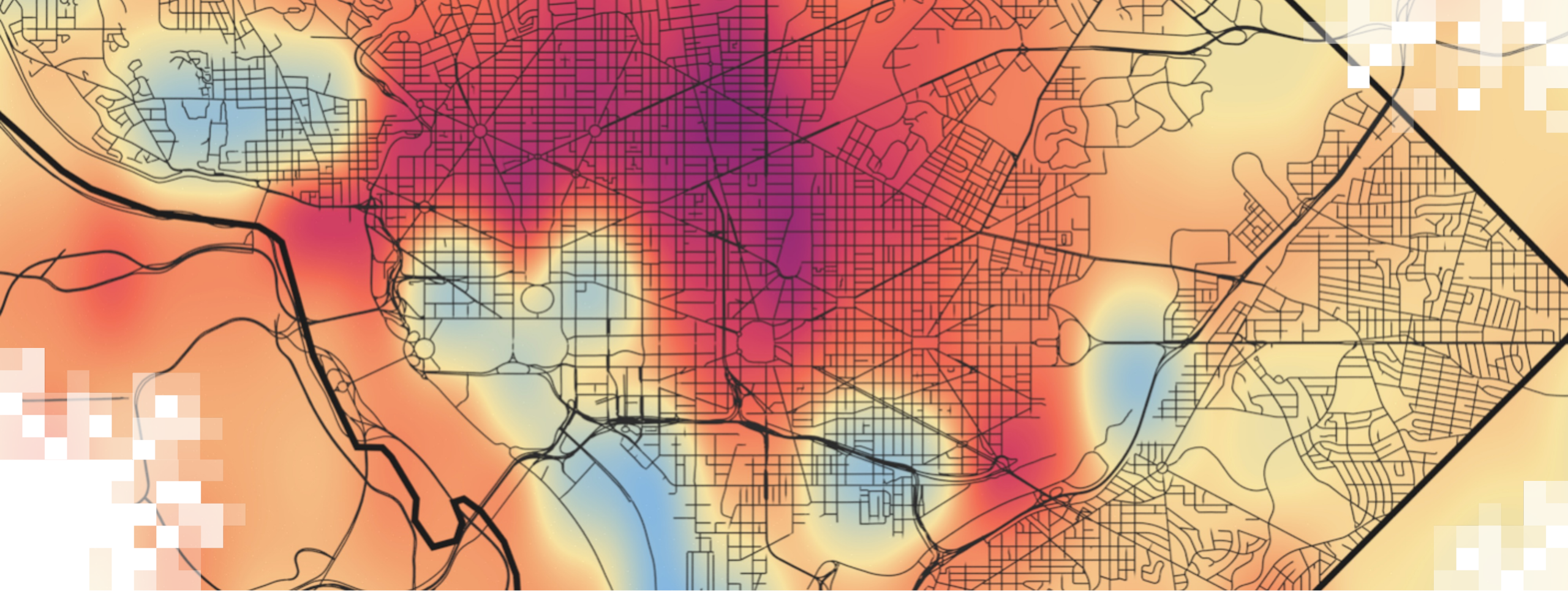
HEALTH & AIR QUALITY

WATER RESOURCES

About ARSET Trainings

- Online or in-person
- Live and instructor-led or asynchronous and self-paced
- Cost-free
- Bilingual and multilingual options
- Only use open-source software and data
- Accommodate differing levels of expertise

- Visit the ARSET website to learn more.

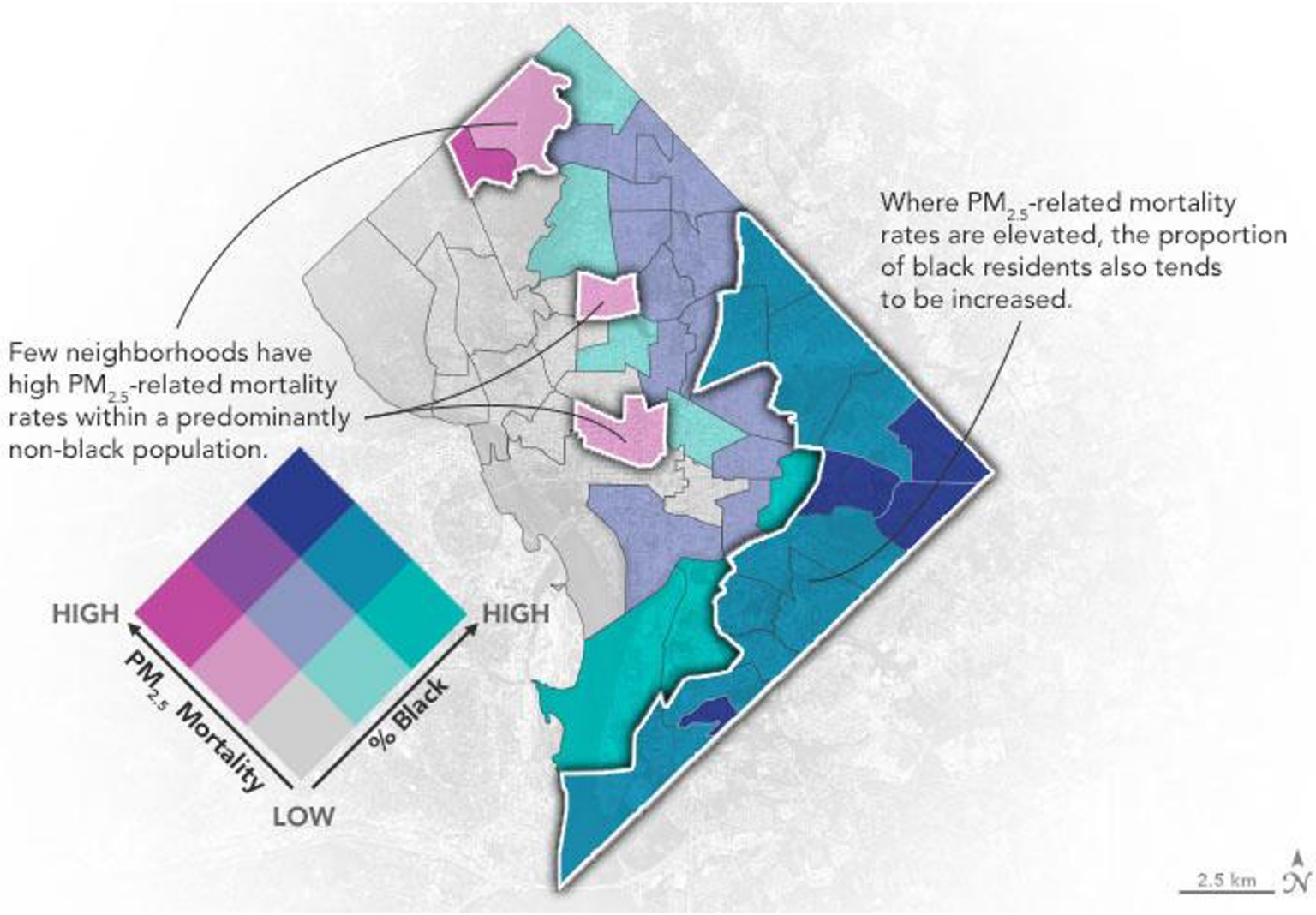


Satellite Data for Air Quality Environmental Justice and Equity Applications

Training Overview

Some Environmental Justice Issues Can be Seen from Space

- Minoritized and marginalized populations often experience disproportionate exposure to a range of environmental hazards.
- Satellite remote sensing data can supplement on-the-ground efforts to investigate such disparities in risk exposure from global to local scales.



Training Learning Objectives

By the end of this training, participants will be able to:

- Describe, at a high level, how satellite data have been combined with socioeconomic information to investigate EJ issues such as heat exposure or access to green space.
- Identify remote sensing data products which are most relevant to assessing EJ related to air quality and pollutant exposure.
- Articulate the benefits and limitations of using remote sensing data to assess EJ concerns related to air quality.
- Import relevant air quality datasets into EJSCREEN, and use EJSCREEN to investigate and compare air quality with other environmental and demographic datasets.
- Pair appropriate satellite datasets for environmental indicators (air quality) with demographic information using Python.

Prerequisites

- Fundamentals of Remote Sensing

Training Outline

Part 1

Use of Satellite Data in Environmental Justice Applications

August 23, 2023

13:30-15:30 EDT (UTC-4)

Part 2

Satellite Remote Sensing of Air Quality for Environmental Justice Applications

August 30, 2023

13:30-15:30 EDT (UTC-4)

Part 3

Interactive Exercises for using Satellite and Demographic Data

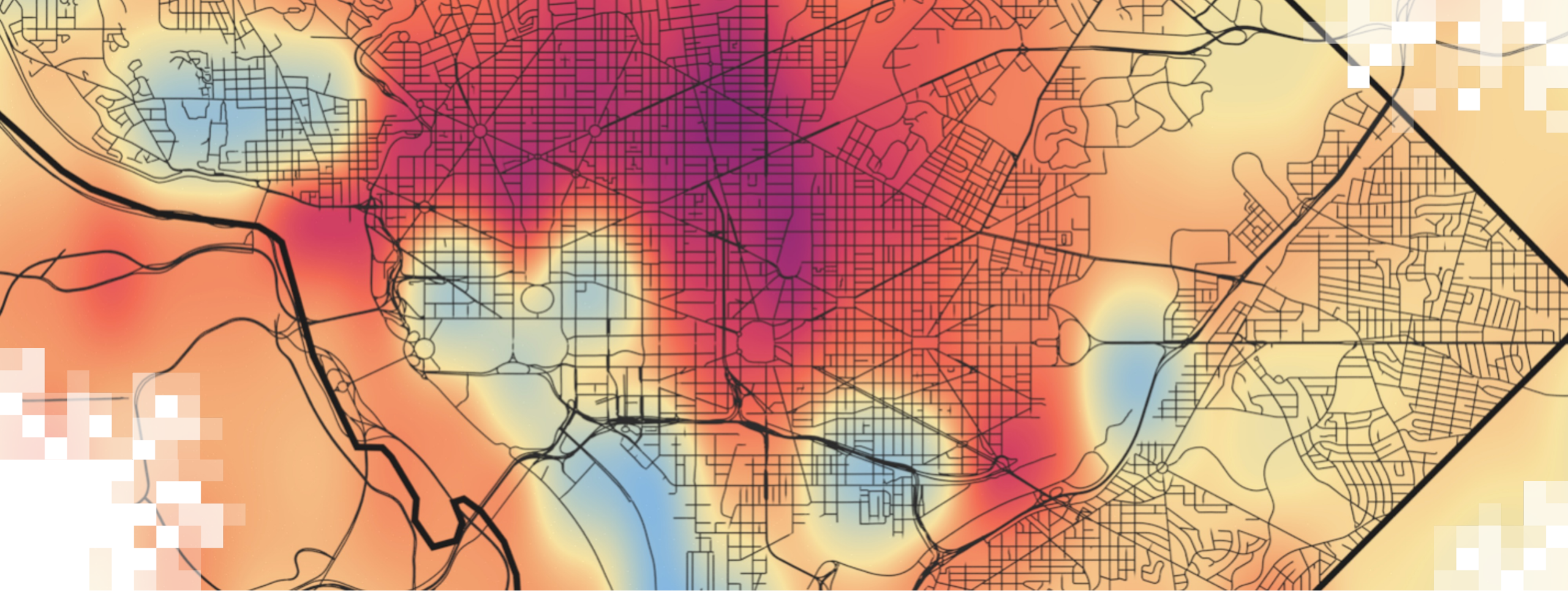
September 06, 2023

13:30-15:30 EDT (UTC-4)

Homework

Opens September 06 – Due September 20 – Posted on Training Webpage

A certificate of completion will be awarded to those who attend all live sessions and complete the homework assignment(s) before the given due date.



Satellite Data for Air Quality Environmental Justice and Equity Applications

Part 1: Use of Satellite Data in Environmental Justice Applications

Part 1 – Trainers

Melanie Follette-Cook

NASA Goddard Space Flight Center

Susan Anenberg

Milken Institute School of Public Health

Shobhana Gupta

Associate Program Manager, NASA Equity and Environmental Justice

Ufuoma Ovienmhada

Massachusetts Institute of Technology

Qian Xiao

Univ. of Texas Health Science Center at Houston

Tanya Kreutzer Sayyed

University of Maryland, Baltimore County

Daniel Carrión

Yale Center on Climate Change and Health

Danielle Wood

Massachusetts Institute of Technology

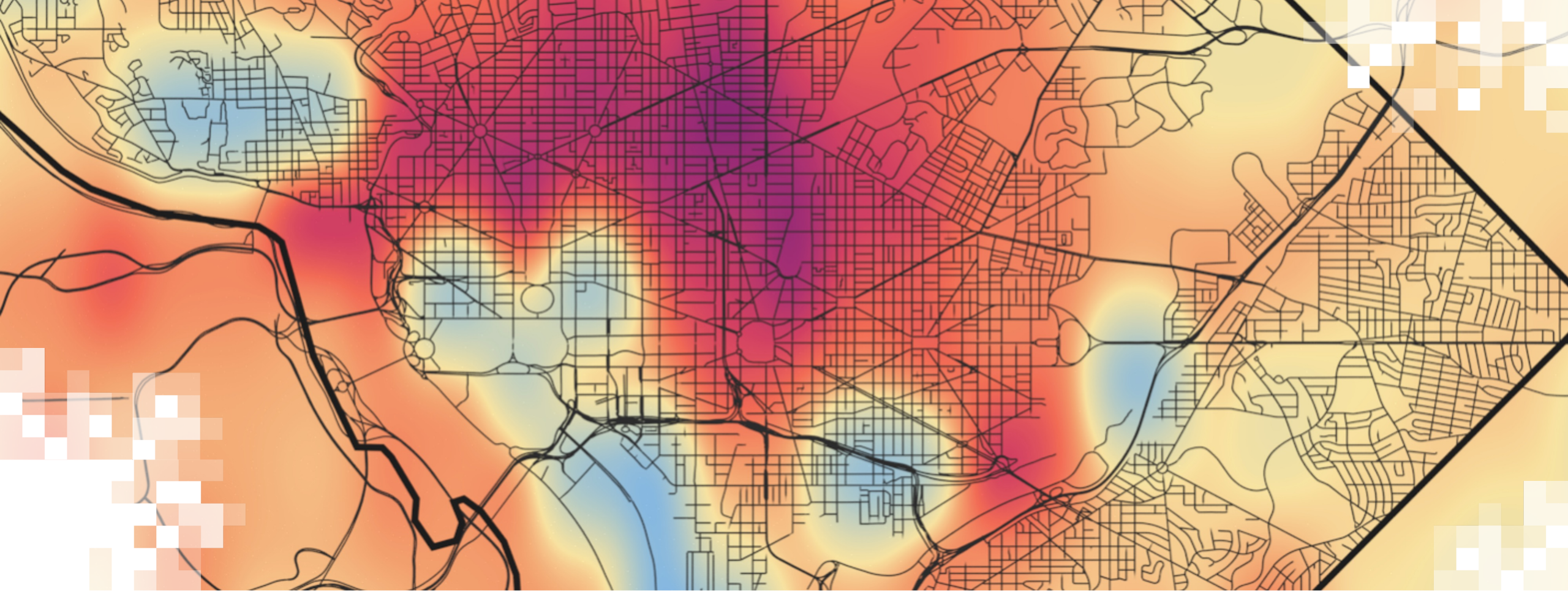
Part 1 Objectives

By the end of Part 1, participants will be able to:

- Describe, at a high level, how satellite data have been combined with socioeconomic information to investigate EJ issues such as heat exposure or access to green space.
- Articulate the benefits and limitations of using remote sensing data to assess EJ concerns related to air quality

How to Ask Questions

- Please put your questions in the Questions box and we will address them at the end of the webinar.
- Feel free to enter your questions as we go. We will try to get to all of the questions during the Q&A session after the webinar.
- The remainder of the questions will be answered in the Q&A document, which will be posted to the training website about a week after the training.



Environmental Justice

What is Environmental Justice?

- The US EPA defines Environmental Justice (EJ) as:

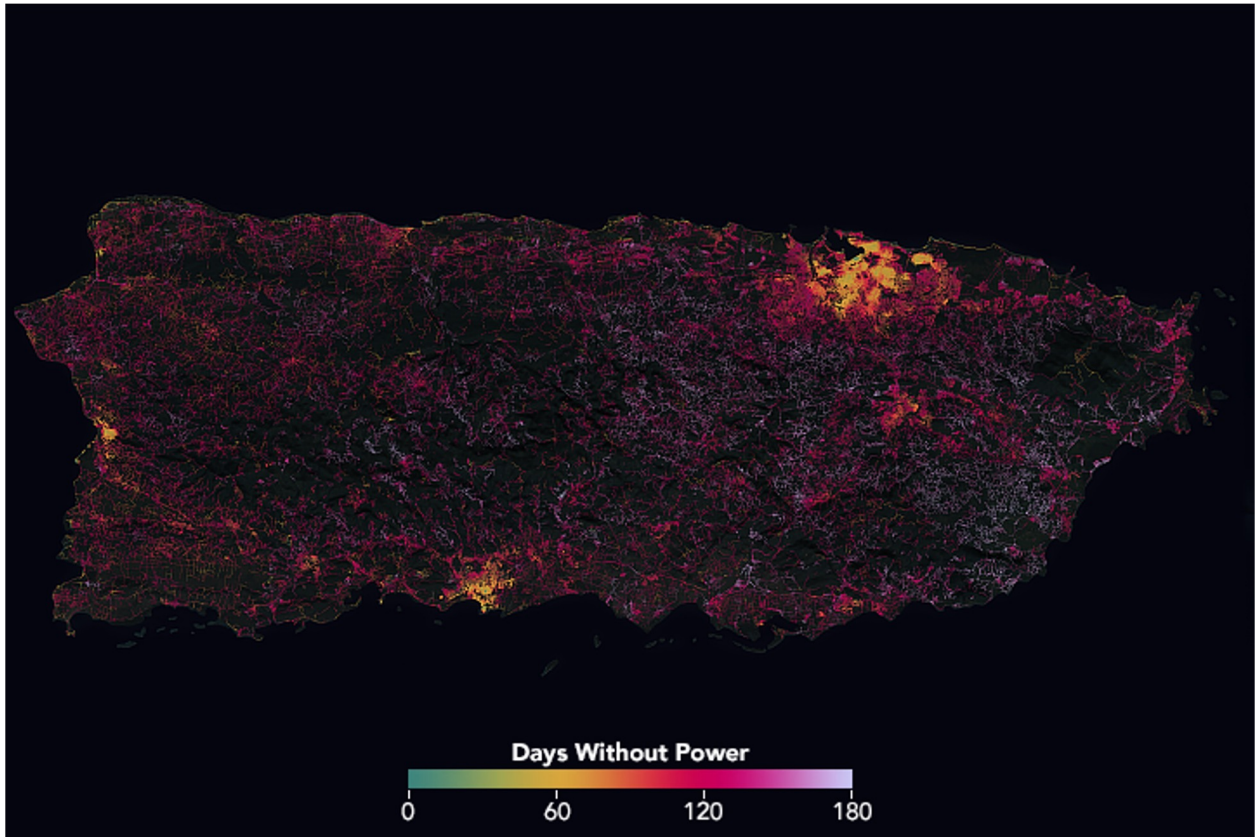
  "The fair treatment and meaningful involvement of all people regardless of race, color, national origin, or income with respect to the development, implementation and enforcement of environmental laws, regulations and policies."

- **Fair Treatment:** no group of people should bear a disproportionate share of the negative environmental consequences resulting from industrial, governmental and commercial operations or policies.
- **Meaningful Involvement:**
  - People have an opportunity to participate in decisions about activities that may affect their environment and/or health.
  - The public's contribution can influence the regulatory agency's decision.
  - Community concerns will be considered in the decision-making process.
  - Decision makers will seek out and facilitate the involvement of those potentially affected.

Source: US EPA Environmental Justice

What are Underserved Communities?

- **Underserved Communities:** Populations sharing a particular characteristic, as well as geographic communities, that have been systematically denied a full opportunity to participate in aspects of economic, social, and civic life.
- **EJ Communities:** Geographic locations with significant representation of persons of color, low-income persons, indigenous persons or members of Tribal nations, where those persons experience, or are at risk of experiencing, higher or more adverse human health or environmental outcomes.



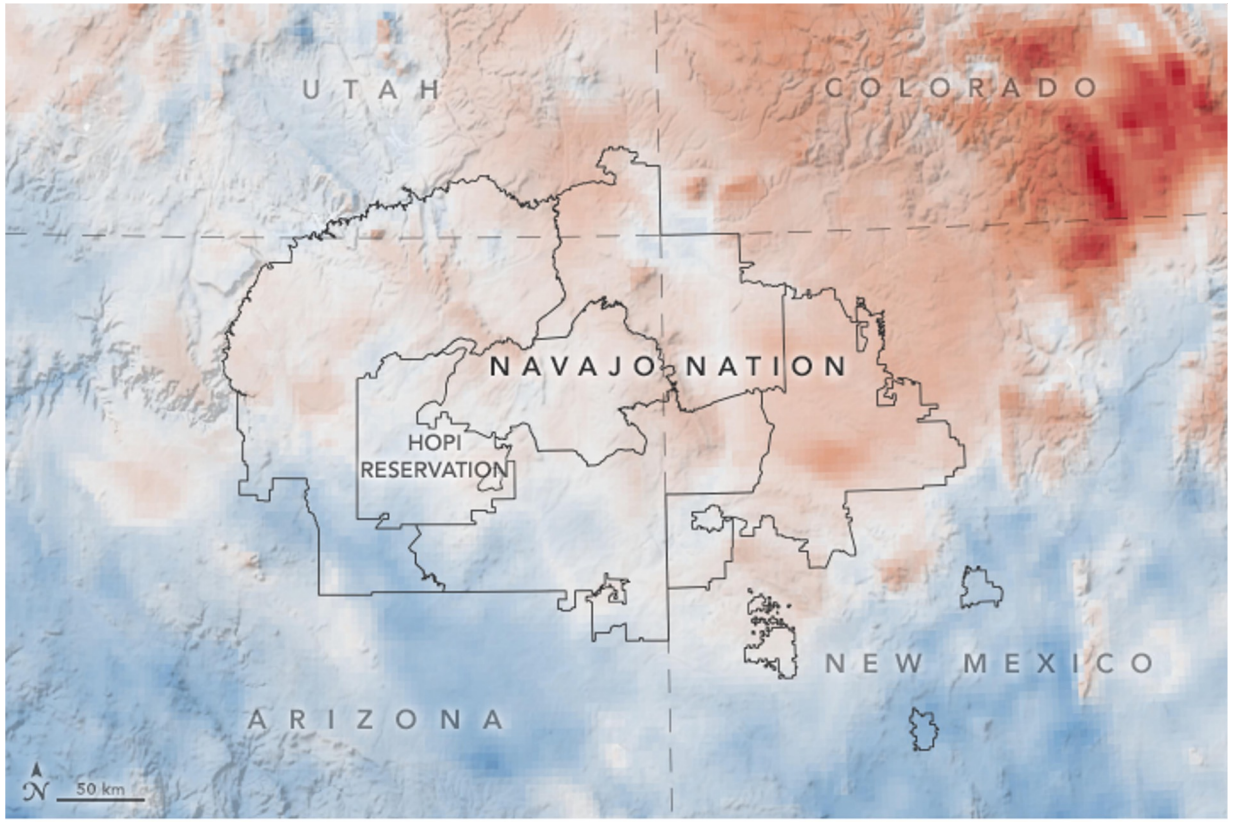
Time to restore power in different regions of Puerto Rico after Hurricane Maria in 2017, estimated using NASA VIIRS nighttime light data

Sources: White House Environmental Justice Advisory Council
NASA Earth Observatory. *Night Lights Show Slow Recovery from Maria.*

What is NASA's Role?

- "NASA's Earth Science Division (ESD) is committed to ensuring that the investment the nation has made in NASA satellites and science benefits people across the U.S. and helps them make informed decisions about the very real challenges they face in their communities."
- This includes:
  - Providing free and equitable access to NASA remote sensing data (RSD)
  - Building capacity to use NASA RSD
  - Funding research into using NASA data to investigate & address EJ

Sources: NASA Earth Science Equity and Environmental Justice
NASA Environmental Justice Backgrounder



Drought Severity Assessment Tool map for the Navajo Nation showing the Standard Precipitation Index derived from multiple satellite datasets

NASA Applied Science for Environmental Justice

Applied Sciences Program

- Funding opportunities
- **Capacity Building**
- **HAQAST**

Capacity Building

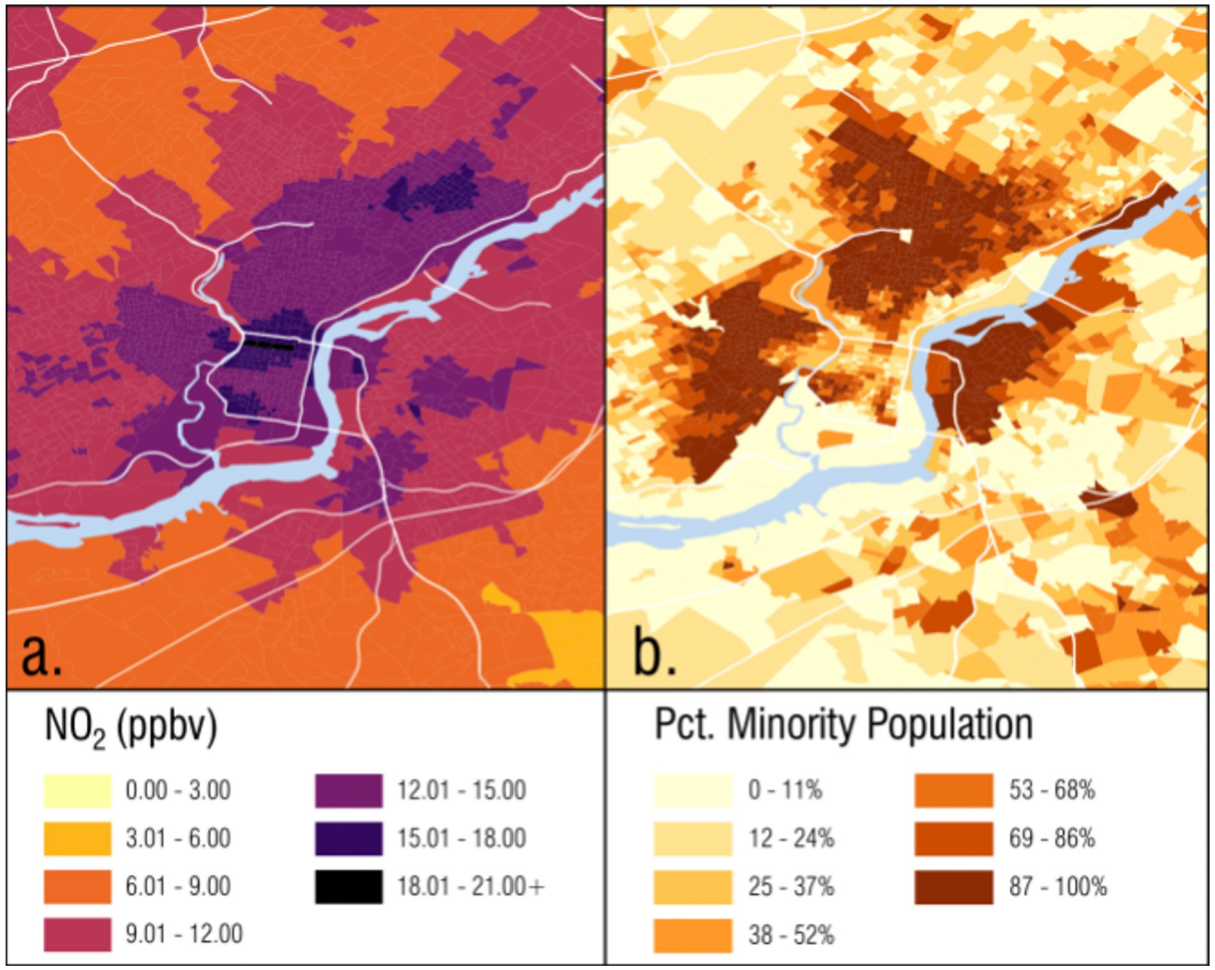
- ARSET
- DEVELOP
- SERVIR
- Community Action

HAQAST

- Health and Air Quality Applied Sciences Team
- Tiger Teams
- Rapid Response Teams

What is Satellite Data for Environmental Justice?

- Satellite Data for Environmental Justice (SD4EJ) is a NASA HAQAST Tiger Team whose goal is to integrate satellite data EJ screening and mapping tools.
- Team partners include:
  - Environmental Defense Fund
  - Centers for Disease Control
  - Consortium for the Valuation of Applications Benefits Linked with Earth Science
  - EPA Office of Environmental Justice
  - University of Maryland Community Engagement, Environmental Justice, and Health
  - South Coast Air Quality Management District
  - New York State Department of Health



Average Block Group NO_2 and Percent Minority Population for Philadelphia in EPA EJScreen

Source: NASA HAQAST SD4EJ

NASA's Equity & Environmental Justice Program

Aims to empower communities across the U.S. and around the globe use Earth data and make informed decisions about issues affecting them, and cultivate new partnerships to support community outreach, training, and the development and application of Earth-data based insights.

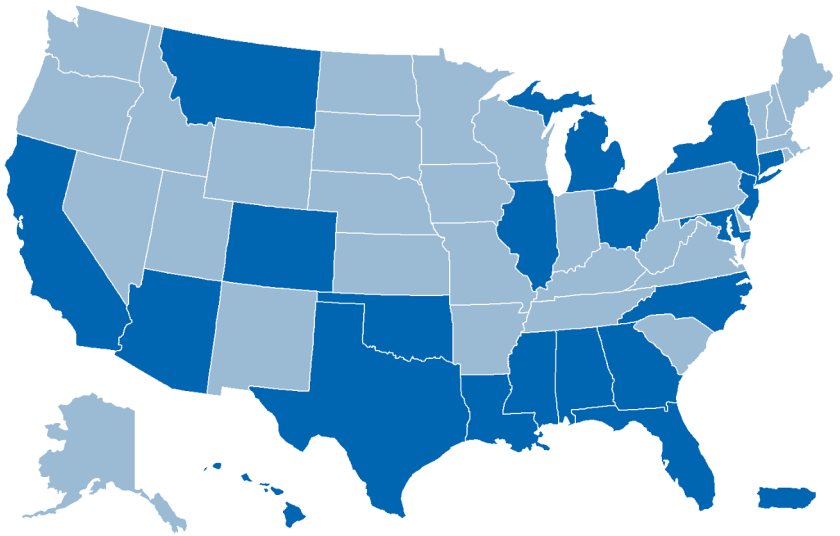
[EEJ Website]

EEJ Activities:

- **39 ROSES A.49 projects**
- 1 FINESST project
- 1 AIST project
- A subset of Indigenous Peoples Capacity Building Initiative activities
- A subset of DEVELOP projects
- A subset of Prizes and Challenges

Geographic Reach of

39 Projects Selected



Direct community impact

Indirect community impact

Ag, Food Security & Ag Burning
Health & Air Quality
Climate Hazards / Heat / UHI
Energy / Utilities
Greenspace / Tree Canopy
Disasters / Flooding
Wildfires
Water Resources
Transit / Prisons
Urban Development
Cross-Cutting

EEJ A.49 Projects

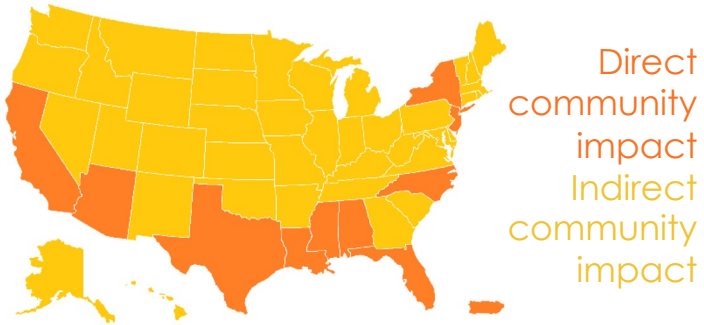
NASA Research Opportunities **NSPIRES website**

Landscape Analyses

Studies that use participatory data collection and assessment processes to increase NASA's understanding of the EEJ "landscape". Projects support characterization of EJ communities, environmental issues they face, their familiarity/use of EO, and opportunities for working with them to support planning and investment decisions.

Length: 6-9 months

10 Landscape Analyses

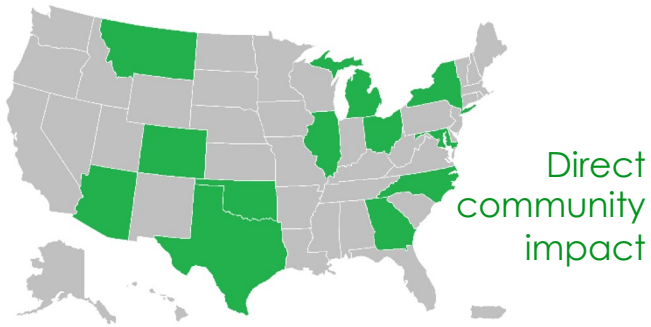


Community-based Feasibility Studies

Short-term projects that explore and test ways to address environmental issues facing EJ and underserved communities with the help of Earth science and geospatial information. Address community needs by co-designing with community organizations projects tailored to community needs, test and validate use of EO for local decision making.

Length: 12-18 months

13 Feasibility Studies

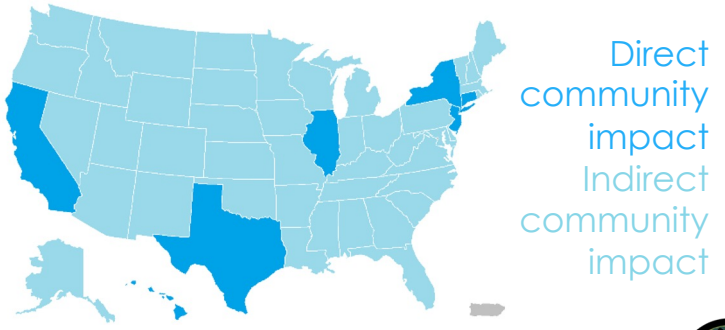


Data Integration Projects

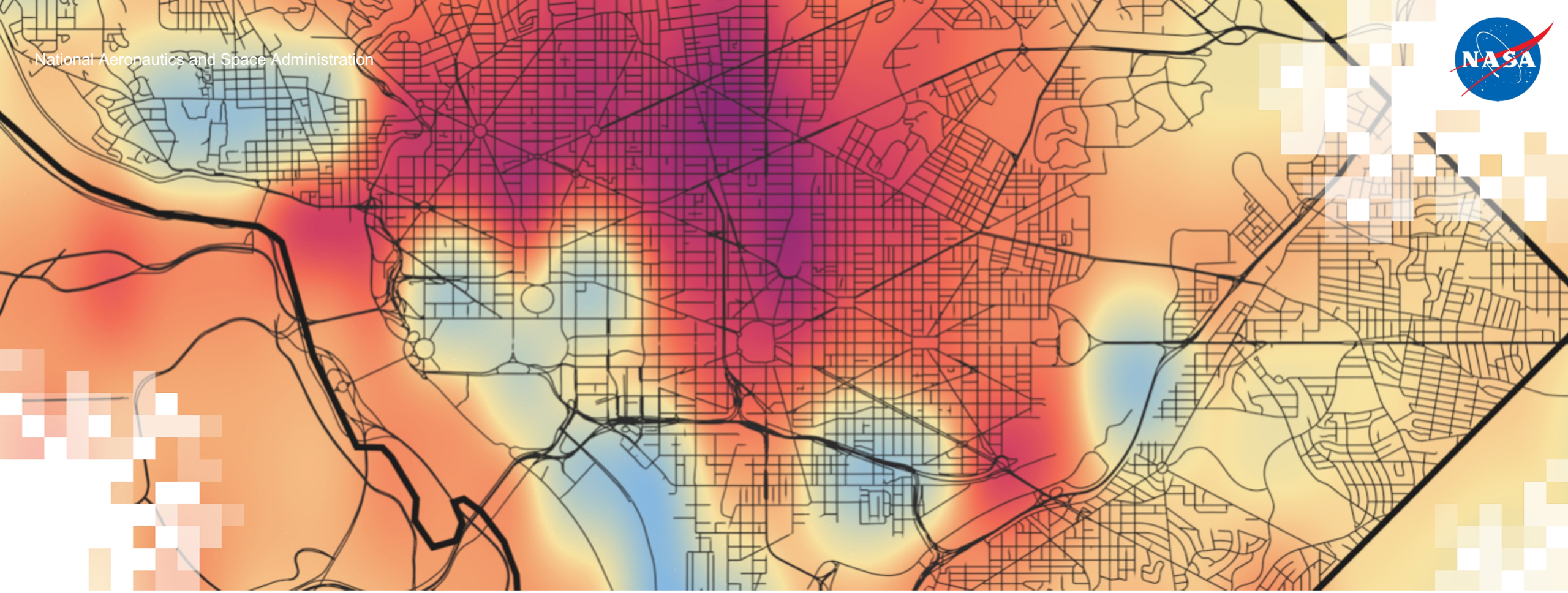
Projects that develop, test, and demonstrate sustained use of integrated Earth science, geospatial, and socioeconomic data, tools, and/or applications to support EJ communities with novel insights into community-level management. Culminate in GIS-enabled products or tools for public dissemination to support EEJ communities.

Length: 12-24 months

16 Data Integration Projects



National Aeronautics and Space Administration

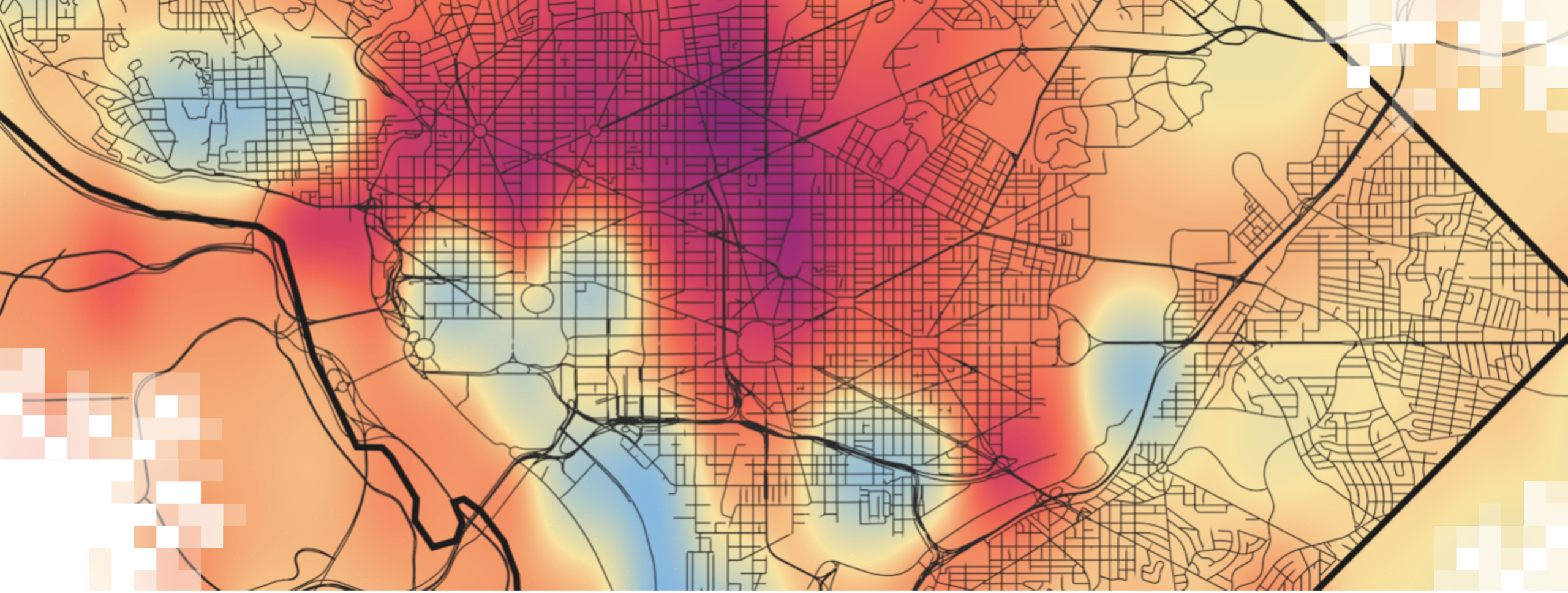


Satellite Data for Air Quality Environmental Justice and Equity Applications

Part 1: Use of Satellite Data in Environmental Justice Applications

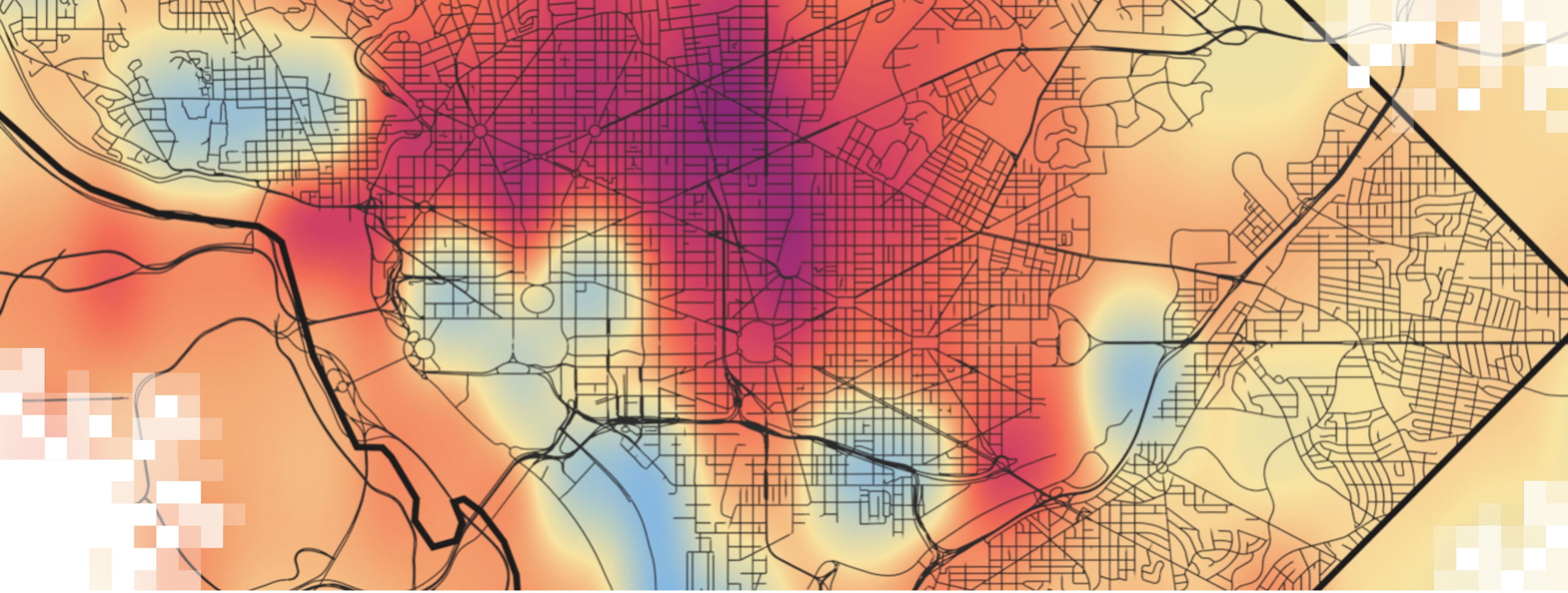
Tanya Kreutzer Sayyed (University of Maryland, Baltimore County), Ufuoma Ovienmhada (Massachusetts Institute of Technology) & Mitra Kashani (U. S. Centers for Disease Control and Prevention & Oak Ridge Institute of Science and Technology)

August 23, 2023



Satellite Data for Environmental Justice: A Scoping Review

Sayyed, T.K.*, Ovienmhada, U*, Kashani, M*, Vohra, K., Kerr, G., O'Donnell, C., Harris, M., Gladson, L., Titus, A., Adamo, S., Fong, K., Gargulinski, E., Soja, A., Anenberg, S., and Kuwayama, Y. (2023). "Satellite Data for Environmental Justice: A Scoping Review". In Prep. (* indicates co-first authorship)



Aims, Methods, & Results

Research Aims

1) **Explore trends** in study types, topics, geographic scope, and satellite **datasets** used to research EJ,

2) synthesize findings from studies that use **satellite data to characterize population disparities** across various topics, and

3) capture how **satellite data** is relevant to **policy and real-world impact**.

Research Methods & Inclusion Criteria

U.S., 2000 - 2022 Peer-Reviewed

Direct/Indirect Satellite Data

Population Disparities

Most Common Environmental Category of Studies Reviewed?

A. Light pollution

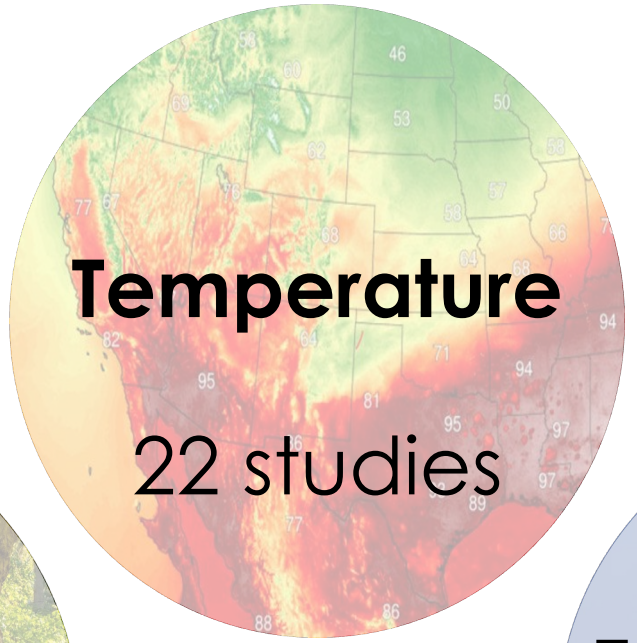
B. Temperature/Urban heat

C. Access to green spaces

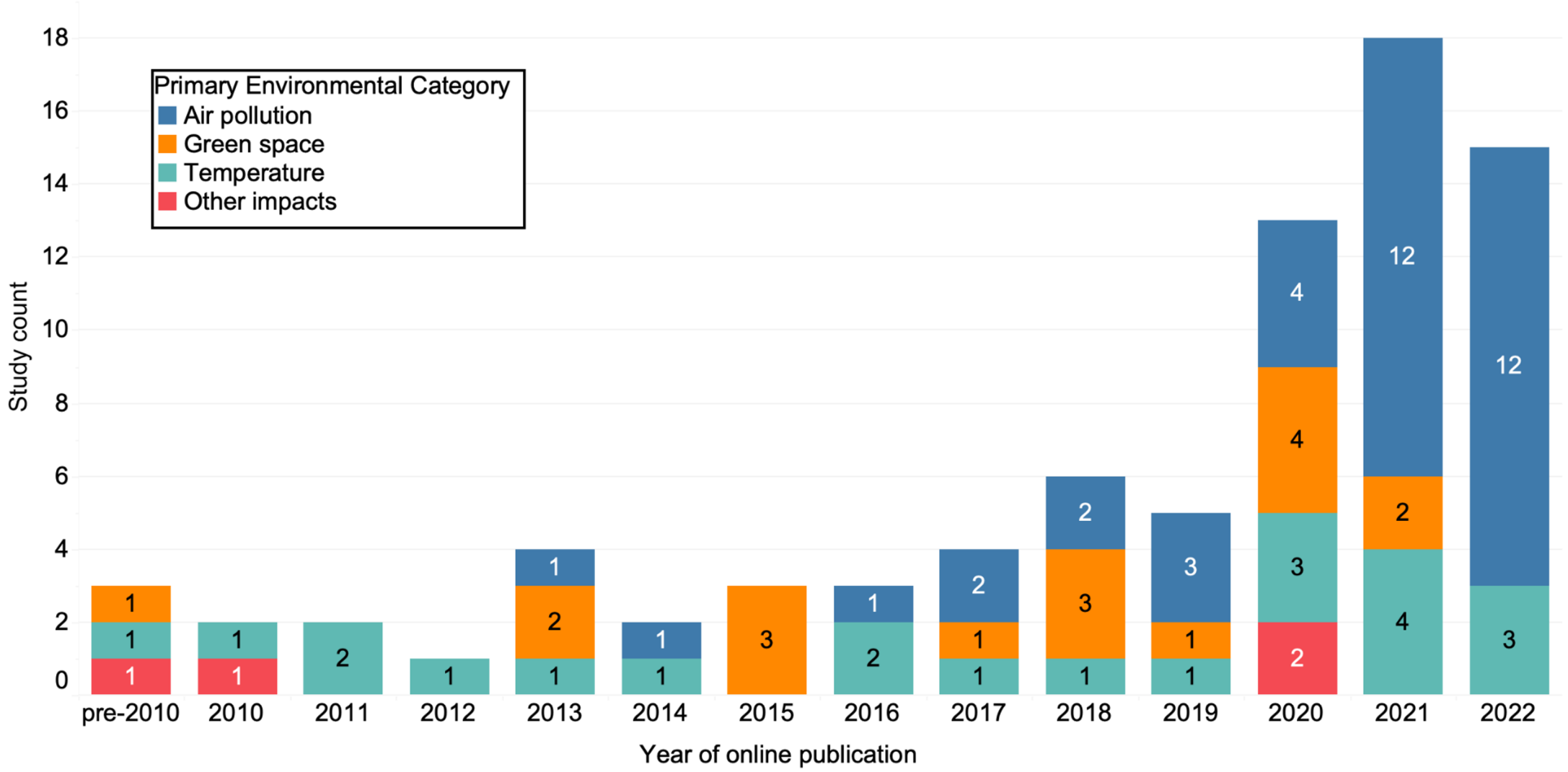
D. Air pollution

E. Flooding

Results: Studies Reviewed by Environmental Category



Results: Studies by Environmental Category & Year



Results: Social Categories of Difference and Datasets Examined

Social Category Examples:

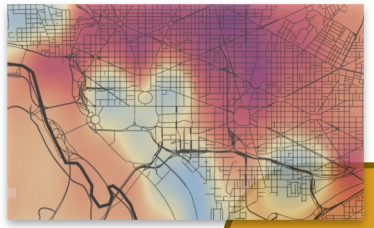
- **Race (n=66)**
- **Ethnicity (n = 46)**
- Poverty/Income
- Medicaid eligibility
- Education
- (Un)employment
- Redlining

Dataset Examples:

- Census Bureau/American Community Survey
- Centers for Medicare & Medicaid Services
- CDC's Social Vulnerability Index
- Social or Area Deprivation Index
- Department of Housing and Urban Development
- Mapping Inequality
- NASA's Socioeconomic Data & Applications Center

Results: Environmental Epidemiology Using Satellite Data

Environmental epidemiology is the study of relationships between environmental exposures and morbidity/mortality.



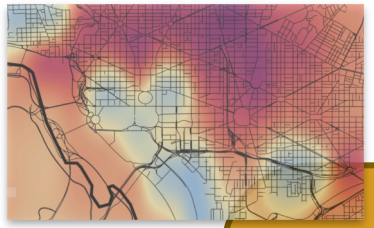
NO_2, O_3, $PM_{2.5}$

Associated with

Asthma in a Medicaid Population

Wei et al. (2022)

Results: Environmental Epidemiology Using Satellite Data



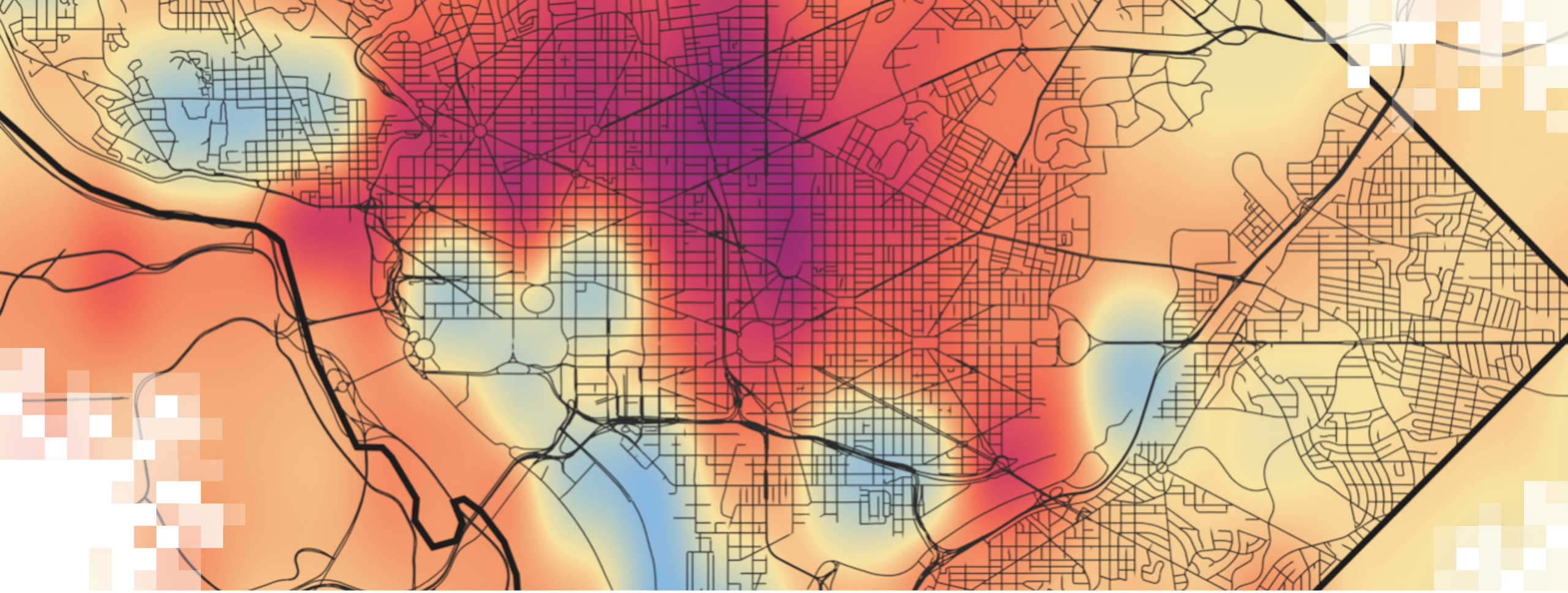
$PM_{2.5}$

Associated with

All-cause mortality and health risks attributable to air pollution

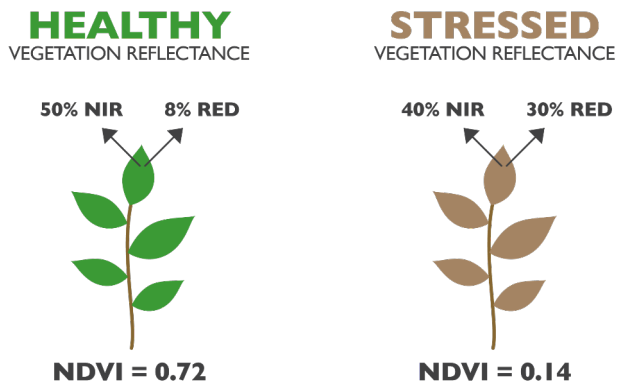
Castillo et al. (2020)

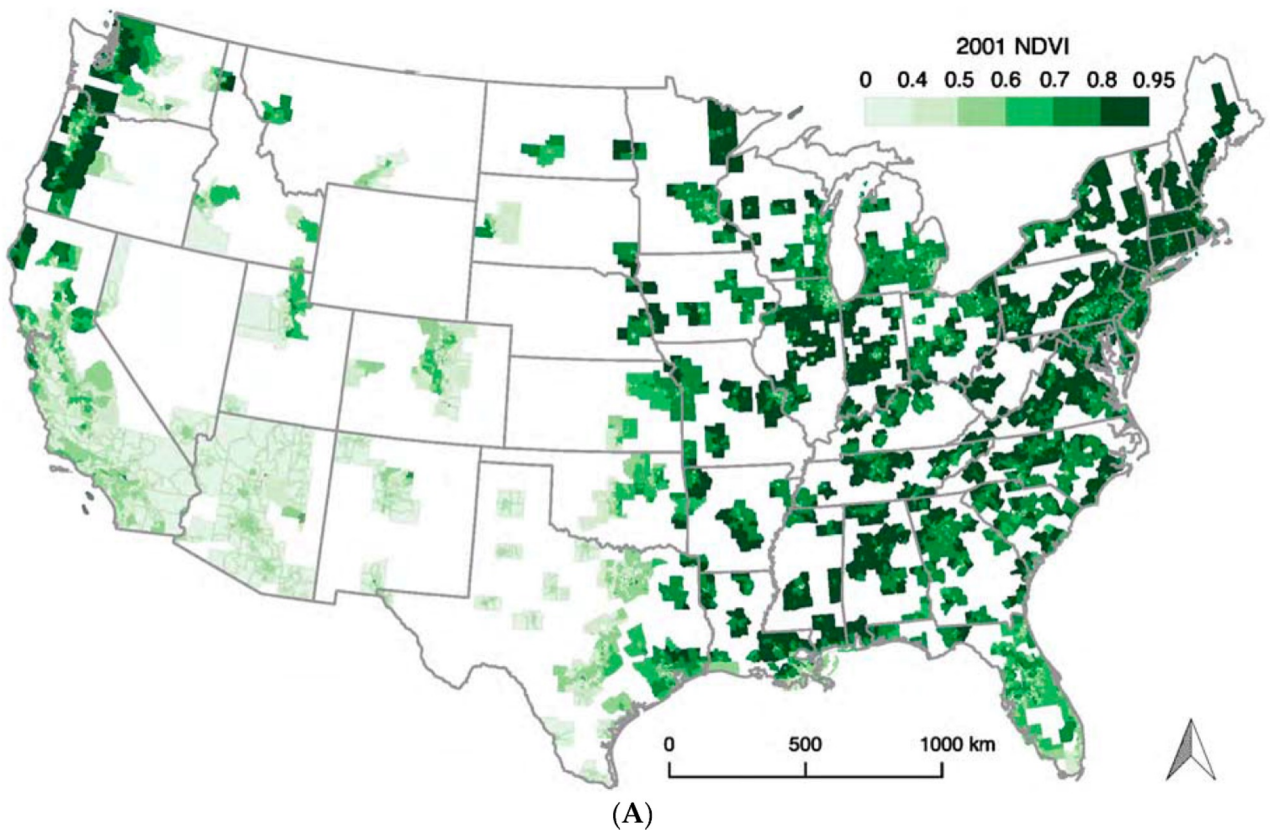
Synthesis:
Satellite Data Provides Evidence of Inequality and Injustice.



How is Satellite Data Used in Studies Reviewed?

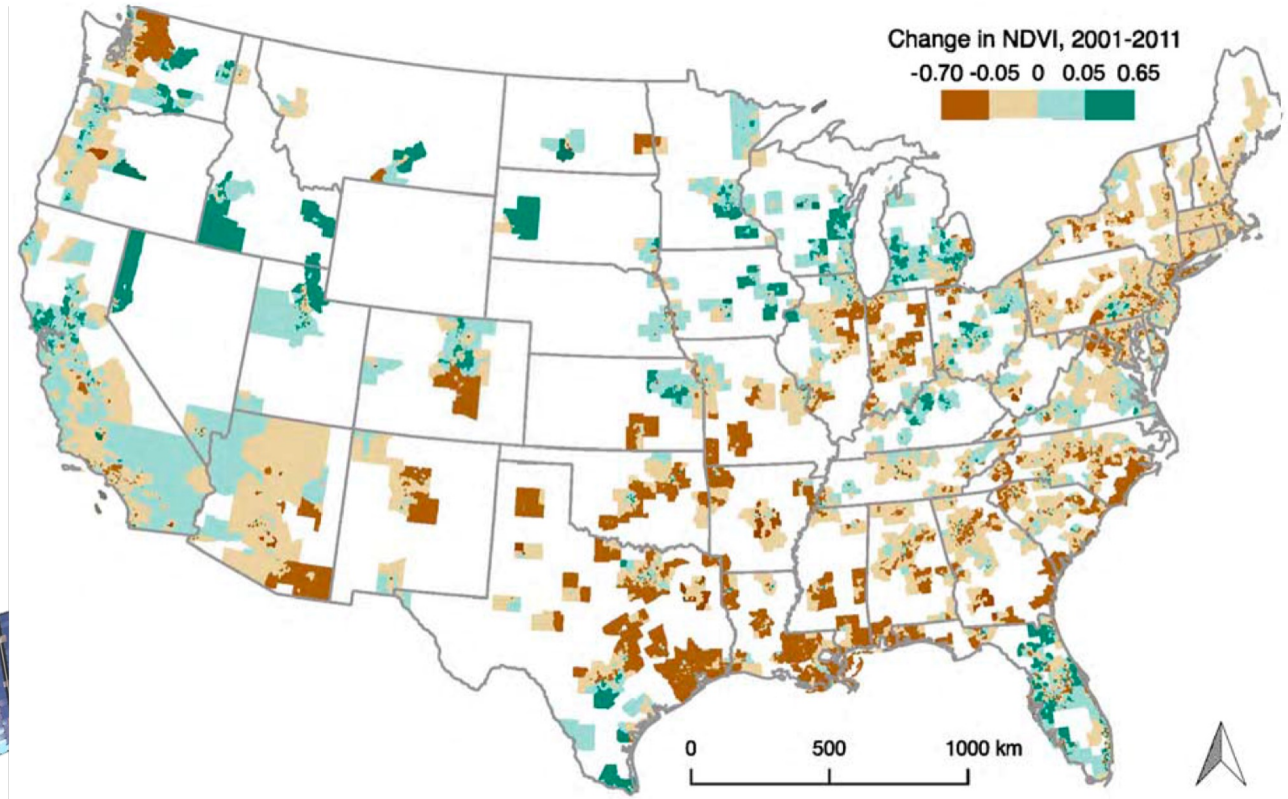
Satellite Data Provides Wide Spatial Coverage for Studies to Show Nationwide Disparities in Green Space.



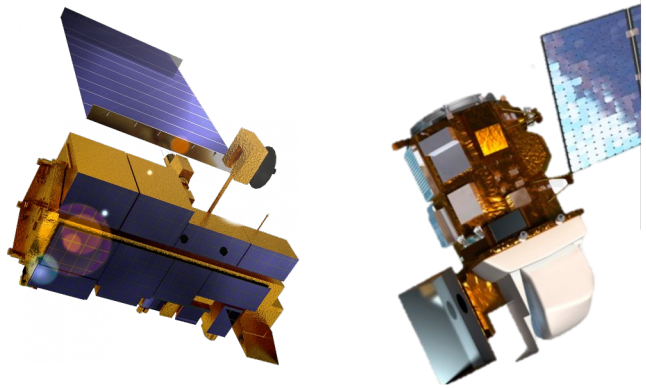


Casey et al. (2017)

Satellite Data Provides Long Temporal Coverage for Time Series Analysis.



Commonly used satellites include TERRA (left) and Landsat (right)



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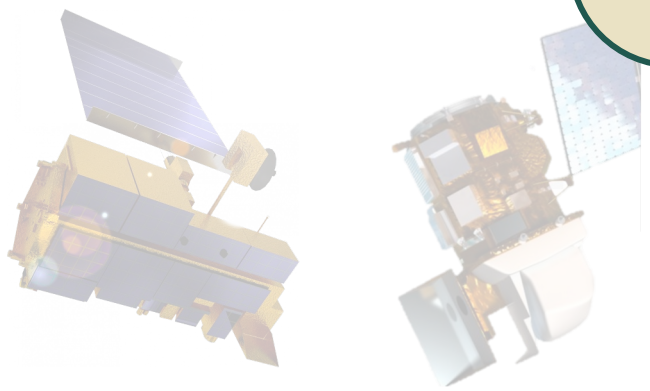
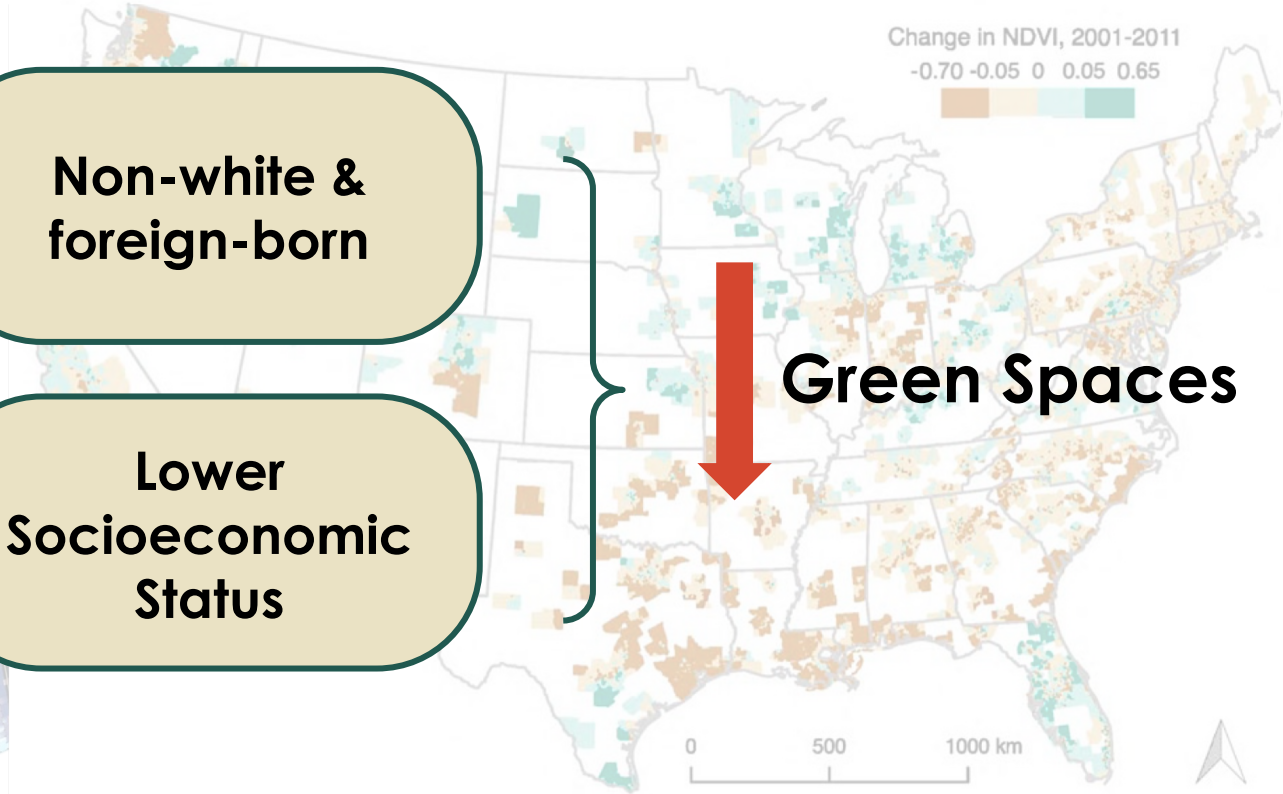


Non-white & foreign-born

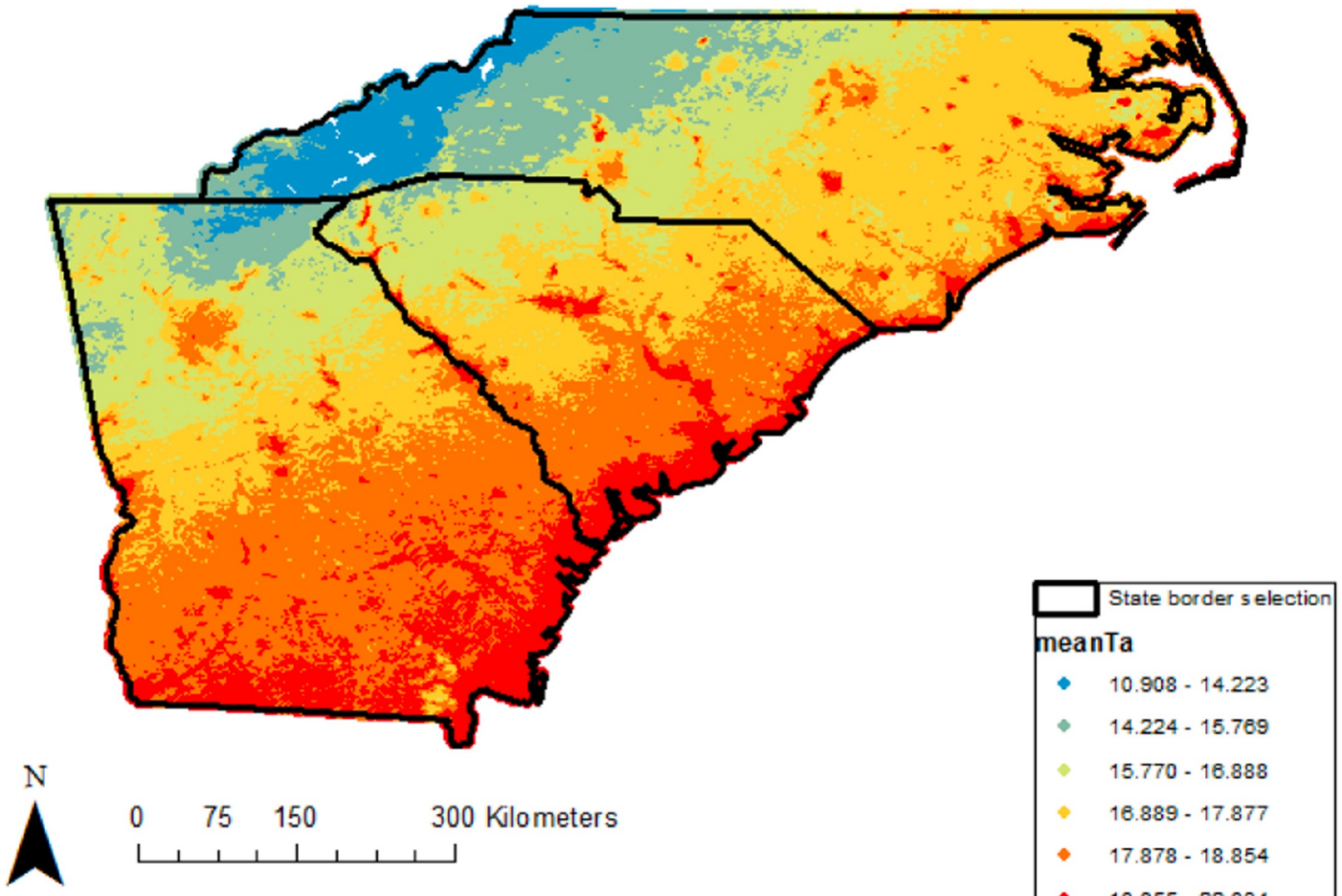
Lower Socioeconomic Status

Green Spaces



Casey et al. (2017)

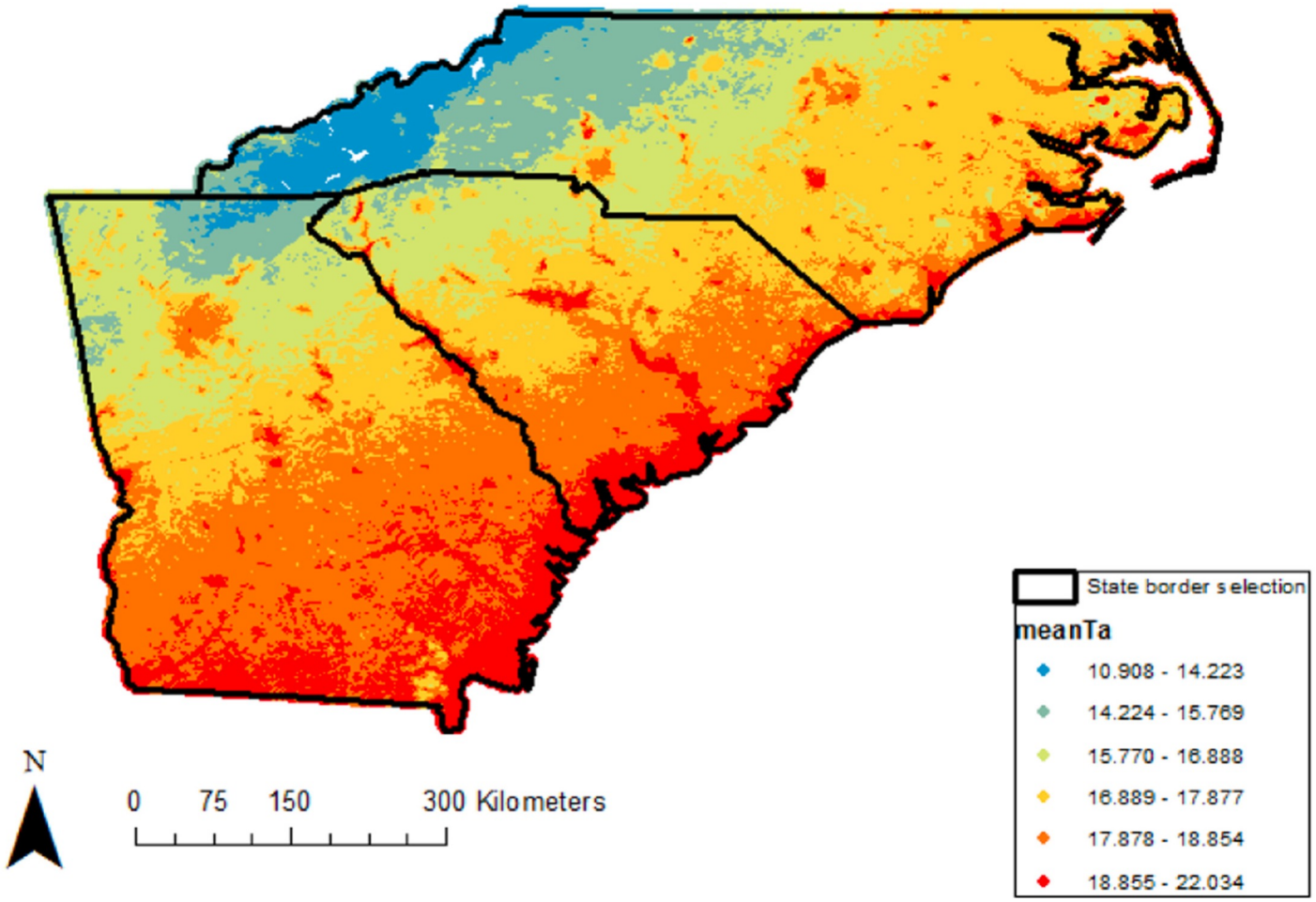
Satellite Data Improves Estimates of Exposure in Areas with Sparse Ground Monitors.



Used **Terra MODIS** to **model air temperature** at 1km2.

Lee et al. (2016)

Satellite Data Improves Estimates of Exposure in Areas with Sparse Ground Monitors.



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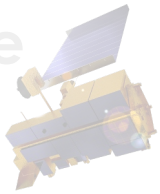
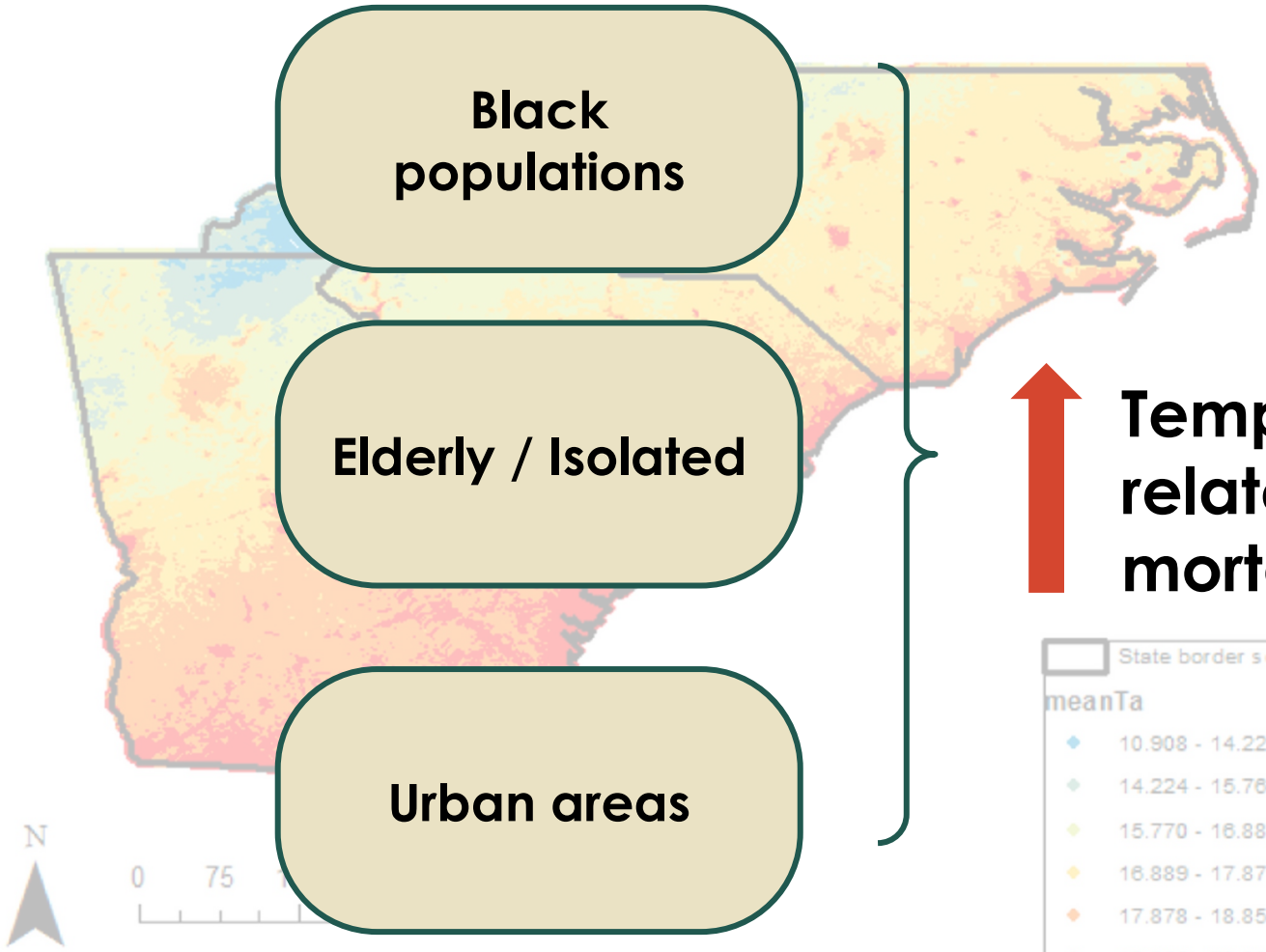


High-resolution data yielded **stronger relationships between temperature** and **mortality.**

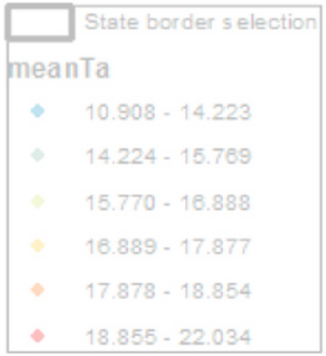
Lee et al. (2016)

Satellite Data Improves Estimates of Exposure in Areas with Sparse Ground Monitors.



Used **Terra MODIS** to **model air temperature** at 1km2

Temperature related mortality



High-resolution data yielded **stronger relationships between temperature** and **mortality.**

Lee et al. (2016)

Satellite Data Enables Assessment of Effect Modification.

Lower Socioeconomic Status

Air pollution related mortality

Modeled PM 2.5 using Terra MODIS

Son et al. (2021)

Satellite Data Enables Assessment of Effect Modification.

Lower Socioeconomic Status

+

Green Spaces

Terra MODIS

Air pollution related mortality

Modeled PM 2.5 using Terra MODIS

Son et al. (2021)

Satellite Data Enables Assessment of Effect Modification.

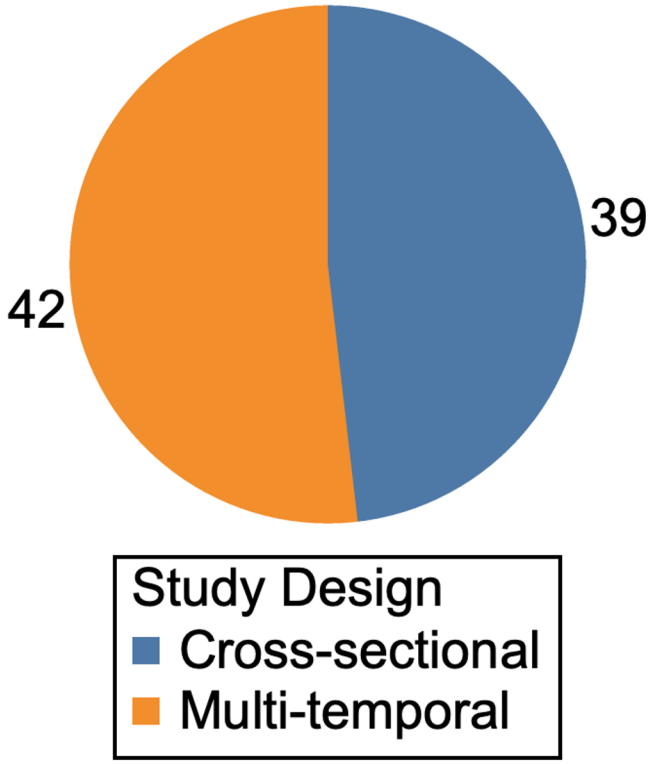
Lower Socioeconomic Status + ↓ **Green Spaces** = ↑ **Air pollution related mortality**

Terra MODIS

Modeled PM 2.5 using Terra MODIS

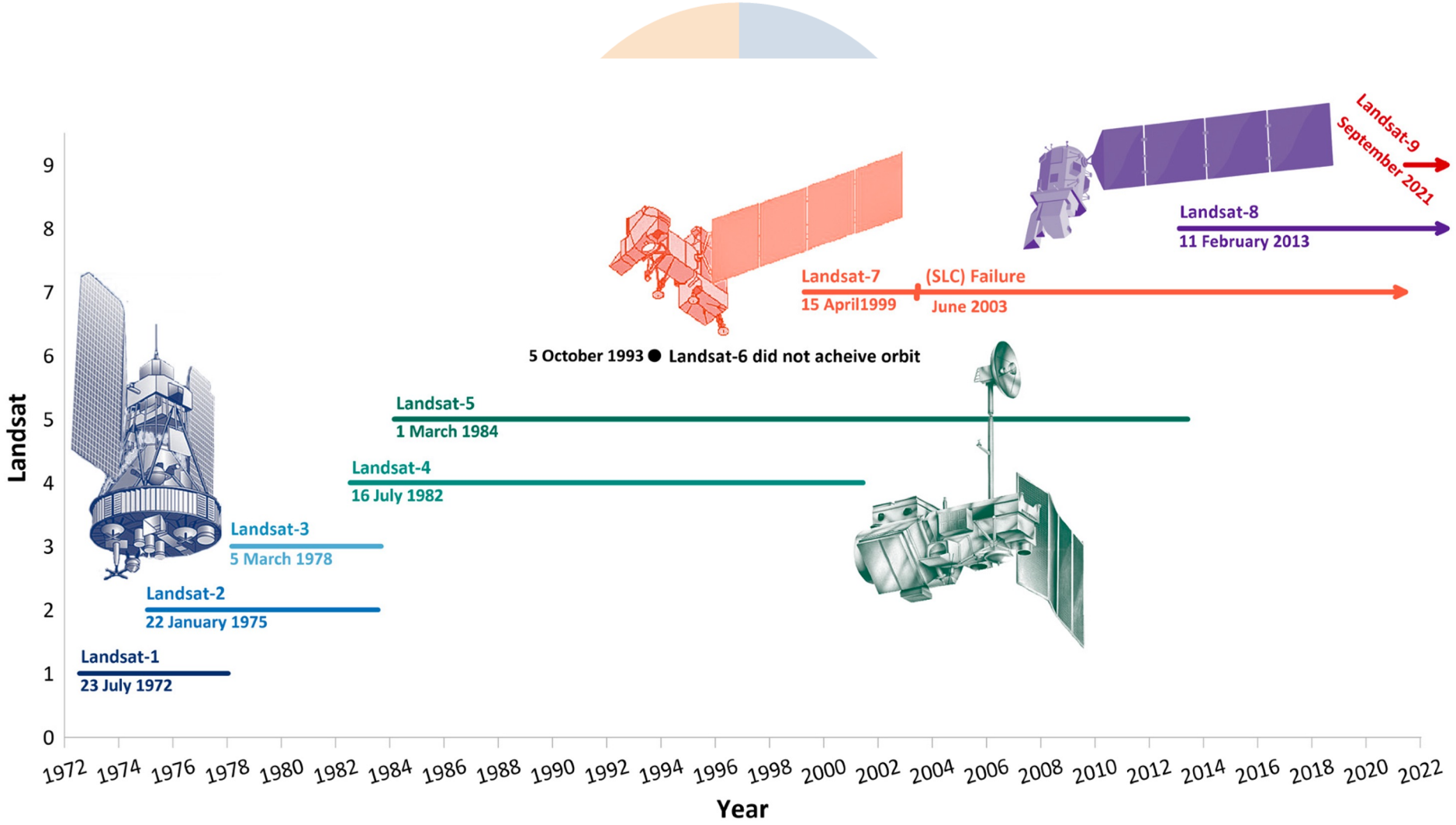
Son et al. (2021)

Other Insights on the use of Satellite Data: Temporal Coverage

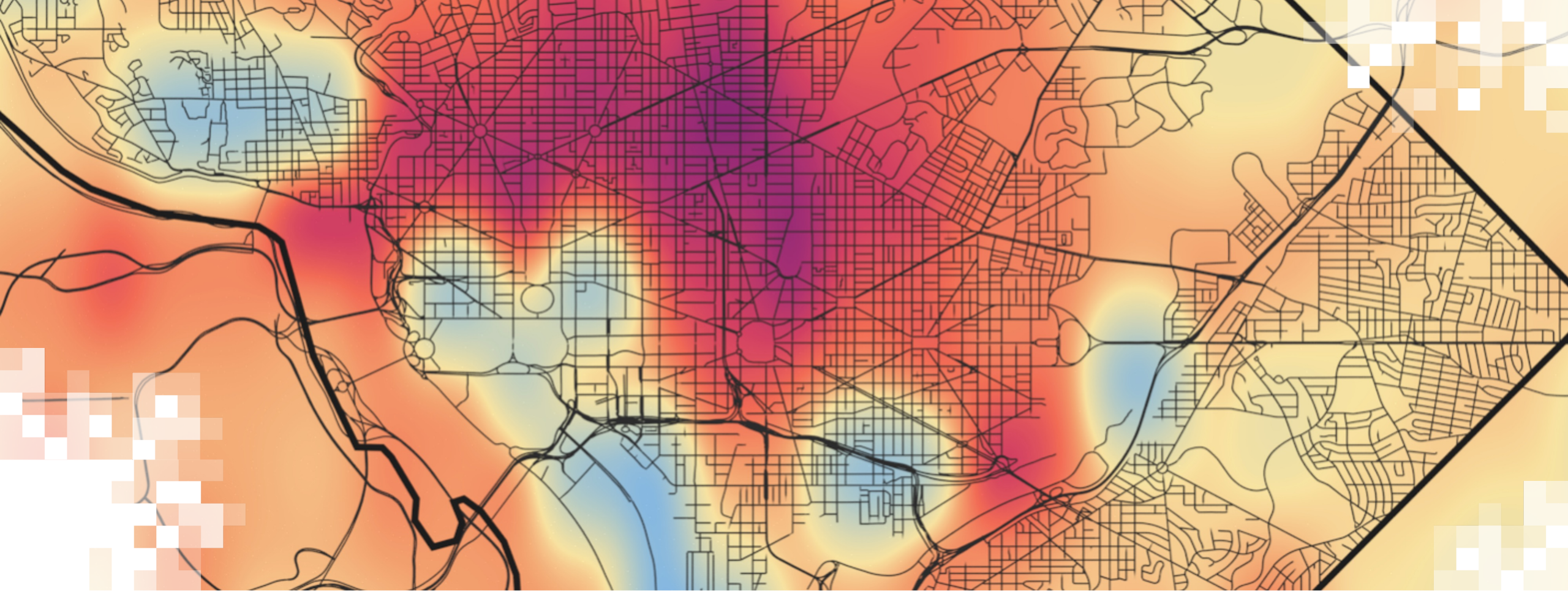


Breakdown of Total Studies Included in our Review (n=81) by Study Design.

Other Insights on the use of Satellite Data: Temporal Coverage



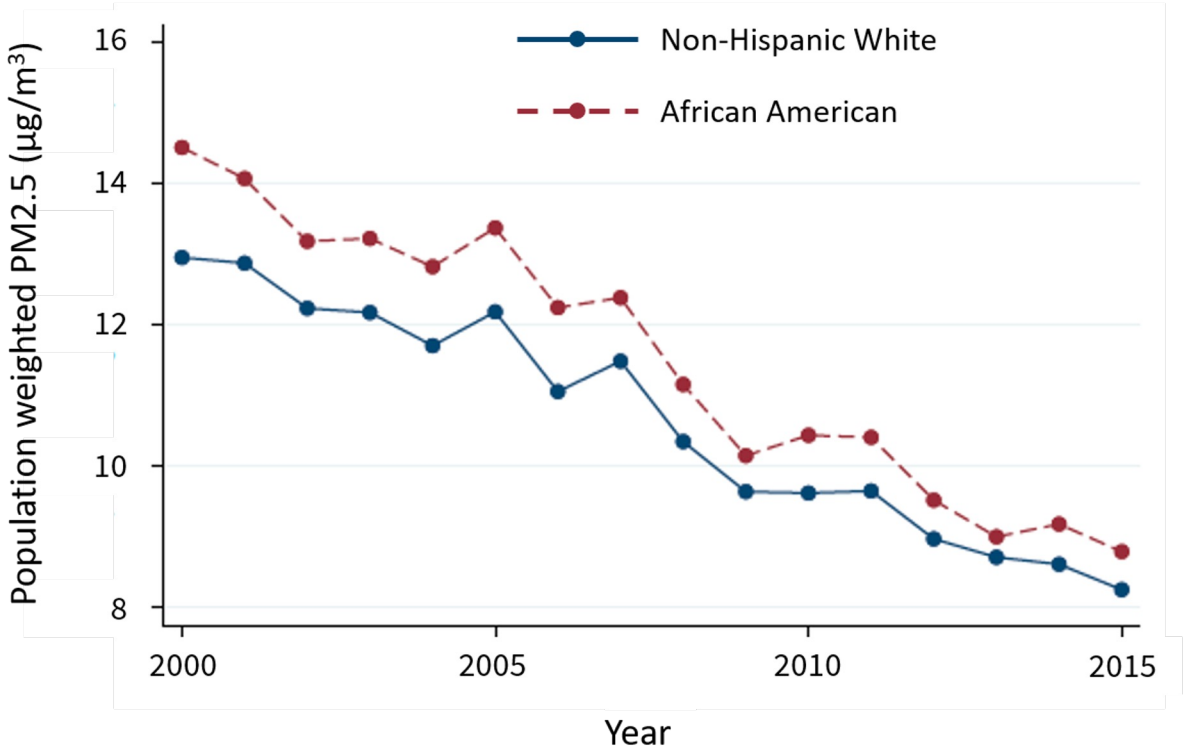
Hemati et al. (2021)



Public Health & Policy Implications

Satellite Data can Inform Real-World Impact of Environmental Policies, like the EPA's Clean Air Act.

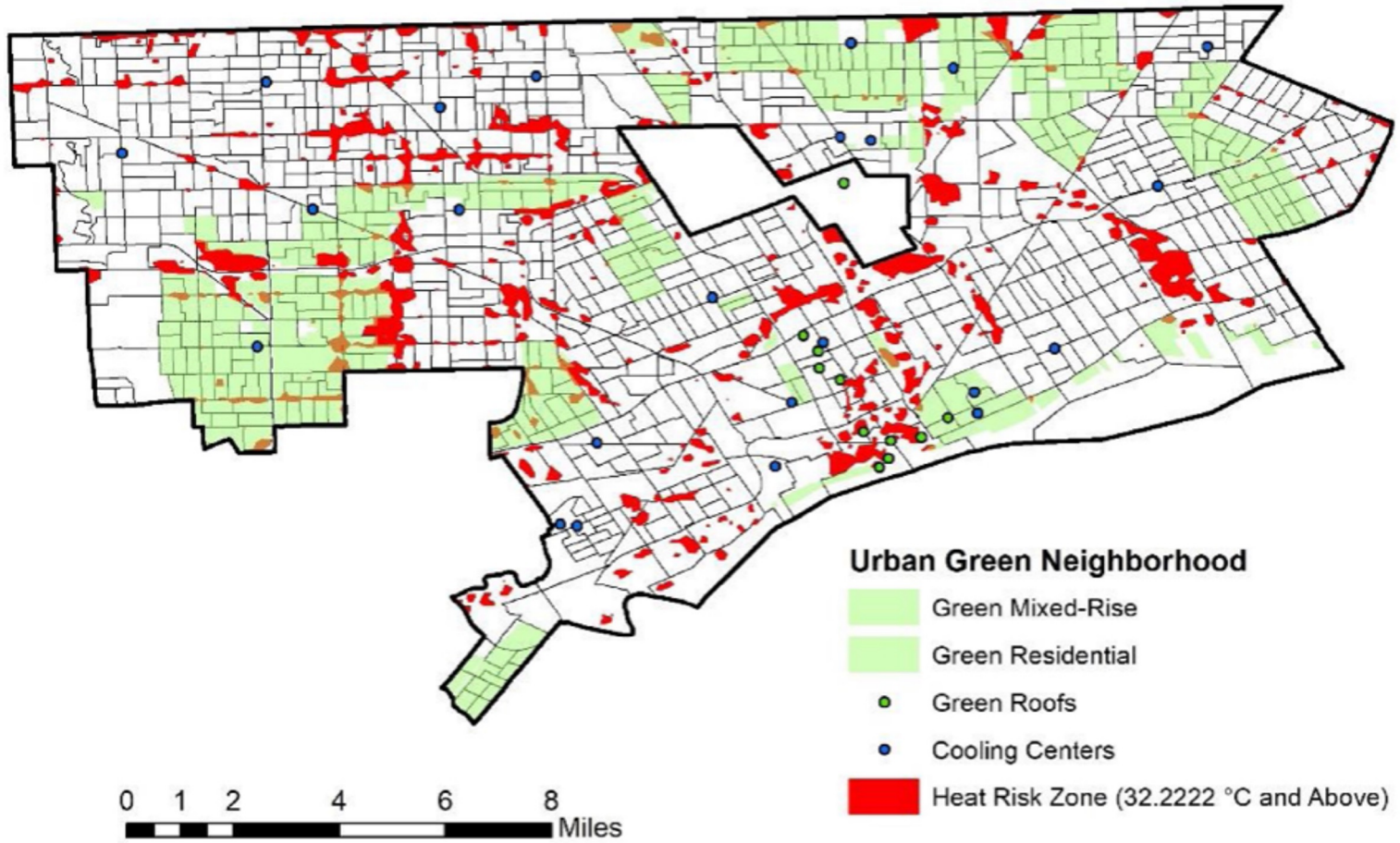
Using multitemporal satellite data showed that the **Clean Air Act reduced PM2.5 exposure among Black communities** more than in White communities, **but there is a persistent difference in exposure.**



Currie et al., (2020), Currie et al. (2023)

Using Satellite Data to Evaluate Equity of Heat Mitigation Plans

- Combined temperature data with Detroit's ***Future City*** plan for **heat mitigation through greening**
- **Existing green roofs** are in most **affluent areas.**
- **Black populations** with high heat risk would have **highest access** to **green space.**

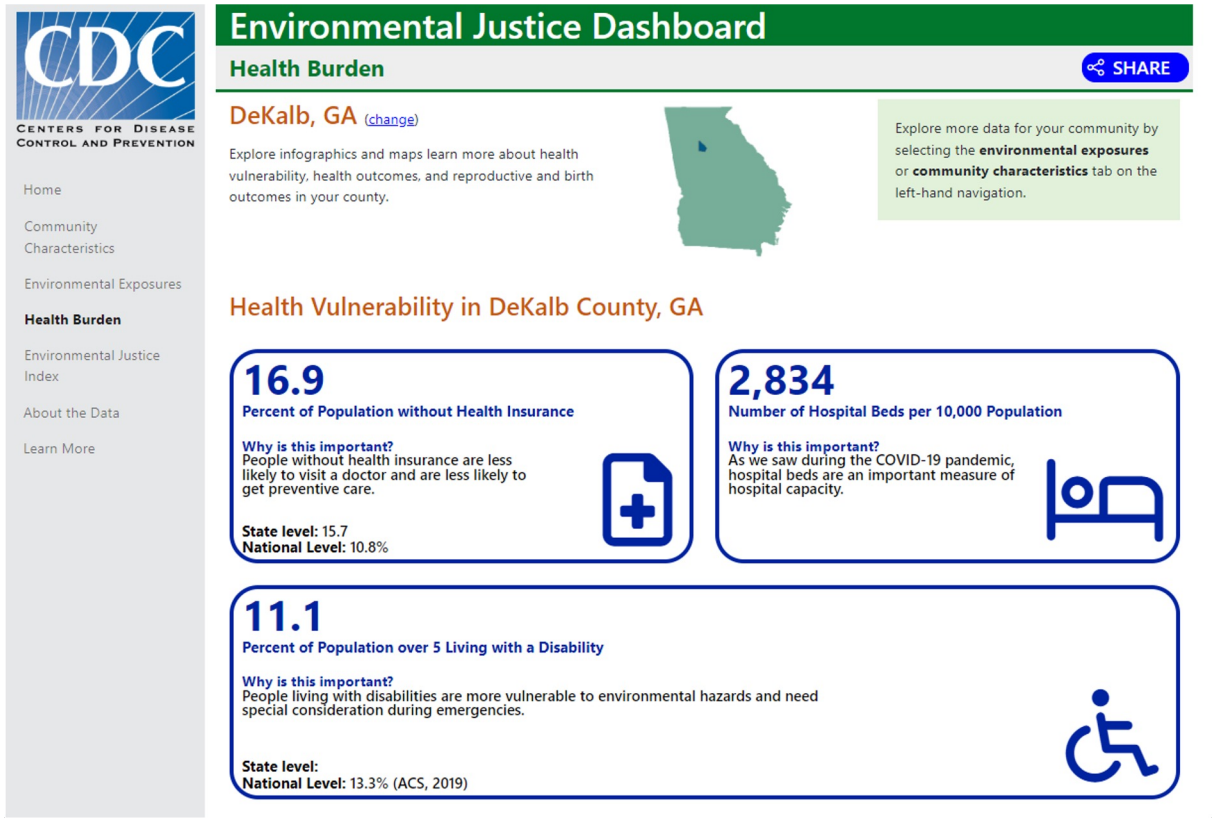


Sanchez and Reames, 2019

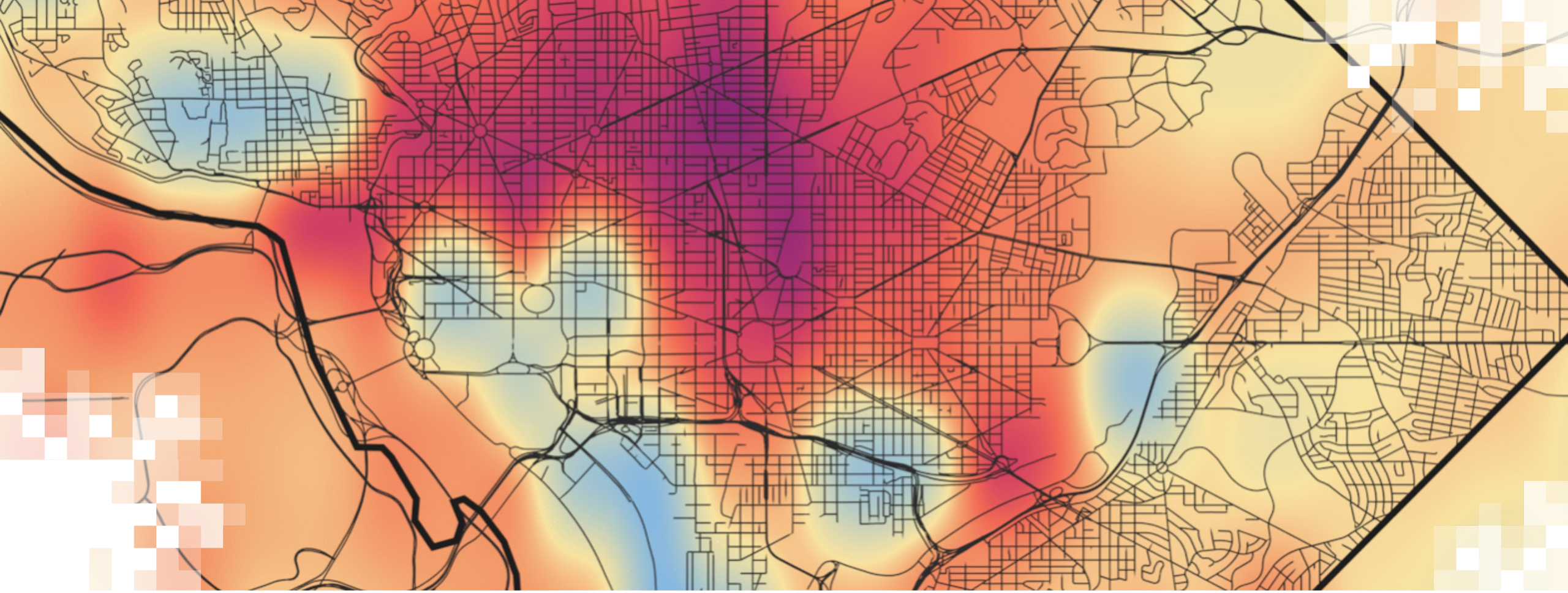
Environmental Justice Screening Tools

- The ability to link satellite data with health data could also **improve public health monitoring and screening tools.**

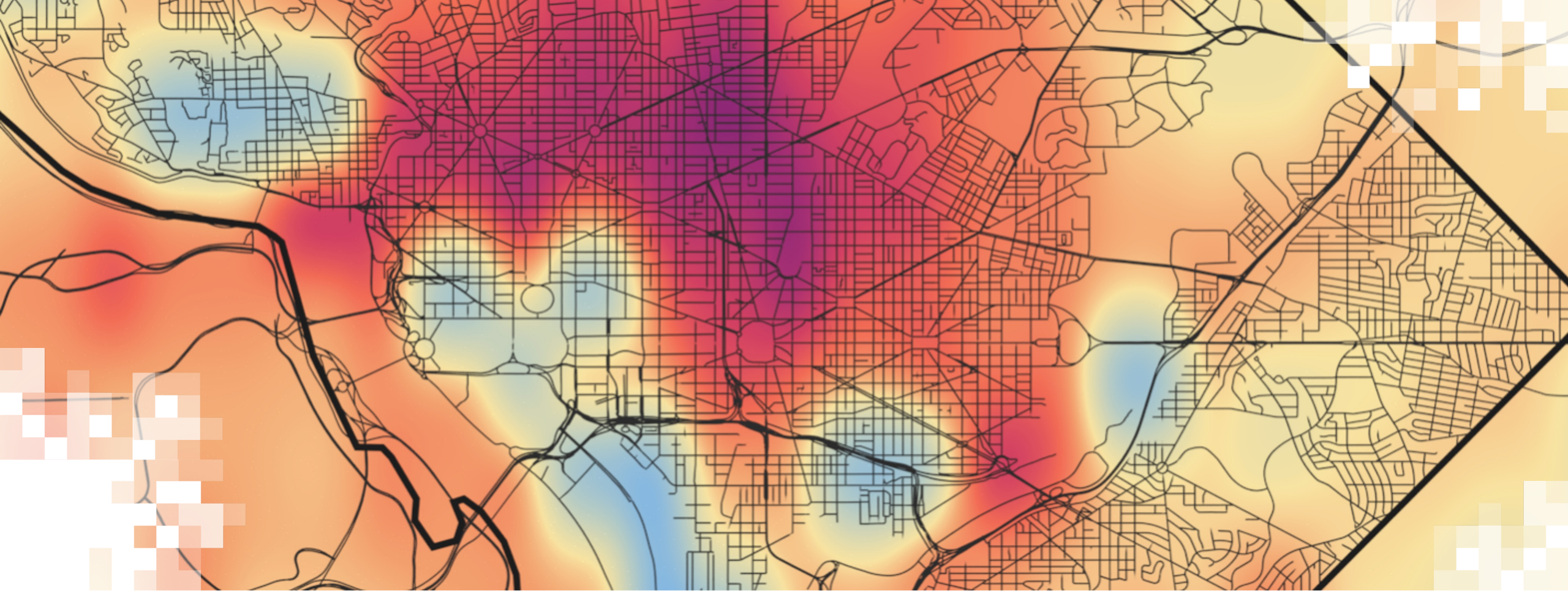
- **Examples:**
  - The Centers for Disease Control and Prevention's *Environmental Justice Dashboard*
  - California's *CalEnviroScreen*



CalEnviroScreen

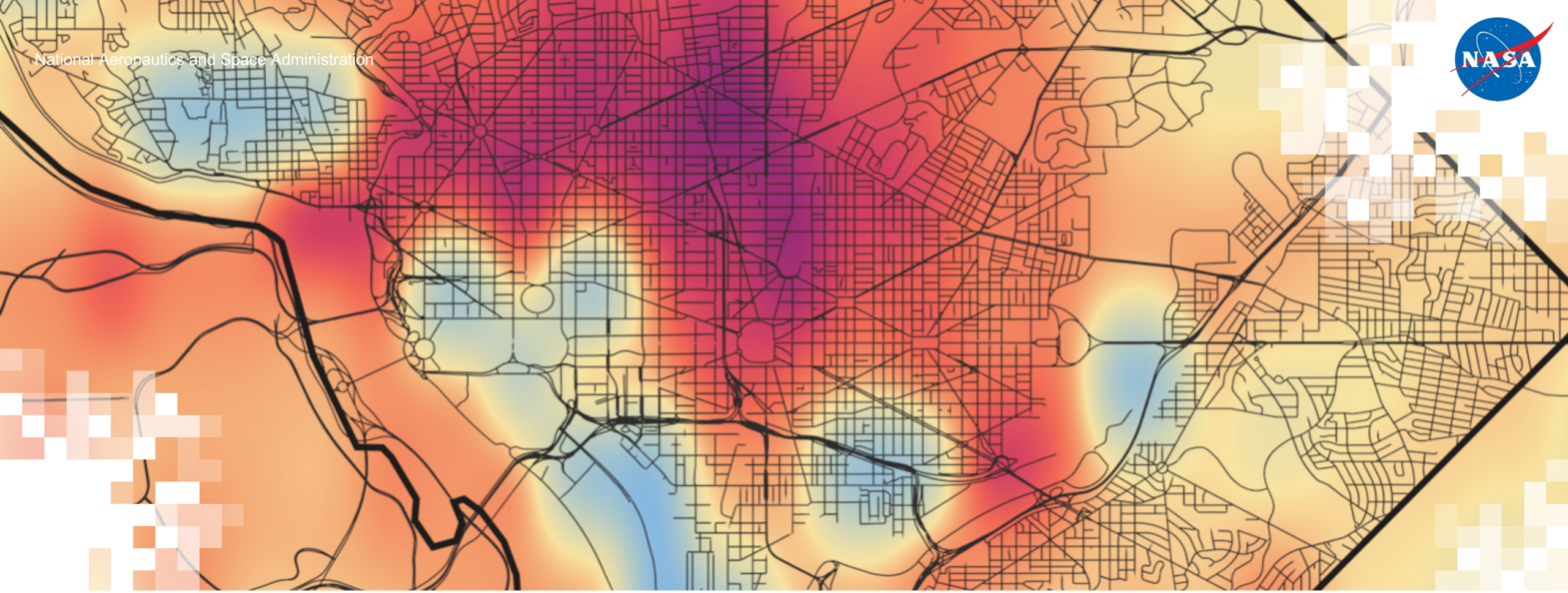


Conclusion



Case studies

1. Light at Night (LAN): A Public Health and Environmental Justice Issue
2. The Environment-Vulnerability-Decision-Technology (EVDT) Framework to support social and environmental sustainability
3. Temperature and Energy Justice Mapping Tool

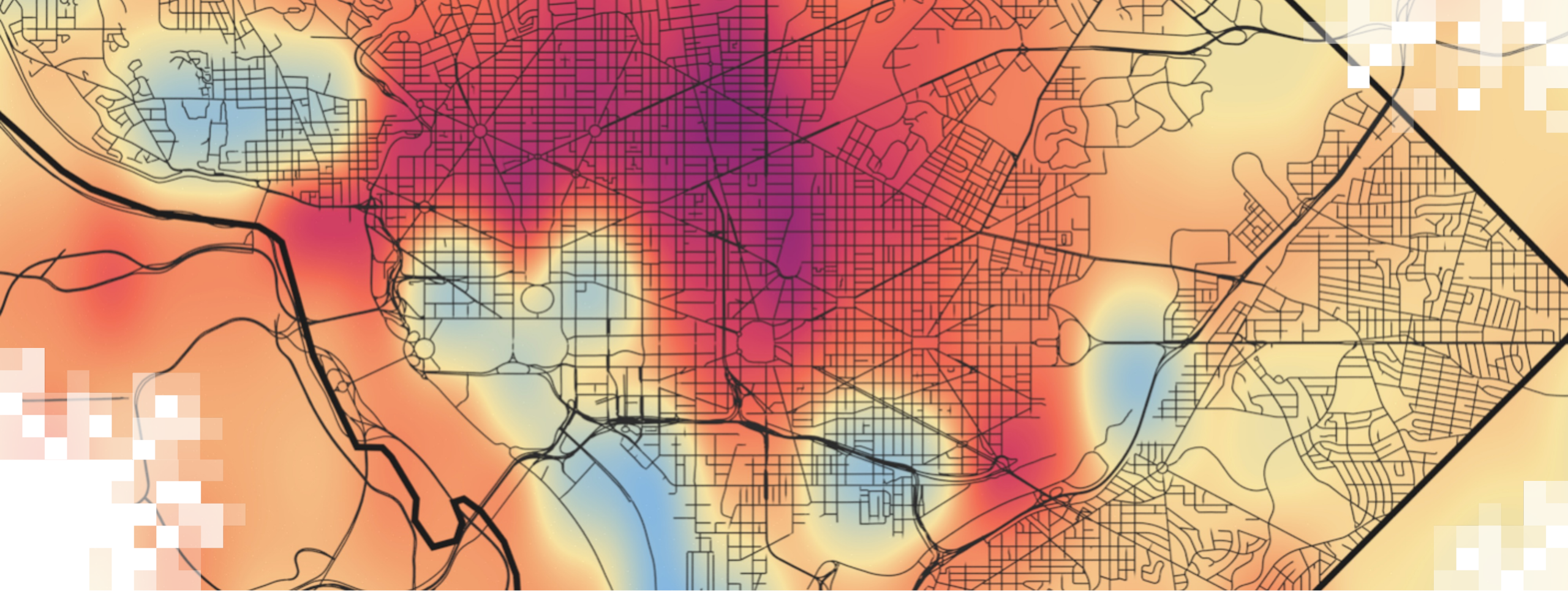


Satellite Data for Air Quality Environmental Justice and Equity Applications

Part 1: Use of Satellite Data in Environmental Justice Applications

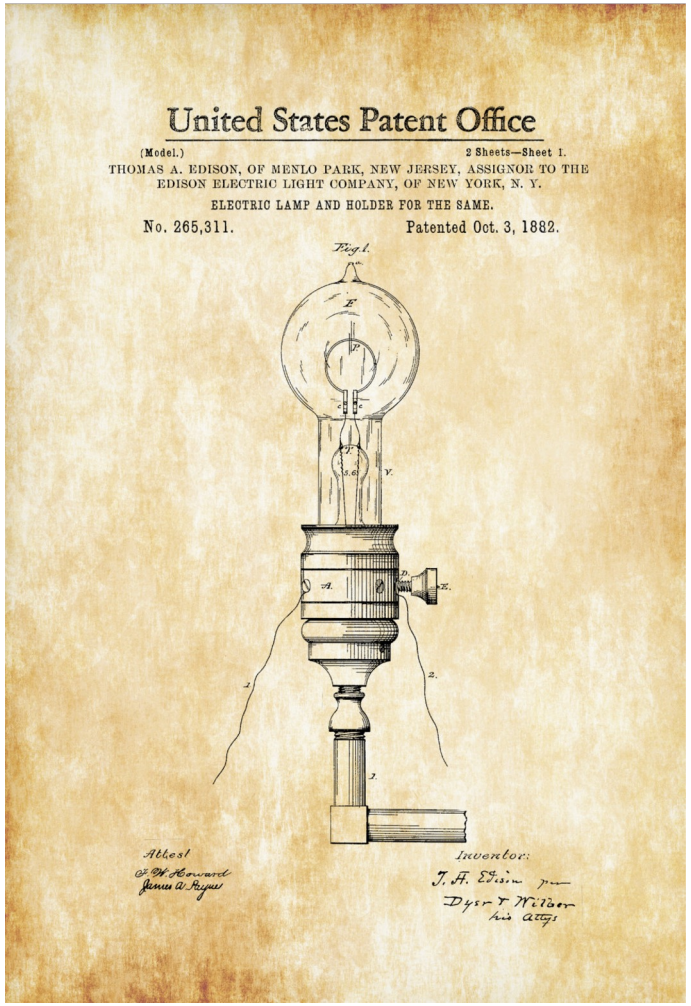
Xiao, Qian PhD (Department of Epidemiology, Human Genetics, and Environmental Sciences
University of Texas Health Science Center at Houston)

August 23, 2023



Light at Night (LAN): A Public Health and Environmental Justice Issue

The United States at Night



United States Patent Office.

(Model.) 2 Sheets—Sheet 1.

THOMAS A. EDISON, OF MENLO PARK, NEW JERSEY, ASSIGNOR TO THE EDISON ELECTRIC LIGHT COMPANY, OF NEW YORK, N. Y.

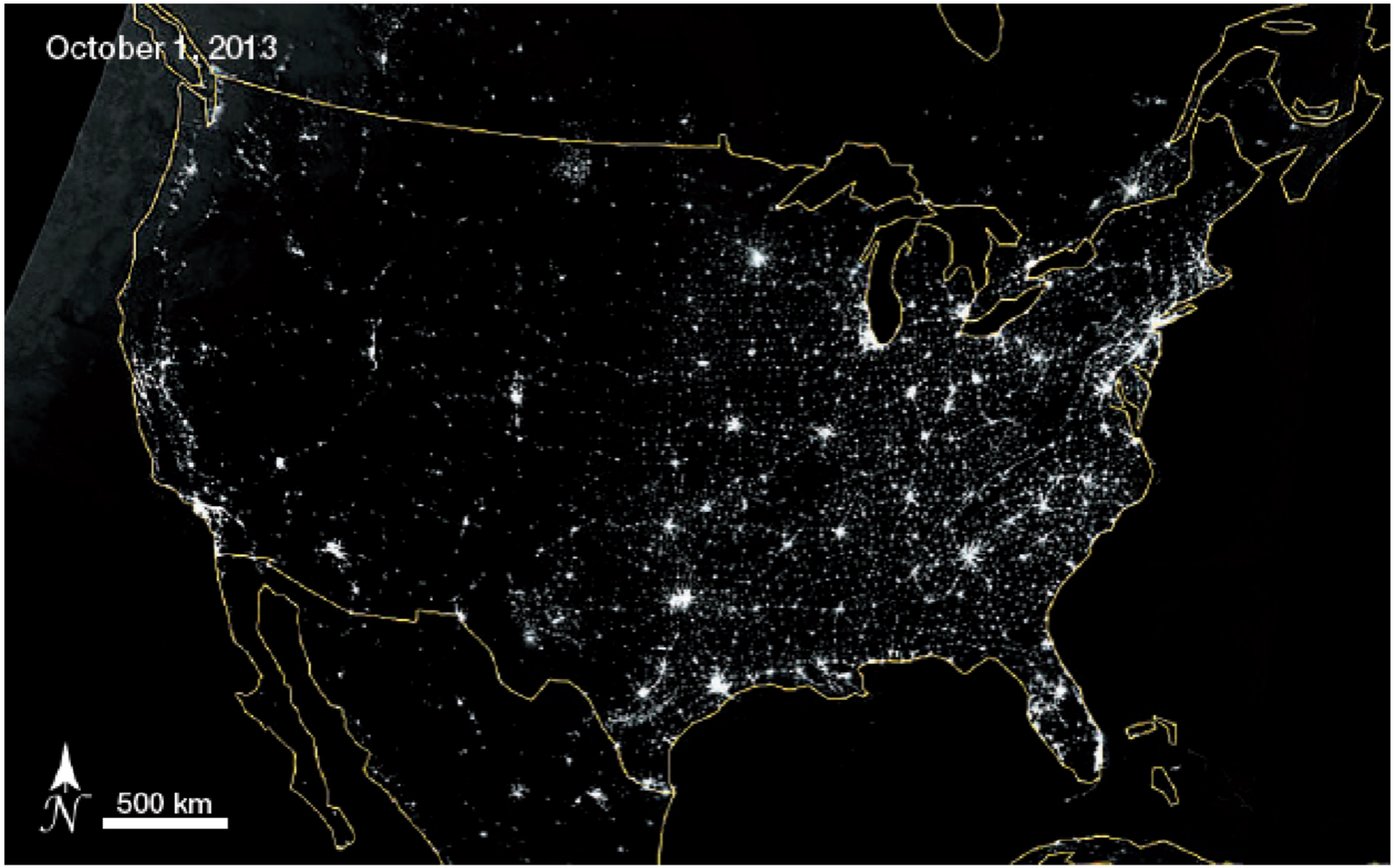
ELECTRIC LAMP AND HOLDER FOR THE SAME.

No. 265,311. Patented Oct. 3, 1882.

Fig. 1.

Attest
C. M. Howard
James A. Ryder

Inventor:
T. A. Edison
Dyer & Wilson
his attys



LAN: Circadian Disruptor and Health Consequences

- LAN is a ubiquitous environmental exposure.
- The benefits of electric lighting are also accompanied by serious ecological, economical and public health consequences.
- LAN suppresses melatonin and enables nighttime activities that are misaligned with the circadian clock.
- LAN has been linked to numerous health problems:
  - Sleep deficiency
  - Mental disorders
  - Cognitive decline and dementia
  - Cancer
  - Type 2 diabetes
  - Obesity

LAN as an Environmental Justice Issue

Contents lists available at ScienceDirect

Environmental Research

journal homepage: www.elsevier.com/locate/envres

Light pollution inequities in the continental United States: A distributive environmental justice analysis

Shawna M. Nadybal [a], Timothy W. Collins [a,*], Sara E. Grineski [b]

"Americans of Asian, Hispanic or Black race/ethnicity had population-weighted mean exposures to light pollution in their neighborhoods that are approximately two times that of White Americans."

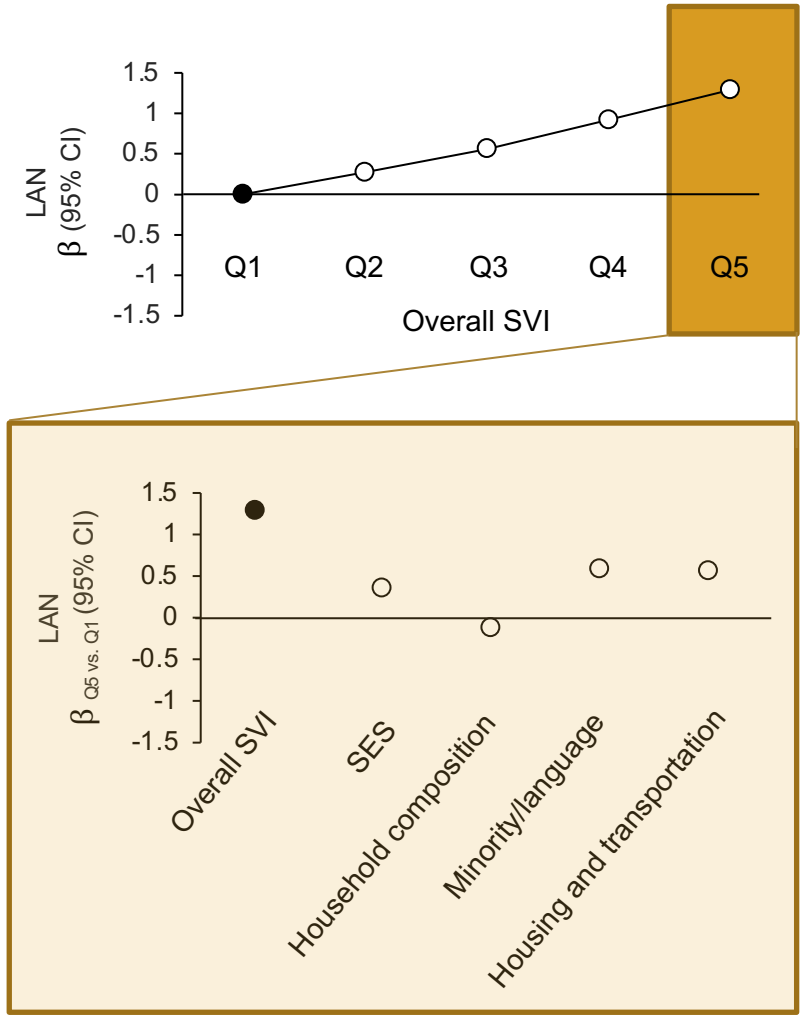
LAN and Social Vulnerability: A Nationwide Analysis

- LAN was estimated using the Black Marble data suite (2012-2019).

- Social Vulnerability Index (SVI, 2014-2018) was derived by the CDC.
  - Overall
  - Individual components: SES, household composition/disability, minority/language, housing and transportation

- We conducted analysis at census-tract level across the contiguous US.
  - Examine the association between LAN and SVI (overall and individual components).
  - Examine how this association differs by rural-urban status (RUCA code, 1-10) and US regions.

Social Vulnerability is Associated with Higher LAN



- There was a linear and positive relationship between SVI and LAN – higher vulnerability, higher LAN.
- The association differed by individual SVI components.
  - SES, minority status and housing/transportation were the drivers of the positive association.
  - Household composition was not associated with LAN.

Rural-Urban and Regional Differences: A Complex Picture

- The association between LAN and SVI was not universal across different tracts with different rural-urban status.
- The positive relationship with overall SVI was strong in urban cores and in rural areas, but weak in suburbs.
- Rural-urban differences for individual SVI components are even more complex.
- We also observed regional differences (i.e., Northeast, Midwest, South, West).

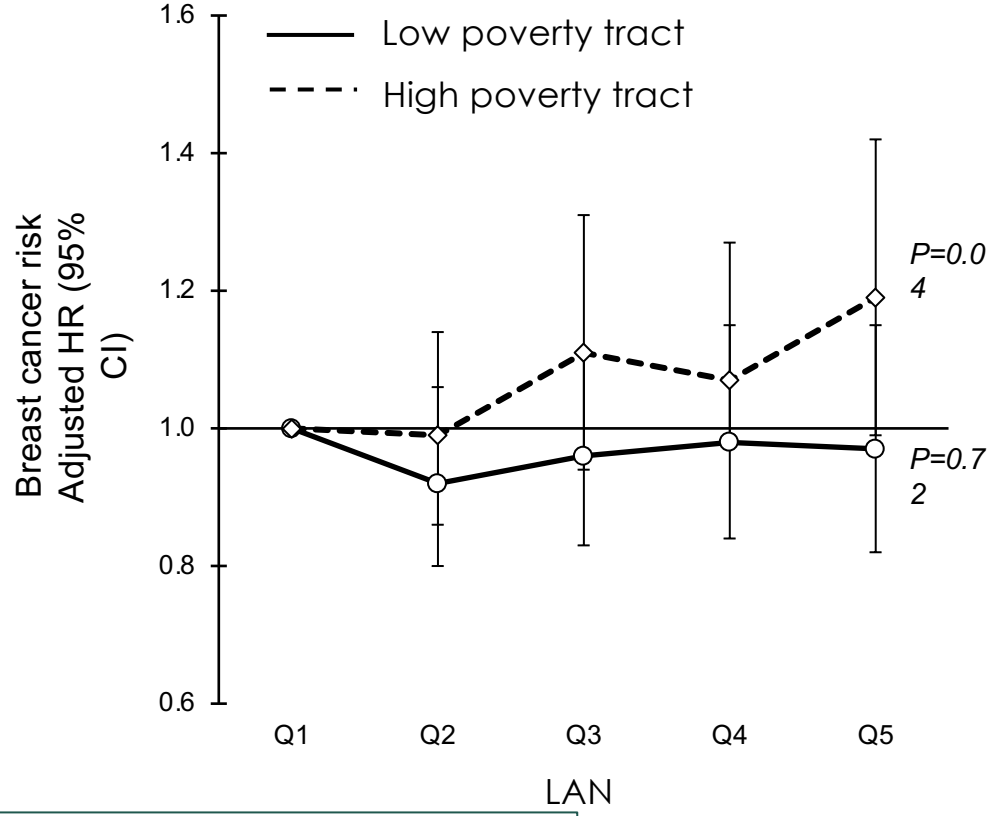
Conclusions

- Overall, more vulnerable communities are exposed to higher LAN.
- However, the relationship differs by SVI components, rural-urban status and regions.
- Therefore, multiple factors need to be considered in order to identify communities with highest light pollution.
- Future direction: How may environmental injustice in LAN have contributed to health disparities?

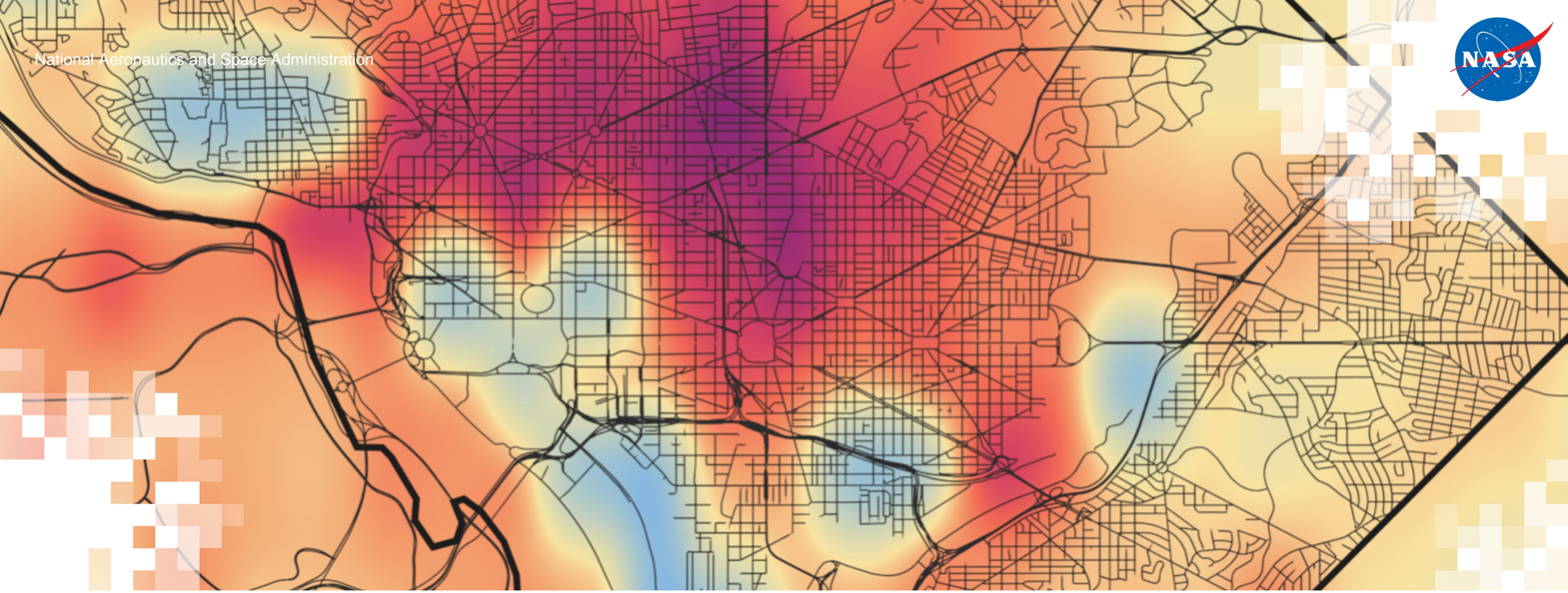
LAN and Breast Cancer: Different Neighborhoods, Different Responses

- The link between LAN and breast cancer was **stronger** for women living in high poverty neighborhoods.

- Women living in disadvantaged neighborhoods may be more vulnerable to the adverse effects associated with high LAN.
  - Poor housing/sleep conditions.
  - Challenging work schedule.
  - Stress.



LAN as an EJ issue
- Identify vulnerable communities.
- Develop, implement and evaluate interventions.

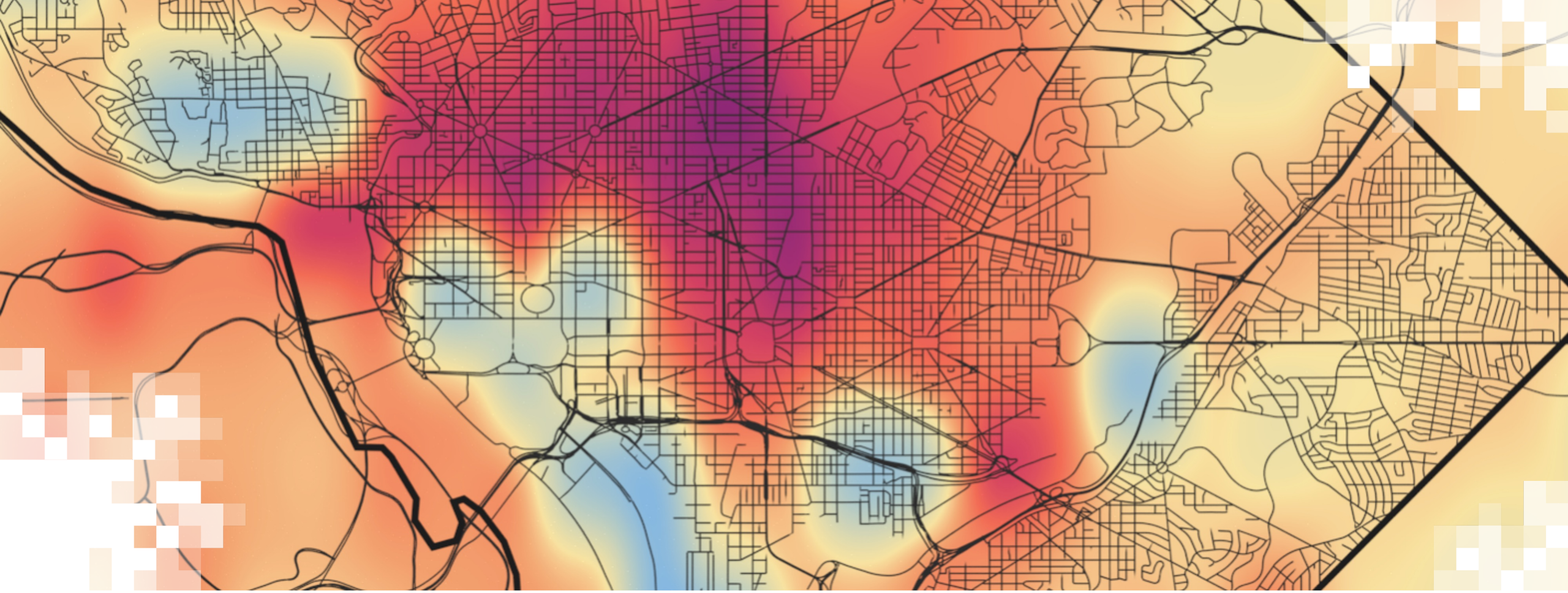


Satellite Data for Air Quality Environmental Justice and Equity Applications

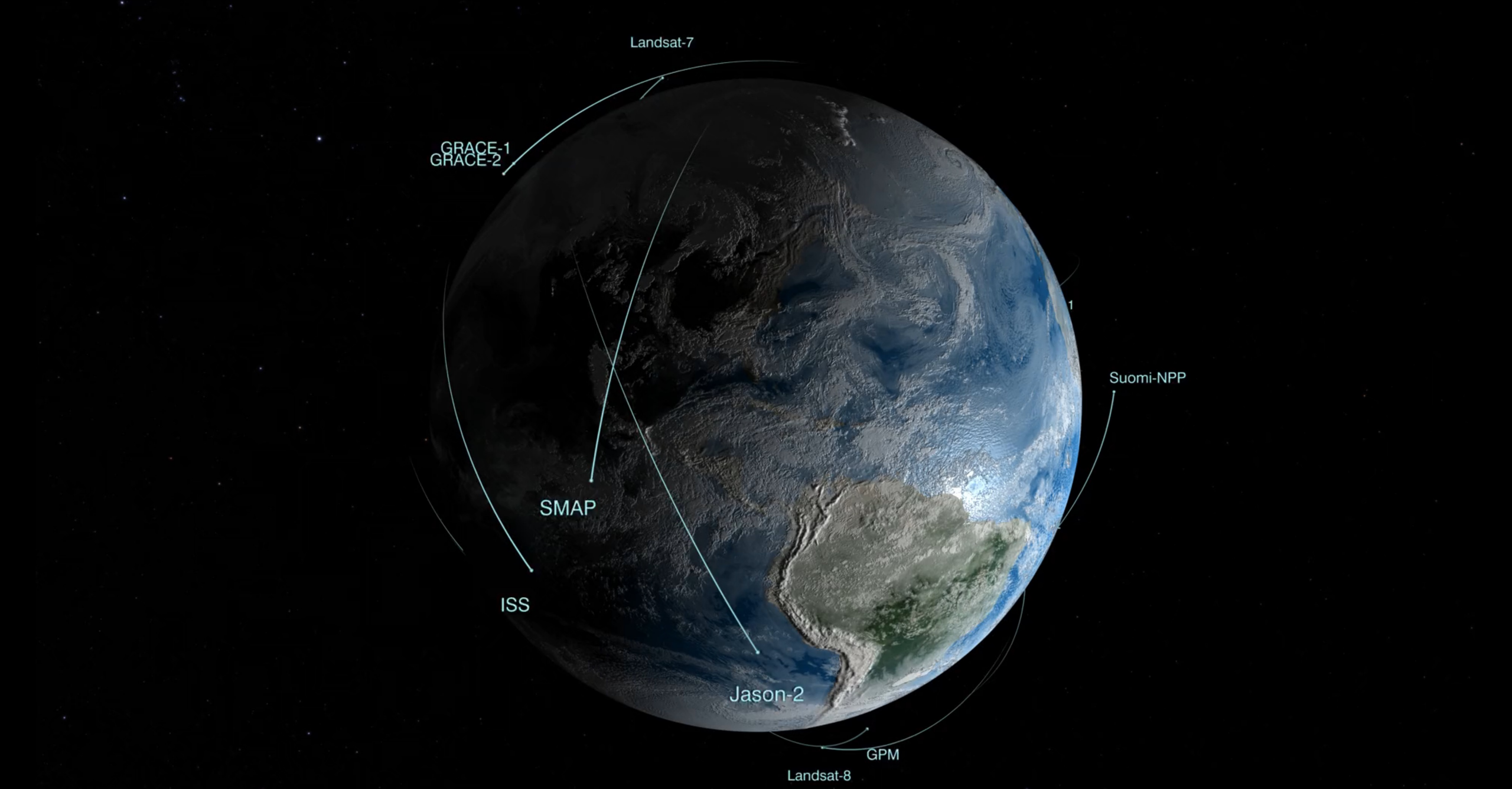
Part 1: Use of Satellite Data in Environmental Justice Applications

Danielle Wood (Massachusetts Institute of Technology), Ufuoma Ovienmhada (Massachusetts Institute of Technology)

August 23, 2023



The **Environment-Vulnerability-Decision-Technology (EVDT) Framework** to Support Social and Environmental **Sustainability**.



https://svs.gsfc.nasa.gov/vis/a000000/a004500/a004558/final_earth_obs_fleet06_1080p60.mp4

1. • Earth Observation (EO) System Design and Implementation
2. • EO System Operation, Data Retrieval, Calibration & Validation
3. • EO Data Correction and Processing
4. • Earth Science Modeling and Assimilation of Earth Observations
5. • EO Data Discovery & Visualization: Providing interface to find and explore data
6. • EO Data Transformation: Creating data interface based on user needs
7. • Knowledge Integration: Combining physical, social, economic and other data
8. • Decision Support: Providing recommendations for action

Raha Hakimdavar, Danielle Wood, John Eylander, Christa Peters-Lidard, Jane Smith, Brad Doorn, David Green, Corey Hummel, Thomas C Moore, "Transboundary Water: Improving Methodologies and Developing Integrated Tools to Support Water Security," NASA Goddard Space Flight Center, Technical Report, February 2018. NASA/TM–2018-219026

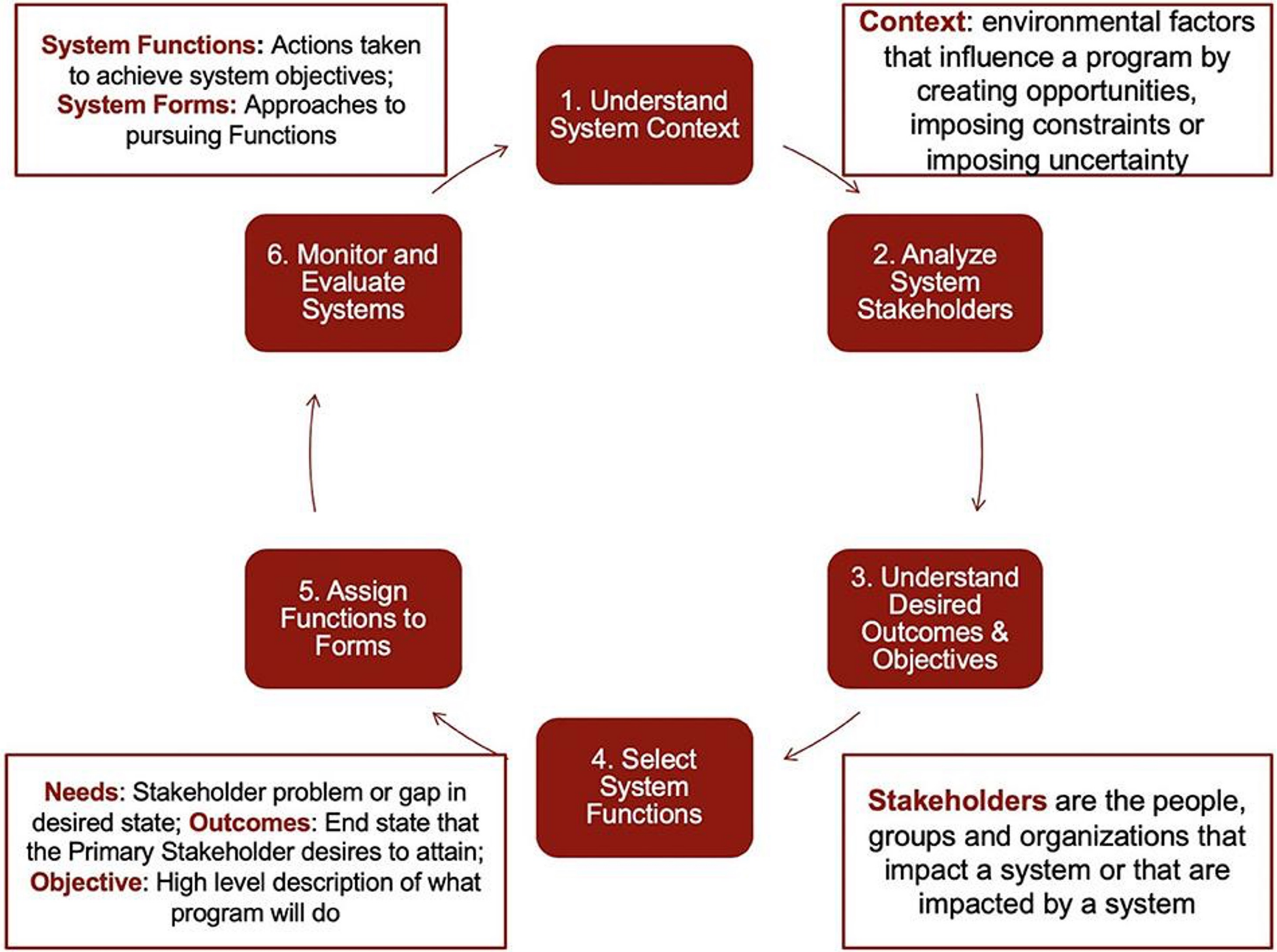
Kenya

South Africa

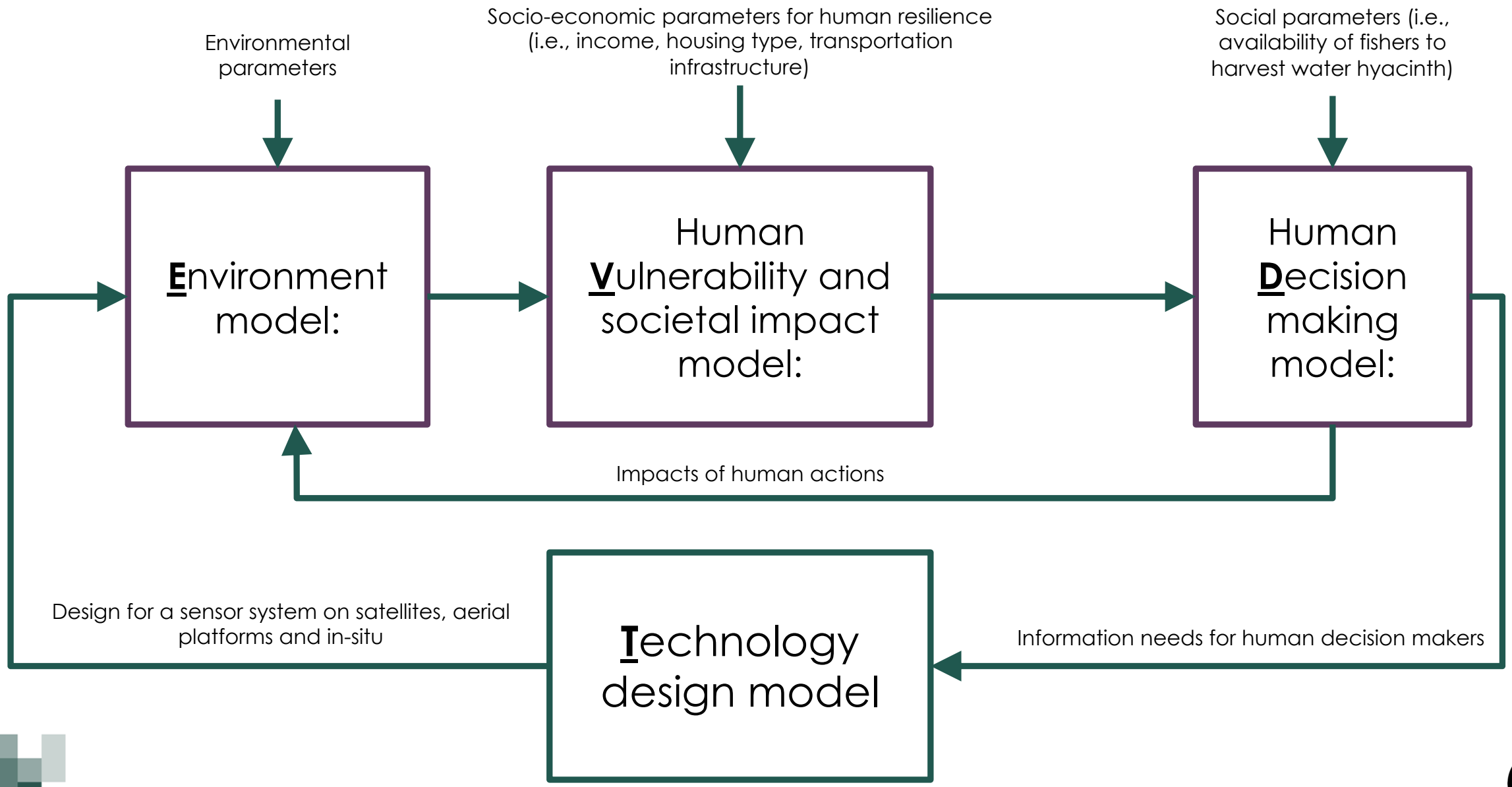
Nigeria

TELEMEDICINE PROJECT IN NIGERIA:
A DIGITAL BRIDGE
IN HEALTHCARE DELIVERY
TELEMEDICINE SERVICES VIA SATELLITE:

1 NO POVERTY
2 NO HUNGER
3 GOOD HEALTH
4 QUALITY EDUCATION
5 GENDER EQUALITY
6 CLEAN WATER AND SANITATION
7 RENEWABLE ENERGY
8 GOOD JOBS AND ECONOMIC GROWTH
9 INNOVATION AND INFRASTRUCTURE
010 011
10 REDUCED INEQUALITIES
11 SUSTAINABLE CITIES AND COMMUNITIES
12 RESPONSIBLE CONSUMPTION
13 CLIMATE ACTION
14 LIFE BELOW WATER
15 LIFE ON LAND
16 PEACE AND JUSTICE
17 PARTNERSHIPS FOR THE GOALS
THE GLOBAL GOALS
For Sustainable Development


1. Understand System Context
Context: environmental factors that influence a program by creating opportunities, imposing constraints or imposing uncertainty
2. Analyze System Stakeholders
Stakeholders are the people, groups and organizations that impact a system or that are impacted by a system
3. Understand Desired Outcomes & Objectives
Needs: Stakeholder problem or gap in desired state; Outcomes: End state that the Primary Stakeholder desires to attain; Objective: High level description of what program will do
4. Select System Functions
System Functions: Actions taken to achieve system objectives; System Forms: Approaches to pursuing Functions
5. Assign Functions to Forms
6. Monitor and Evaluate Systems

EVDT Modeling Framework



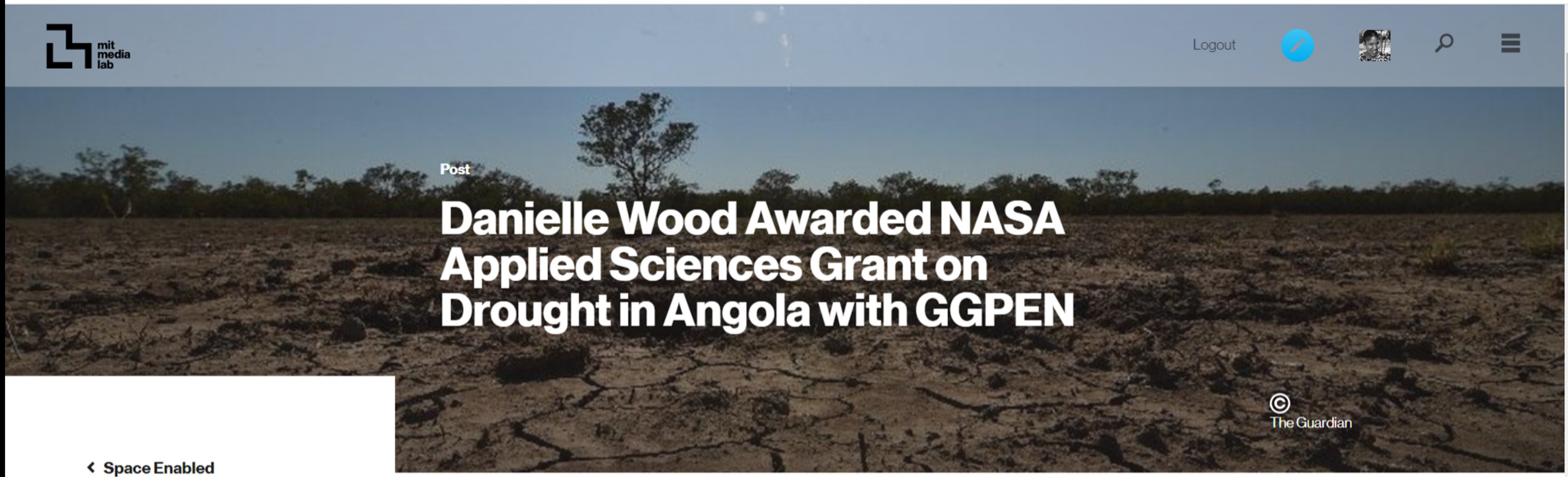
Yurok Tribe (Northern California)

City Government of Rio de Janeiro

GGPEN (National Space Program of Angola)

Scholars and City Planners, Indonesia

media.mit.edu/posts/danielle-wood-awarded-nasa-applied-sciences-grant-on-drought-in-angola/



Post

Danielle Wood Awarded NASA Applied Sciences Grant on Drought in Angola with GGPEN

Space Enabled

by Alessandra Davy-Falconi
Jan. 5, 2023

People

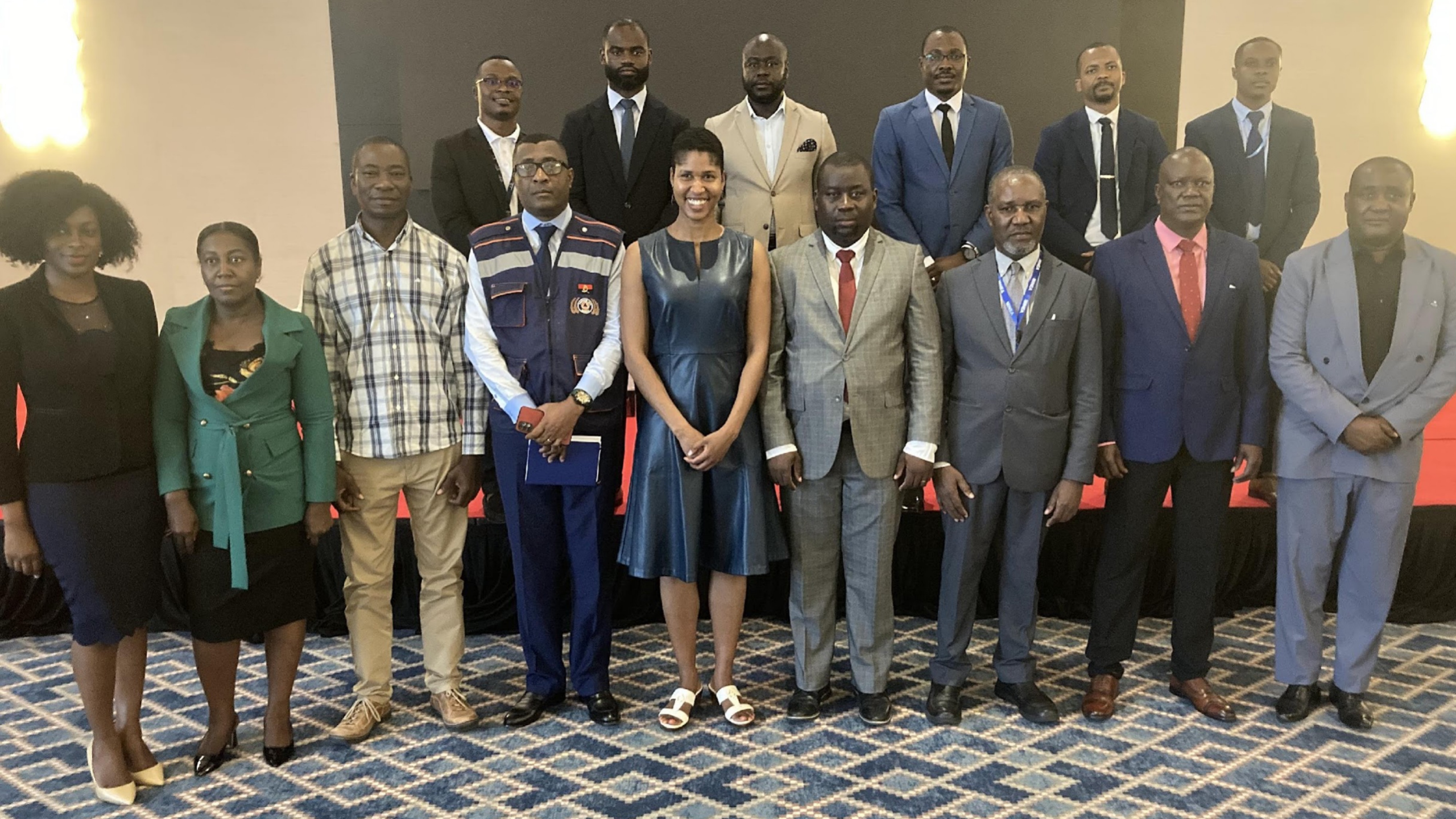
Danielle Wood
Assistant Professor of Media Arts and Sciences; Assistant Professor (Joint) of Aeronautics and Astronautics

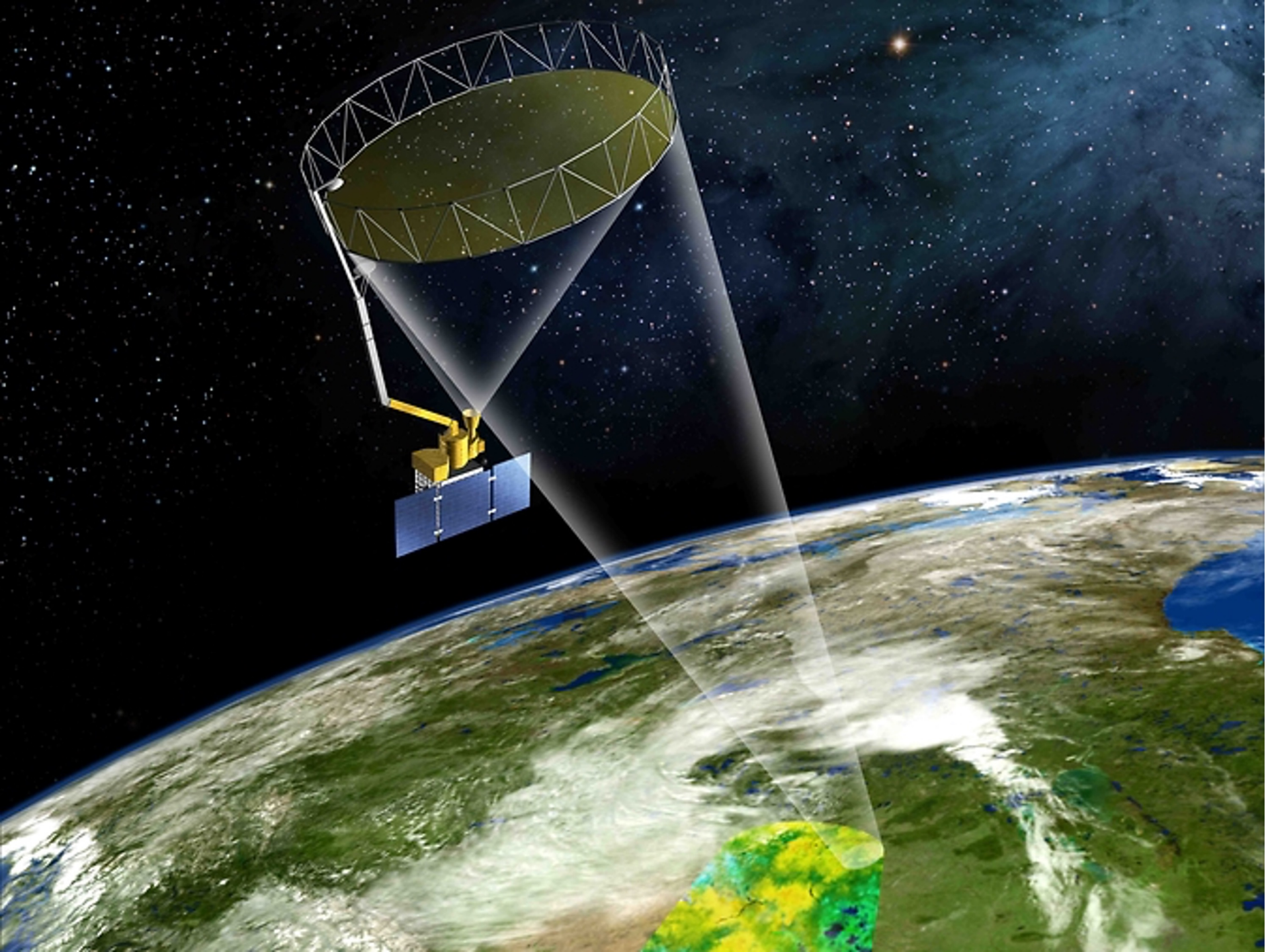
Danielle Wood was awarded a NASA Applied Sciences grant to further work on the Decision Support System for Drought Response in Angola.

Watch a video to learn more about this project here: https://www.youtube.com/watch?v=24oWeAZmBUU.

The project is pursued in collaboration with the Angolan National Space Agency called GGPEN, which will take the lead to coordinate with public and private organizations in Angola that have responsibilities related to drought. The US team also includes Prof Dara Entekhabi and Dr. Katlyn Turner from MIT as well as Dr. Yusuke Kuwayama of the University of Maryland, Baltimore County and support from the Blue Raster data analytics and geospatial design company.

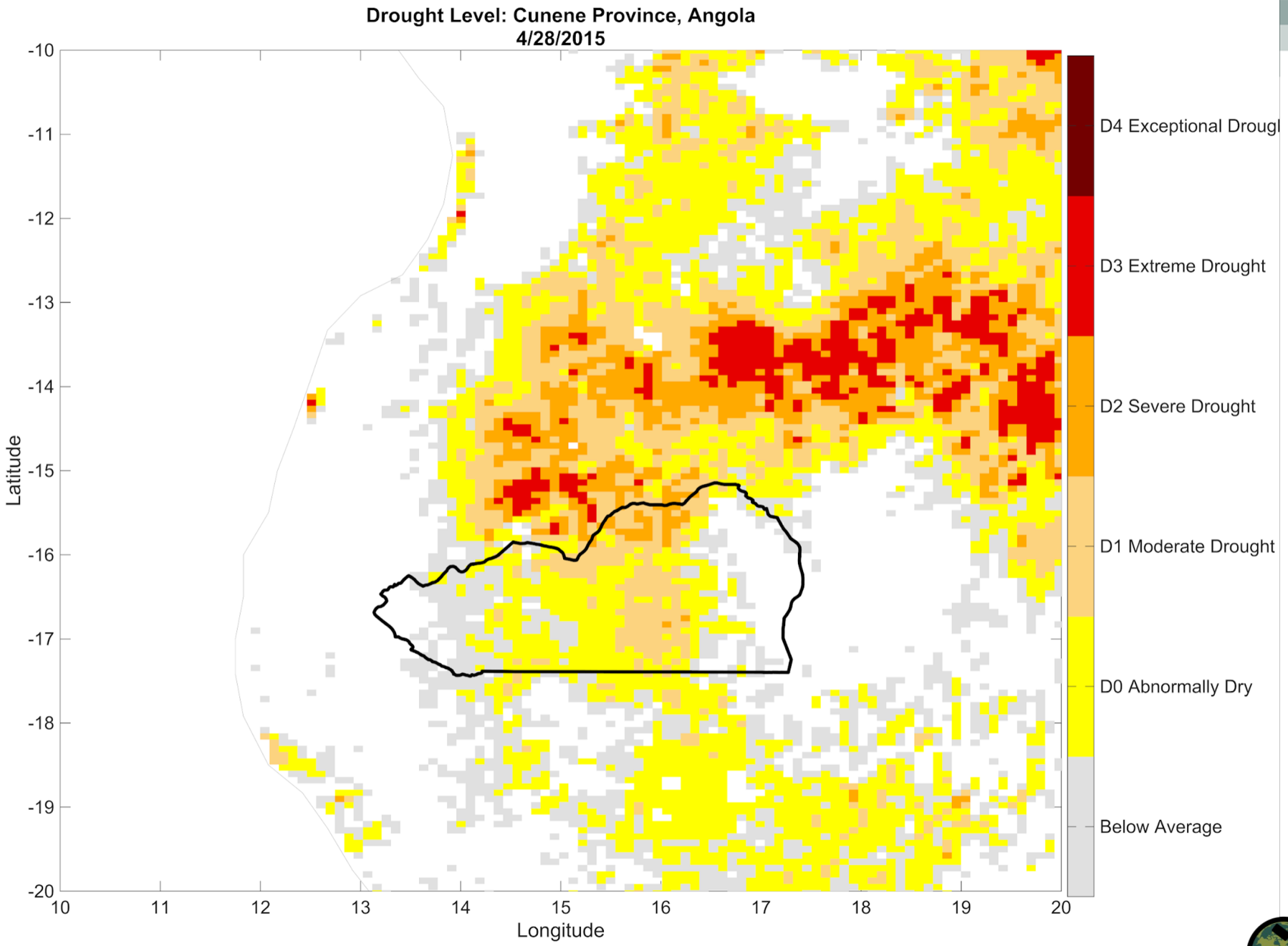
Southern Angola faces recurring cycles of drought and flooding that cause insecurity for local communities who depend heavily on raising cattle as a form of livelihood.

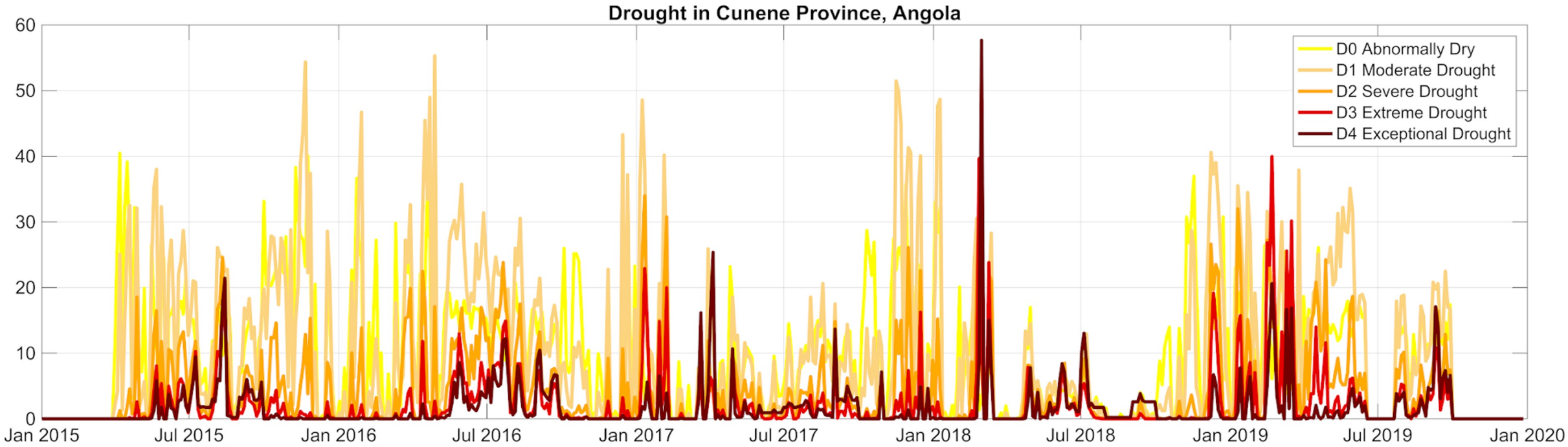




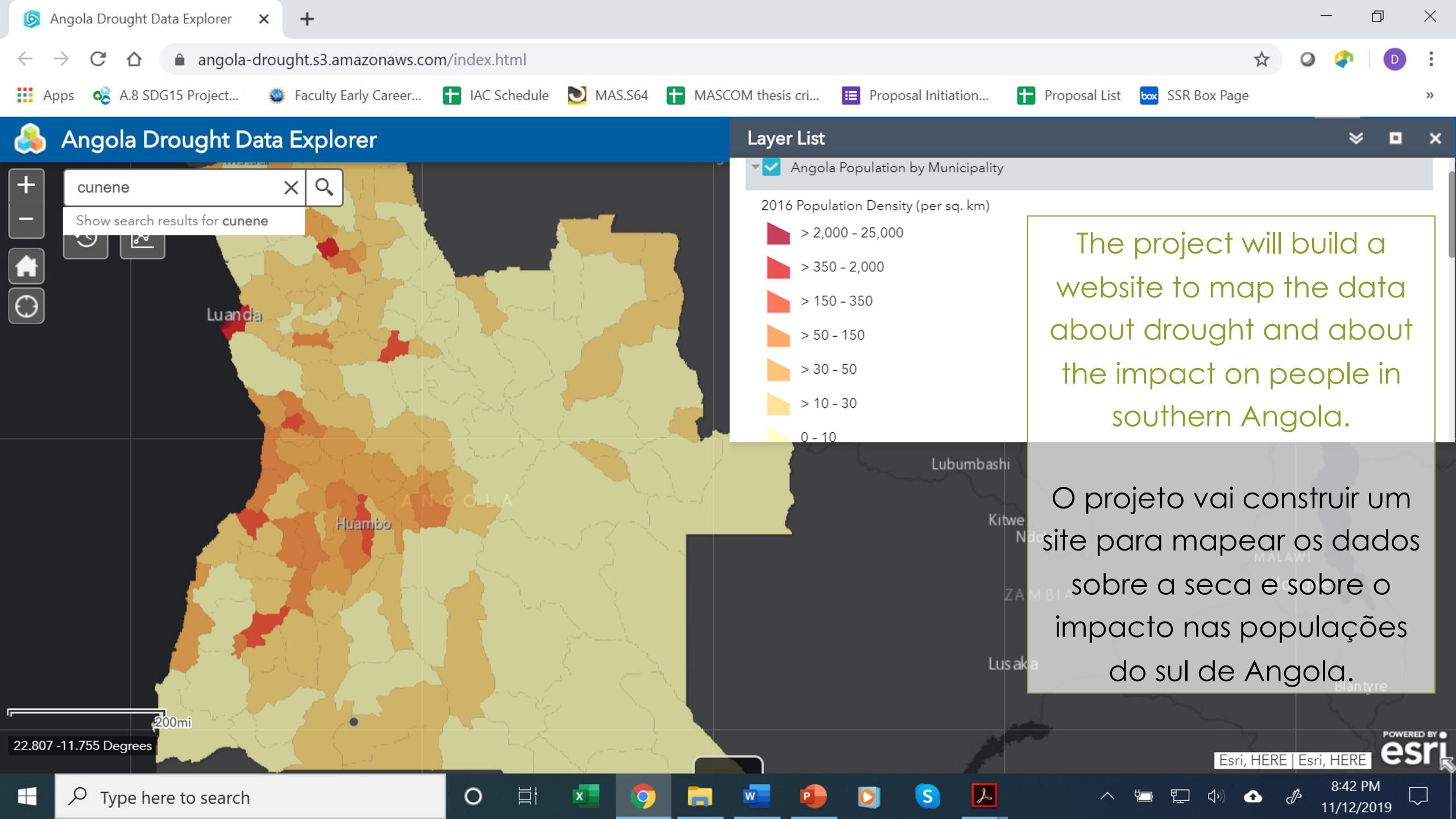
NASA has a satellite called SMAP (Soil Moisture Active Passive) that has a sensor that can measure the microwaves that reflect from the Earth. This allows the sensor to measure water in the soil.

This project maps the level of drought intensity in Angola for multiple years using data from SMAP. Dark red means very dry soil.

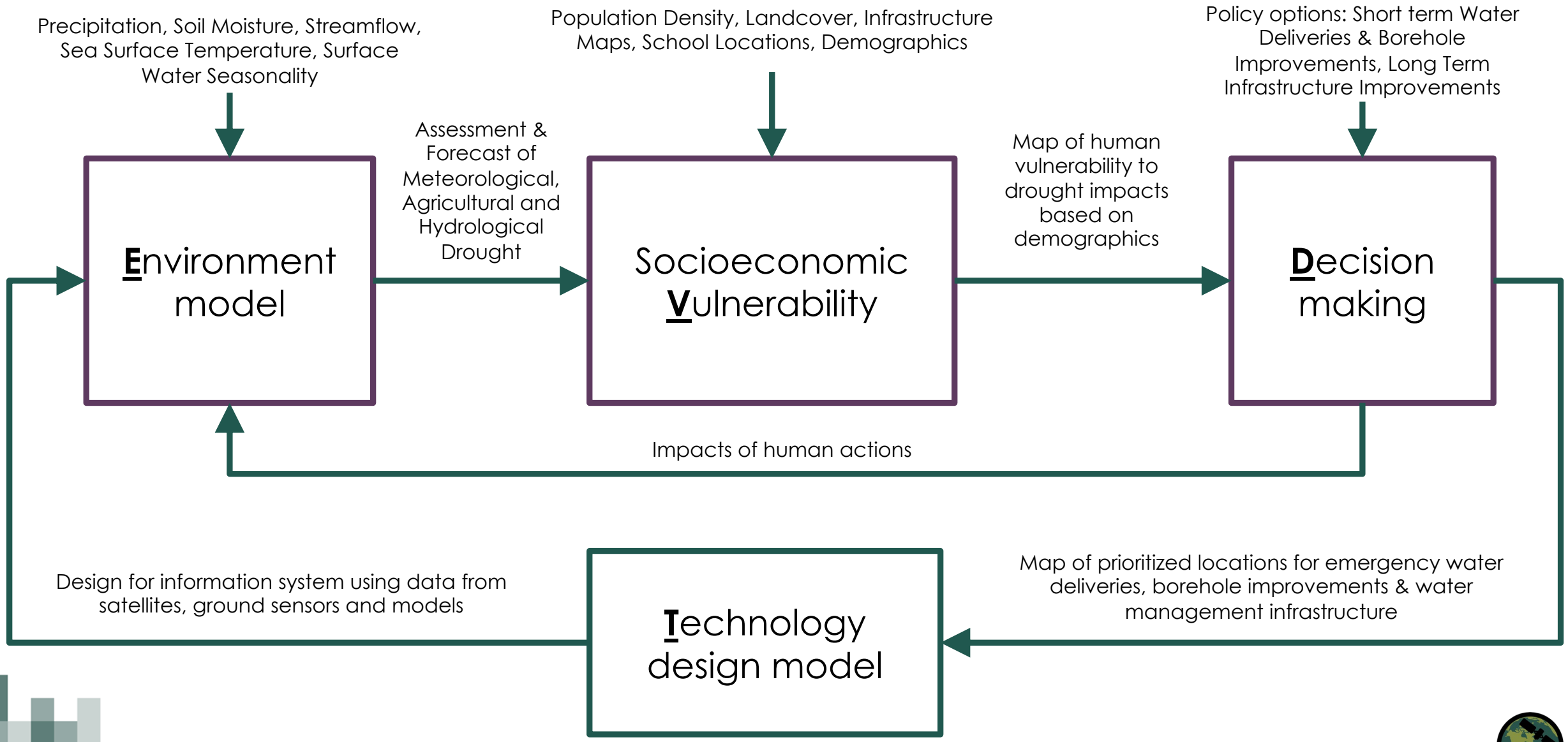


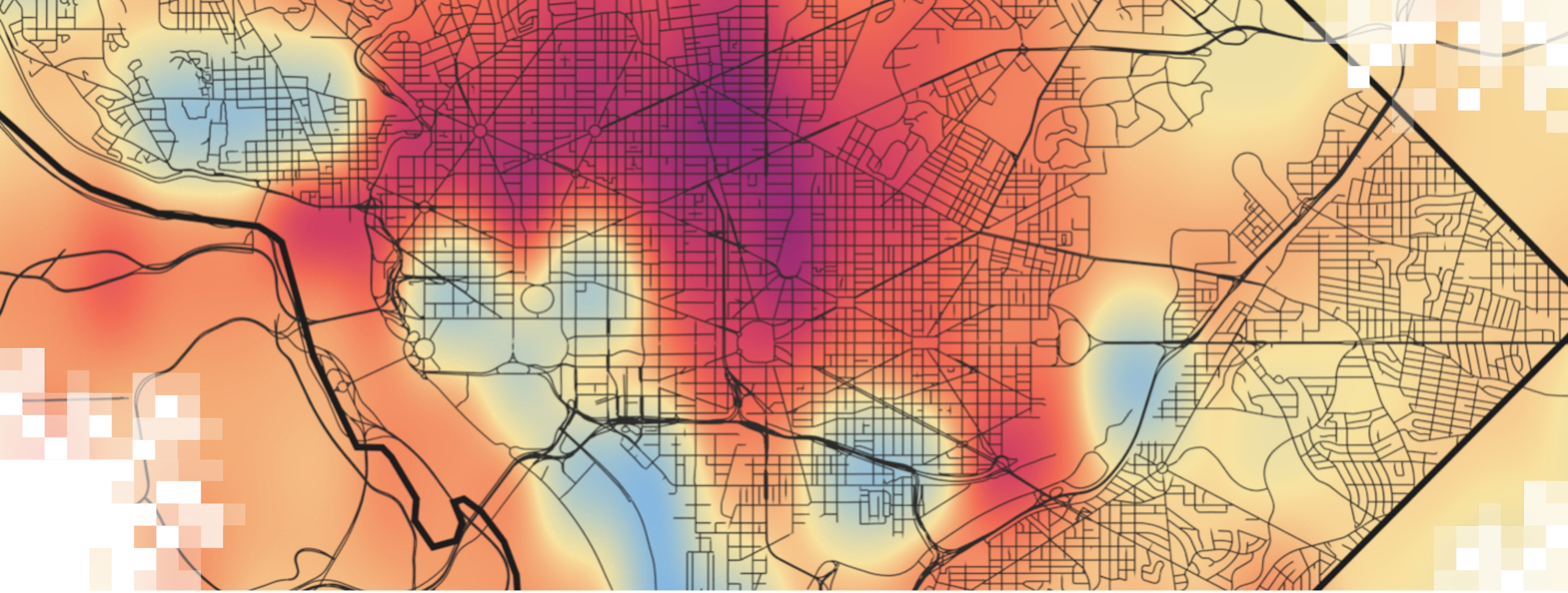


Here is an example of a timeline showing the periods with extreme drought in the Cunene Province.


Angola Drought Data Explorer
angola-drought.s3.amazonaws.com/index.html
Apps
A.8 SDG15 Project...
Faculty Early Career...
IAC Schedule
MAS.S64
MASCOM thesis cri...
Proposal Initiation...
Proposal List
SSR Box Page
Angola Drought Data Explorer
cunene
Show search results for cunene
Layer List
Angola Population by Municipality
2016 Population Density (per sq. km)
> 2,000 - 25,000
> 350 - 2,000
> 150 - 350
> 50 - 150
> 30 - 50
> 10 - 30
0 - 10
Luanda
Huambo
ANGOLA
Lubumbashi
Kitwe
Ndola
MALAWI
ZAMBIA
Lusaka
Blantyre
200mi
22.807 -11.755 Degrees
Esri, HERE | Esri, HERE
POWERED BY esri
The project will build a website to map the data about drought and about the impact on people in southern Angola.
O projeto vai construir um site para mapear os dados sobre a seca e sobre o impacto nas populações do sul de Angola.
Type here to search
8:42 PM
11/12/2019

EVDT Model for Drought Application in Southern Angola



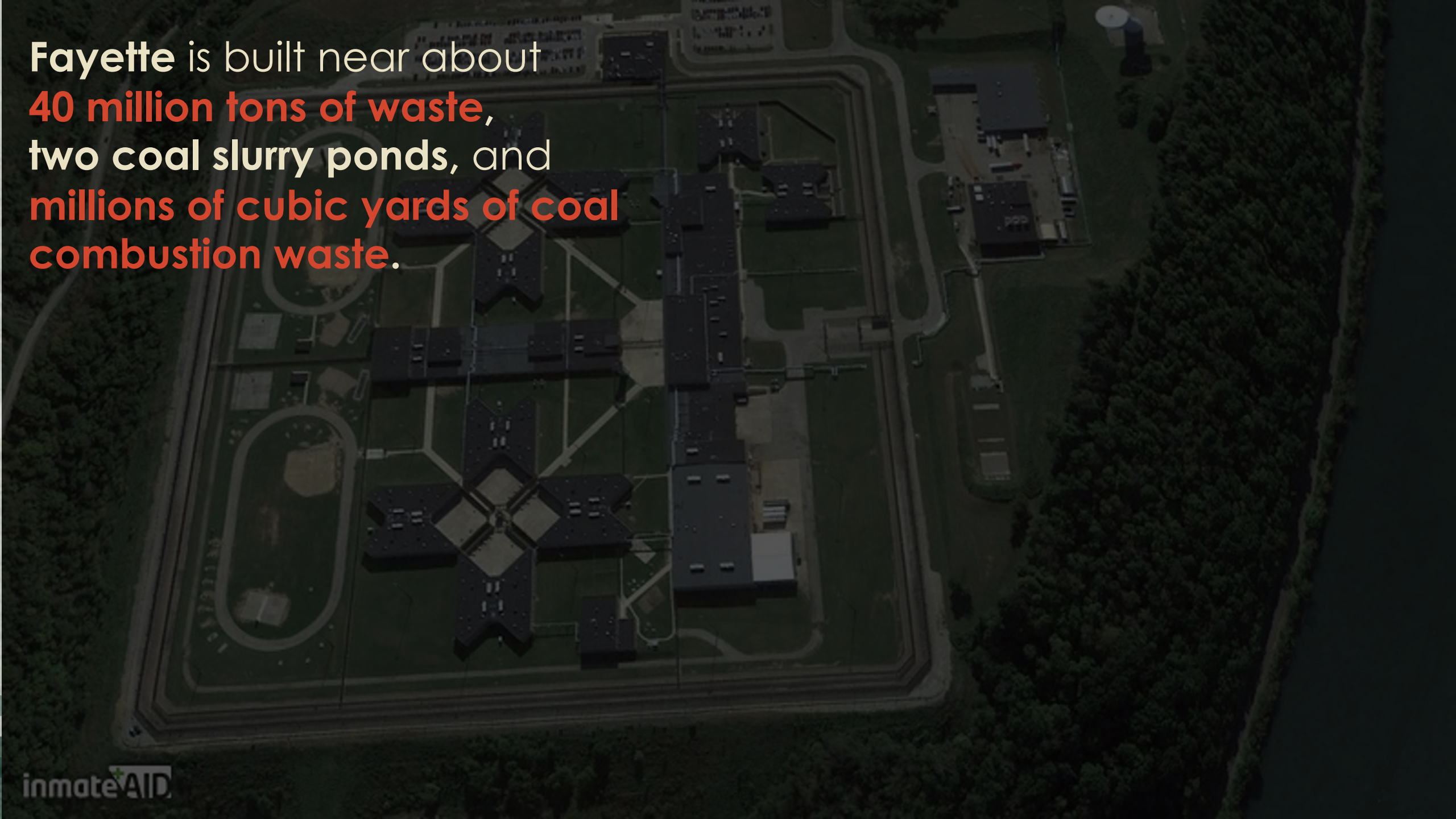


Unequal Protection:
Prisons and Environmental Justice

The material is based upon work supported by NASA under award Number
80NSSC22K1673 and a grant from MIT's IDSS Initiative on Combatting Systemic Racism.

Fayette prison in La Belle, Pennsylvania

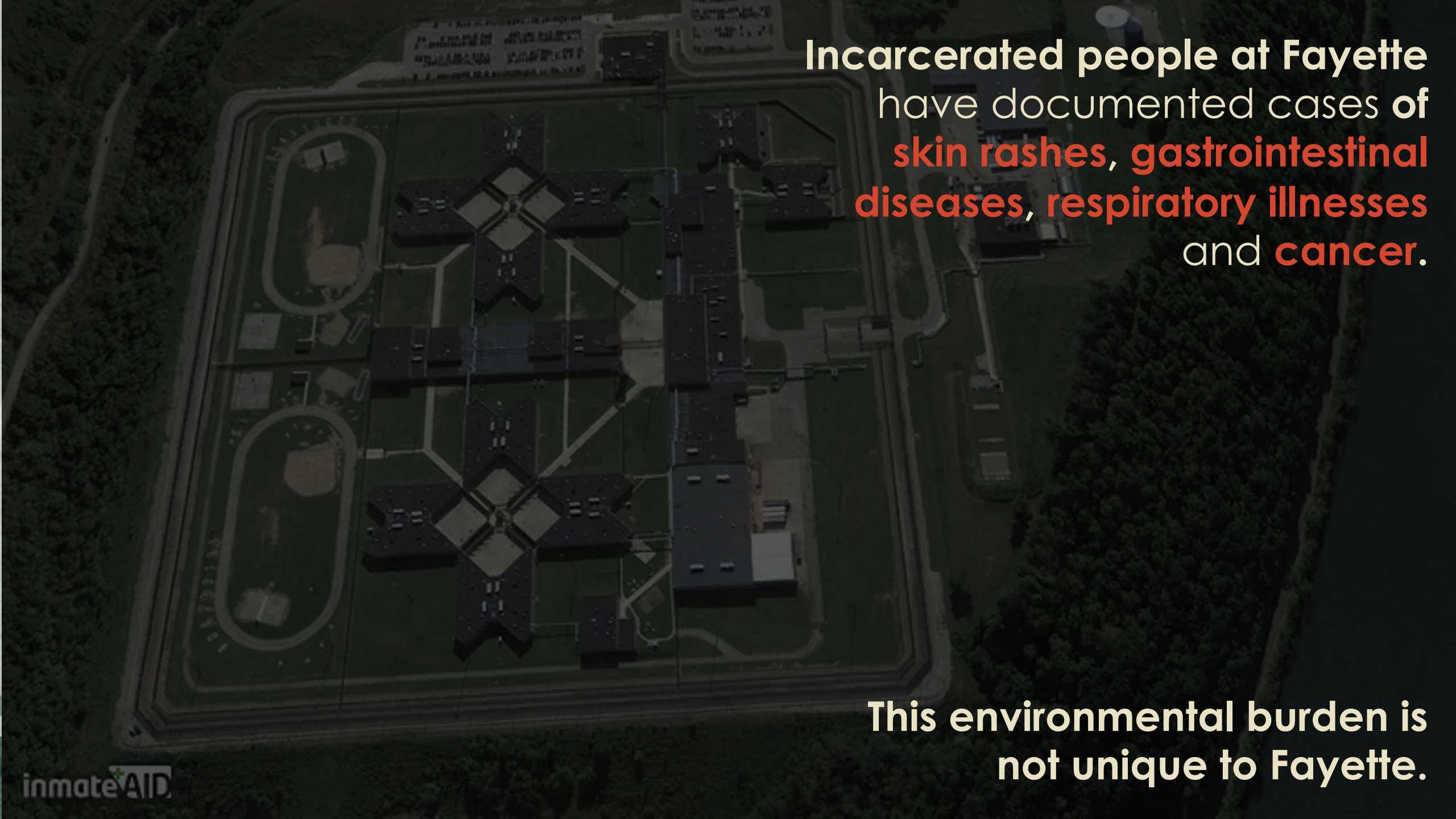
inmate AID


Fayette is built near about
40 million tons of waste,
two coal slurry ponds, and
millions of cubic yards of coal combustion waste.

inmate AID

Incarcerated people at Fayette have documented cases **of skin rashes, gastrointestinal diseases, respiratory illnesses** and **cancer.**

inmate AID



Incarcerated people at Fayette have documented cases **of skin rashes, gastrointestinal diseases, respiratory illnesses** and **cancer.**

This environmental burden is not unique to Fayette.

inmate AID

Limitations of Federal Air Pollution Data (PM 2.5)

- The **federal** and **several state governments use data** that fuse concentrations simulated by the Community Multiscale Air Quality Modeling System (CMAQ) with monitor observations **at a relatively coarse resolution of 12km.**
  - This resolution is too coarse to fully resolve disparities in urban areas[1], where more than 80% of the US population lives[2].

- The vast majority of counties have zero or one ground monitor[3] which may affect the model estimates as air pollution concentrations can vary dramatically over short distances.

[1]Paolella, D. A. et al. (2018)
[2]Manson et al. (2021)
[3]Sullivan, D. M., & Krupnick, A. (2018)

Question & Methods

Are the air pollution burdens of some carceral facilities obscured due to the limitations of model data used in federal tools?

Methods:

- Compare a 1km satellite-derived PM 2.5 dataset[4] to the 12km resolution CMAQf model used by the federal government in the Environmental Protection Agency's (EPA) EJScreen tool and the Council on Environmental Quality's new Climate and Economic Justice Screening Tool (CEJST).

[4]van Donkelaar et al. 2021

In Total, We Identified 42 Carceral Facilities With Higher PM2.5 Than at Least 80% of Their Respective States.

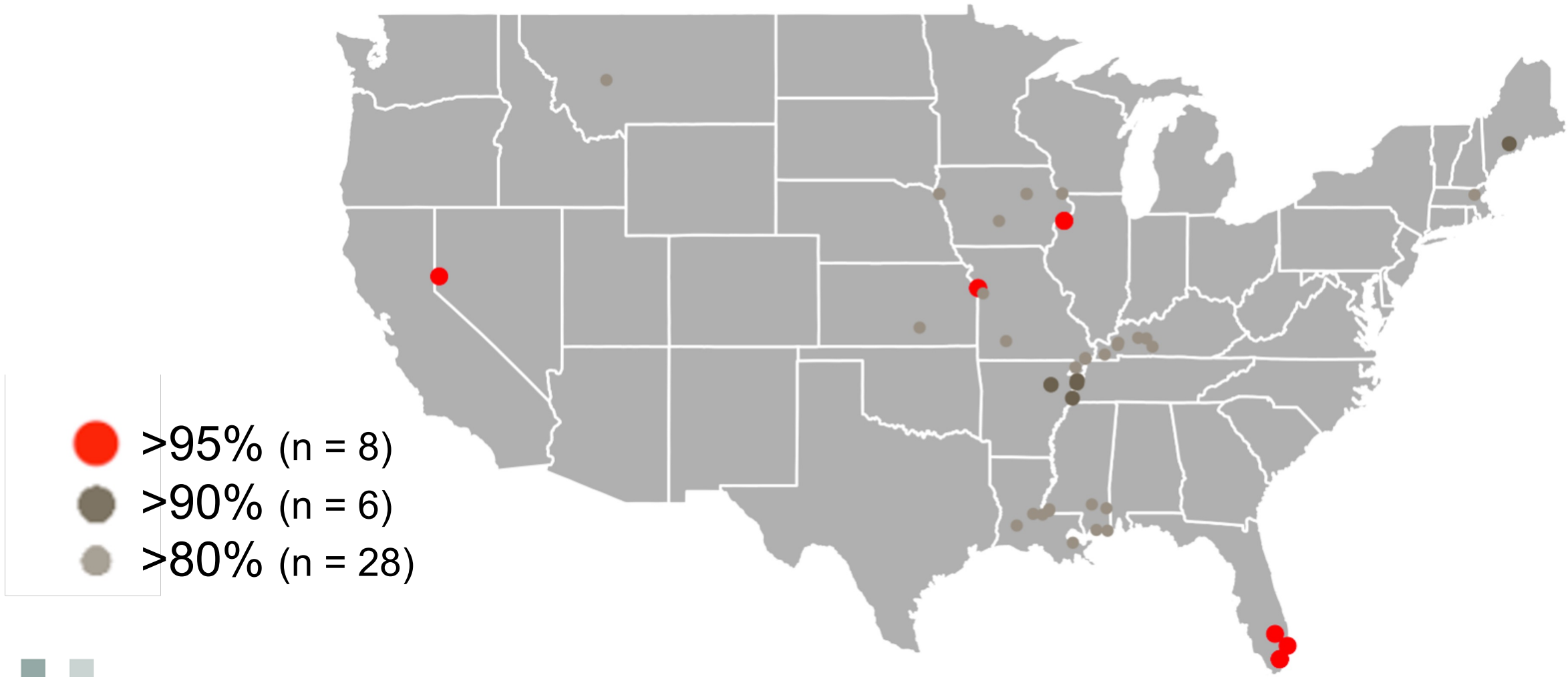


Image Credit: Andrew West

The Differences in PM2.5 Percentiles for the Two Datasets can be Large:

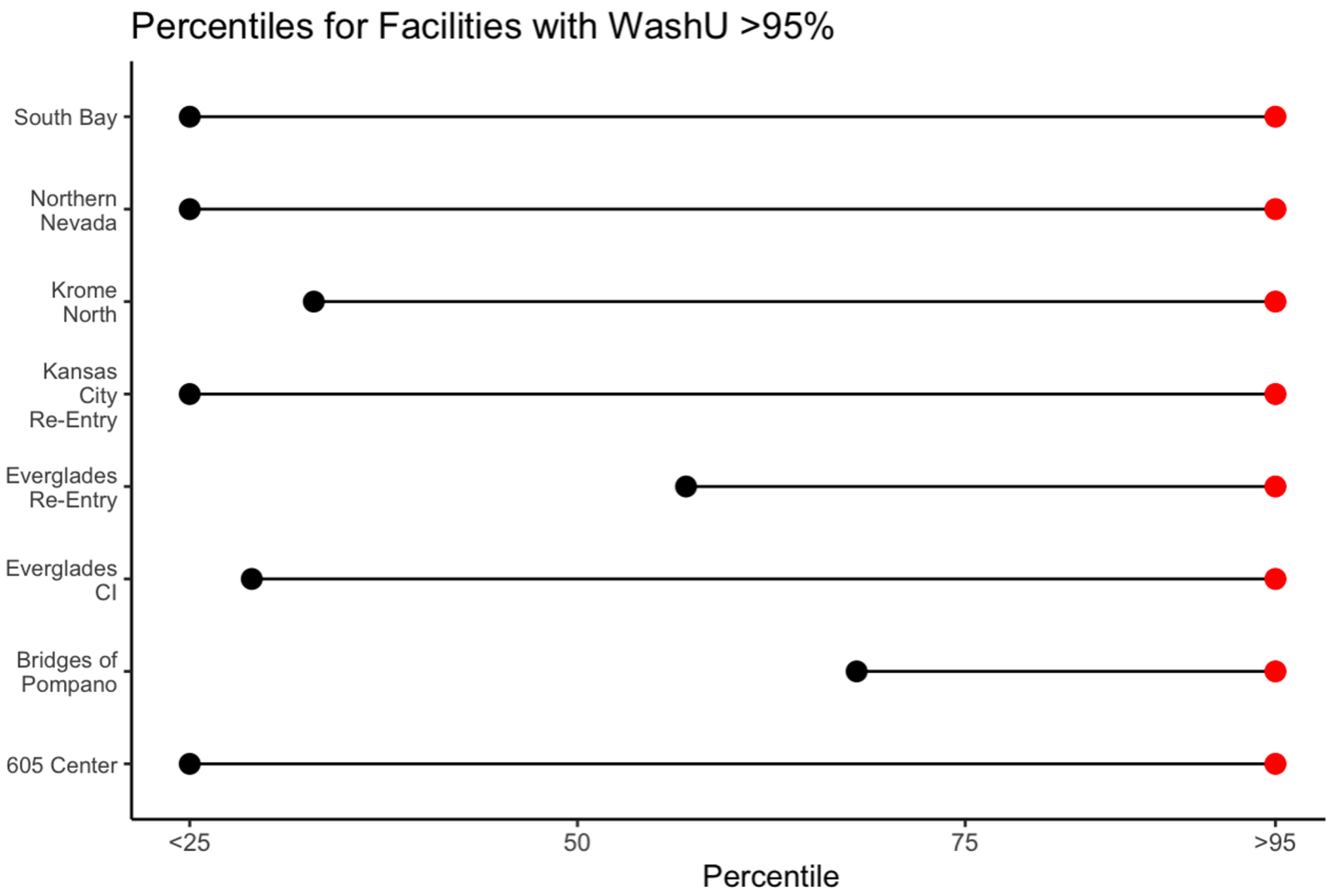
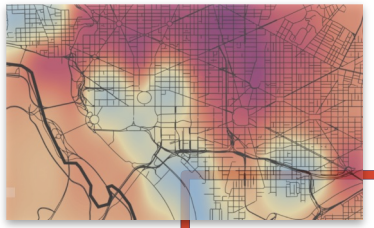


Image Credit: Andrew West

Using the EVDT Framework for Environmental Justice



Environment:

PM 2.5 concentrations

Human **v**ulnerability:

Population, socio-demographic and mortality data

decision king:

mitigation protocols, evacuation protocols, prison closure options

Technology Design:

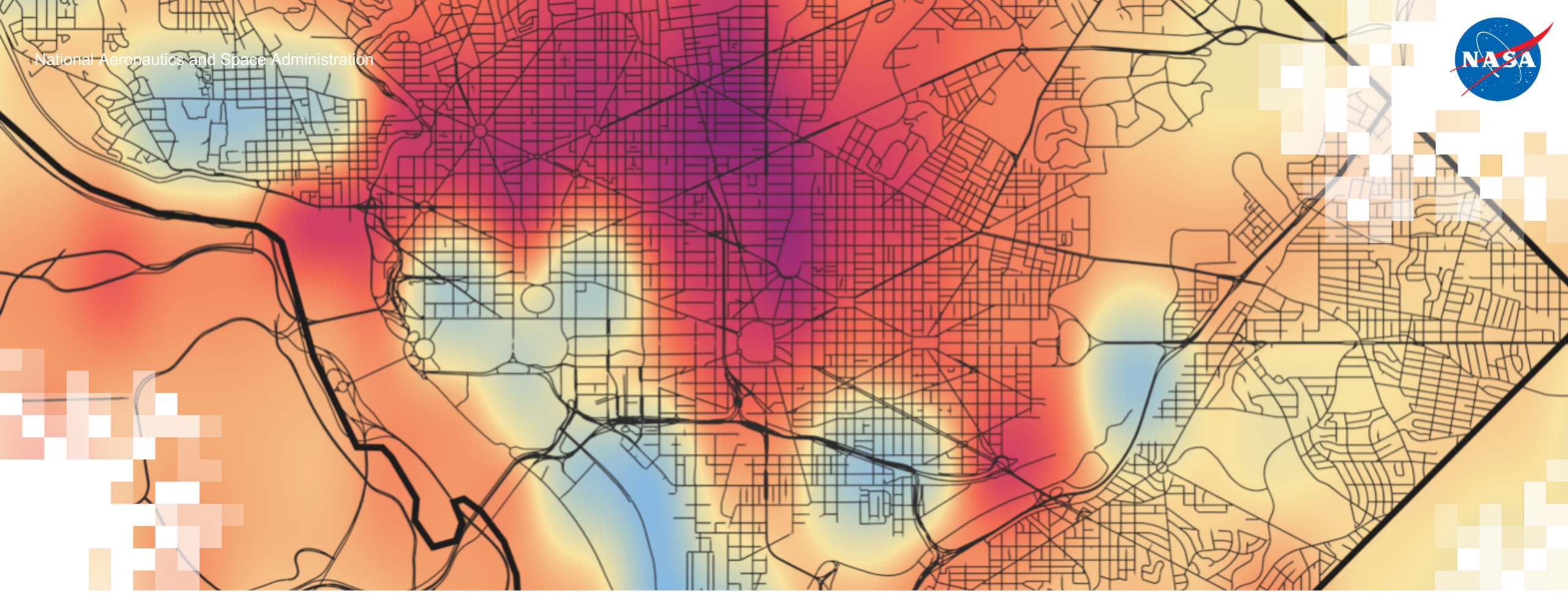
Local air-pollution sensors

Summary

- The satellite-derived dataset can identify carceral facilities likely experiencing poor air quality missed by more coarse federal data.

- Federal funding initiatives designed to address environmental disparities may be discounting the conditions experienced by some people who are incarcerated.

- Satellite-derived data can contribute a new perspective for environmental justice applications.

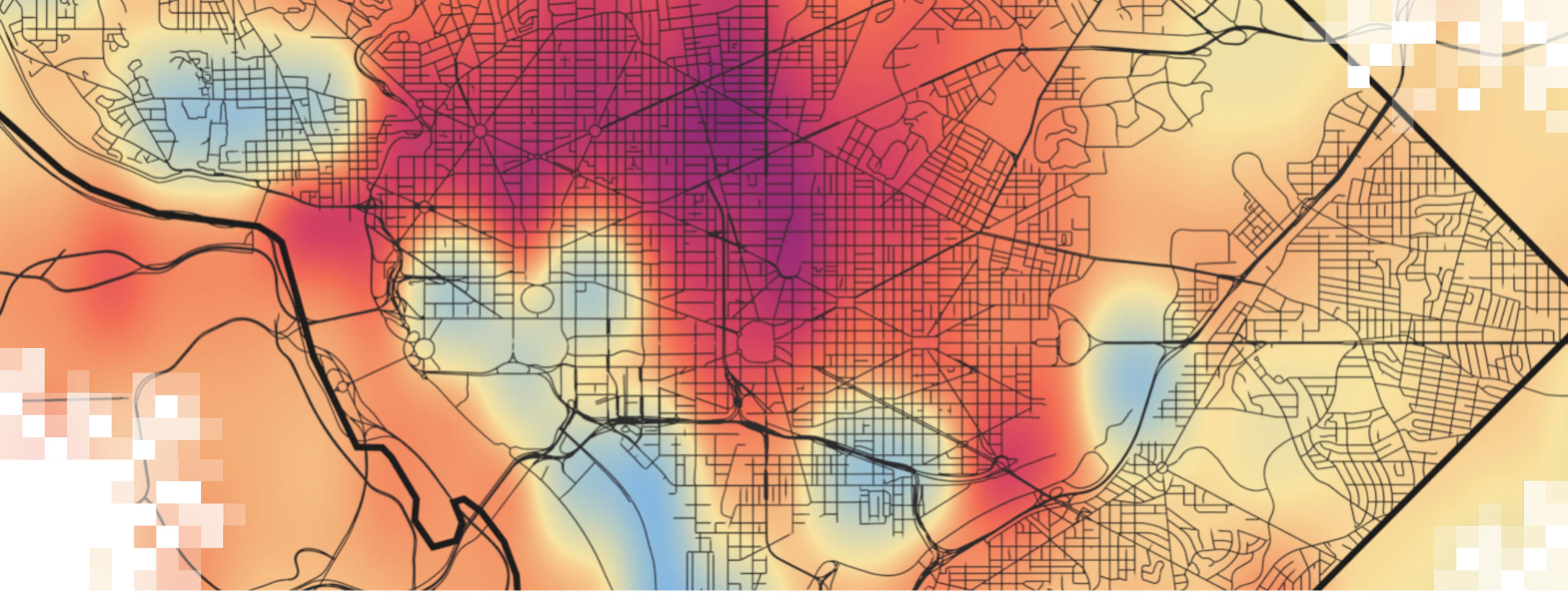


Satellite Data for Air Quality Environmental Justice and Equity Applications

Part 1: Use of Satellite Data in Environmental Justice Applications

Daniel Carrión, PhD, MPH (Assistant Professor, Environmental Health Sciences
Director of Education, Yale Center on Climate Change and Health

August 23, 2023



Temperature and Energy Justice Mapping Tool

Deep Decarbonization

Energy efficiency & conservation

Electrification

Decarbonized electricity production

Reduce non-combustion GHGs

Climate Change and the Residential Sector

- Home energy accounts for 20% of GHGs in US
  - Half from heating and cooling
  - Energy efficiency and electrification

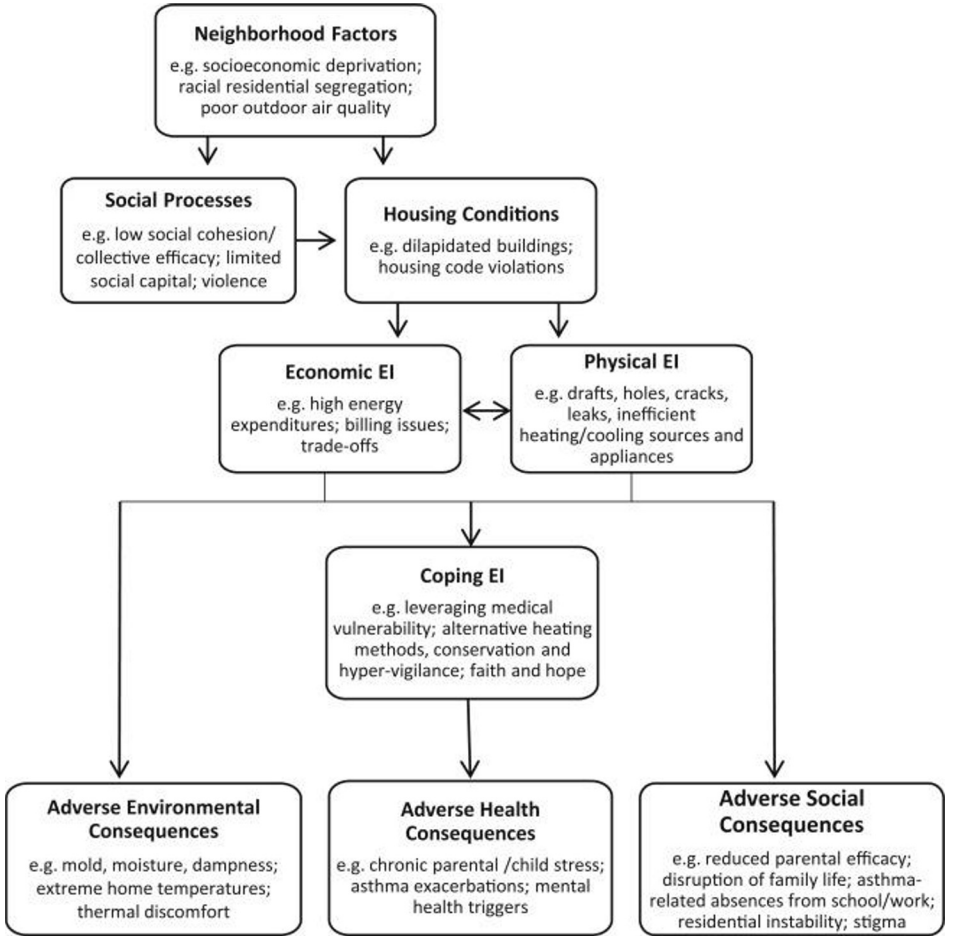
- Residential segregation
  - Environmental & social disparities
  - Air pollution, extreme heat, and energy insecurity

Energy Insecurity

- Framework that outlines the interplay between energy needs, financial constraints, and behavioral adaptations

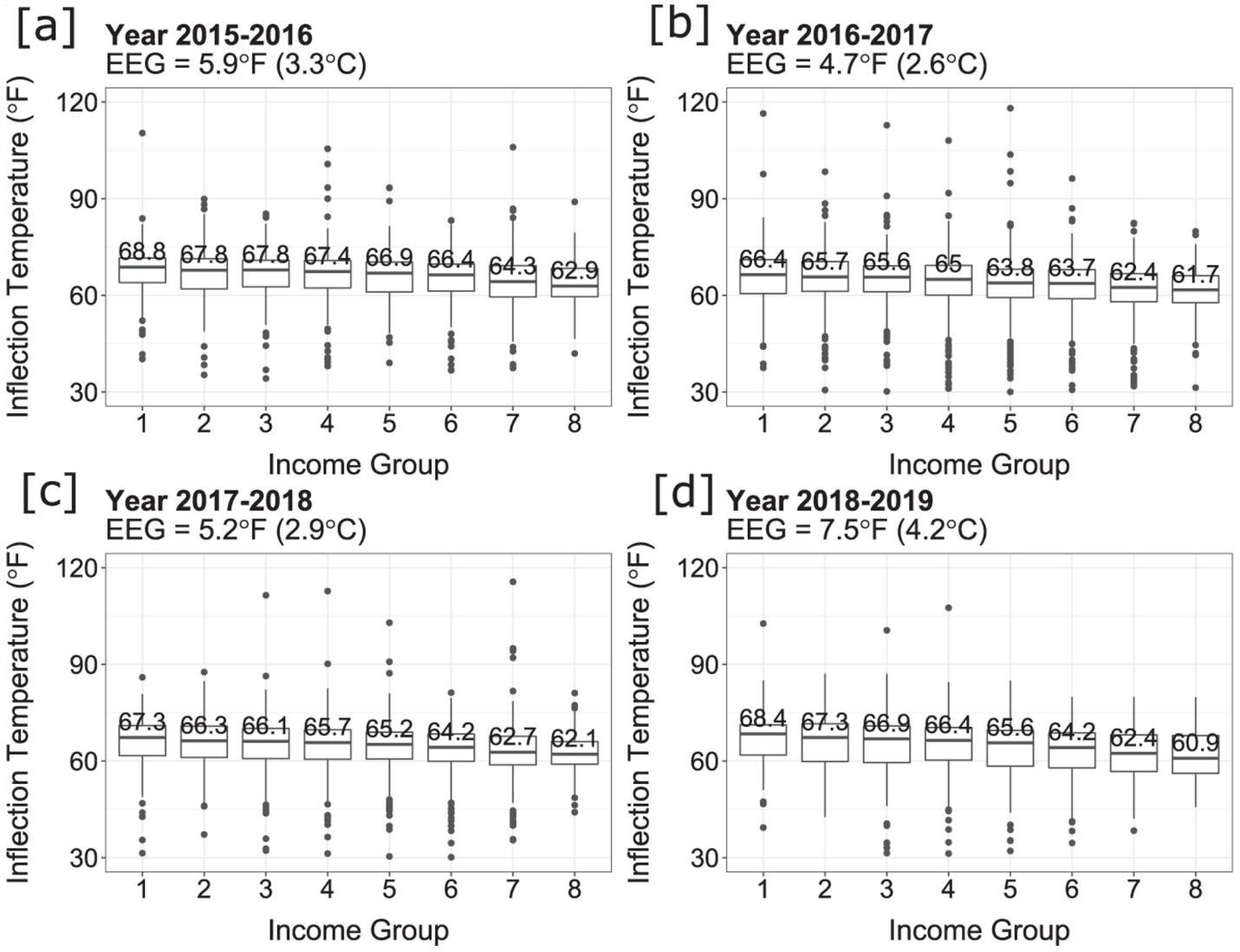
"Heat or eat" dilemma

"Heat stroke or go broke" dilemma



(Hernández, *Soc. Sci. and Medicine*, 2016)

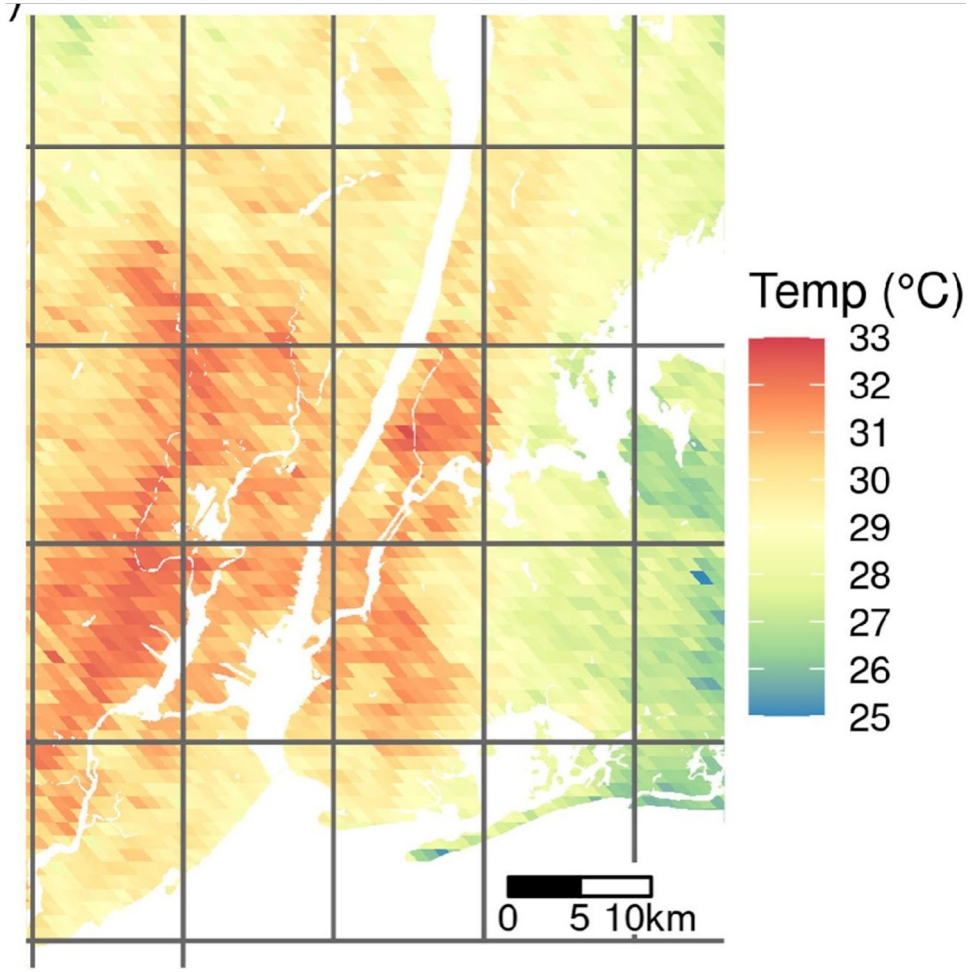
Energy Rationing

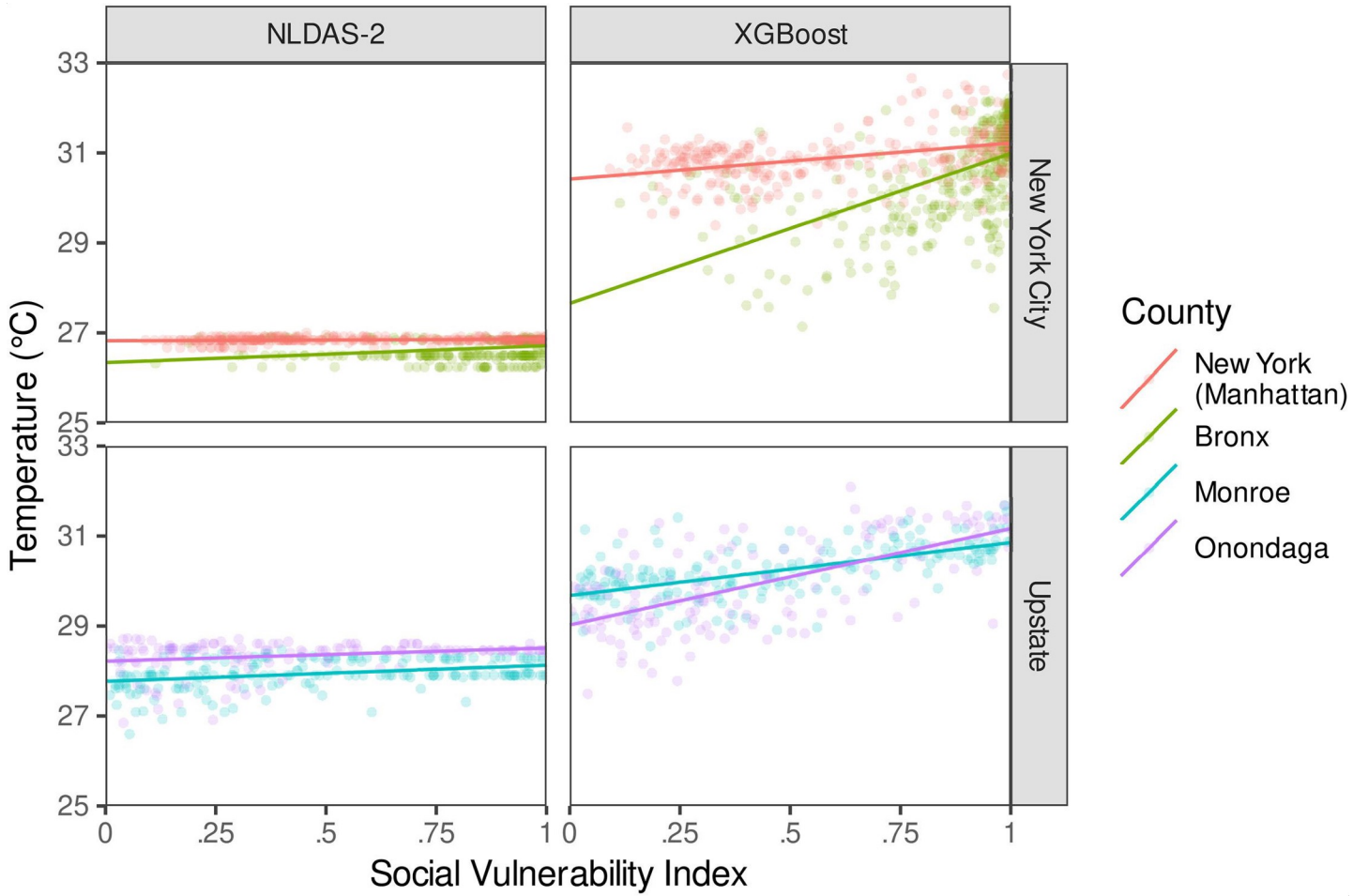


Income Group
1. Less than $15,000
2. $15,000 to $24,999
3. $25,000 to $34,999
4. $35,000 to $49,999
5. $50,000 to $74,999
6. $75,000 to $99,999
7. $100,000 to $149,999
8. $150,000 or more

(Cong et al., 2022)

Understated Disparity Estimates?





(Carrión et al., 2021)

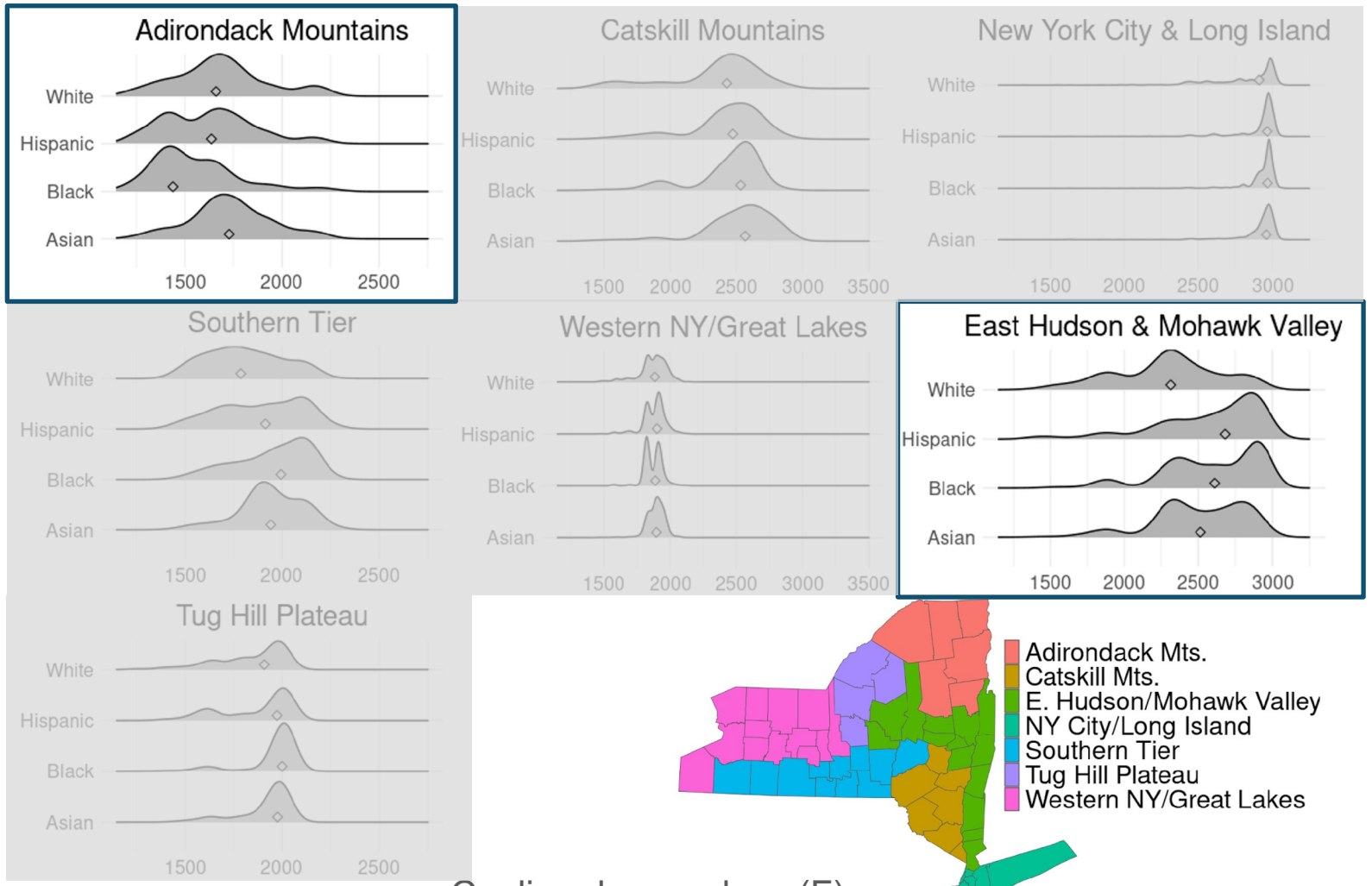
Temperature and Energy Justice Mapping Tool

- NASA feasibility study
- Partner: Green and Healthy Homes Initiative
- Identify the intersection of:
  - Localized temperature disparities
  - Social vulnerability
  - Markers of energy insecurity (evidence of energy rationing)
- Support targeted energy efficiency upgrades

Data Inputs

- Localized (within county) temperature disparities
  - Heat Index CDDs – Daymet
  - LST CDDs – MODIS
- Social vulnerability
  - SEDAC SVI based on CDC
- Markers of energy insecurity (evidence of energy rationing)
  - Utility energy registry

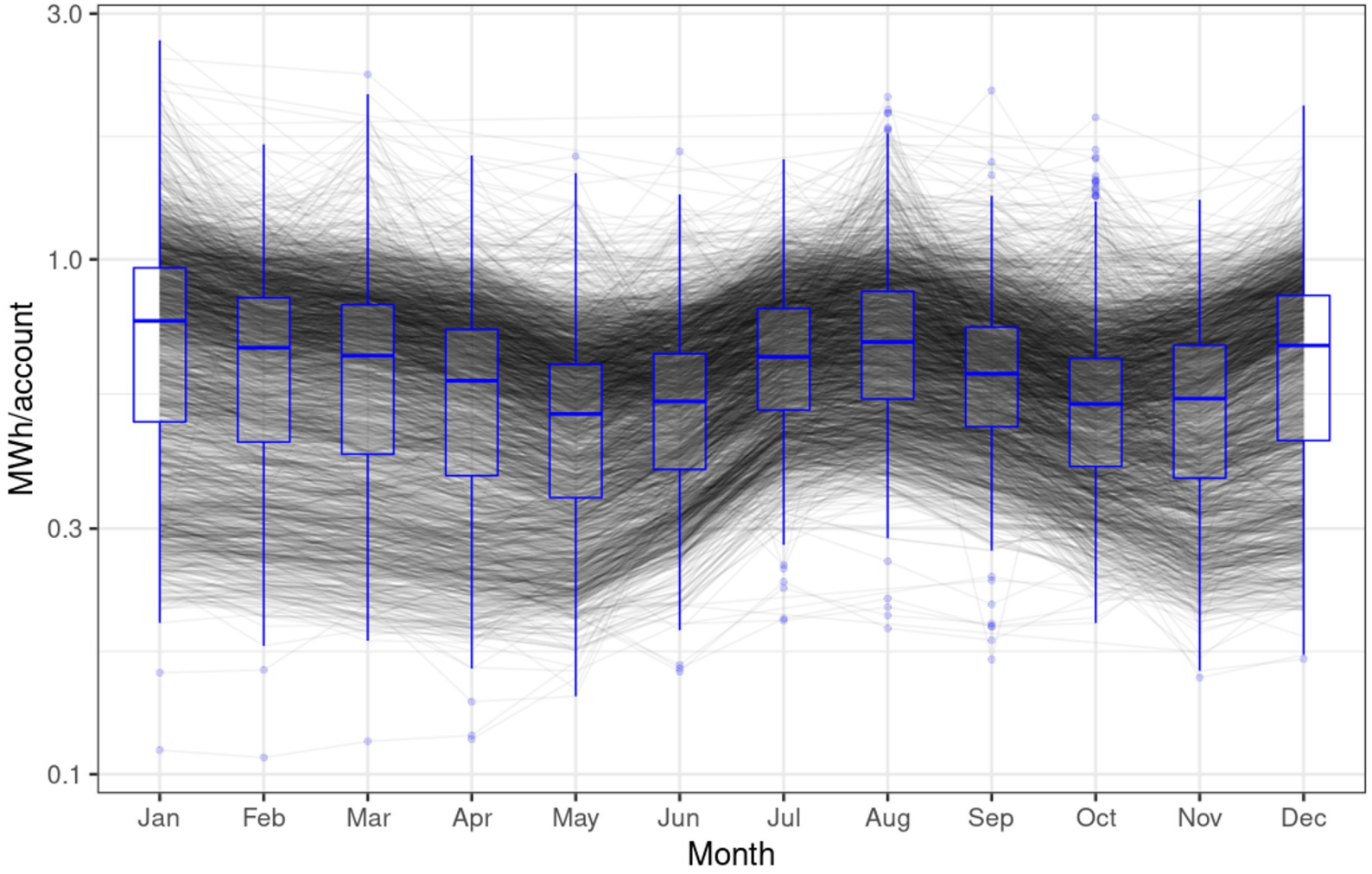
Temperature Disparities in New York State, 2013



Cooling degree days (F)

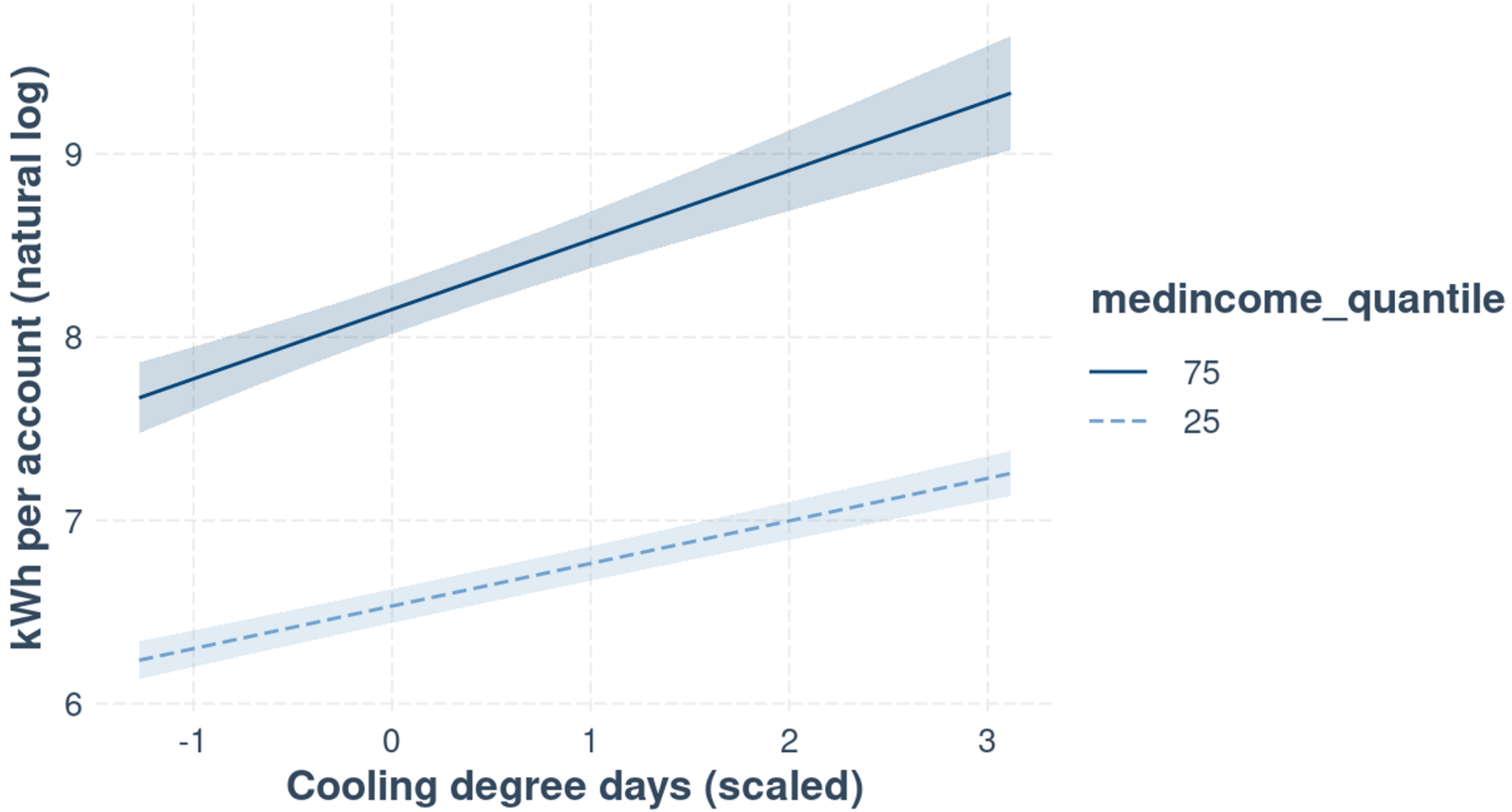
(Carrión, *unpublished*)

Residential Electricity Usage 2016 – 2019, New York State zip codes



(Carrión, *unpublished*)

Assessing Effect Modification by Area-Level Income



(Carrión, *unpublished*)

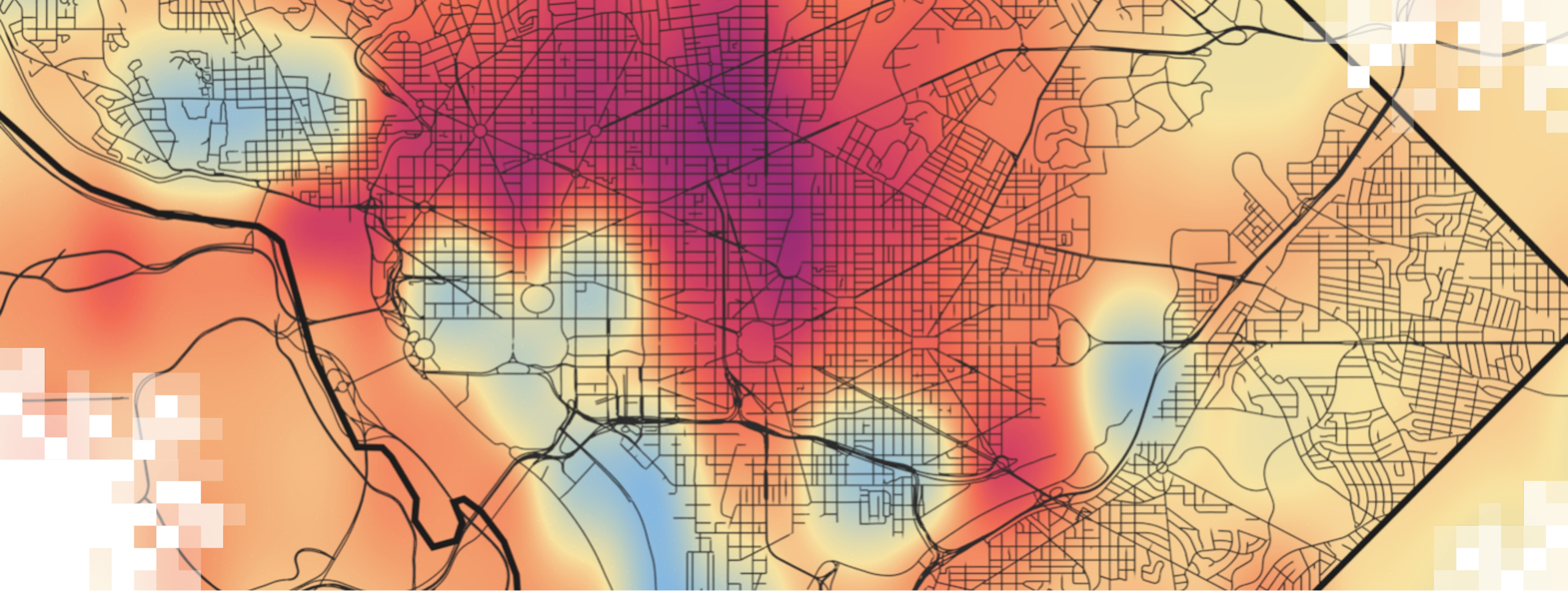
Policy Implications

- Low-income home energy assistance program
- Energy protections
- Targeted energy improvements

Thank You

Collaborators

- Ruth Ann Norton
- Brendan Brown
- Isabel Shargo
- Anna Stouffer
- Weixi Wu
- Xuezhixing Zhang
- Michelle Bell
- Allan Just



Strengths and Weaknesses of Satellite Data for Environmental Justice Applications

Strengths of Satellite Remote Sensing

- Provide information where ground-based data are lacking.
- Provide long-term data records for trend analysis.
- Provide continuous global monitoring with the same well-characterized instruments.
- Data are freely available and there are web-based tools for data analysis, as well as an international user community.
- Earth systems models can integrate surface-based and remote sensing observations to provide uniform spatially and temporally complete datasets.

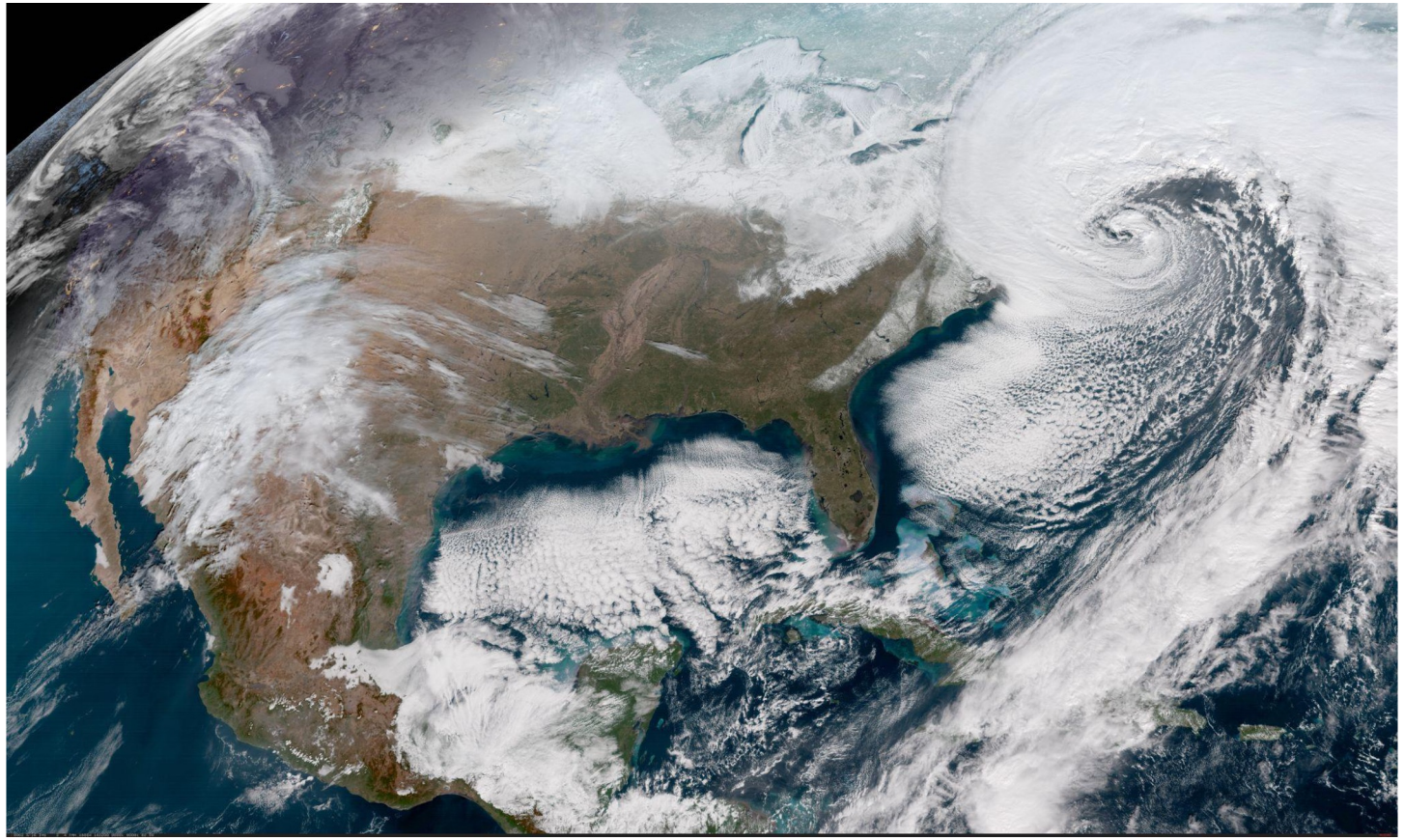


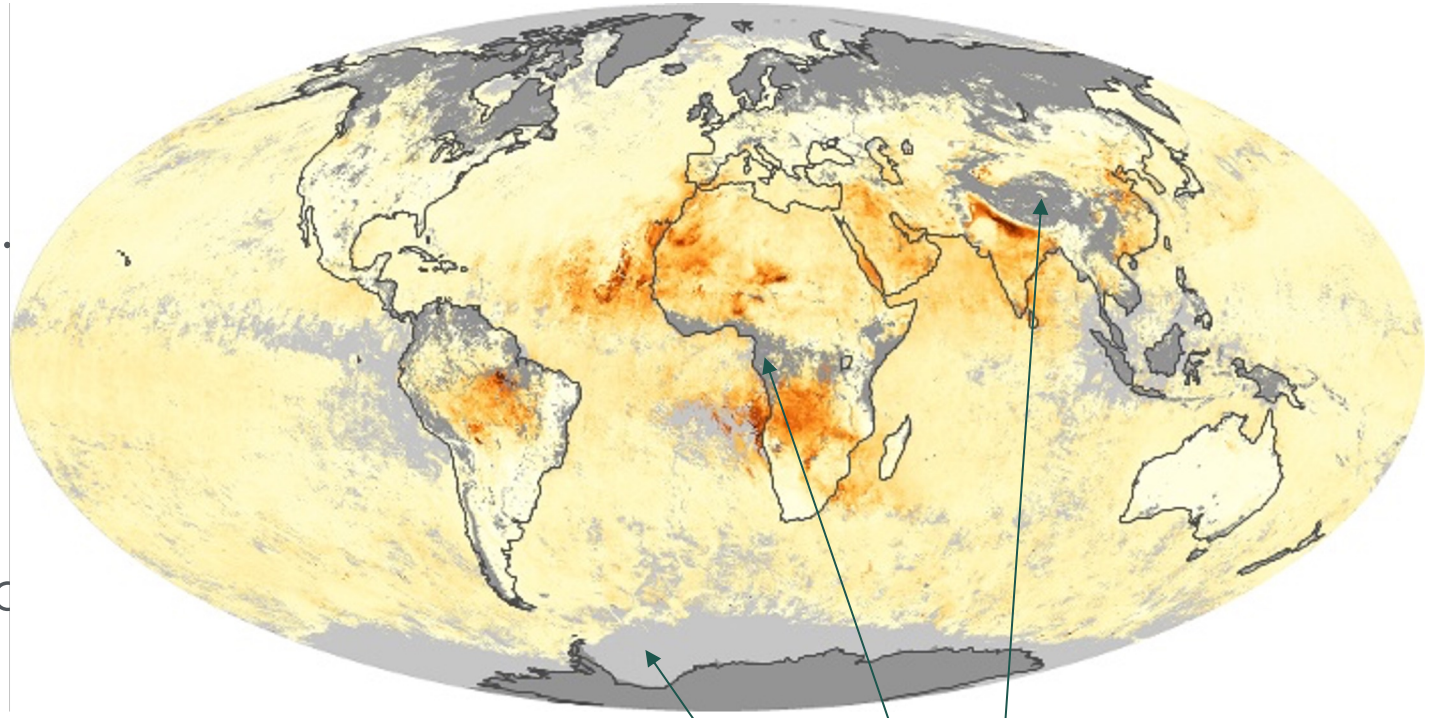
Image Credit: NOAA

Source: *ARSET - Fundamentals of Remote Sensing*. NASA Applied Remote Sensing Training Program (ARSET).

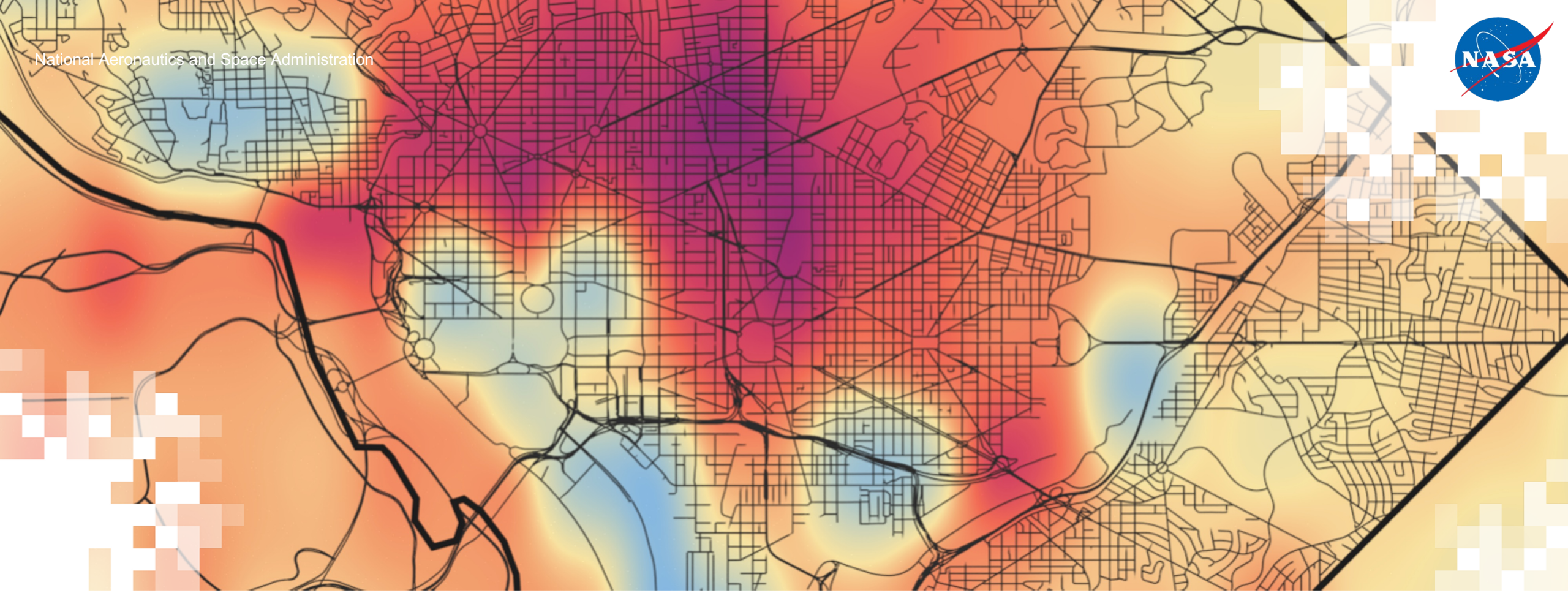
Weaknesses of Satellite Remote Sensing

- It is very difficult to obtain high spatial resolution, temporal resolution, and coverage all at the same time; multiple satellite products may be required to meet different analysis needs, or no product may be suitable.
- Using satellite data requires handling many large files in various formats, requiring specialized processing, visualization, and other tools.
- While the data are generally validated with selected surface measurements, regional and local assessment is recommended to ensure data are fit for regionally-specific studies.

October 2022 Global Aerosol Optical Depth



Source: NASA Earth Observatory

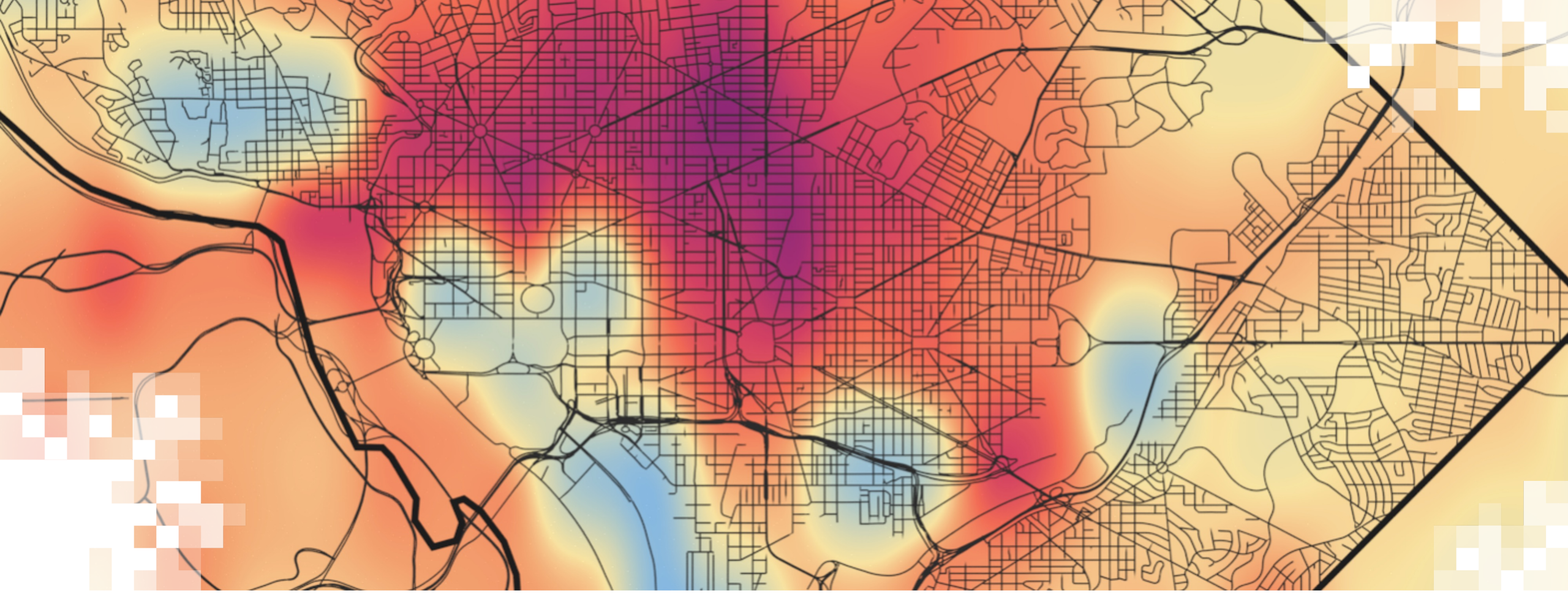


Satellite Data for Air Quality Environmental Justice and Equity Applications

Part 1: Use of Satellite Data in Environmental Justice Applications

Susan Anenberg (George Washington University)

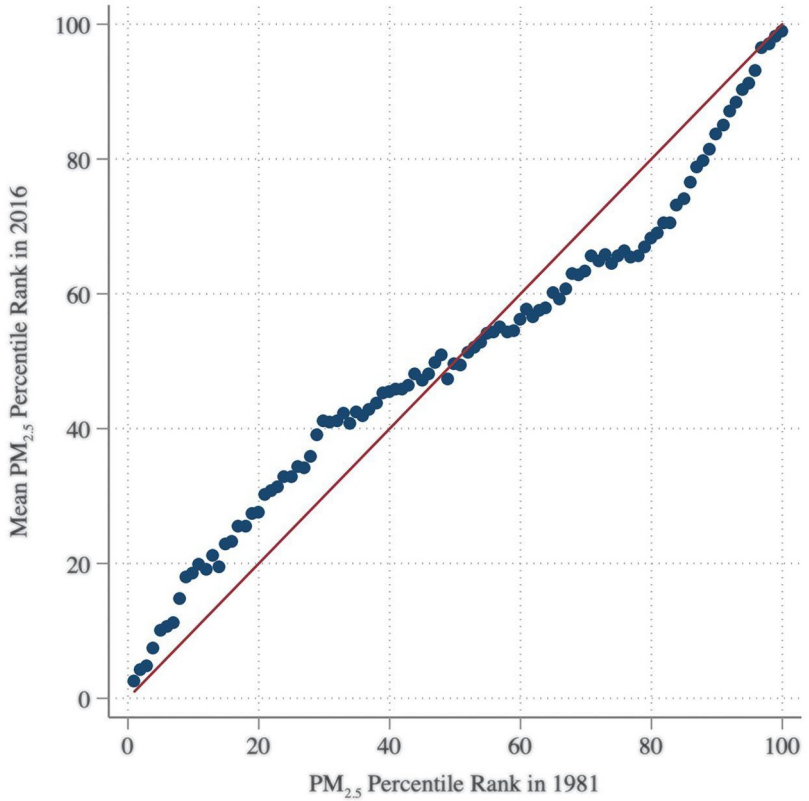
August 23, 2023



Case Study on Air Pollution

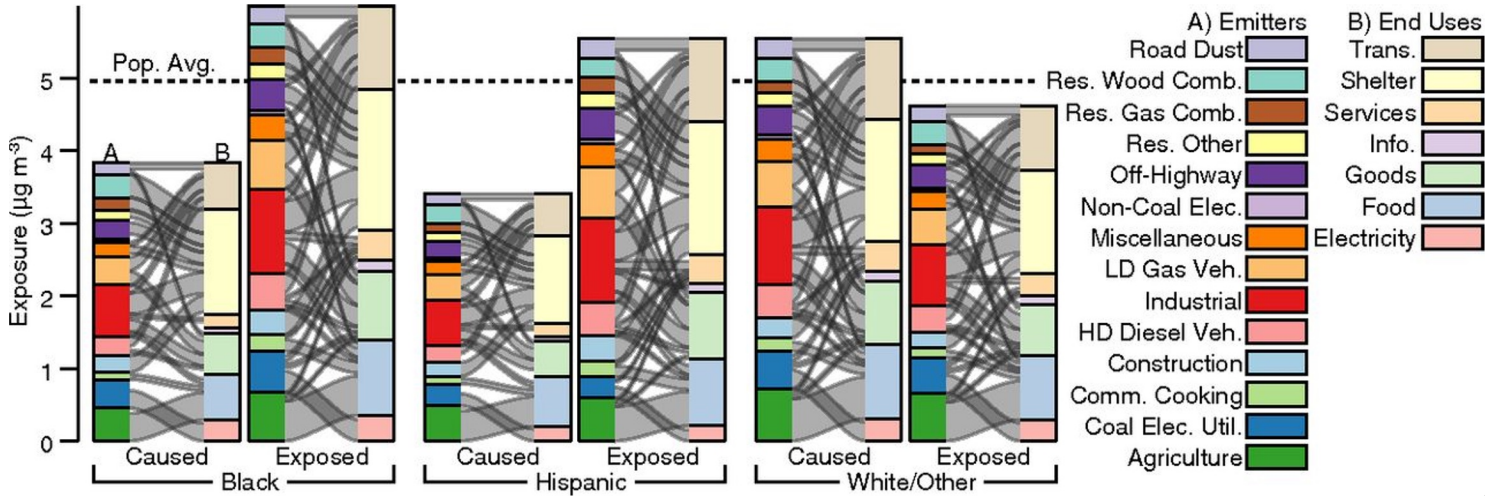
Air Pollution Injustice: New Insights from Big Data

Although $PM_{2.5}$ levels have dropped overall, those areas that were most and least polluted in 1981 remain so today.



Colmer et al., Disparities in $PM_{2.5}$ air pollution in the United States, Science, 2020

There is a large difference between the environmental health damage caused by a racial–ethnic group and the damage that group experiences.



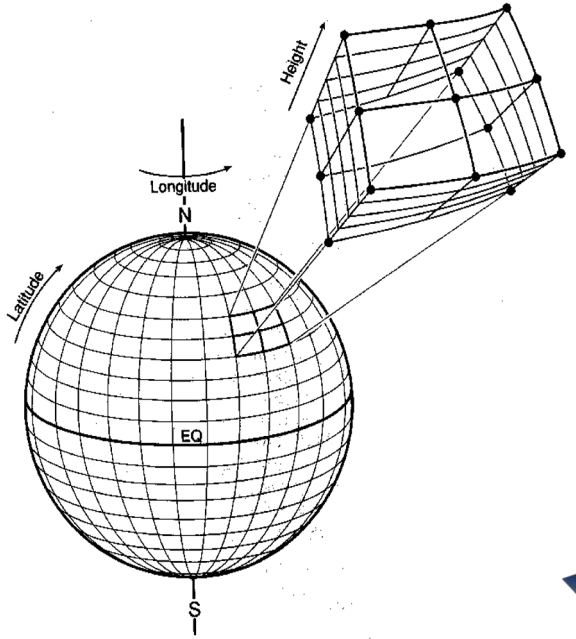
Tessum et al., Inequity in consumption of goods and services adds to racial–ethnic disparities in air pollution exposure, PNAS, 2019

Characterizing Air Pollution Exposure

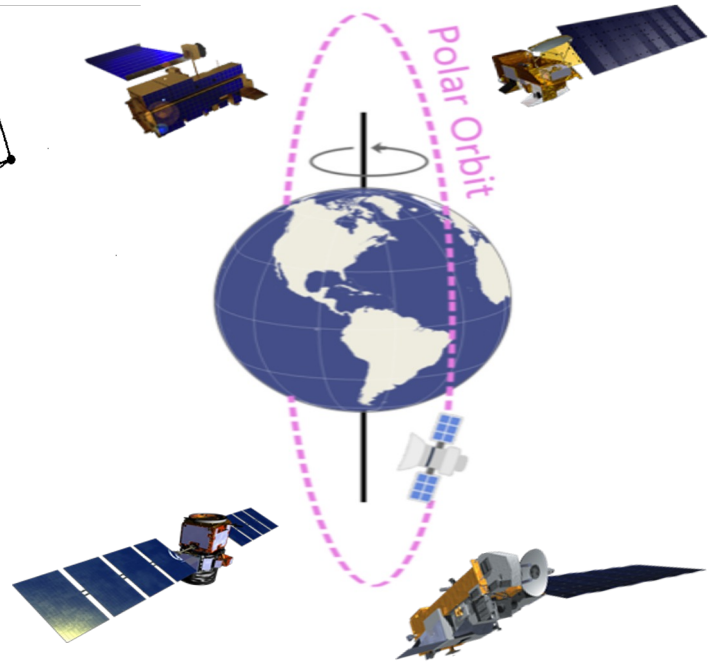
Ground-based monitors

Sensor networks

Models – statistical and physical



Satellite remote sensing



Advantages and Disadvantages of Monitoring

- Advantages
  - Best estimates of our air pollutants (especially with high-cost instruments)
  - Measurements acquired at "nose-level"
  - Monitors (not models or satellites) are used by EPA to determine standard attainment.
- Disadvantages
  - Interspersed; approximately one monitor per 500,000 people in our area
  - Need careful calibration (site visit by technician required once per week)
  - Can only be located on land
  - Sited to capture "regionally representative" levels of pollution
  - Some are not required all year round.

Advantages and Disadvantages of Using Satellites to Measure Air Quality

- Advantages
  - Estimates available for anywhere where there are no clouds and reflective surfaces
  - Can achieve complete geospatial coverage if combined with other information in a model
  - Increasingly high spatial resolution (e.g., 1 km)
  - For some pollutants (e.g., NO_2), high correlation between satellite estimates and ground monitors
- Disadvantages
  - Can't observe all chemical components of the atmosphere
  - Can't monitor surface concentrations: satellites monitor molecules in a column of air between Earth's surface and the satellite
  - Often have to be combined with other information to produce health-relevant estimates
  - Data-intensive
  - Current satellites mostly polar-orbiting (one snapshot over every location on Earth each day), but new launches planned as geostationary (full daytime coverage over one particular region of Earth like the U.S.)

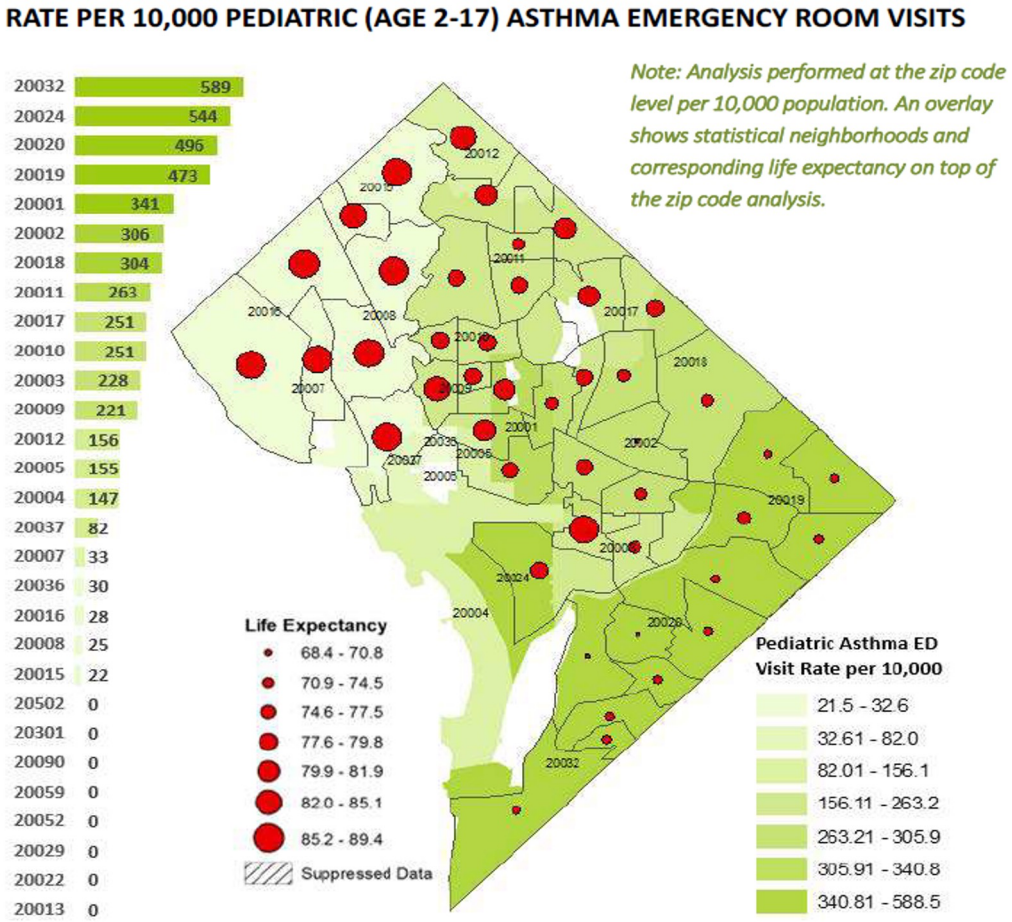
Air Pollutants Measurable from Satellites

- Aerosols (aerosol optical depth, fire detection): can be used to infer "nose-level" $PM_{2.5}$ with atmospheric models.
- Ozone (O_3): currently no information on "nose-level" concentrations
- **Nitrogen dioxide (NO_2): most straightforward to observe and excellent tracer of fossil fuel combustion**
- Carbon monoxide (CO): another tracer of combustion

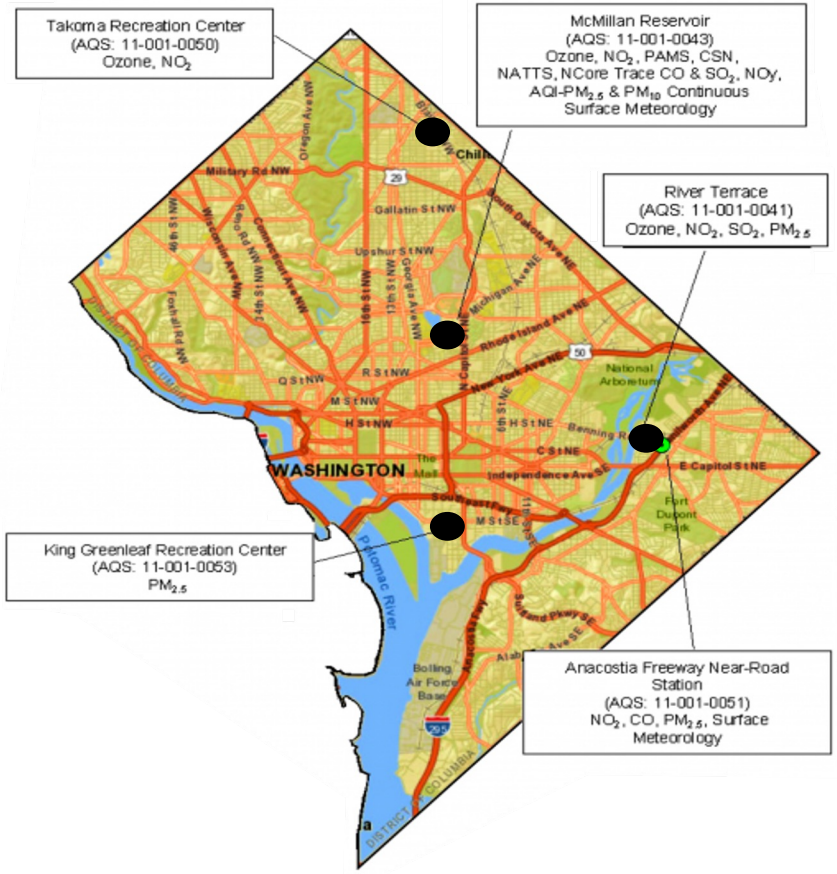
- Sulfur dioxide (SO_2)
- Ammonia (NH_3)
- Formaldehyde (HCHO)
- Surface ultraviolet (UV)

Precision and accuracy are not currently suitable for most health studies.

Case Study: Health and Air Pollution Disparities in Washington, DC



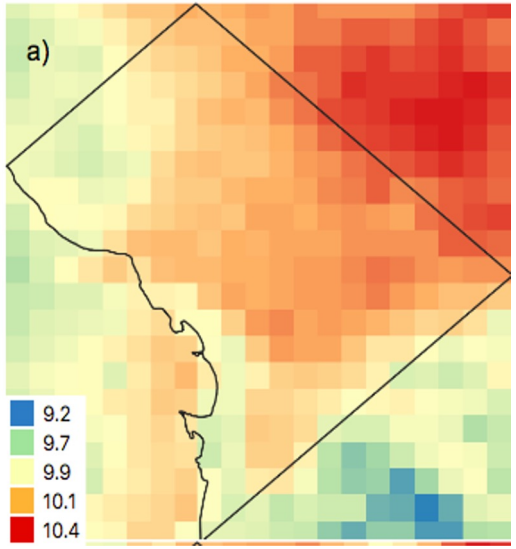
DC Health Equity Report 2018



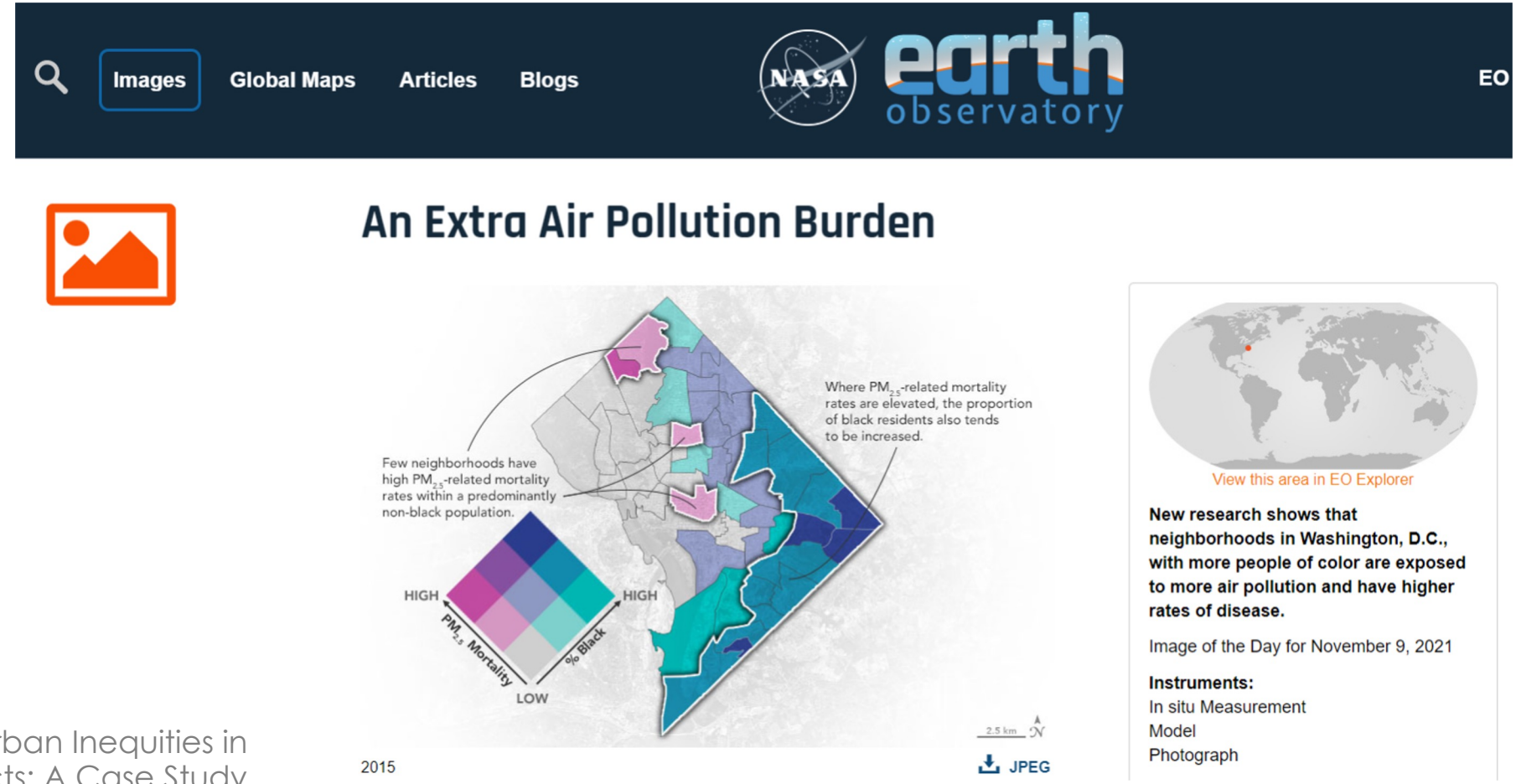
District of Columbia Department of Energy & Environment

Case Study: Health and Air Pollution Disparities in Washington, DC

Satellite-derived $PM_{2.5}$ concentrations provide a continuous spatial surface of exposure estimates.

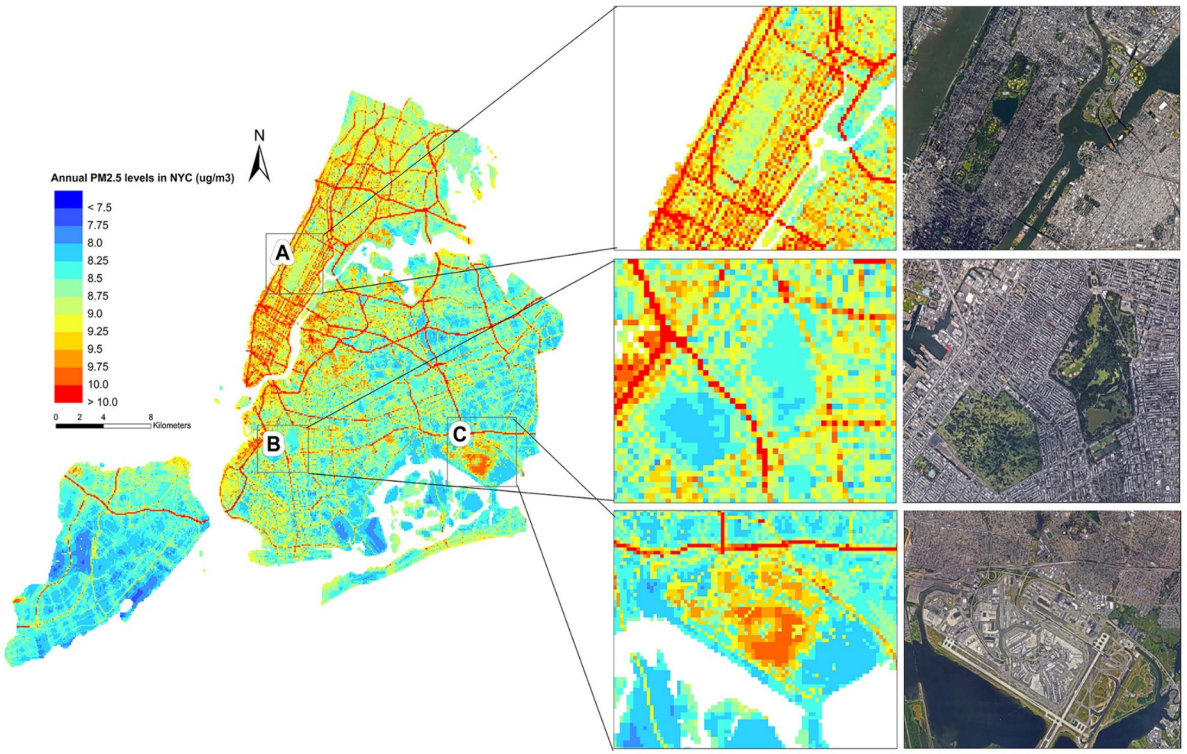


Castillo et al., Estimating Intra-Urban Inequities in $PM_{2.5}$-Attributable Health Impacts: A Case Study for Washington, DC, GeoHealth, 2021



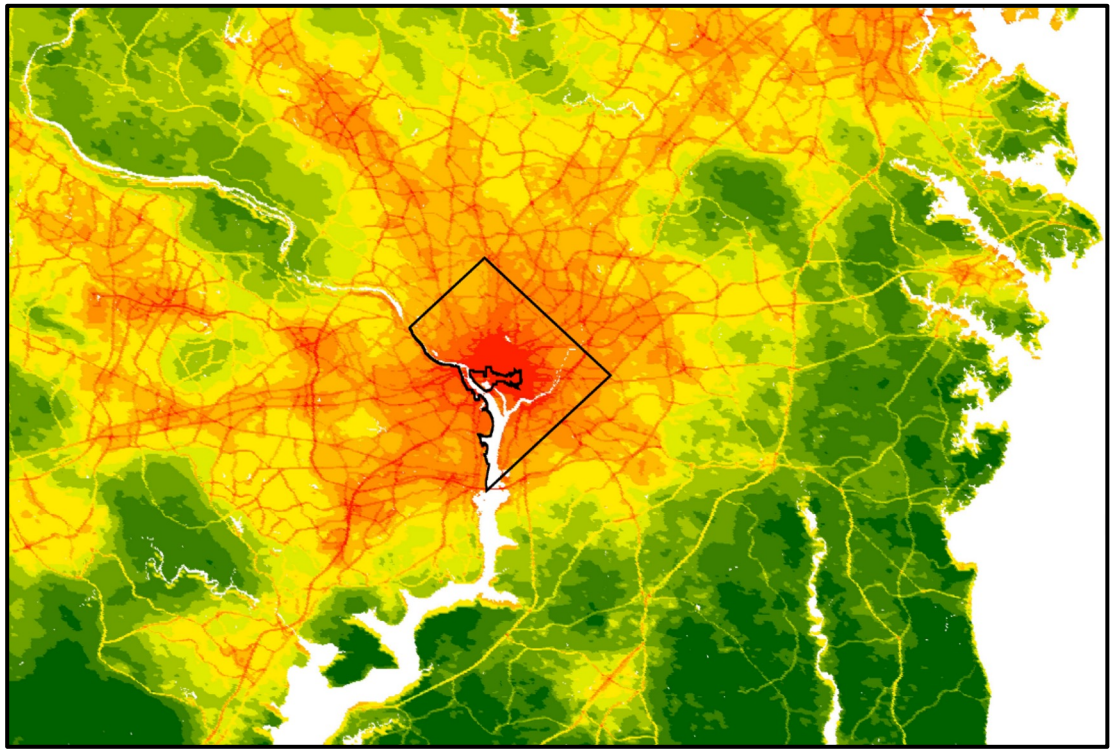
Satellite-derived Datasets: Using Land-Use Variables to Enhance Spatial Resolution

$PM_{2.5}$ in New York City



Huang et al., Estimating daily $PM_{2.5}$ concentrations in New York City at the neighborhood-scale: Implications for integrating non-regulatory measurements, Science of the Total Environment, 2019

NO_2 in Washington, DC



Data from: Anenberg et al., Long-term trends in urban NO_2 concentrations and associated paediatric asthma incidence: estimates from global datasets, Lancet Planetary Health, 2022

Studying Air Pollution Injustice with Satellite-derived NO_2

- NO_2 is a precursor to $PM_{2.5}$ and ozone and as a marker for traffic-related air pollution is associated with respiratory effects, cardiovascular effects, and mortality.
- Compared with total $PM_{2.5}$ mass, NO_2 has sharper gradients near emission sources.
  - Shorter atmospheric lifetime (i.e., hours compared with days) and
  - Less influence from regional pollution sources (e.g., agriculture, wildfire smoke, dust)
- NO_2 is a surrogate for urban combustion-related air pollution, including $PM_{2.5}$ components that exhibit more spatial variation than total $PM_{2.5}$ mass, such as black carbon (BC) and particle-bound polycyclic aromatic hydrocarbons (PAHs).
- Satellite NO_2 "column" observations are tightly correlated with NO_2 observed at ground monitors.

Satellite Data: Spatially Complete, High Resolution, Semi-observational

TROPOMI sensor on the Sentinel-5p satellite, European Space Agency

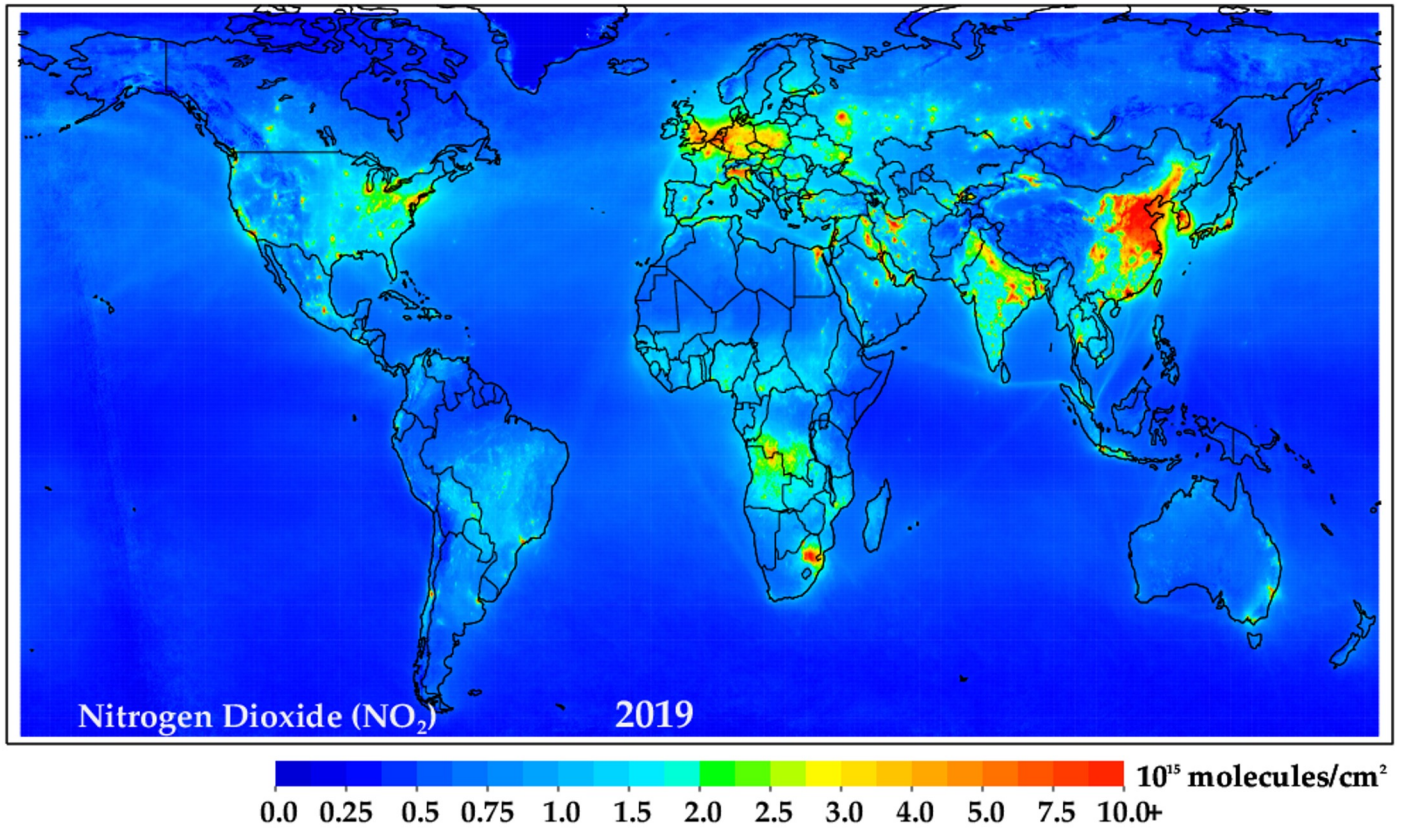
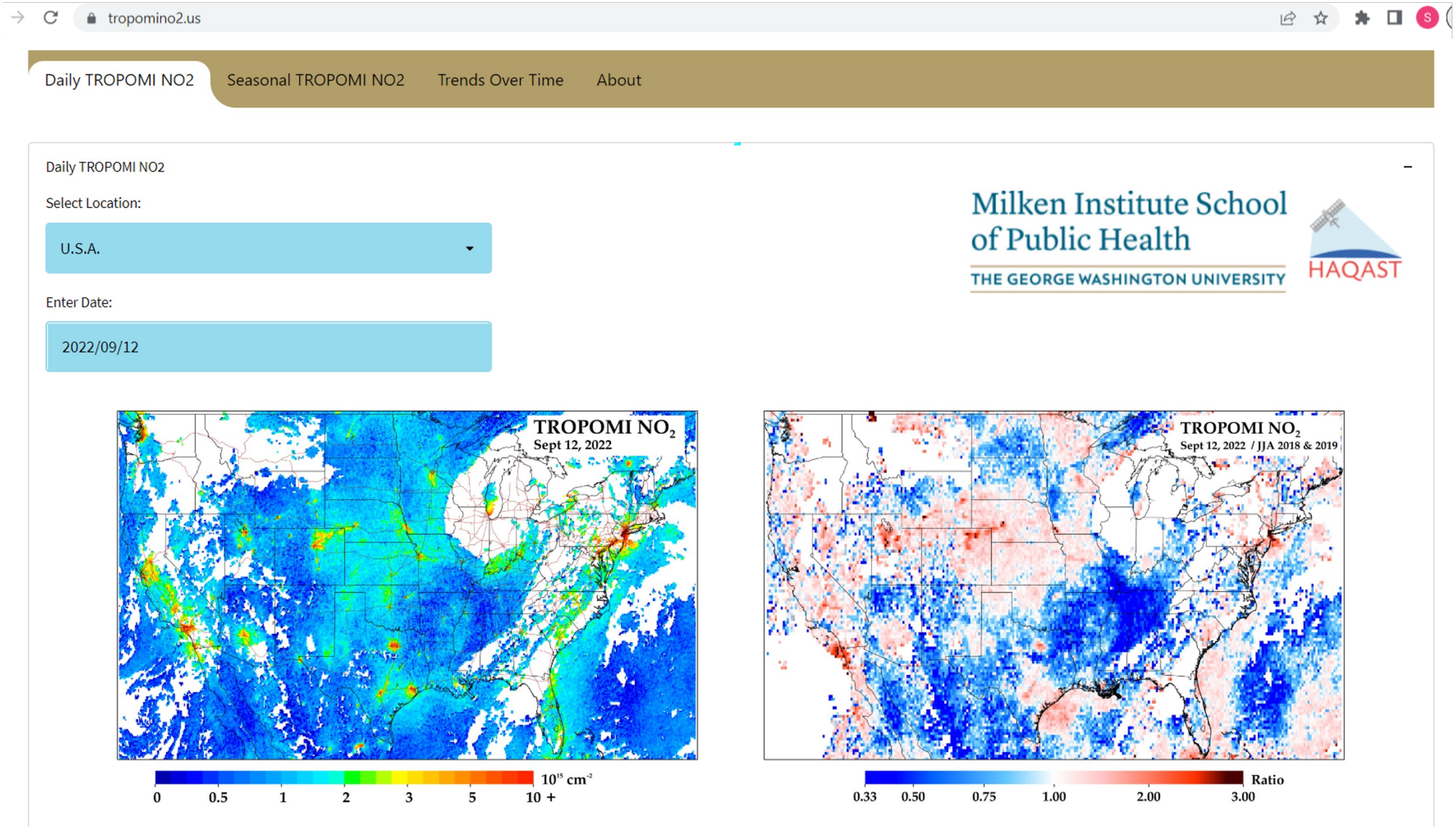
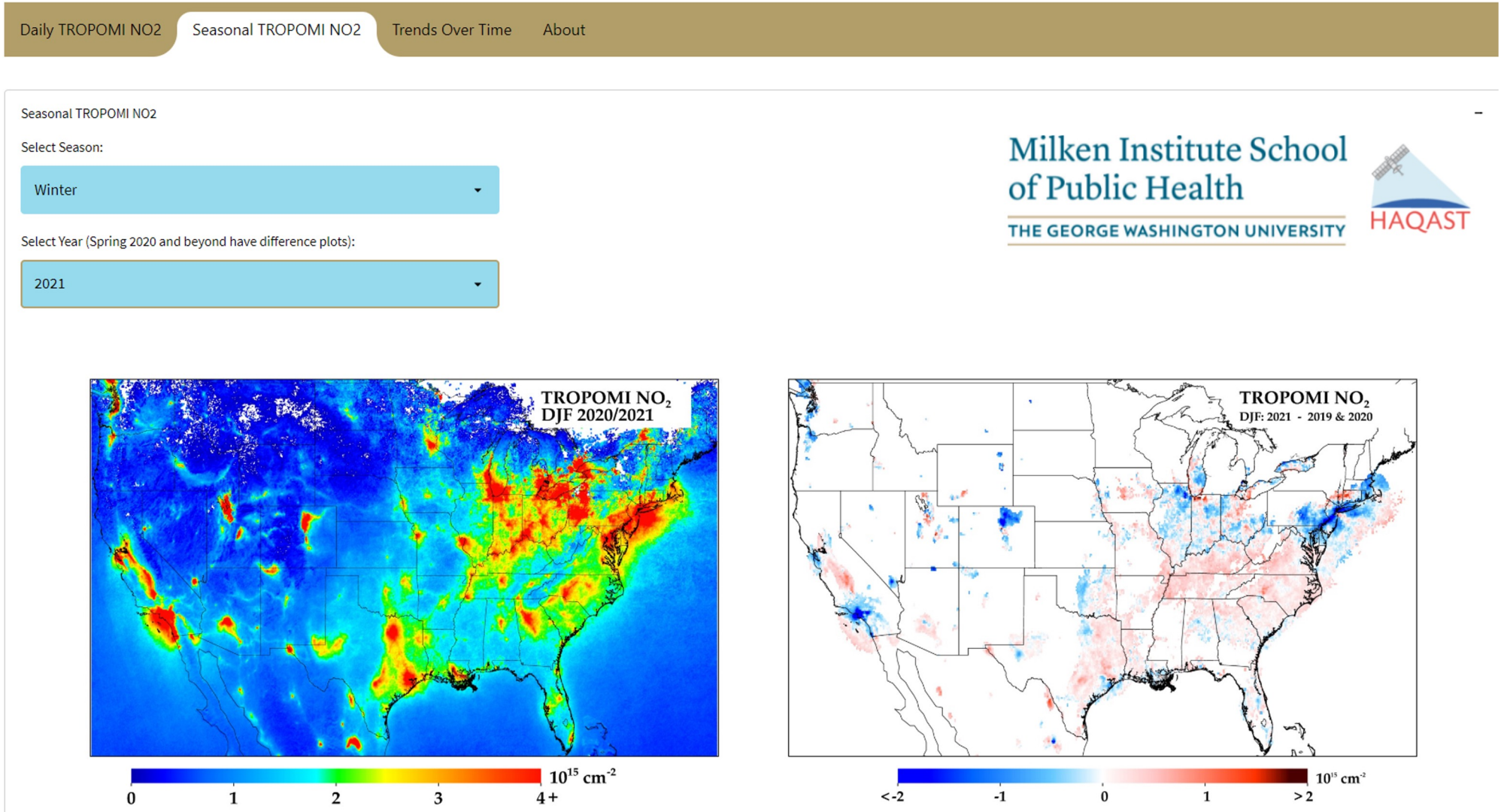


Image by Dan Goldberg

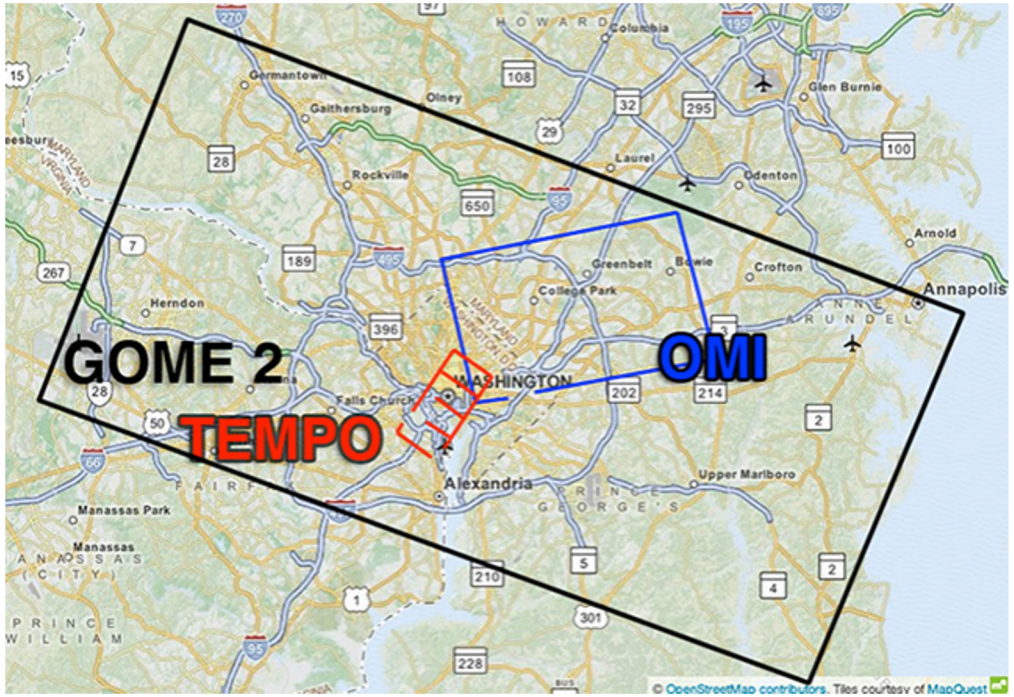
What do DAILY Satellite Data Look Like?

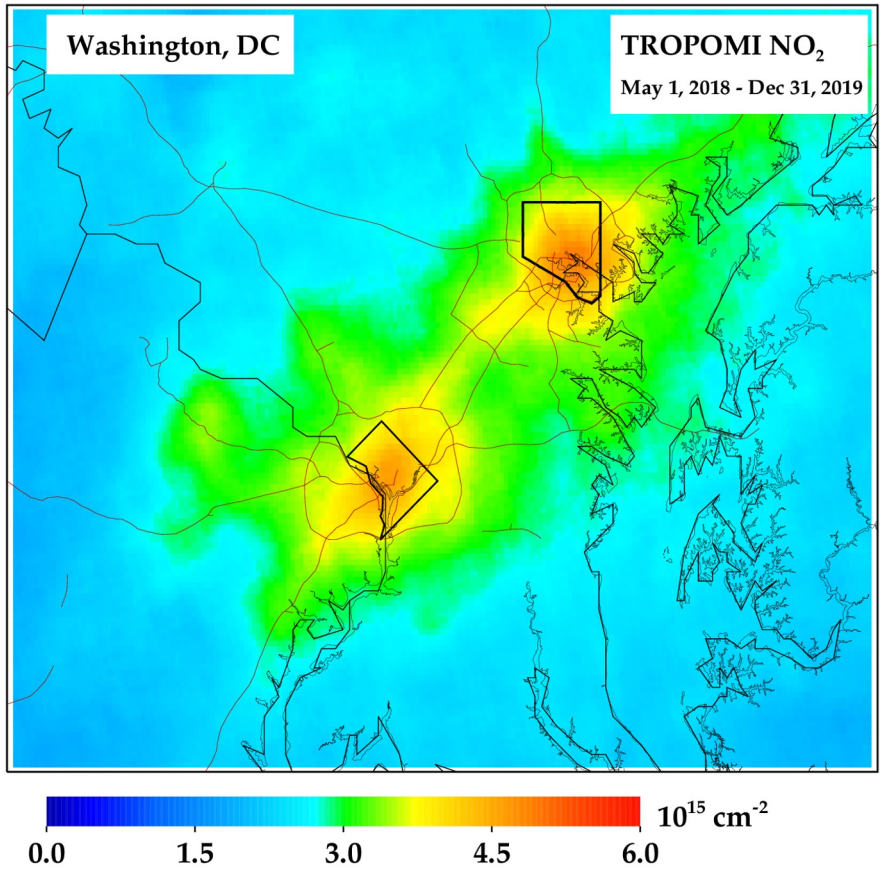


What do SEASONAL Average Satellite Data Look Like?



Measuring Intraurban NO_2 Variation from Space



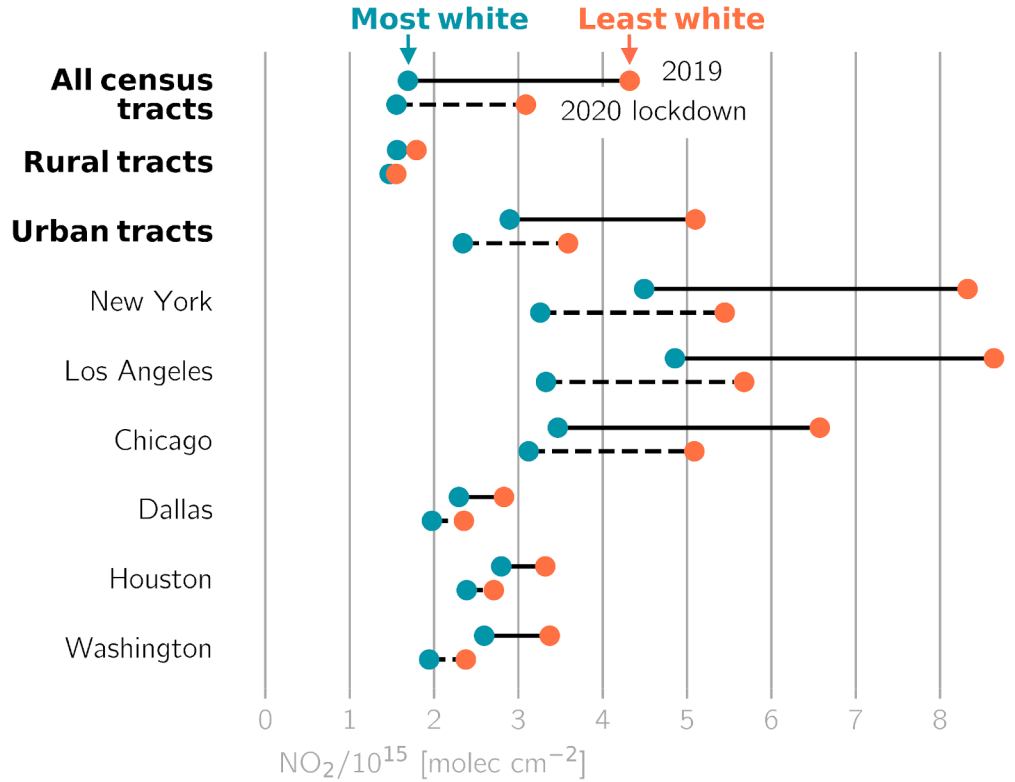


Goldberg et al., TROPOMI NO_2 in the United States: A Detailed Look at the Annual Averages, Weekly Cycles, Effects of Temperature, and Correlation With Surface NO_2 Concentrations, Earth's Future, 2021

COVID-19 Lockdowns did not Eliminate NO_2 Disparities

- Pandemic reduced, but did not eliminate, NO_2 disparities of major urban areas in the U.S.

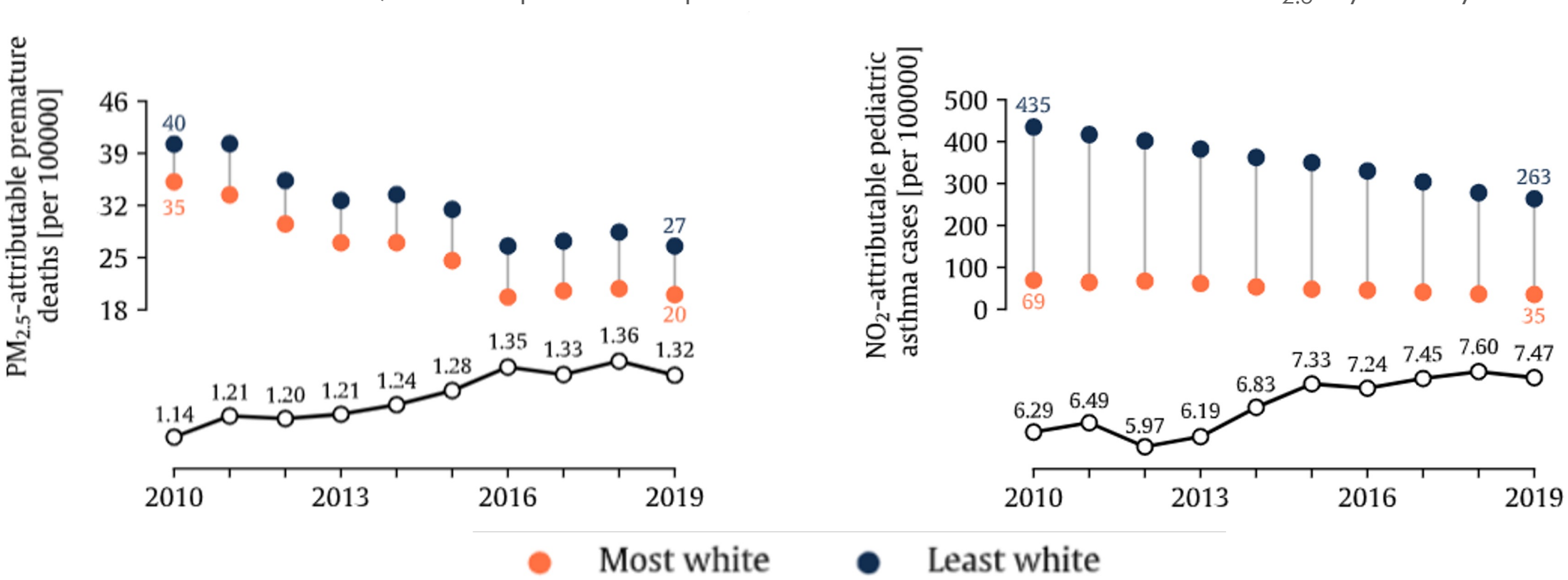
- Proximity of highways and diesel traffic in minoritized communities are a key driver of NO_2 disparities.



Kerr et al. COVID-19 pandemic reveals persistent disparities in nitrogen dioxide pollution, PNAS, 2021.

Widening Disparities in Air Pollution-attributable Health Impacts

Racial relative disparities in pediatric asthma attributable to NO_2 have increased by nearly 20% between 2010 and 2019, and disparities in premature death attributable to $PM_{2.5}$ by nearly 15%.



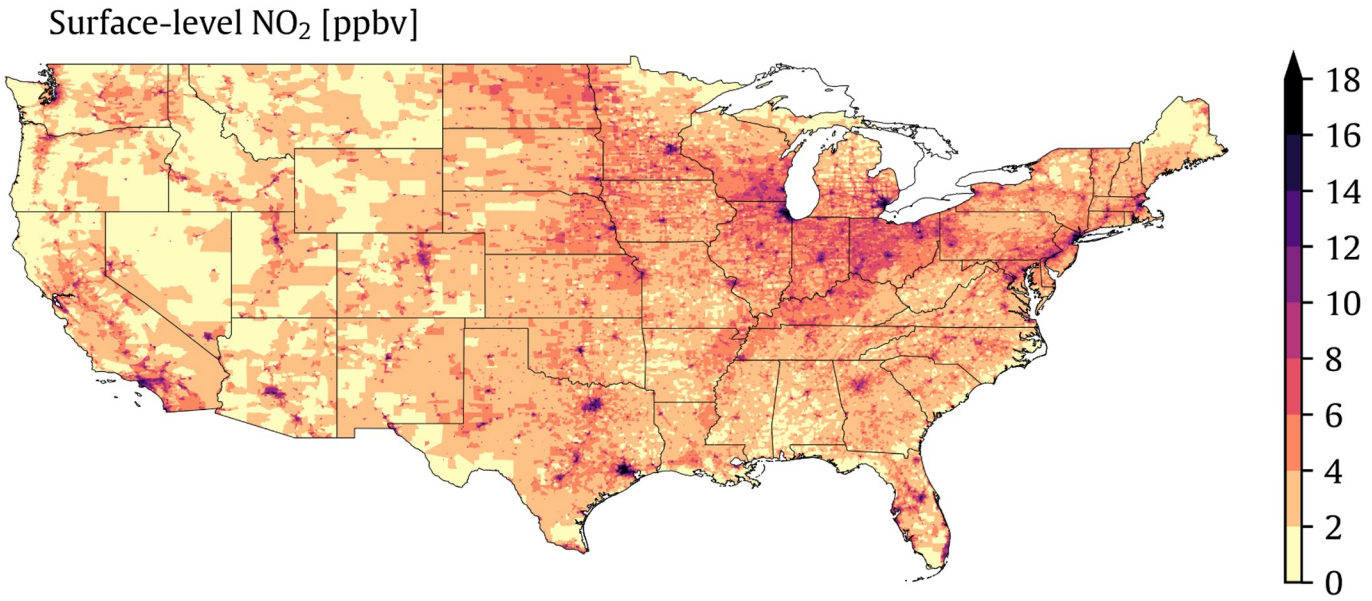
Most White: Census tracts where share of White population >90th percentile
Least White: Census tracts where share of White population <10th percentile
Large dots: Results in most/least White tracts of entire U.S.
Small dots: Results in most/least White tracts of each metropolitan statistical area

Kerr et al. under review, 2023

Air Quality Indicators in EJSCREEN

Indicator	Metric	Source	Spatiotemporal resolution
PM2.5	Annual average PM2.5	EPA model-monitor fusion (CMAQ model)	12km x 12km aggregated to census tract, 2019
Diesel PM2.5	Diesel PM2.5 in the air	National Emissions Inventory (NEI)	Census tract, 2019
Ozone	Annual mean top 10 of daily maximum 8-hour concentration	EPA model-monitor fusion (CMAQ model)	12km x 12km aggregated to census tract, 2019
Air toxics	Air toxics cancer risk	National-Scale Air Toxics Assessment (NATA)	Census tract, 2019
	Air toxics respiratory hazard index	National-Scale Air Toxics Assessment (NATA)	Census tract, 2019
	Toxic releases to air (modeled toxicity-weighted concentrations of TRI listed chemicals)	Calculated from 2021 Risk-Screening Environmental Indicators (RSEI)	Census tract, 2021

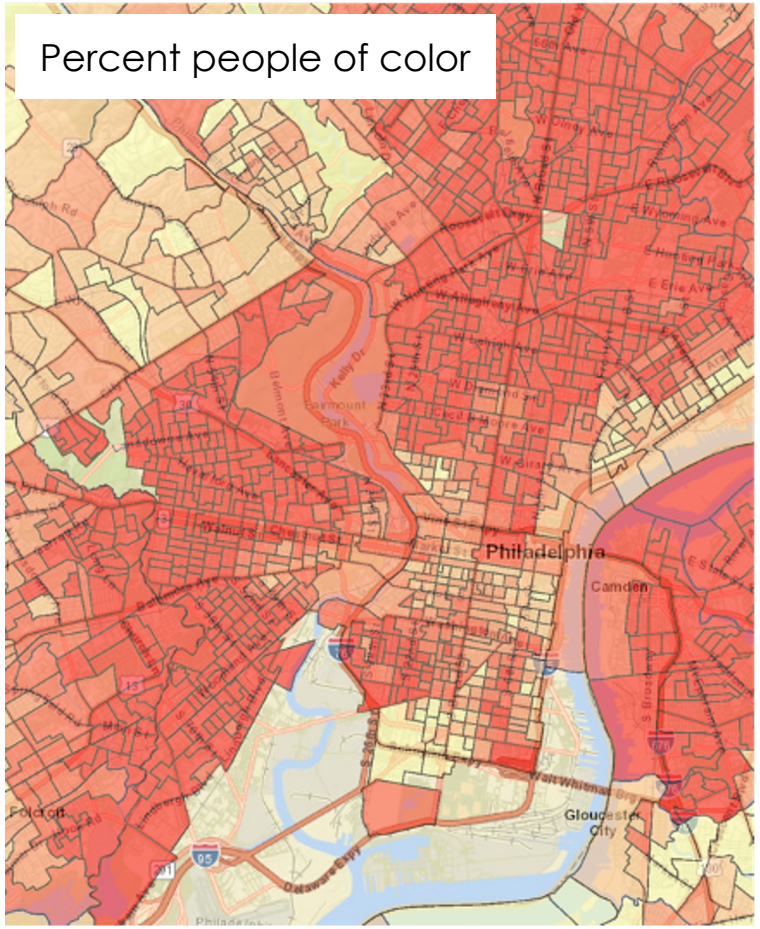
Novel Datasets Provide Means to Assess NO_2 Levels at Environmental Justice-Relevant Scales

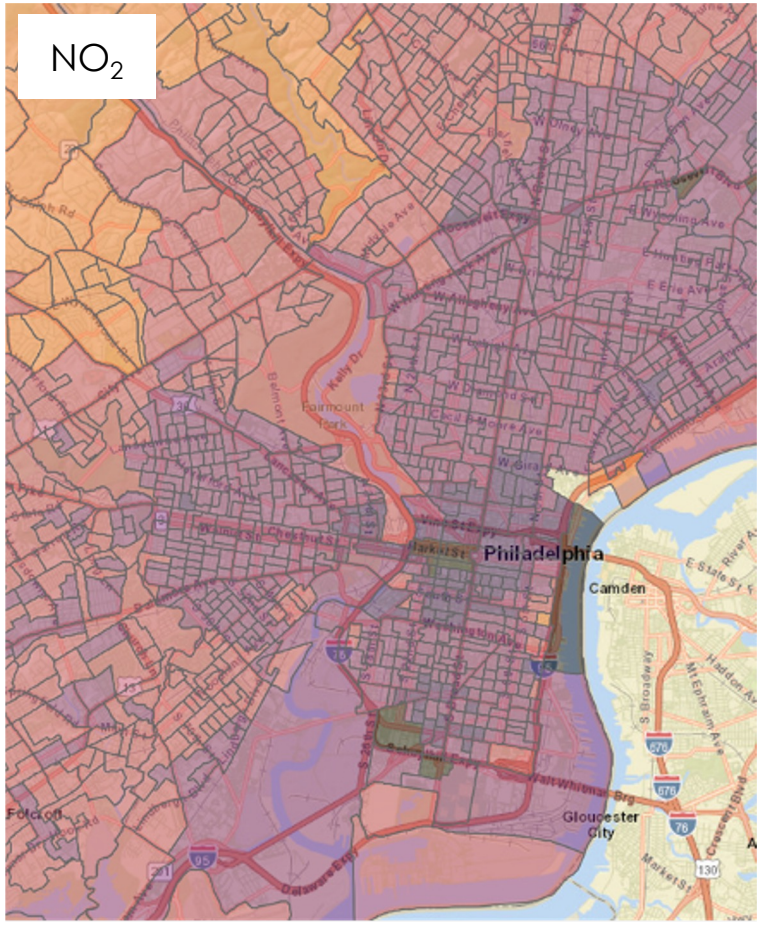


- High resolution datasets that fuse satellite data with physical models allow NO_2 to be assessed for individual block groups (map on left).

- Block group-level NO_2 can be directly integrated into EJSCREEN to explore inequities associated with this pollutant and compare with existing environmental indicators.

NO_2 Displays Different Spatial Patterns of Injustice in EJSCREEN than Current Indicators

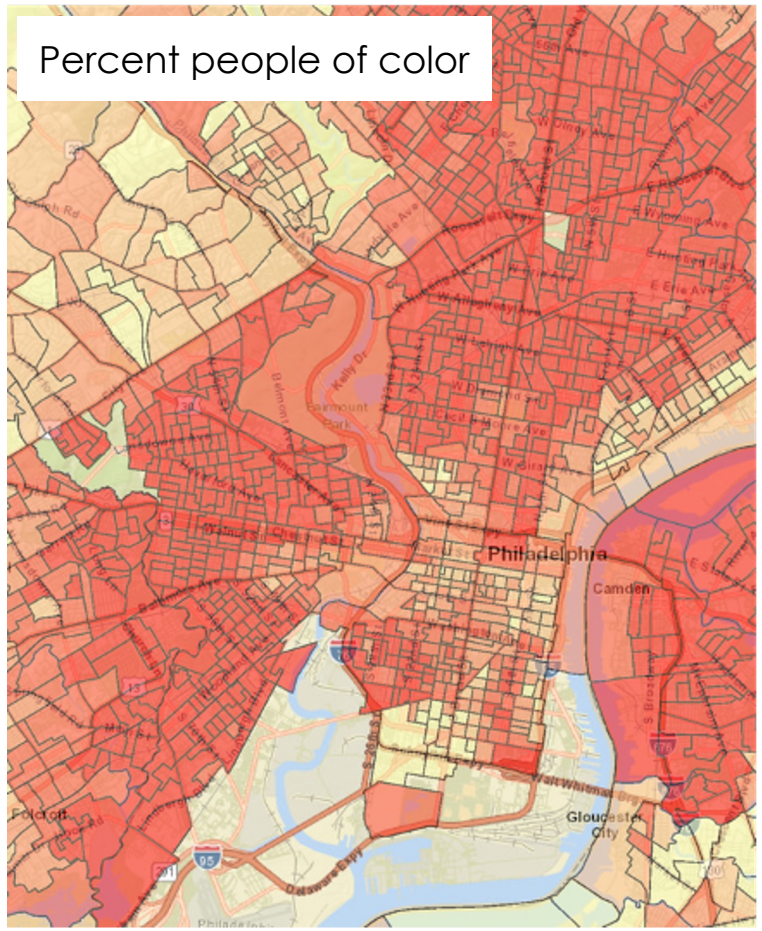


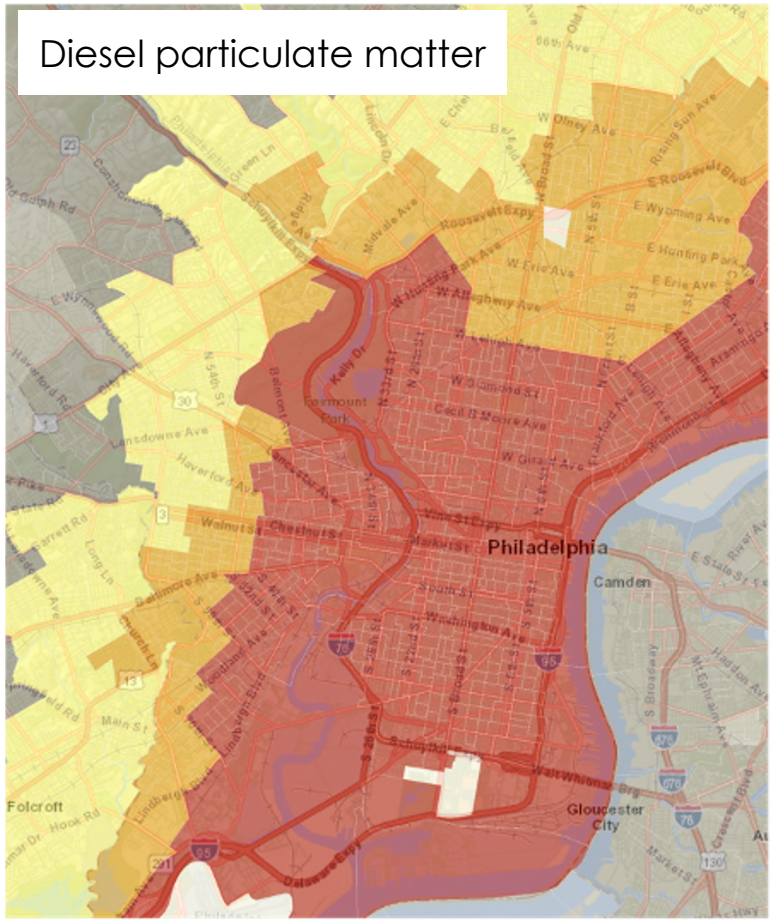


Source: EJSCREEN

- In Philadelphia, we find a correspondence between race and NO_2 levels.

NO_2 Displays Different Spatial Patterns of Injustice in EJSCREEN than Current Indicators





Source: EJSCREEN

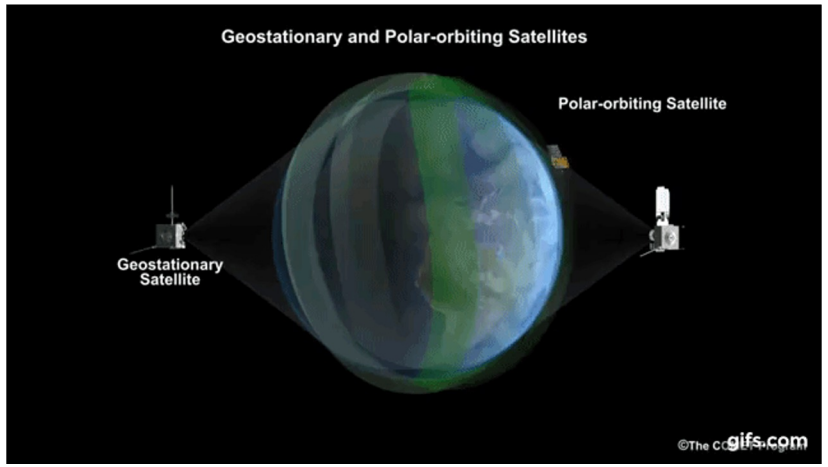
- In Philadelphia, we find a correspondence between race and NO_2 levels.

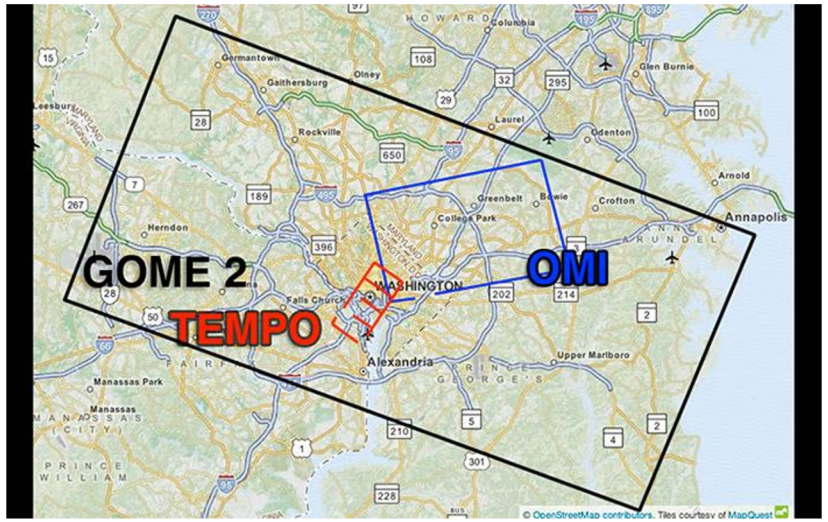
- Current indicators related to NO_2, such as diesel particulate matter, do not have the same heterogeneities and patterns of injustice as NO_2.

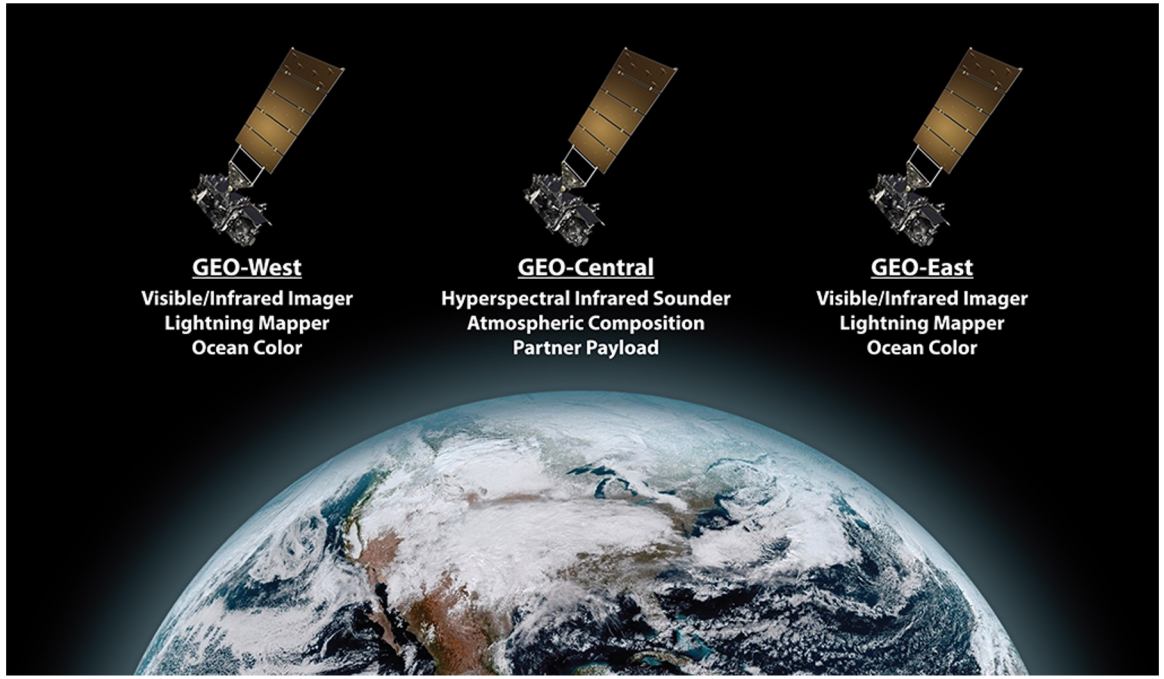
Future of Satellite Data for Air Pollution Injustice Research

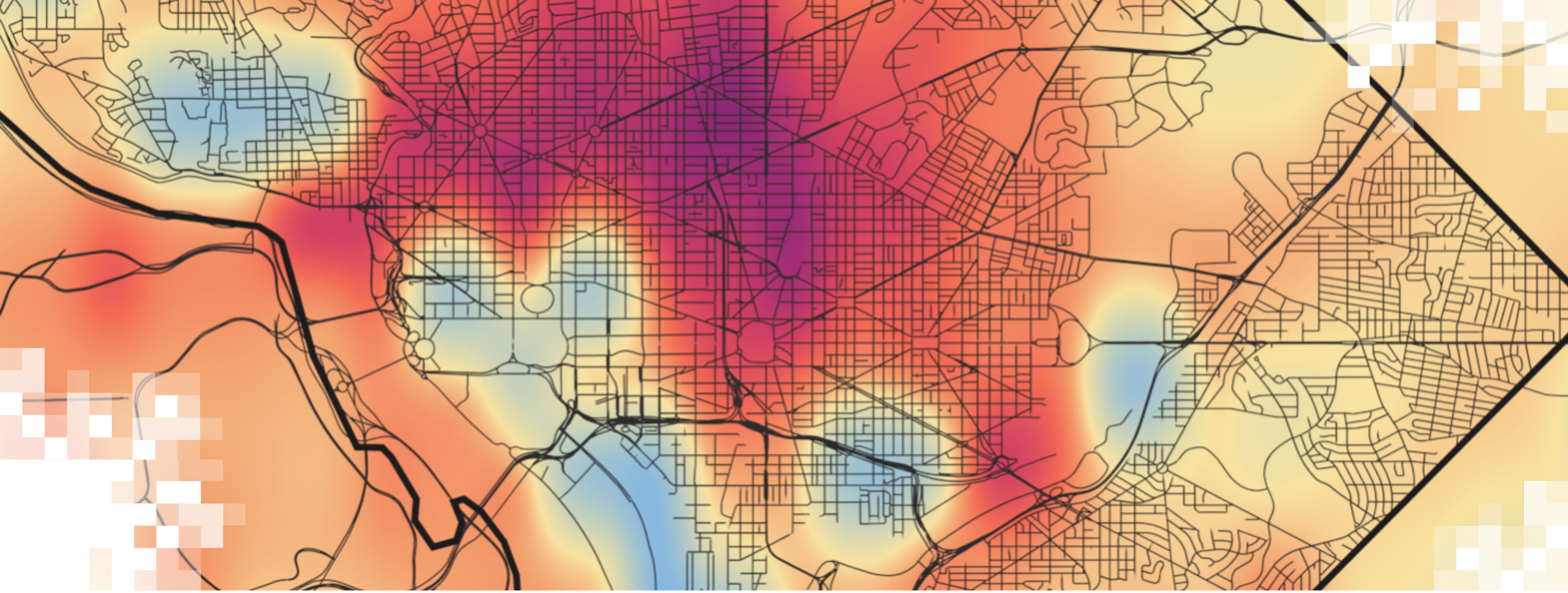
- Incorporating satellite data into EJ research can reveal new insights beyond what's available from other monitoring sources:
  - Disparities stronger for NO_2 vs. $PM_{2.5}$
  - Disparities larger for health impacts vs. concentrations
  - Can also use satellite data to understand source contributions
- Opportunity to enhance information in EJ screening tools
- Further advance knowledge and tracking by combining information from multiple sources
- Engage with new SD4EJ community of practice
- Support new satellite missions that continue the monitoring record

Future: TEMPO and GEO-XO Geostationary Satellites









How satellite data can be used in EJ applications

How Satellite Data Can be Used in EJ Applications

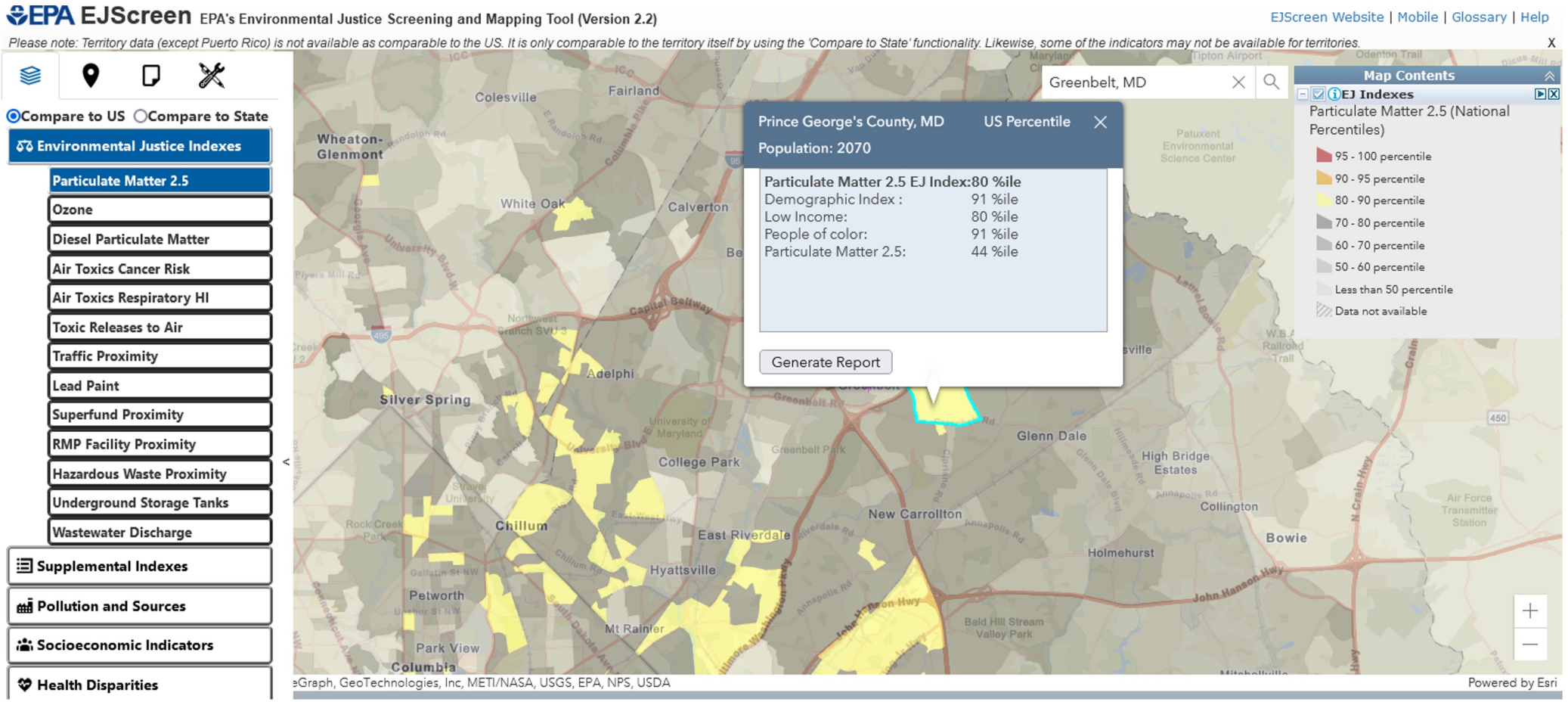
- Improve information in EJ mapping tools
- Identify disadvantaged communities (e.g., using the Climate and Economic Justice Screening Tool developed for the Justice40 Initiative)
- Characterize disproportionate environmental burdens and associated health risks
- Discover associations between environmental health risk factors and health outcomes
- Understand contributions of different emission sectors and sources to environmental injustice
- Identify and address local polluting sources
- Track air pollution from emerging industries (e.g., oil and gas development, transportation related to warehousing and goods movement)
- Evaluate emissions and concentration estimates from other sources (e.g., models)

EJScreen

- EPA's EJ mapping and screening tool
- Provides demographic socioeconomic and environmental information for region of choice
- Includes:
  - 13 environmental indicators (e.g., PM2.5, ozone)
  - 7 socioeconomic indicators
  - 13 EJ indexes
  - 13 supplemental indexes
- EPA video overview of EJSCREEN

EPA's EJScreen tool

Map the PM2.5 Where You Live

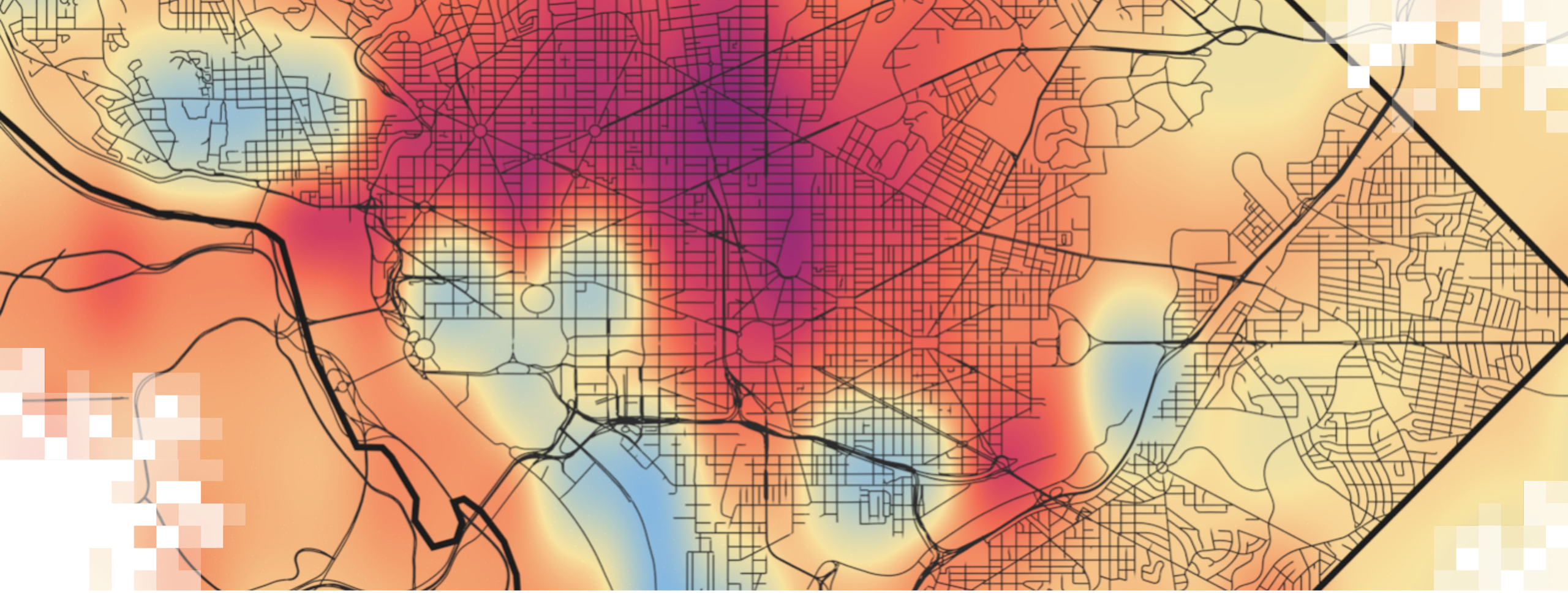


Location: NASA Goddard Space Flight Center

Exploring the EJScreen Tool

- Use EPA's EJScreen tool to map $PM_{2.5}$ where you live.
- What are some strengths and weaknesses of the tool and the data it uses to characterize $PM_{2.5}$?
- How might satellite data provide additional information about air pollution injustice?
- In Part 3, we will learn how to incorporate satellite-derived air pollution datasets into EJScreen.

EPA's EJScreen tool



Part 1:
Summary

Summary

- Satellite data have been used to investigate environmental justice issues such as:
  - Exposure to air pollution
  - Access to green space
  - Extreme temperatures (heat & cold)
  - Access to water
  - Exposure to light pollution
- Combining satellite remote sensing data with socio-economic information can provide evidence of disparities, inequality, and environmental injustice.
- Satellites' wide spatial coverage and long data records can help track changes in exposures and disparities across regions and through time.
- Data resolution & coverage should be considered when identifying suitable remote sensing data to answer different environmental justice questions.

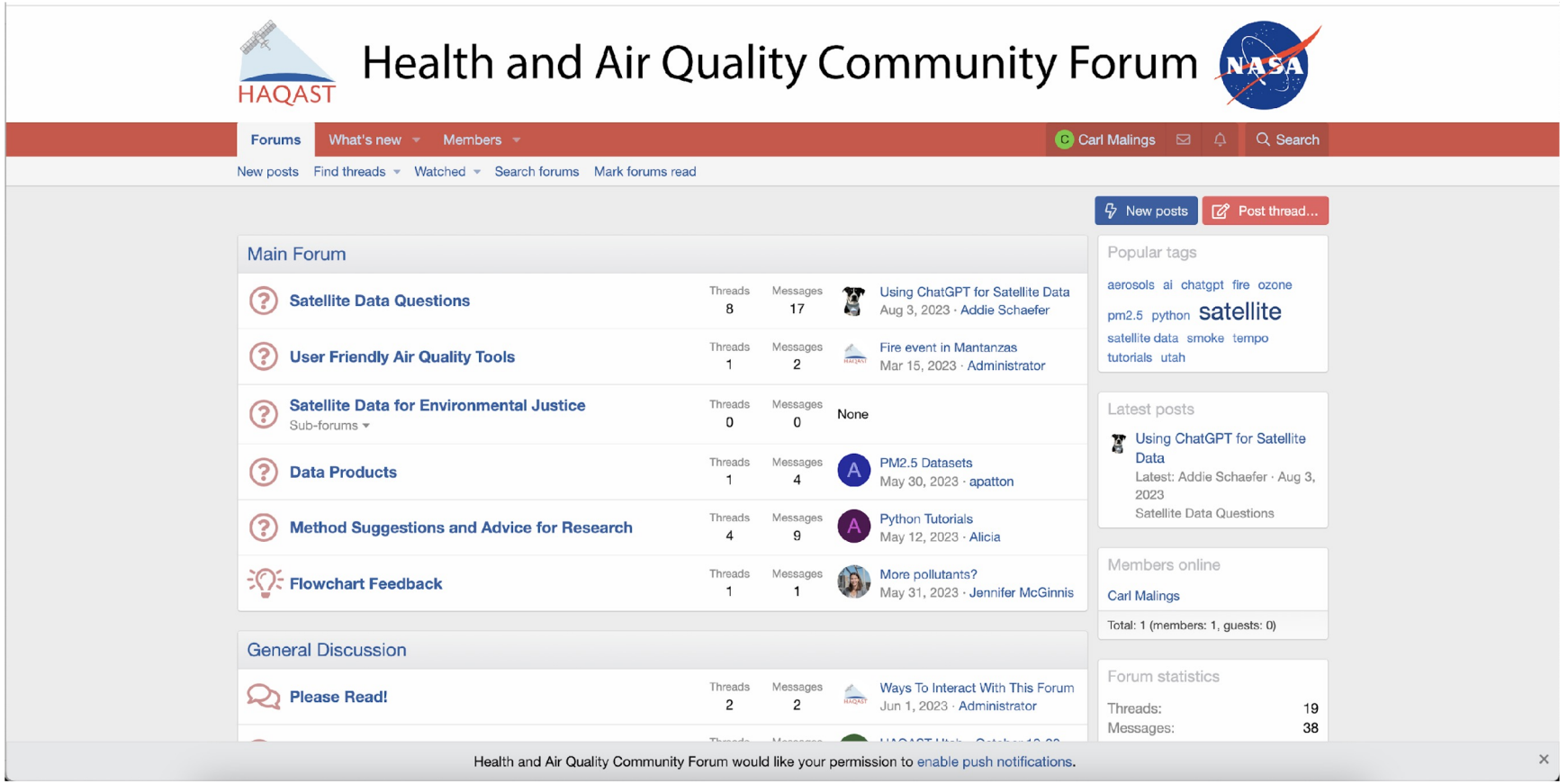
Looking Ahead to Part 2

In Part 2, we will learn more about air quality remote sensing, including:

- How different types of satellites measure different kinds of air pollution.
- What satellites can and can't measure in terms of air quality.
- How satellite data can be used to track surface-level air quality.
- Current and upcoming NASA missions relevant to air quality.
- What free NASA resources exist for visualizing, accessing, and analyzing satellite data related to air quality.

Optional Activity

Join the NASA Health and Air Quality Community Forum, where you can introduce yourselves to others attending this training and discuss your EJ work.



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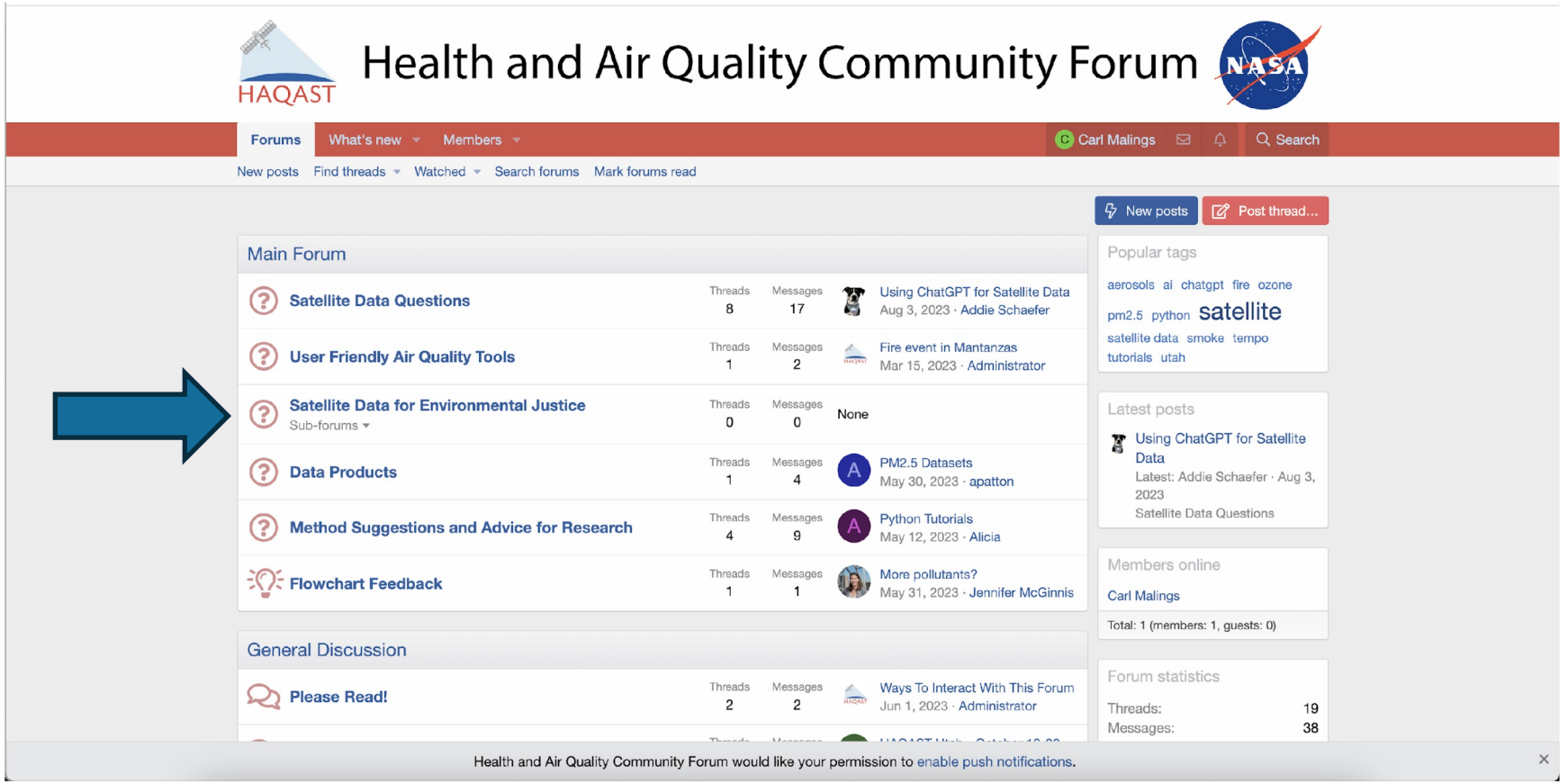

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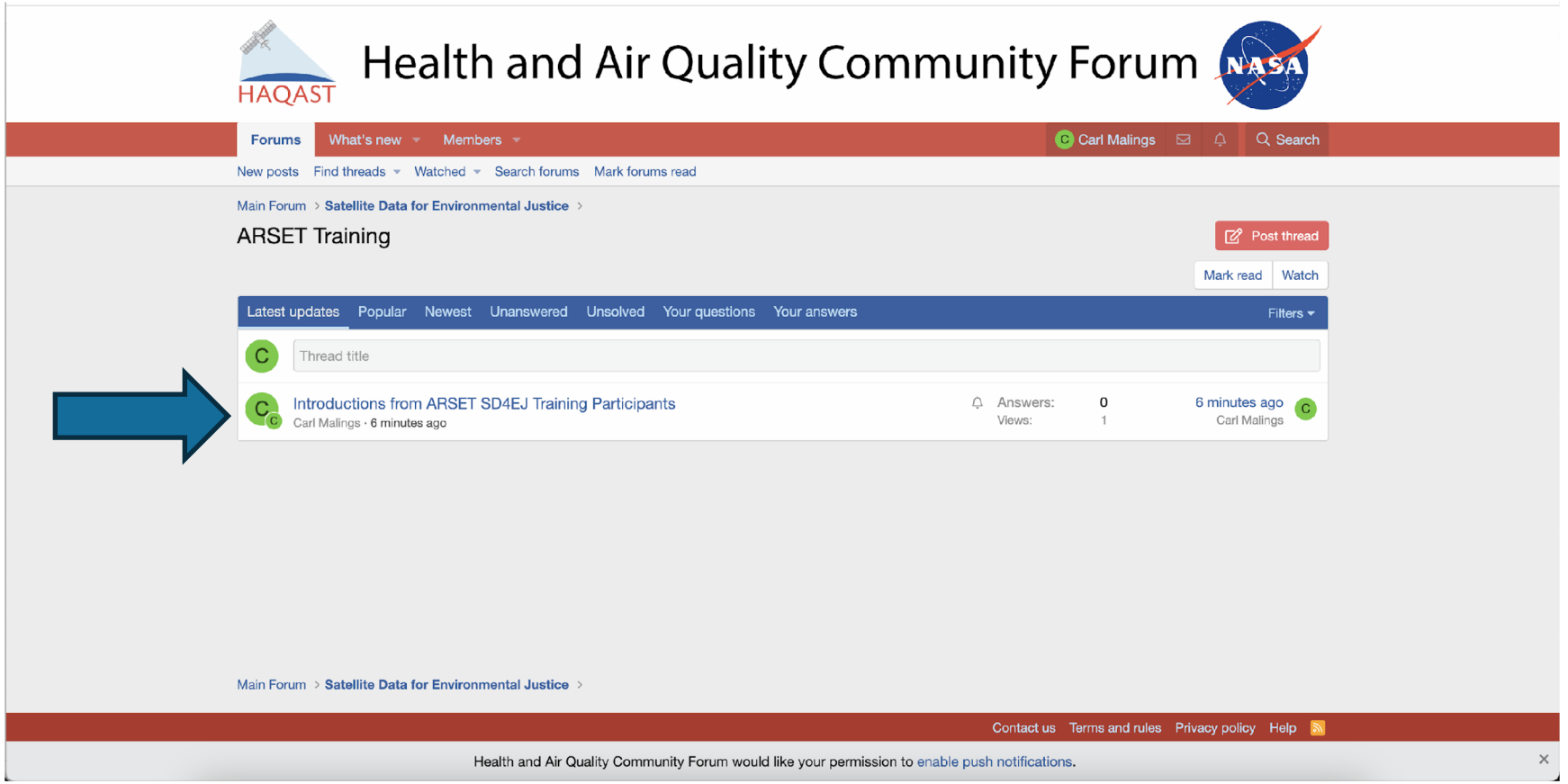

Homework and Certificates

- **Homework:**
  - One homework assignment
  - Opens on September 06, 2023
  - Access from the training webpage
  - Answers must be submitted via Google Forms
  - **Due by September 20, 2023**

- **Certificate of Completion:**
  - Attend all three live webinars (attendance is recorded automatically)
  - Complete the homework assignment by the deadline
  - You will receive a certificate via email approximately two months after completion of the course.

Contact Information

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- ARSET Website
- Follow us on Twitter!
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Resources

- Prior ARSET Trainings
  - Fundamentals of Remote Sensing
- NASA Environmental Justice Backgrounder
- NASA Applied Sciences Equity and Environmental Justice Program
- NASA HAQAST (Health & Air Quality Applied Sciences Team)
  - guide to getting started with satellite data
  - Satellite Data for Environmental Justice
  - Health and Air Quality Community Forum
- George Washington University TROPOMI data visualization website
- US EPA EJScreen Tool

APPLIED REMOTE SENSING TRAINING PROGRAM
TRAIN - EMPOWER - ADVANCE

Thank You!