Metropolitan Water Reclamation District of Greater Chicago

Welcome to the January Edition of the 2024 M&R Seminar Series

NOTES FOR SEMINAR ATTENDEES

- Remote attendees' audio lines have been muted to minimize background noise. For attendees in the auditorium, please silence your phones.
- A question and answer session will follow the presentation.
- For remote attendees, please use the "**Chat**" feature to ask a question via text to "**Host.**" For attendees in the auditorium, please raise your hand and wait for the microphone to ask a verbal question.
- The presentation slides will be posted on the MWRD website after the seminar.
- This seminar is pending approval by the ISPE for one PDH and has been approved by the IEPA for one TCH. Certificates will only be issued to participants who attend the entire presentation.

Ashish Sharma, Ph.D.
Adjunct Professor/Climate and Urban Sustainability Lead, Department of Atmospheric Sciences, University of Illinois Urbana-Champaign, Illinois

In addition to faculty positions at UIUC, Dr. Sharma holds a joint appointment as a Climate Scientist at Argonne National Laboratory. He received a Bachelor's degree in Electronics and Communication Engineering from Jaypee University of Information Technology, a Master of Science and Ph.D. in Aerospace Engineering from Arizona State University. Dr. Sharma has expertise in atmospheric sciences, focusing on regional climate, air quality, and assessing adaptation and mitigation strategies. Through collaborative research across science, engineering, social sciences, and policy, he studies environmental justice issues including heat, fog, air quality, and high-impact weather. He is a fellow of the Royal Meteorological Society. He serves on the Trust for Public Land's Natural Solutions Tool advisory committee (2022). As a co-author of the first climate action plan for the Chicago metro region (2021), he has received numerous awards, including the American Planning Association Merit in Sustainability Award (2022) and the Center for Climate and Energy Solutions Climate Leadership Award (2021).

CLIMATE SCIENCE TO ACTIONABLE URBAN SOLUTIONS

Ashish Sharma

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DISCOVERY PARTNERS INSTITUTE
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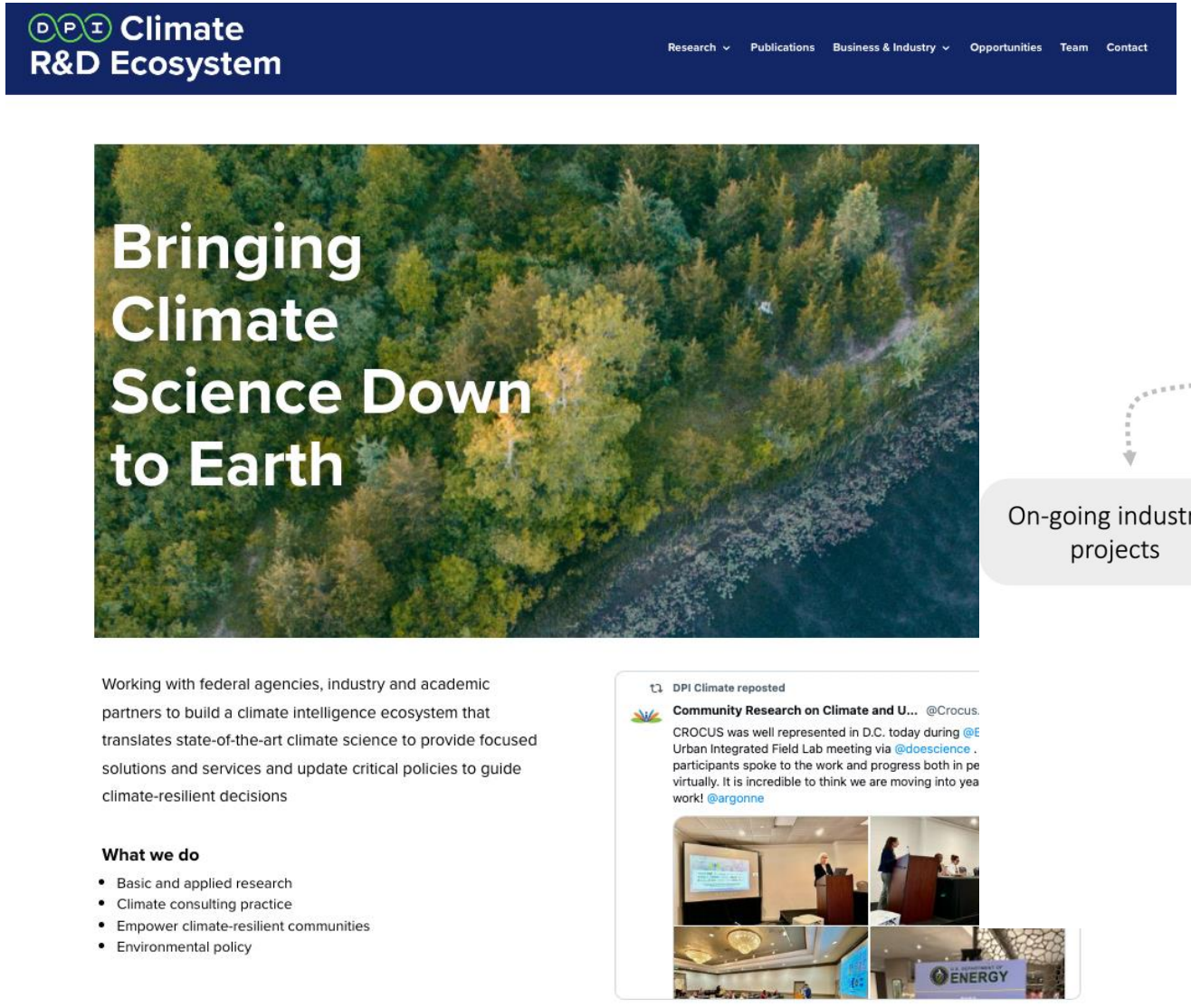
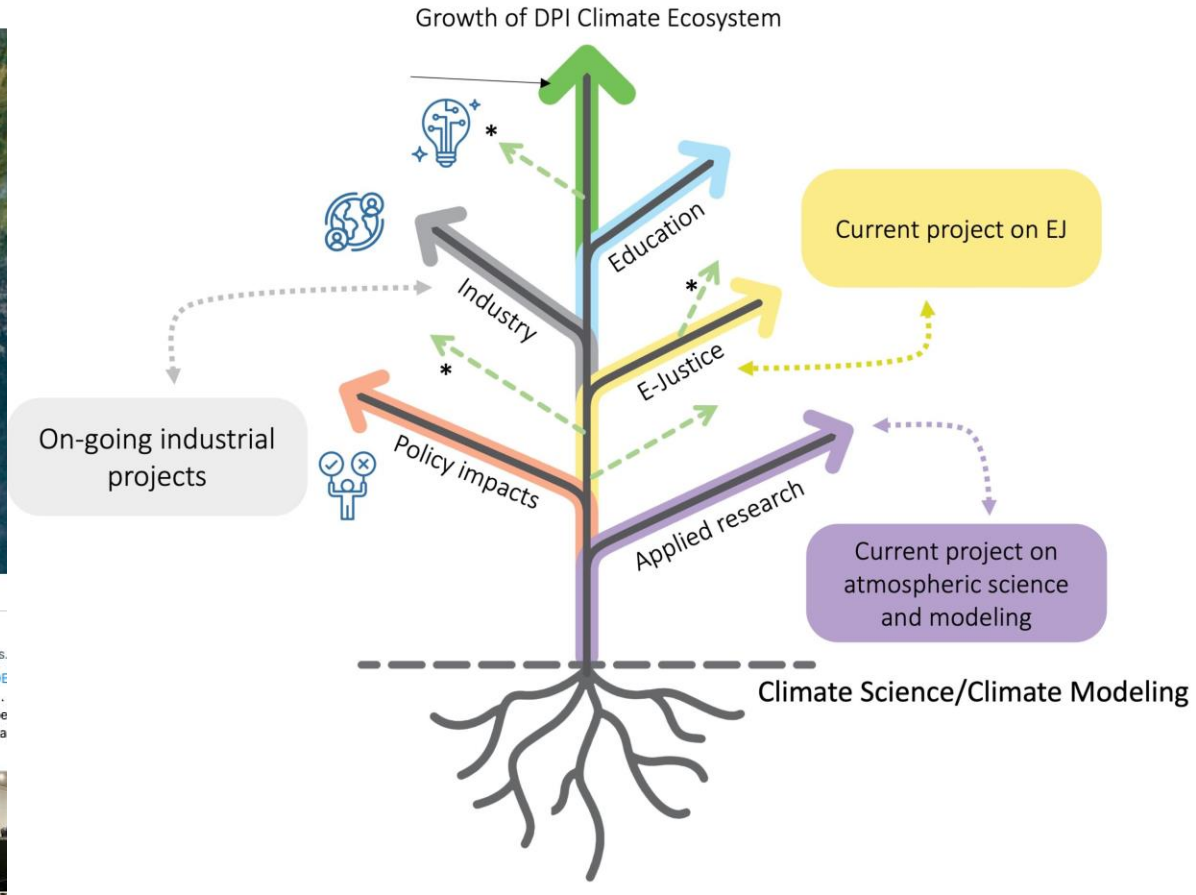
U.S. DEPARTMENT OF ENERGY

Fundamental

Applied

Translational





DPI Climate Ecosystem Tree

https://www.climate-dpi.org/

AGU Advances

Commentary | Open Access

The Need for Urban-Resolving Climate Modeling Across Scales

Ashish Sharma, Donald J. Wuebbles, Rao Kotamarthi

First published: 26 January 2021 | https://doi.org/10.1029/2020AV000271 | Citations: 1

Studying via multiple lens!

Framework for Integrated Urban Research

Drivers of Change
- Climate change
- Economic development
- Population dynamics and mobility
- Urbanization
- Governance, equity ($, opportunity) and health
- Emerging technologies (autonomous vehicles, AI-assisted learning, etc.)

Critical Issues / Research Strategies
- Effects of urban systems on climate at different scales
- High resolution climate models
- Representation of cities in climate model
- Scale-resolving urban land cover and urban processes
- Future evolution of the urban landscape
- Observations: data & analysis

Critical Considerations
- Irreversibility of potential impacts
- Adaptive capacity of sectors and urban assets
- New science and analyses toa evaluate interactions among natural, engineered, and social and behavioral urban subsystems

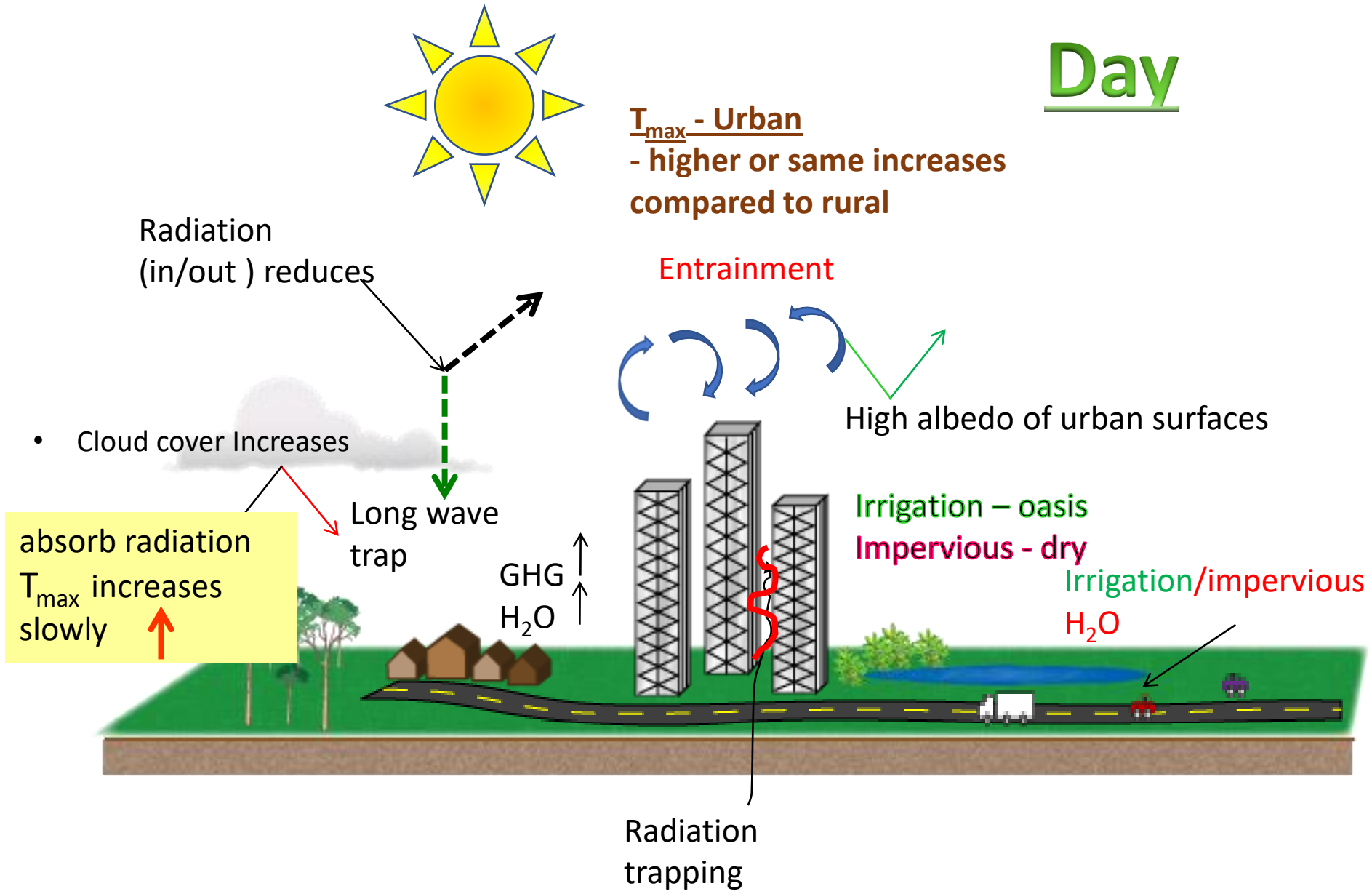
Critical Evaluations
- Viability / co-benefits / trade-offs in evaluating outcomes
- Effects on social systems and equity ($, opportunity, health, …)
- Effects on finance and governance
- Effects on natural resources

Sharma et al. (2021) *AGU Avd.*

Urban climate research capabilities

- Bridging urban scales: multiscale modeling
  - global <—> regional <—> local <—> hyper-local
  - heat islands, lake breeze, heat waves, air quality
- Numerical modeling
  - data assimilation, subgrid variability
- Urban meteorology + AQ forecasting
- Urban adaptation and mitigation strategies
  - green, cool, and photovoltaic roofs
  - energy consumption, vulnerability analysis
  - nature-based solutions for heat, air quality, and flooding
- Urban climate action plans + policies + transdisciplinary research
- Other focus areas…
  - urban climate + crime; machine learning

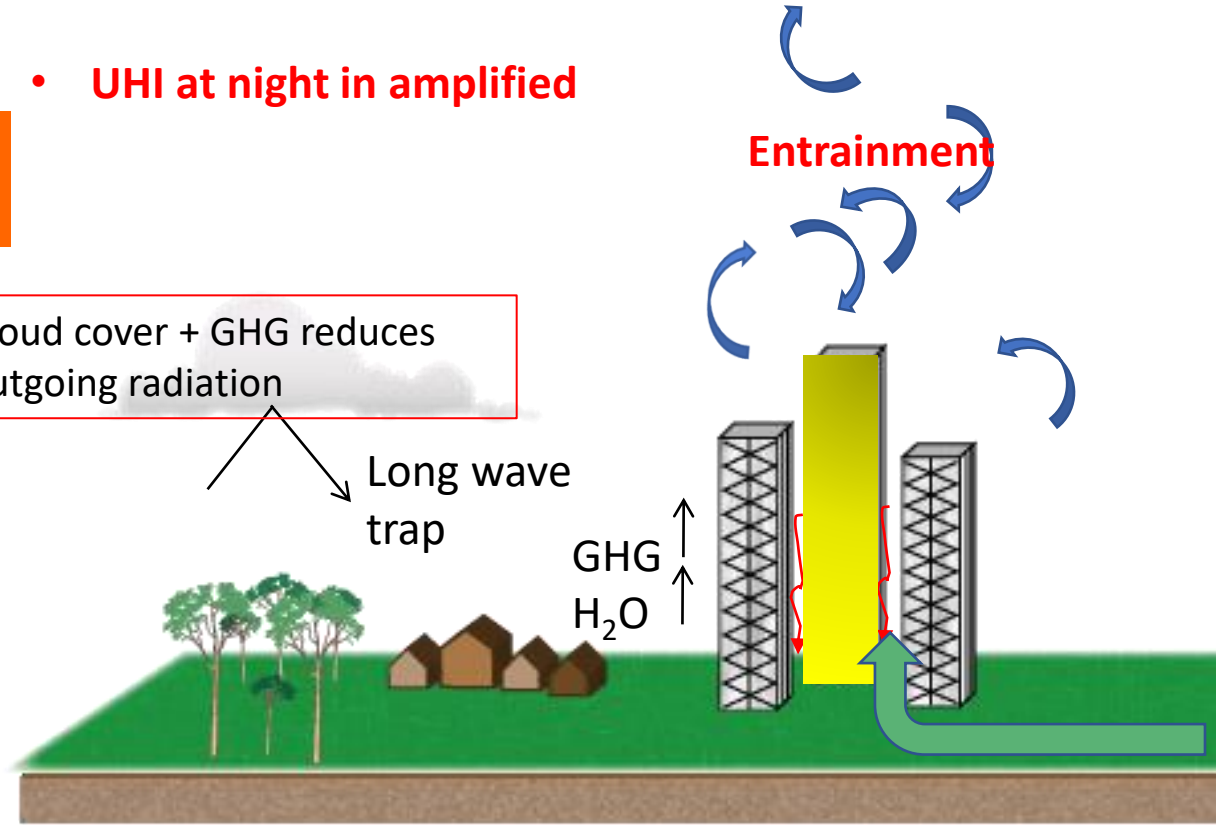
Day


T_{max} - Urban
- higher or same increases compared to rural
Radiation (in/out) reduces
Entrainment
High albedo of urban surfaces
• Cloud cover Increases
absorb radiation
T_{max} increases slowly
Long wave trap
GHG
H_2O
Irrigation – oasis
Impervious - dry
Irrigation/impervious
H_2O
Radiation trapping

Night

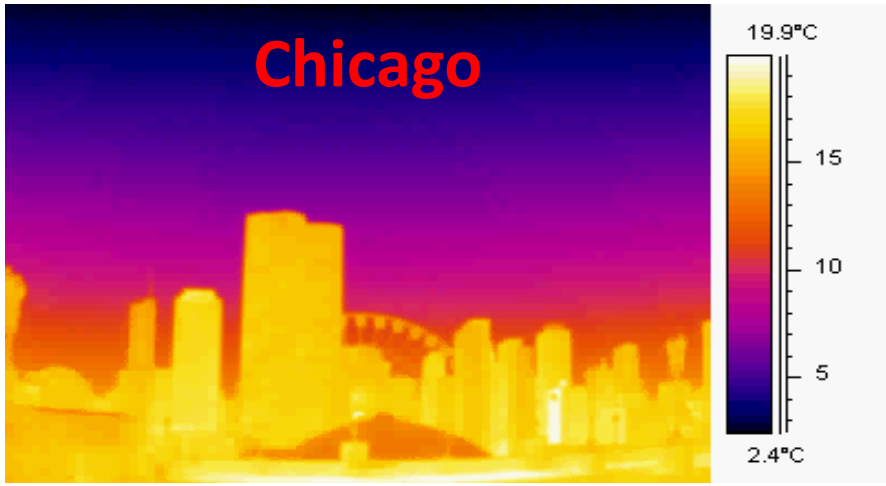
- Significant increase of T_{min} (compared to rural)
- reduction of DTR is larger
- UHI at night in amplified

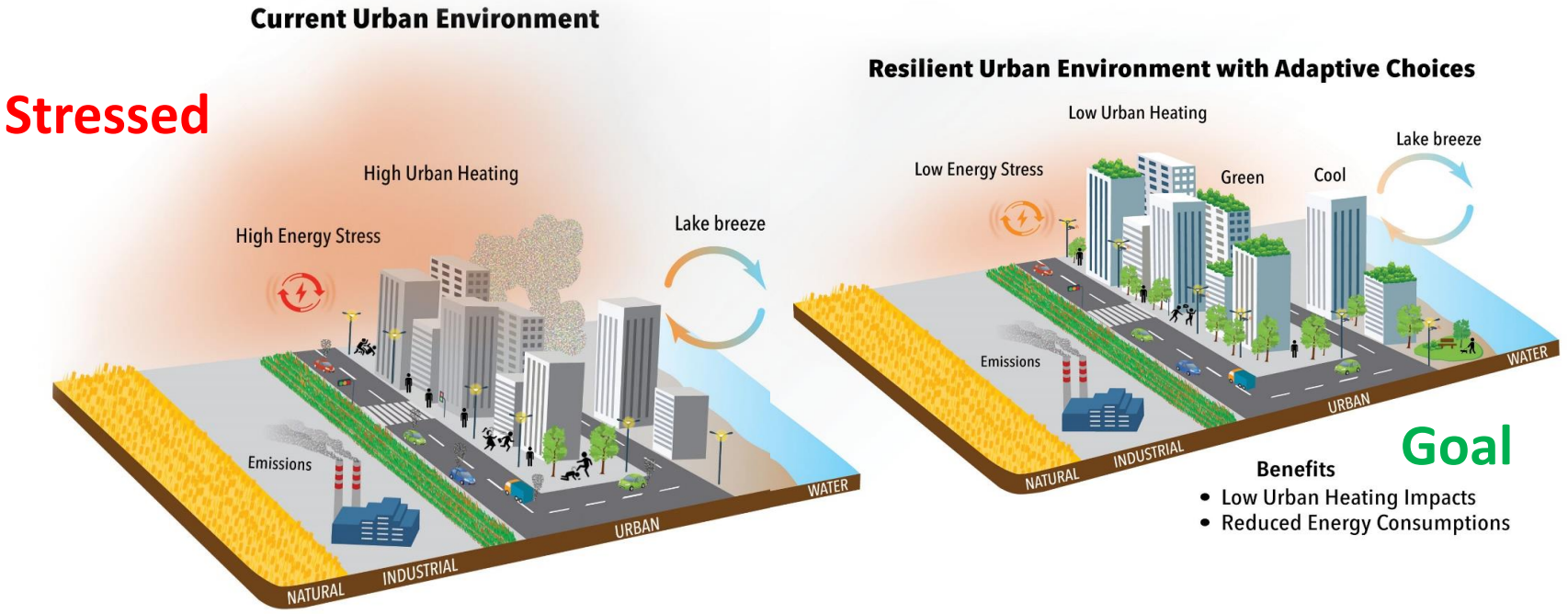
T_{min} increases faster than T_{max}



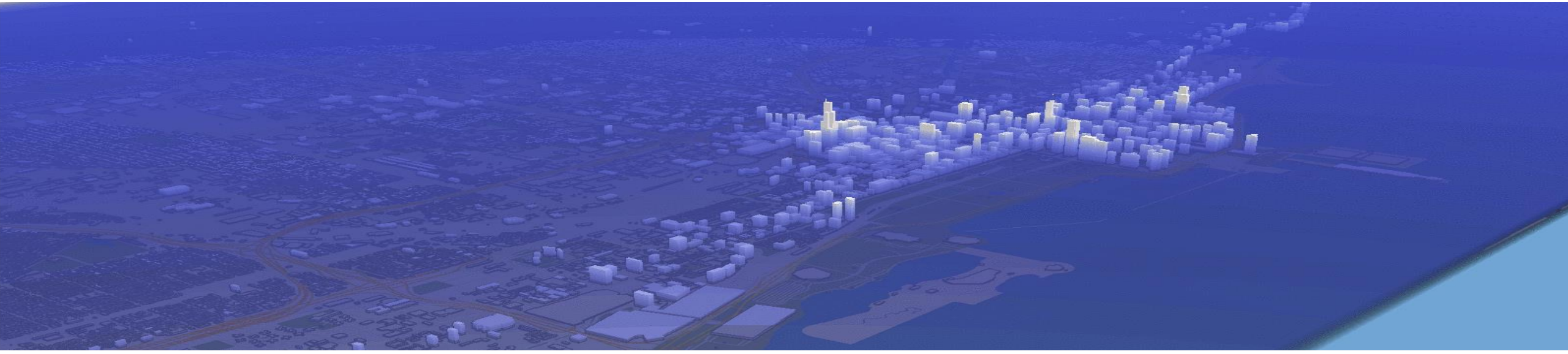
Urban systems

Flooding Heat Housing Marginalization Health
Stress Food security Extremes Tornadoes
Gentrification Jobs Green spaces Deterioration
Variability





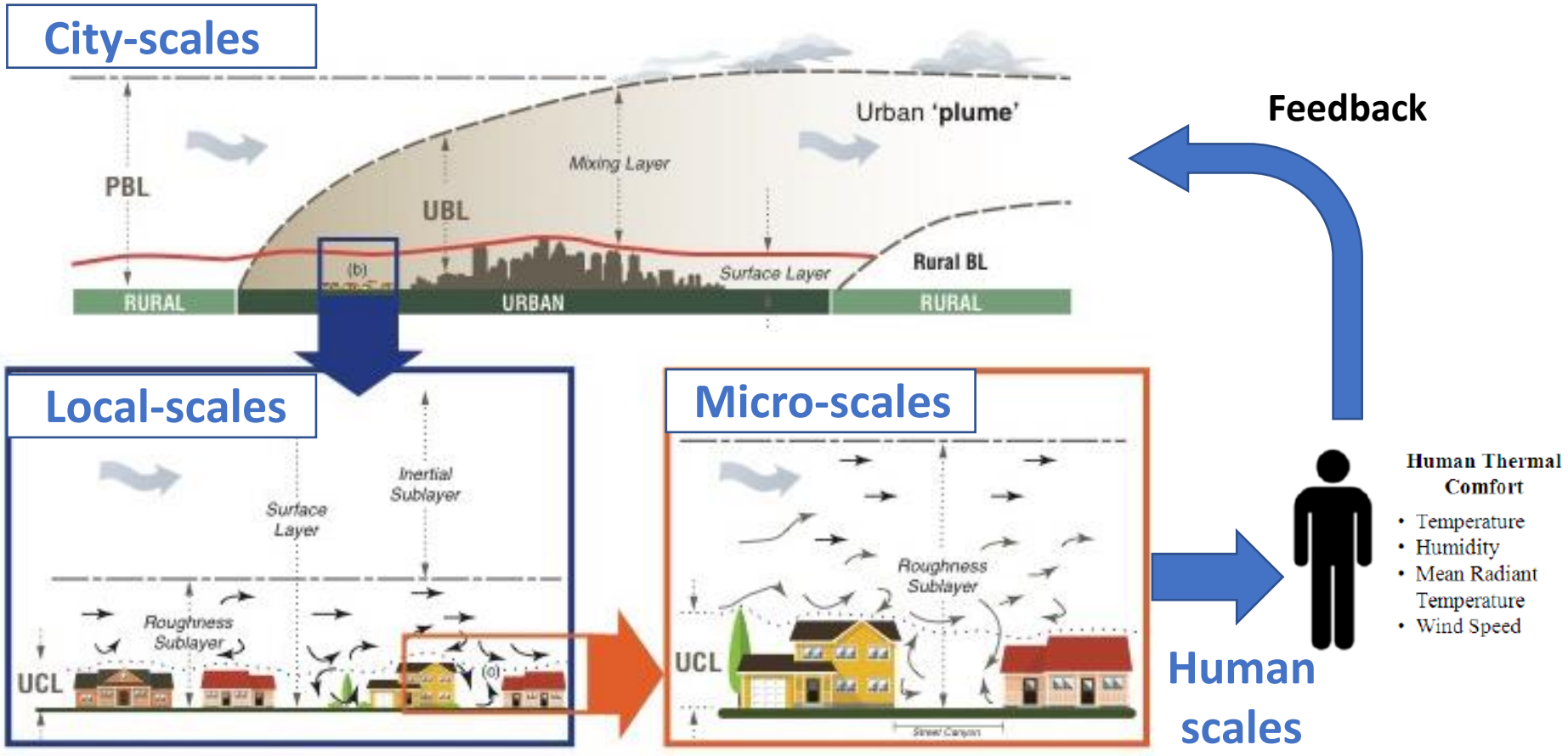
Urban systems: Multiscale, interdependent, social, natural and engineered complex systems.



Visualization: Miranda and Sharma

- Improvements in urban boundary layer processes.
- Fundamental and translational research that uses **science to serve the society**.

Bridging urban scales



- Need tools with which large- and small- cities will benefit.
- Complicated models to train simplistic models.

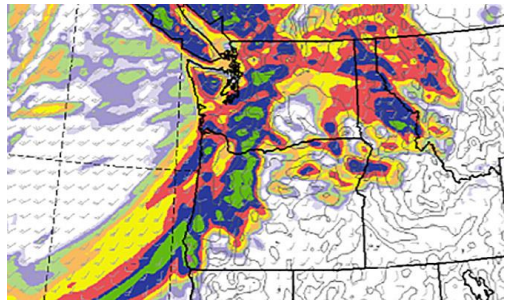
Vertical scale interactions in urban areas

Atmosphere

Land surface

Sub-surface

WRF
regional climate modeling

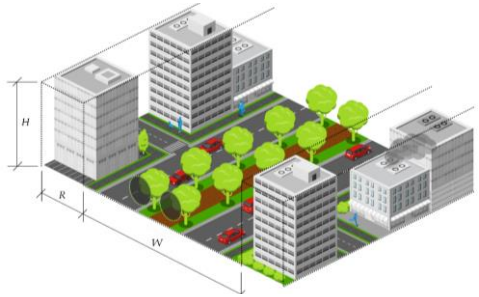


Atmosphere

Land surface

Coupling

UCM
Urban land surface modeling



Land surface

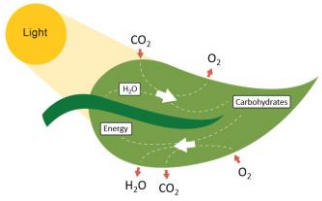
Sub-surface

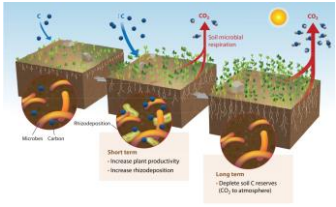
Coupling

Hydrometeorology

Biogenic CO_2 exchange
(ecosystem services)

Process-based
Photosynthesis and respiration modeling

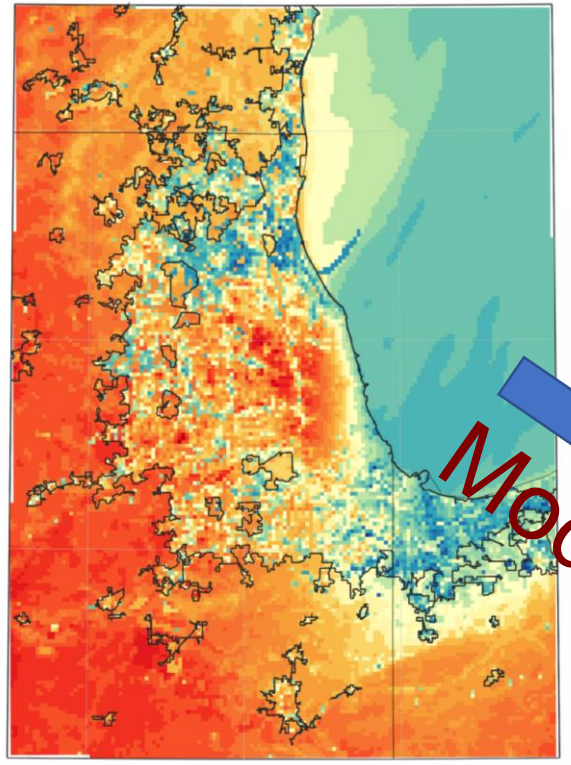




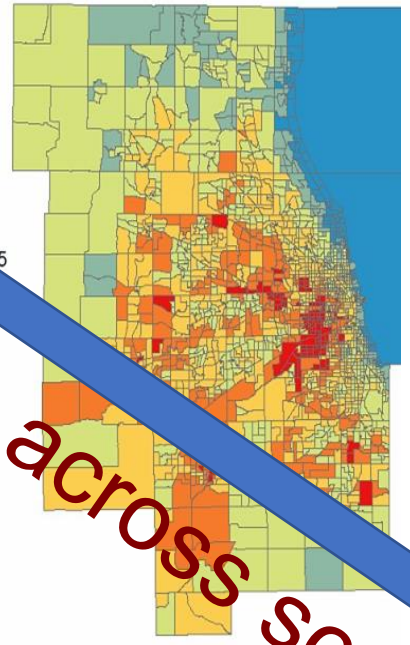
Li and Sharma (in prep.)

Computer (climate) urban models

Regional-scale models

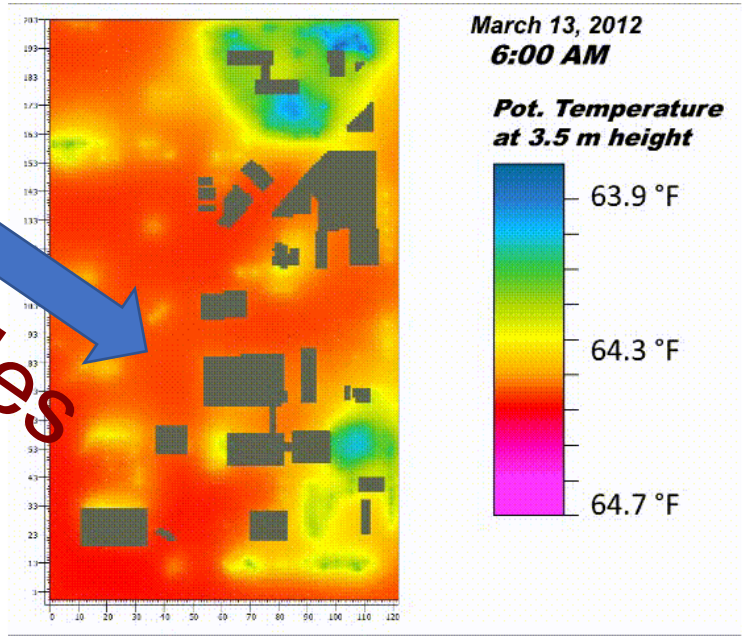


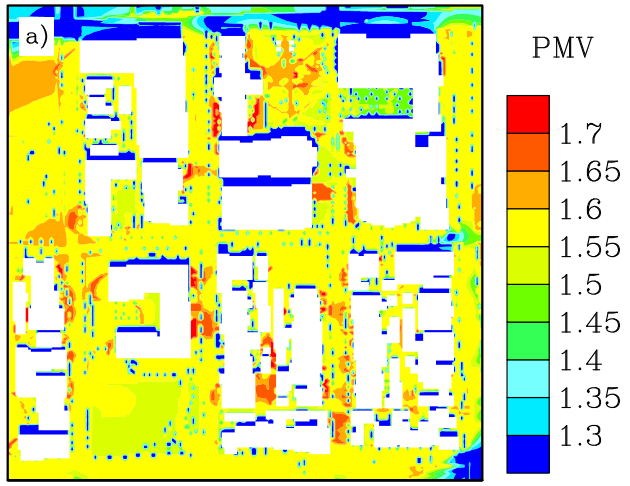
City-scale models



Models across scales

Neighborhood models (2 m resolution)





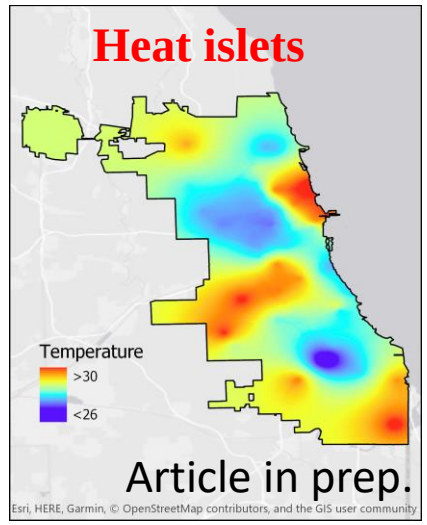
Conry et al. (2015)

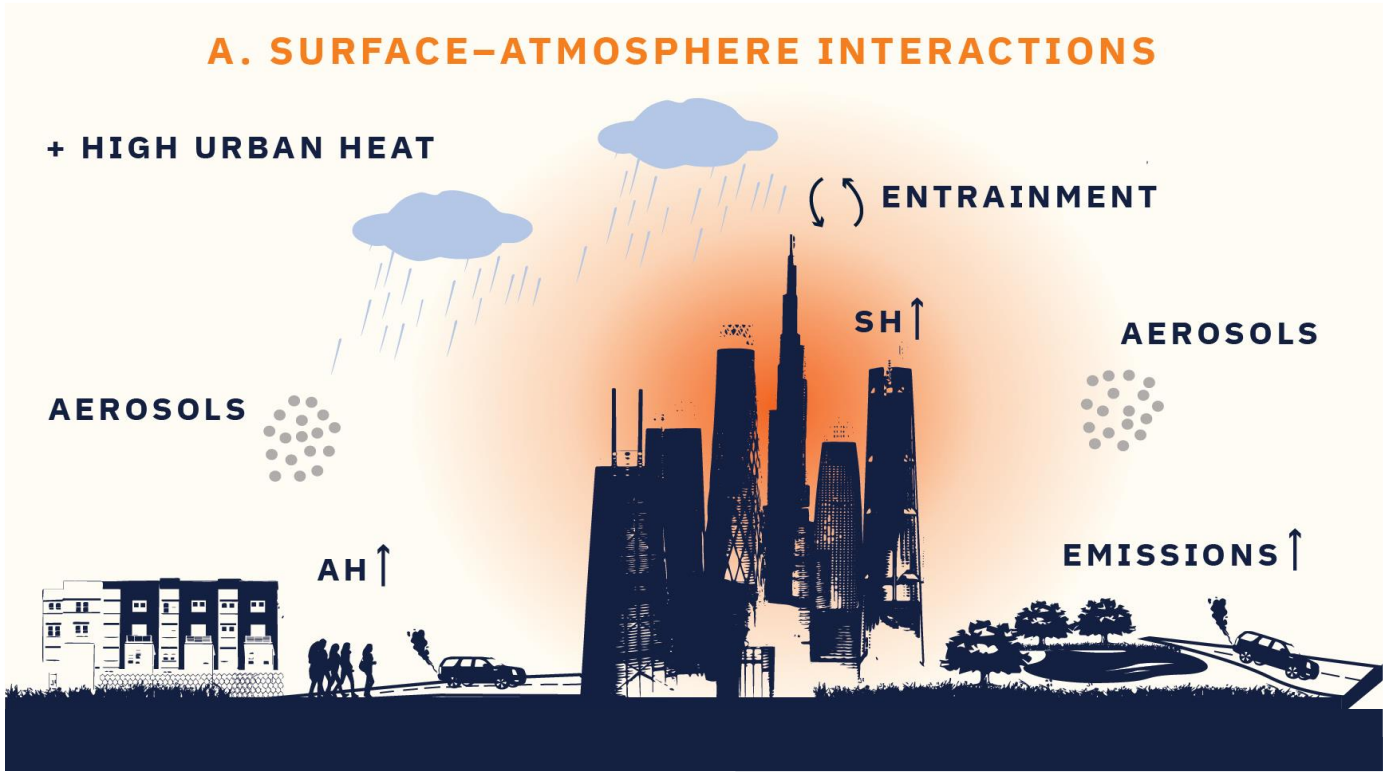
Urban heterogeneity

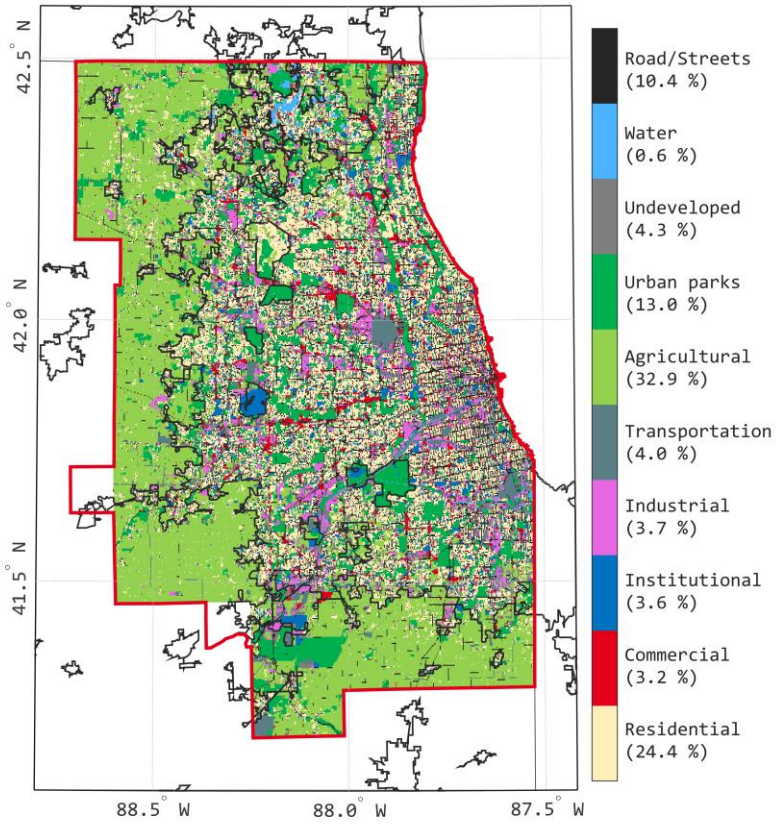
Atmosphere

Land surface

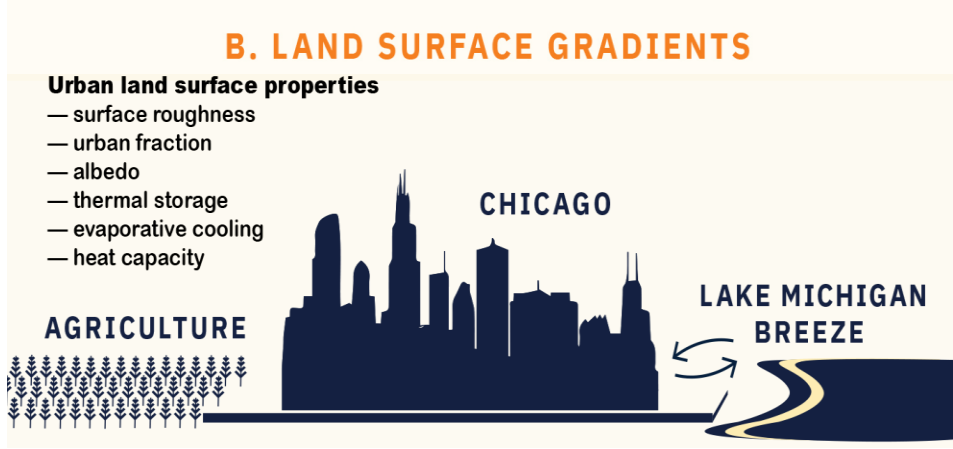
Sub-surface

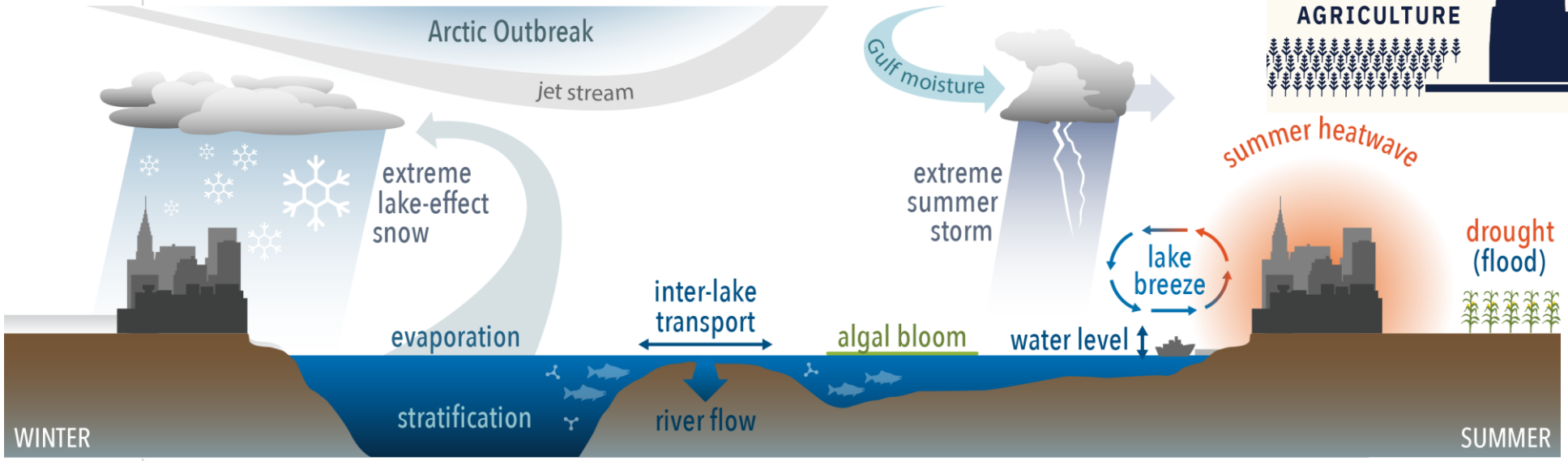






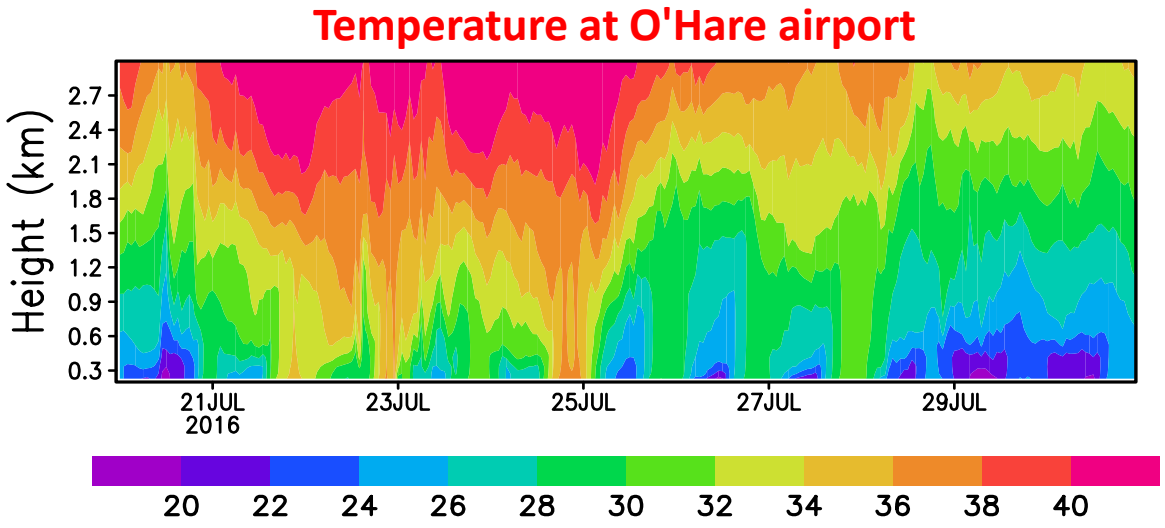
Regional interactions





Sharma et al. (2018) *Earth's Future*

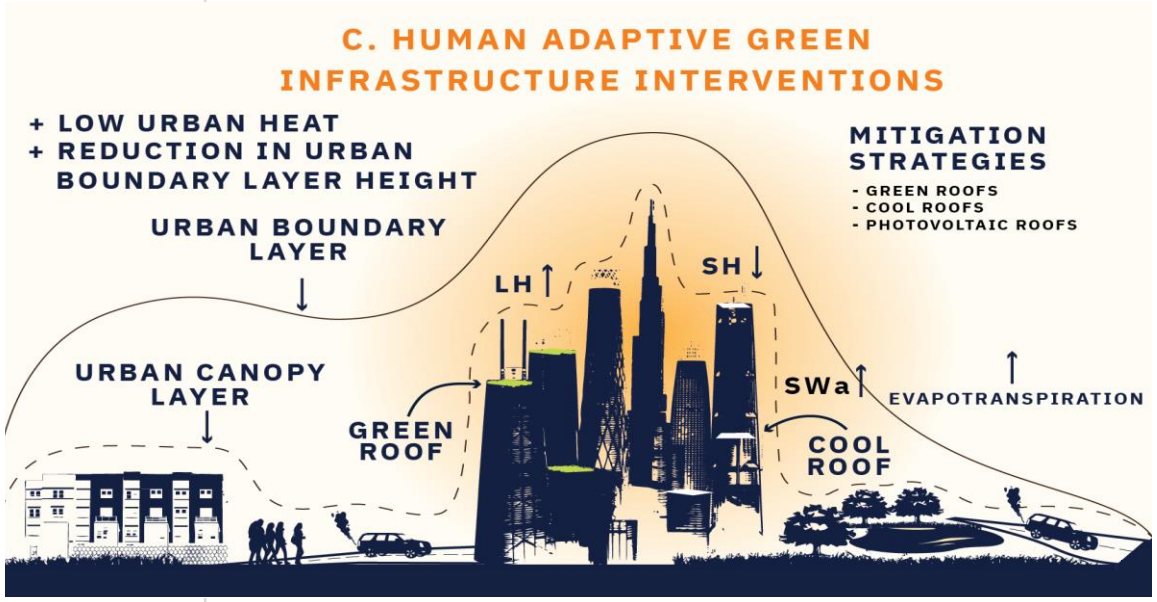
Urban heat island + heatwave interactions



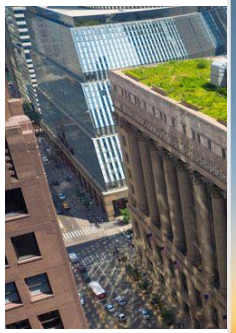
Sharma et al. (in prep)

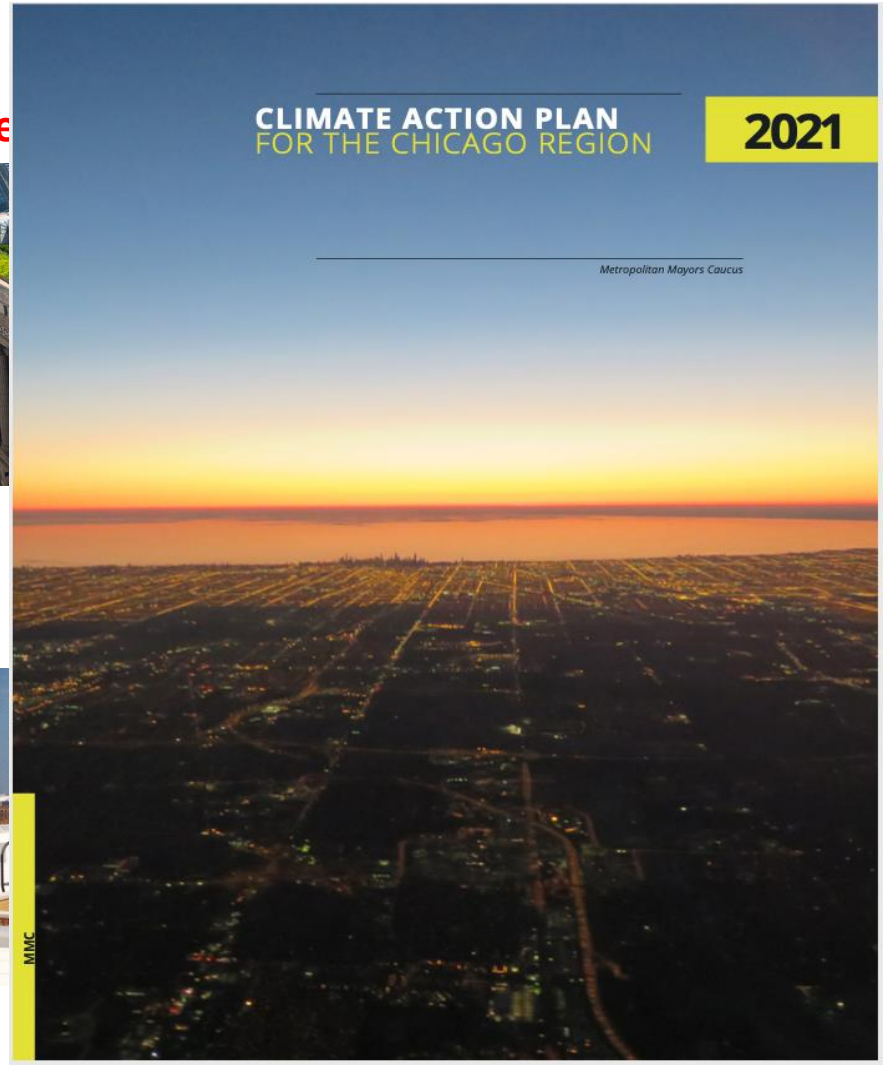
What solutions do we have?

Solutions to mitigate heat and flooding

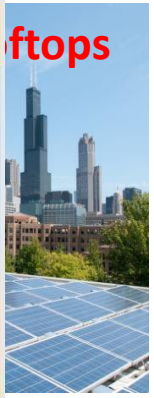


Gre



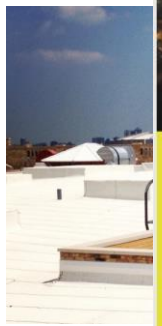


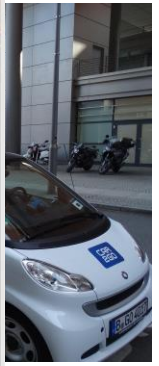
ftops



Urban forests

Permeable pavements



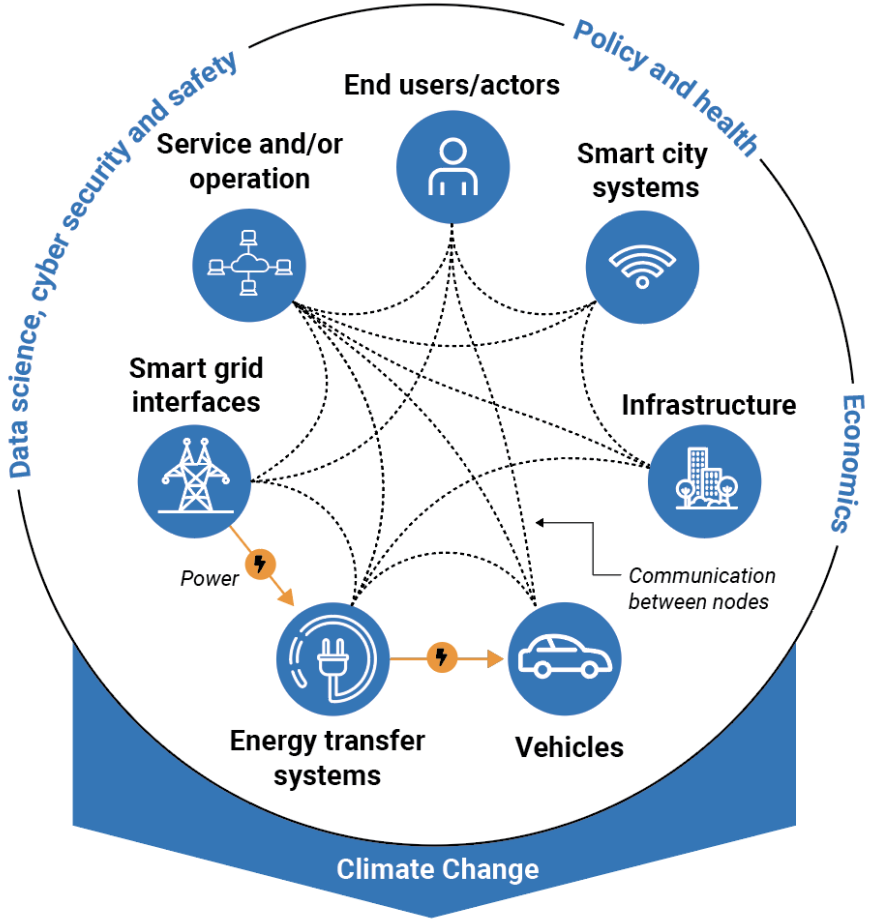


✓ Technological-engineered-ecological mix of urban solutions.

Urban solutions

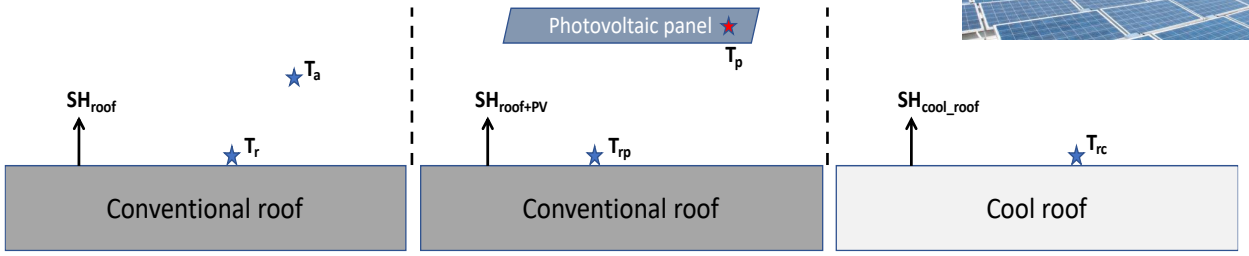
Should benefit the larger urban ecosystem

- Investing in cleaner energy sources
- Nature-based solutions
- Decarbonize energy & transportation sector and promoting public transportation
- Enforcing regulations on emissions from industries and vehicles
- Nature-based solutions (heat + air quality + flooding)
- Improved urban planning + urban design (urban landscape)

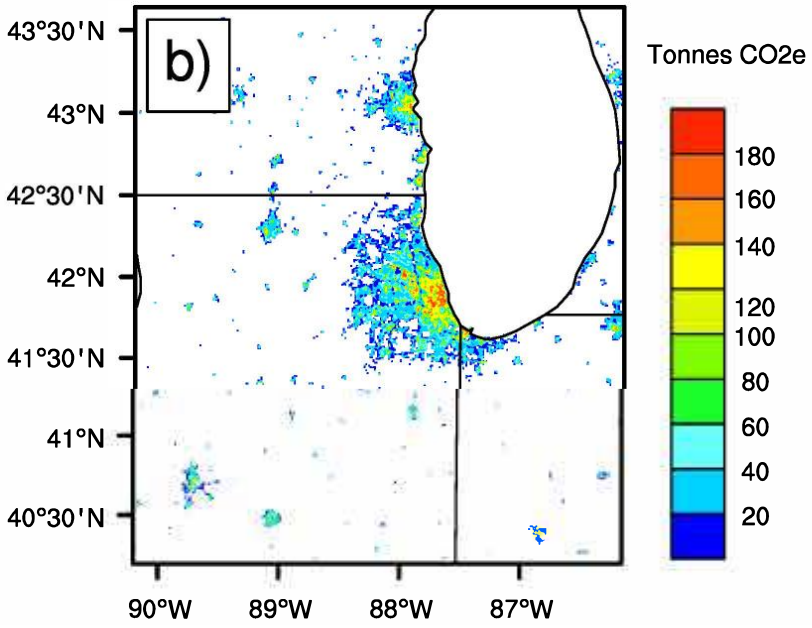


Let’s look at a few of these solutions and how different tools can help us make decisions!

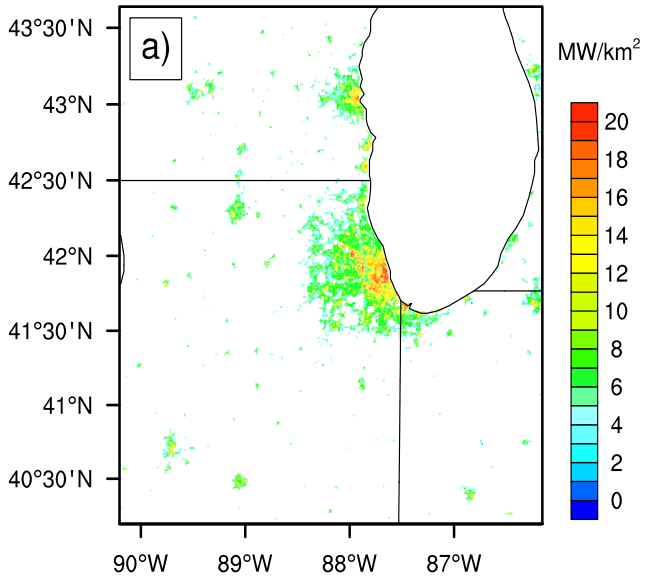
Photovoltaic roofs



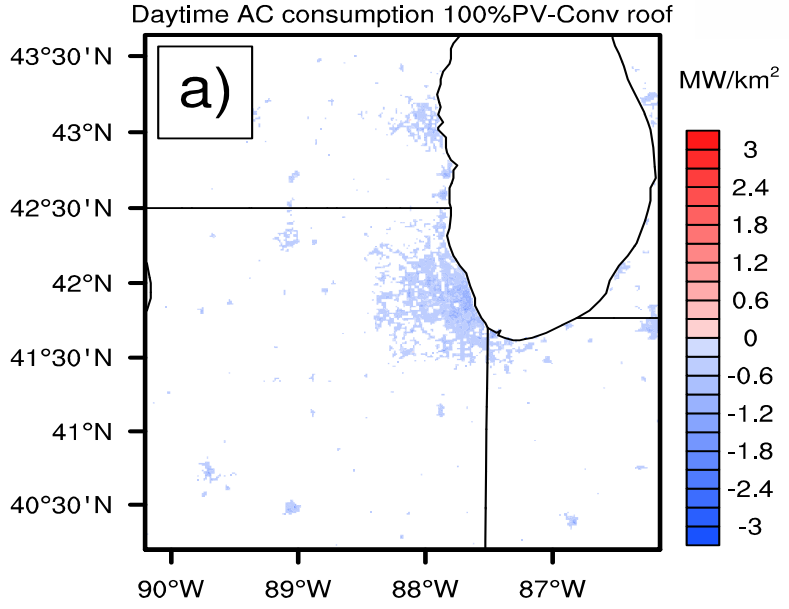
Photovoltaic CO_2 emissions offset



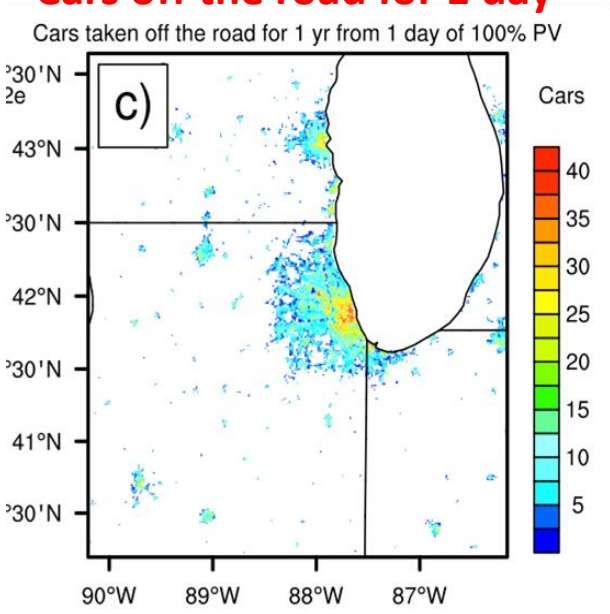
Rooftop photovoltaic production potential



AC consumption Photovoltaic - conventional

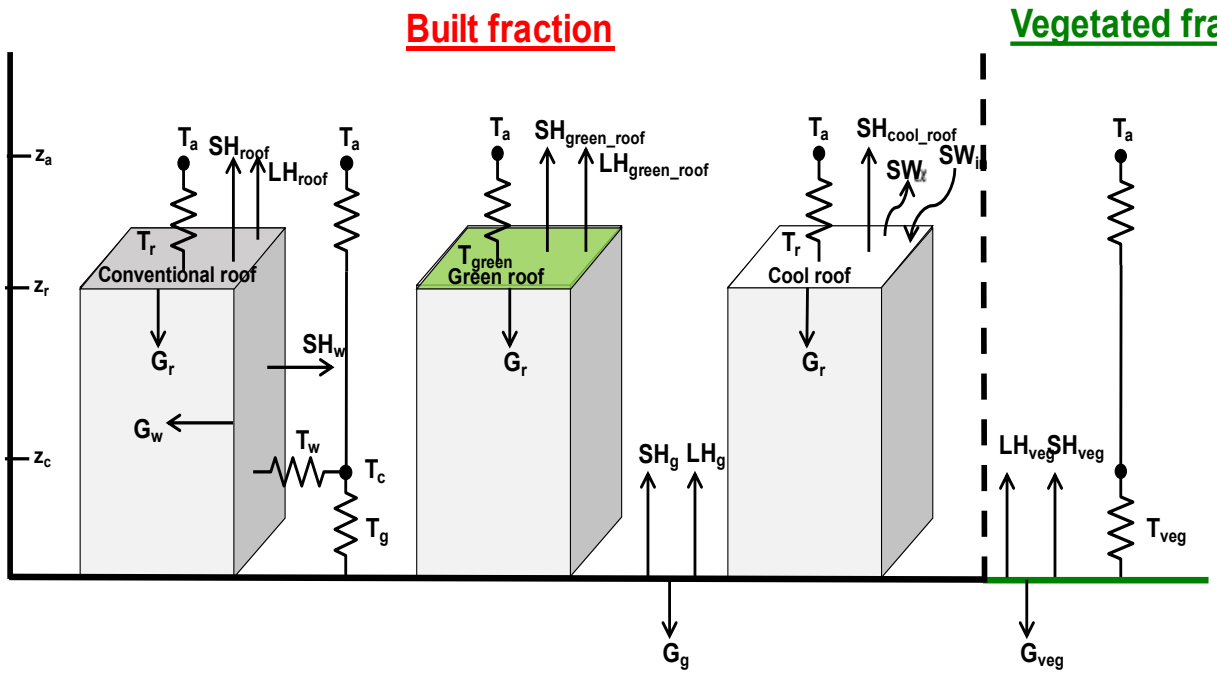


Cars off the road for 1 day



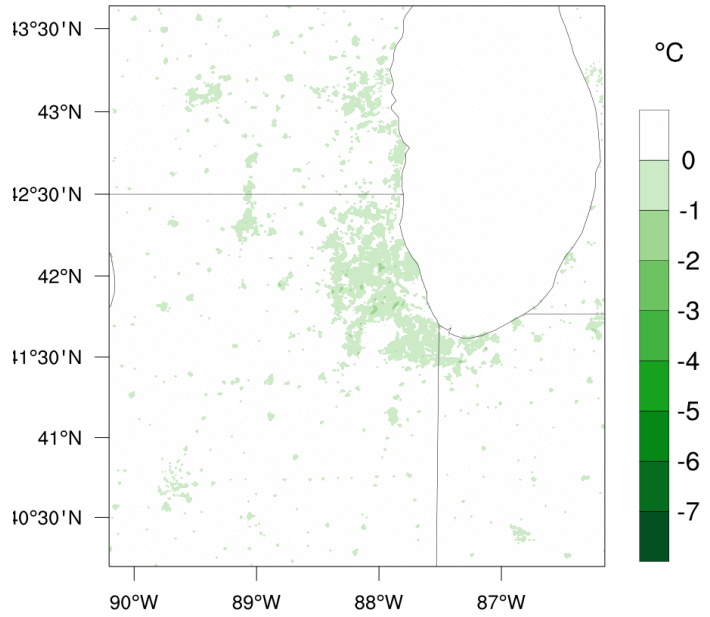
Sharma et al. (in prep)

Green/cool roofs

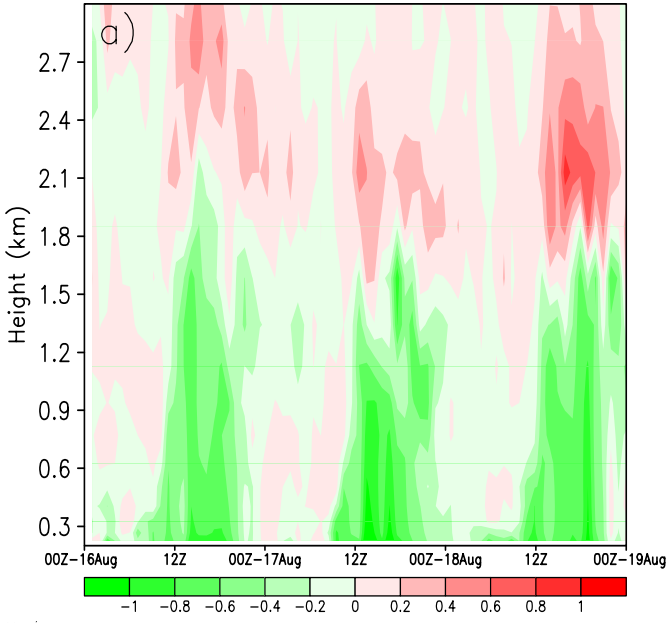


Sharma et al. (2018) *Env. Res. Lett.*

Green roof temperature

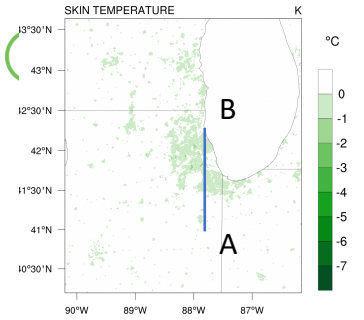


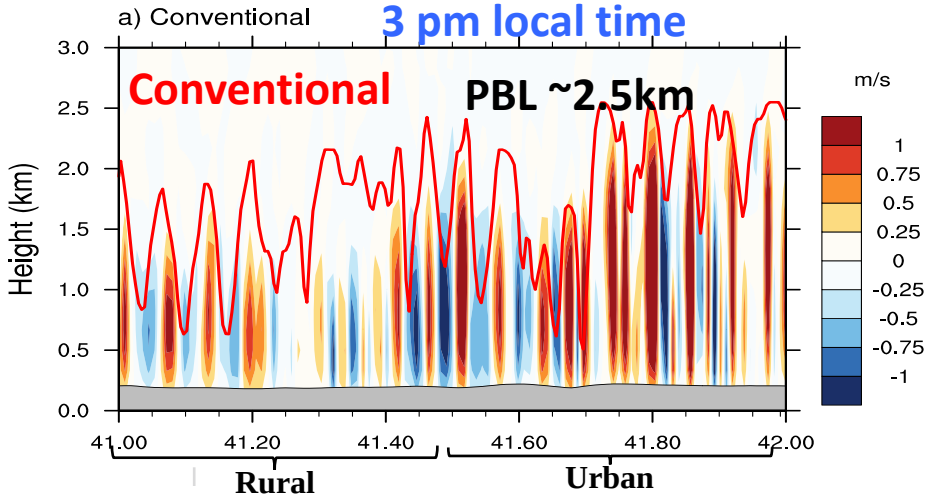
T (Green-Conventional)

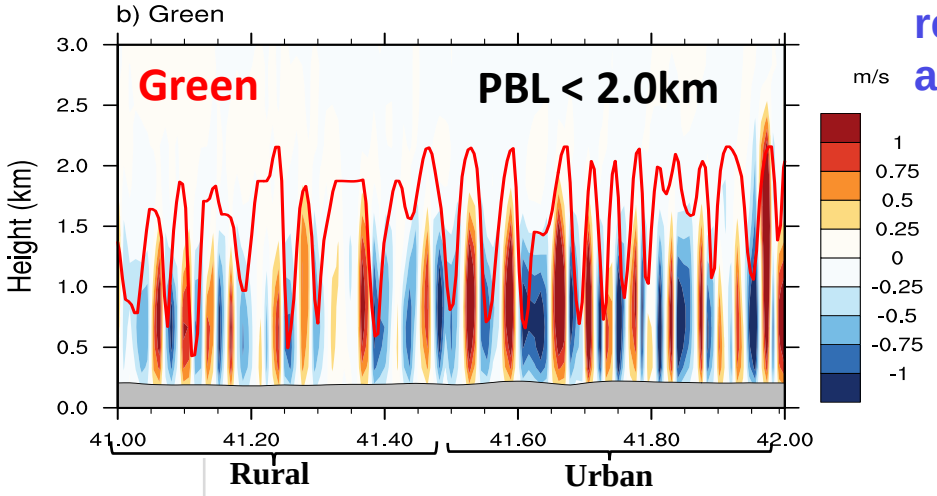


Rooftop solutions: Transport OR photochemical processes

— Which are dominant?

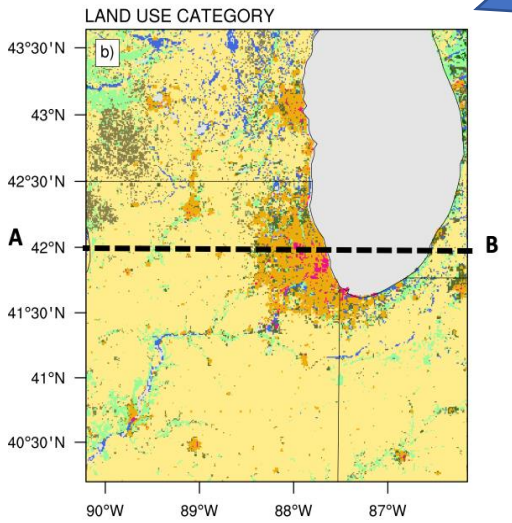




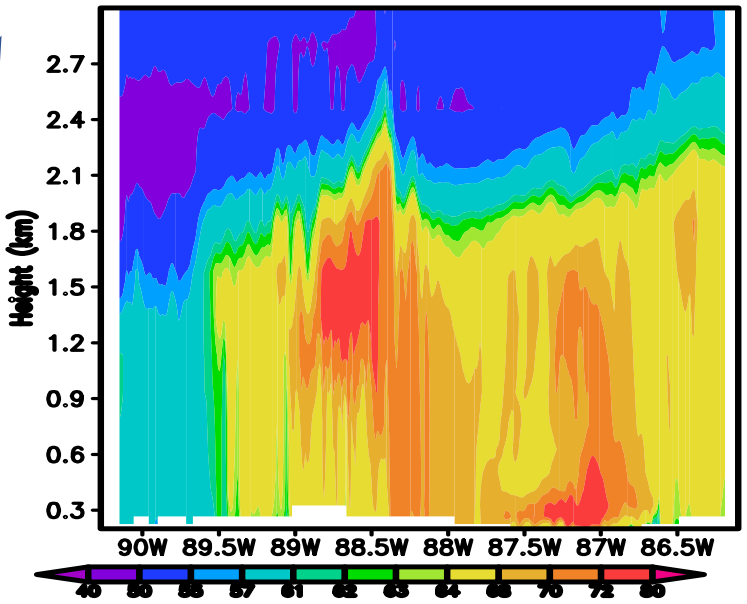


reduced convection
and thinner updrafts

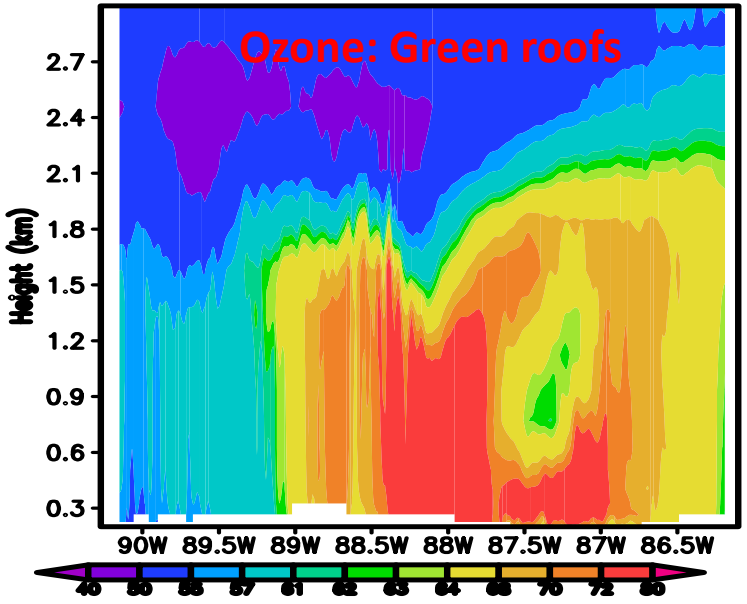
Sharma et al. (2018) *Env. Res. Lett.*



Ozone: Conventional roofs



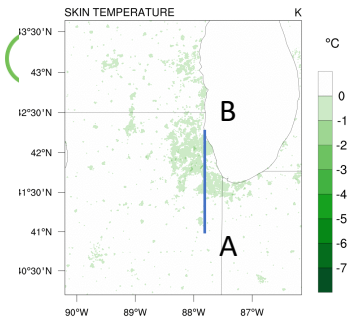
Ozone: Green roofs



Sharma et al. (in prep.)

Rooftop solutions: Transport OR photochemical processes

— Which are dominant?



reen and cool roofs provide relief for hot cities, but should be sited carefully

June 30, 2016 5.49am EDT

Reflective roof and skylights on a Walmart store, Las Vegas, NV. Walmart/Flickr, CC BY

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More than half of the world's population lives in cities, and the United Nations projects that this share will rise to 70 percent by 2050. During the daytime, these expanding urban areas absorb more solar energy than the surrounding countryside. At night they radiate the heat back to the atmosphere. Higher temperatures in cities compared to the areas around them create what are known as urban heat islands (UHIs).

Listen
Beyond Zero Radio podcast interview with Dr. Sharma
00:00 29:17
Download
MP3 / 13 MB

Urban heat islands threaten urban sustainability and public health in cities. The heat island effect raises death rates, increases energy demand for cooling, and makes life uncomfortable even for healthy residents. It affects various communities differently: poor and elderly residents and small children are most

Author

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Disclosure statement

Ashish Sharma is affiliated with the Environmental Change Initiative, ND Energy and the Department of Civil and Environmental Engineering and Earth Sciences at the University of Notre Dame. Research described in this article is supported by the National Science Foundation, the Notre Dame Environmental Change Initiative, the Notre Dame Center for Sustainable Energy, and the City of Chicago.

Partners

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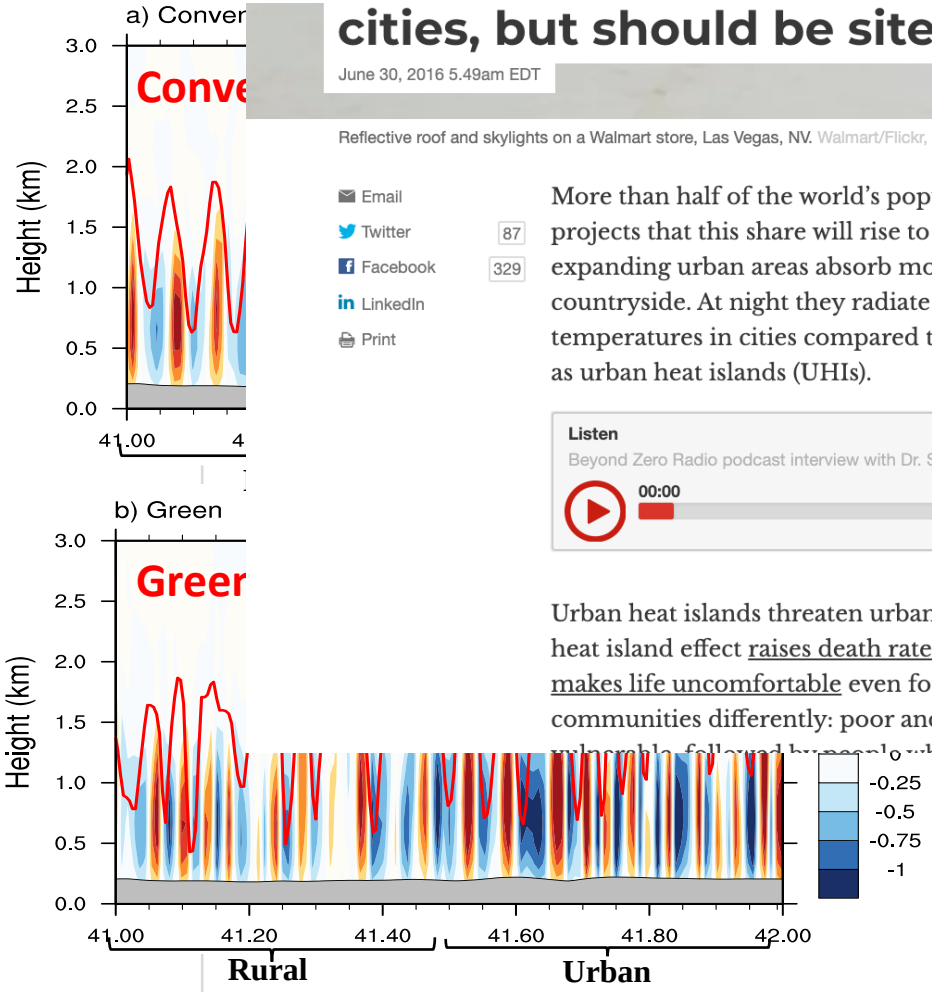
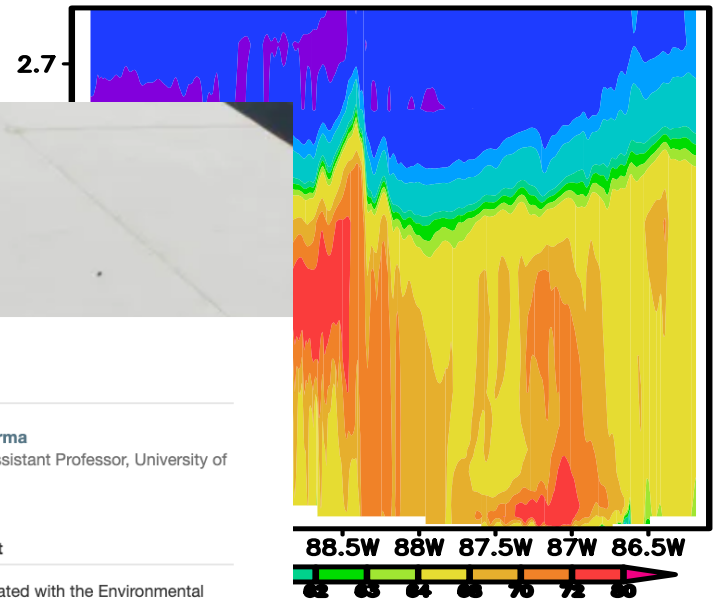
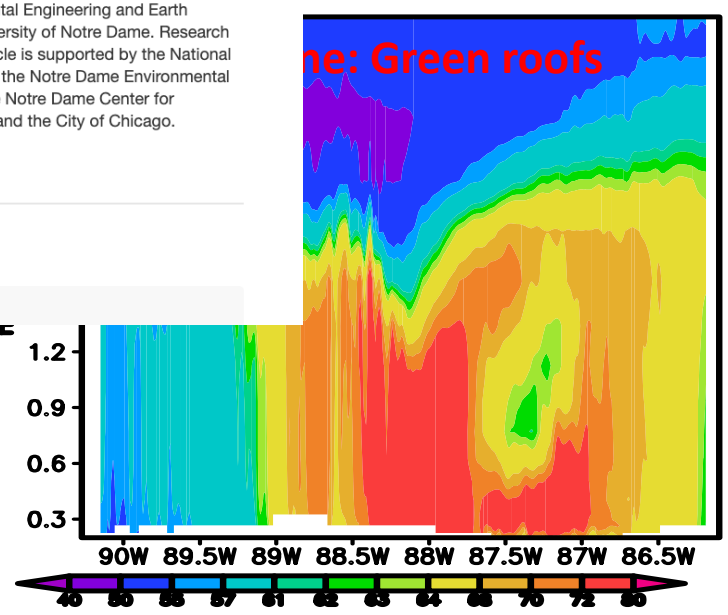


Sharma et al. (2018) *Env. Res. Lett.*

✓ One solution can't fit all.
✓ Need a mix of solutions.

Ozone: Conventional roofs





Sharma et al. (in prep.)

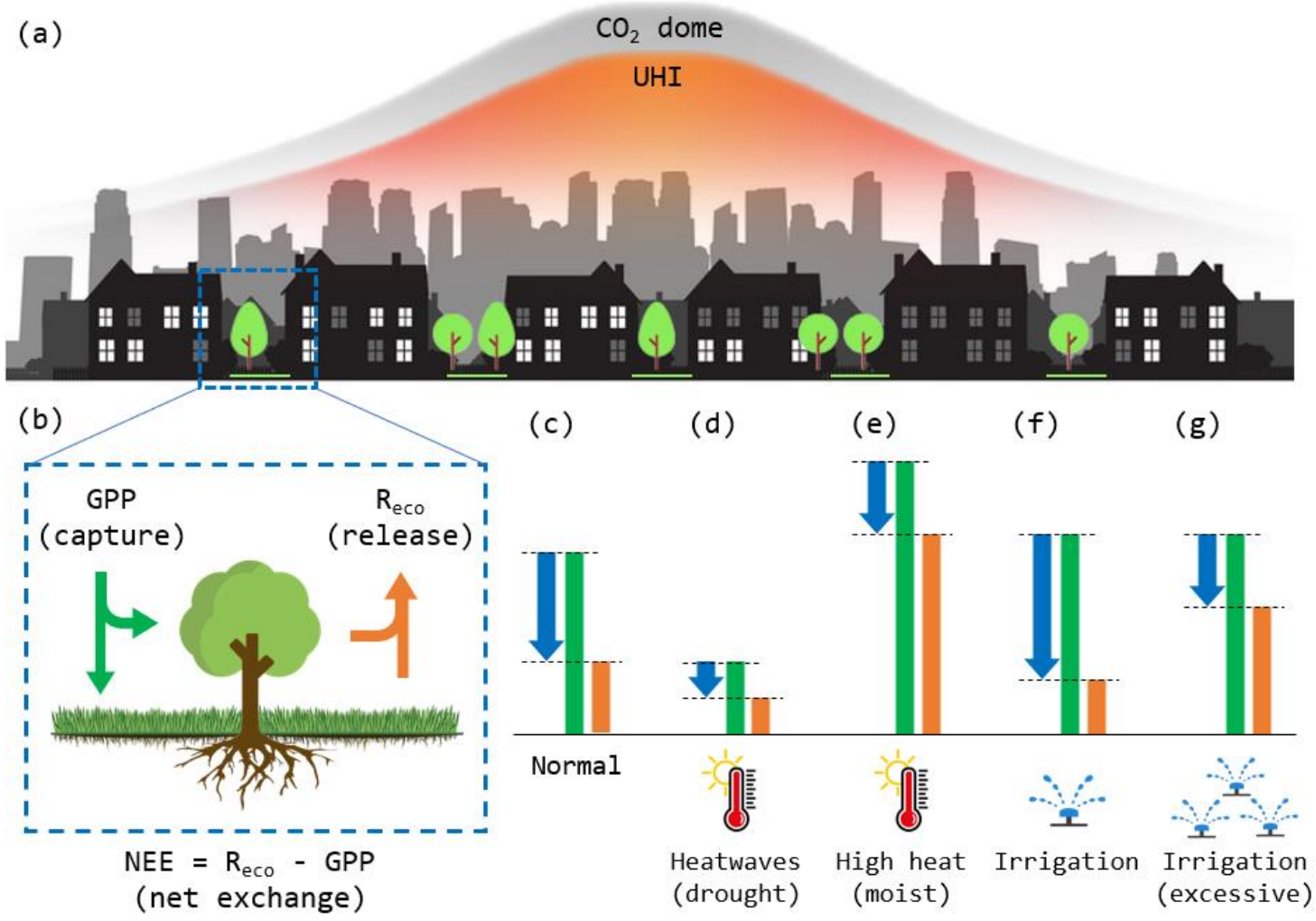
Urban vegetation – trees, urban parks forests, etc.

Atmosphere

Land surface

Sub-surface

Carbon exchange in urban areas



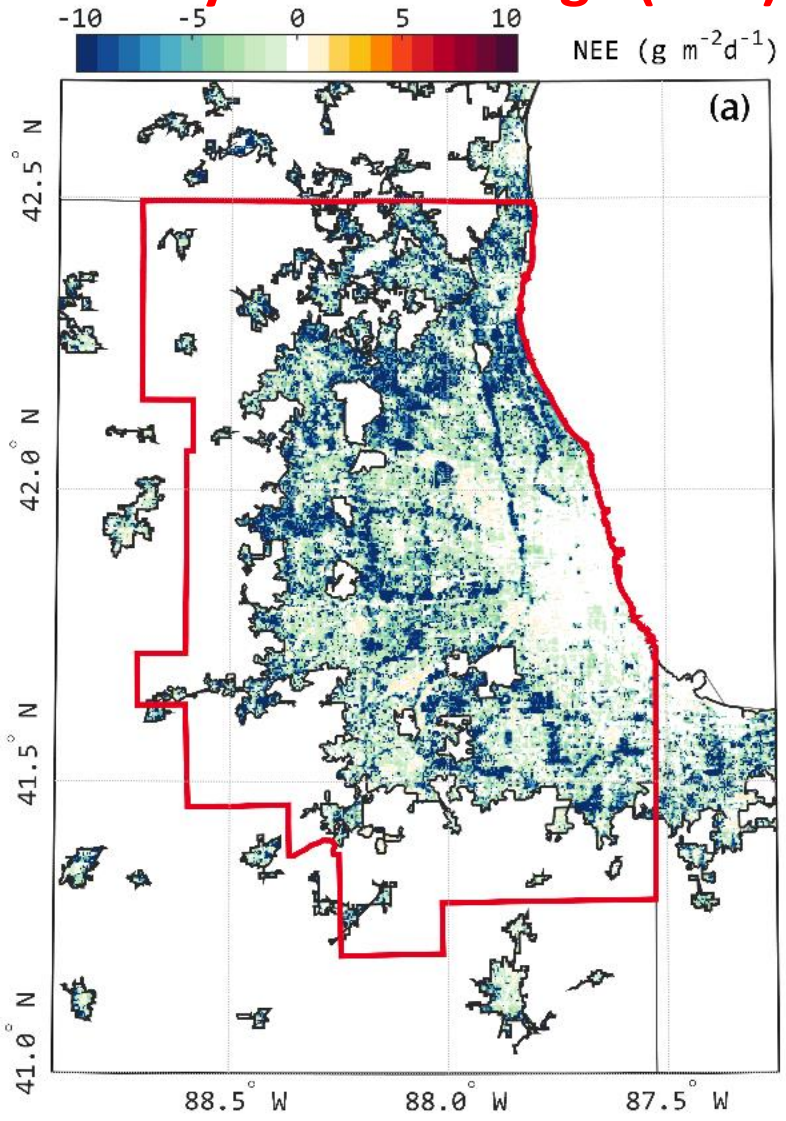
- Passive impacts from heat and elevated background CO_2 level alter growth of plants.

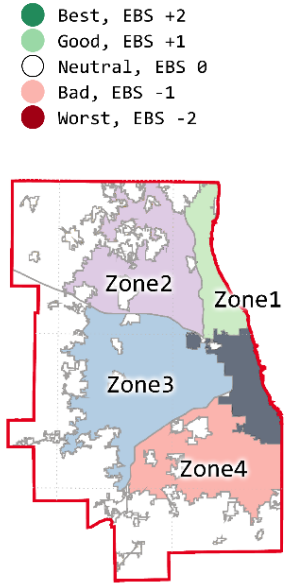
Li et al. (J. Adv. Model. Earth Syst., 2023)

Changes in CO_2 due to urban vegetation

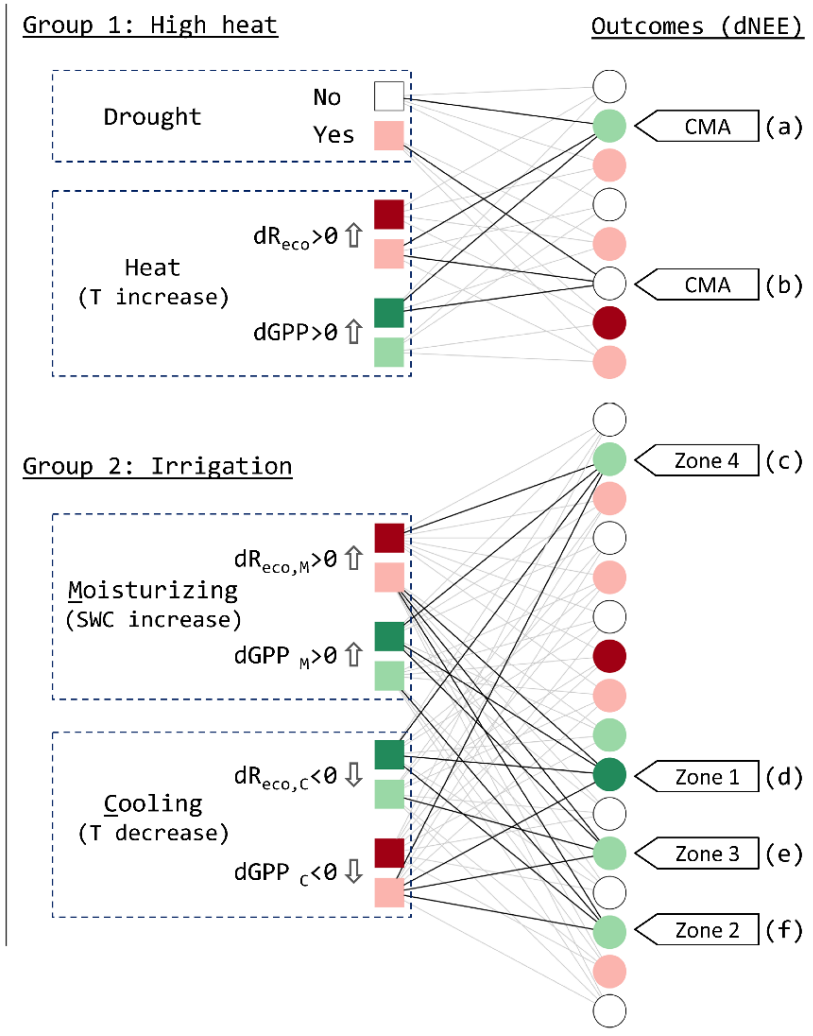
- High spatial variability
- Active CO_2 sequestration in urban parks, followed by vegetated land in residential areas.

Net ecosystem exchange (NEE)





Environmental benefit score

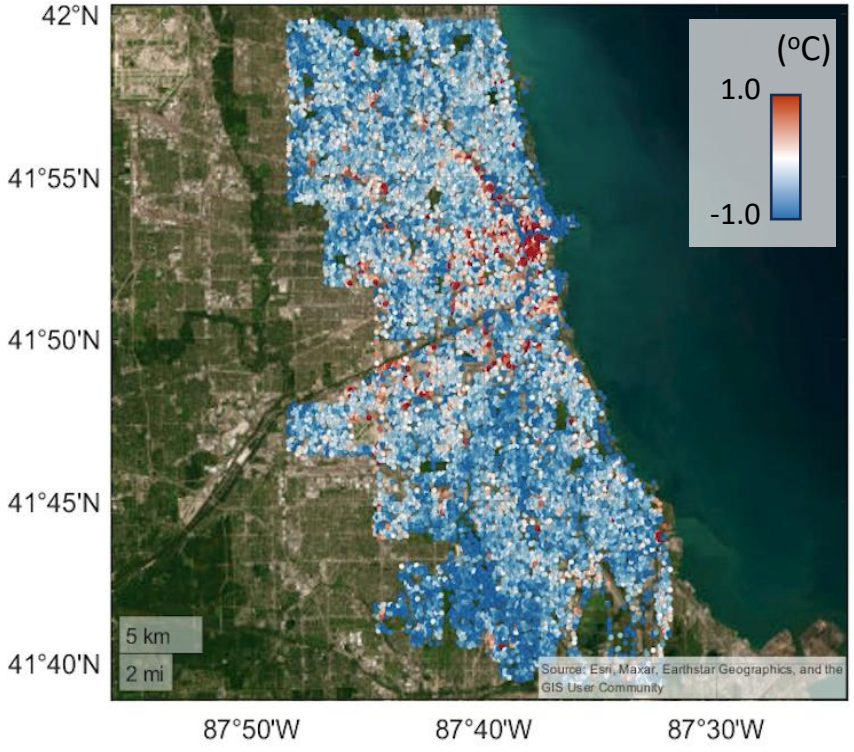


Li et al. (J. Adv. Model. Earth Syst., 2023)

Solutions at scales it matters

- A physical-informed machine learning framework to estimate street-level environmental stressors

Temperature deviation from areal mean (hourly)

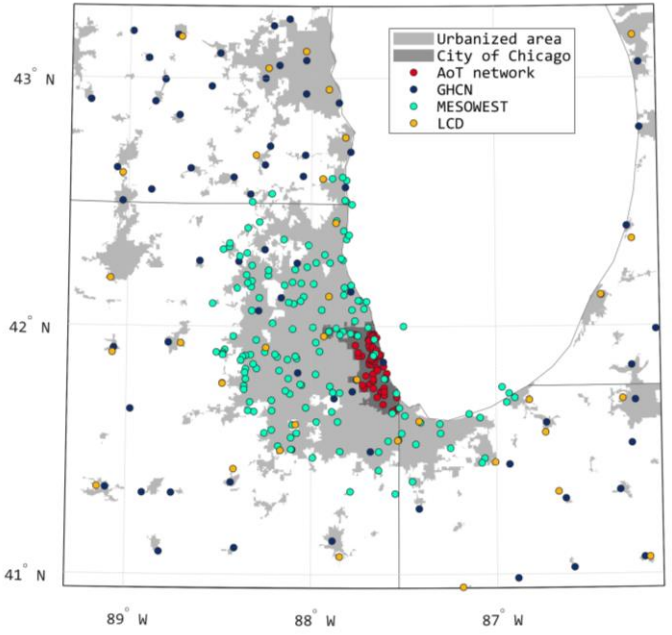


Li and Sharma (in review; JAMES)

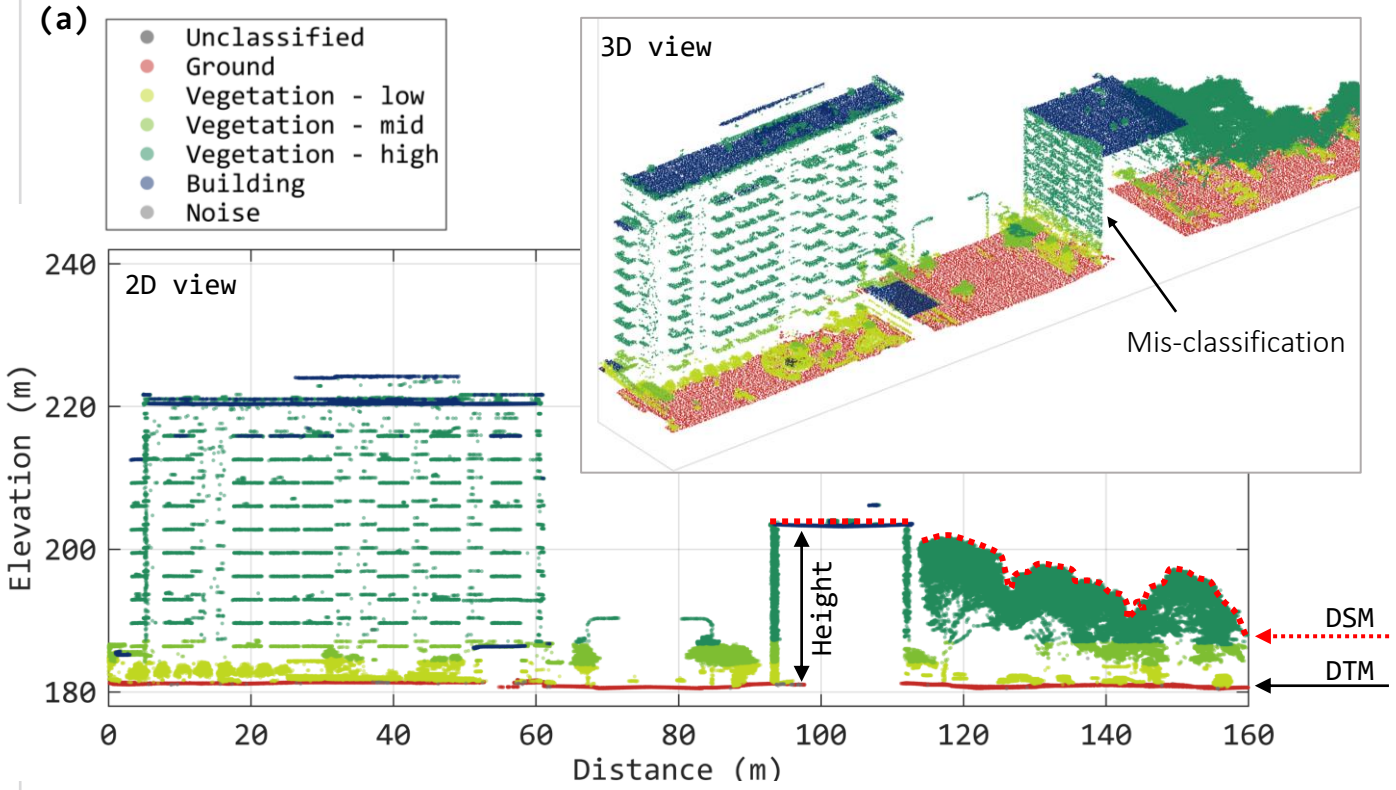
LiDAR point cloud dataset (ILHMP, 2018)

Li and Sharma (in review; ERL)

Weather stations and nodes around Chicago area



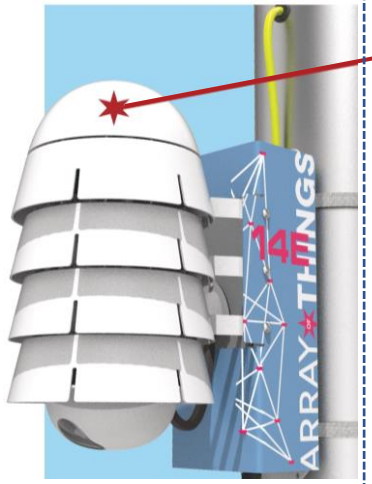
- LiDAR data at an exemplary street block

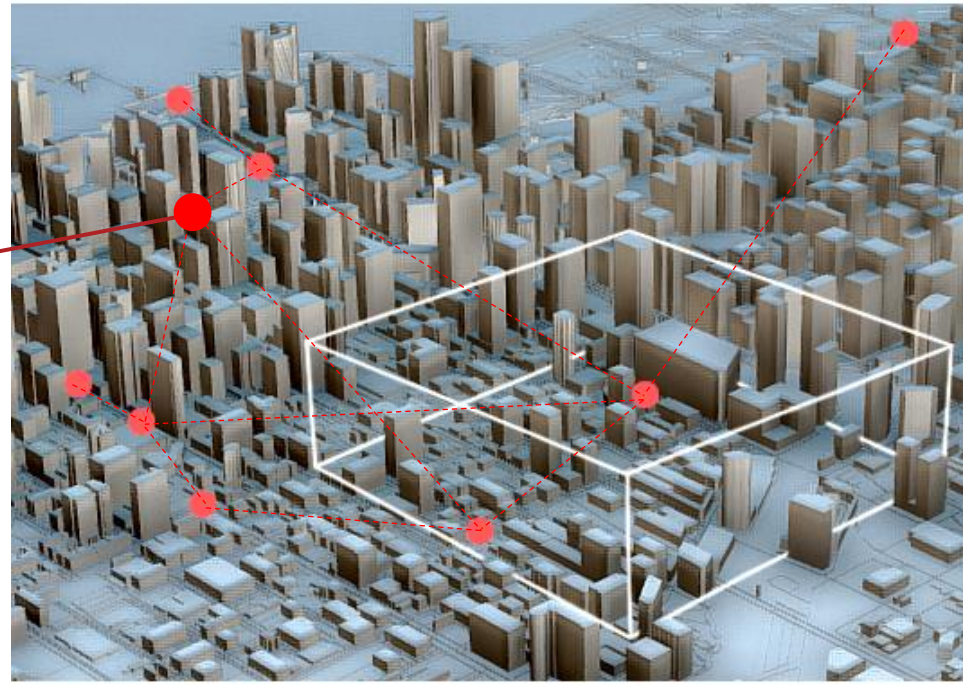


Li and Sharma (in review; ERL)

Urban informatics

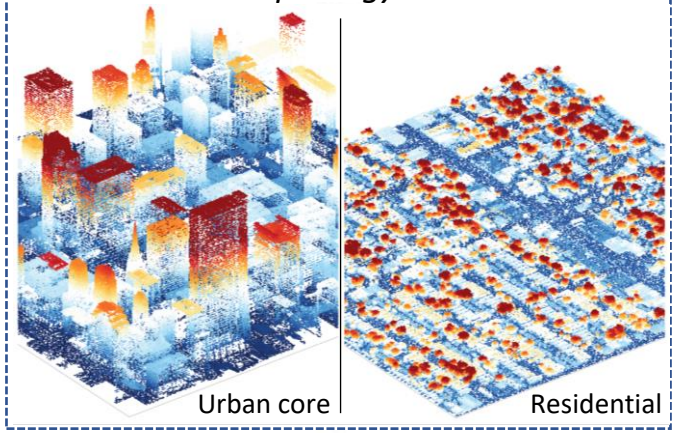
Street-level observation network





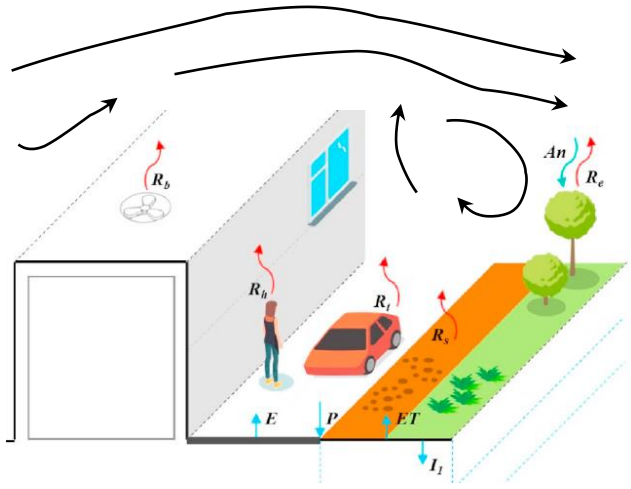
Parcel-level land use inventory

LiDAR urban morphology



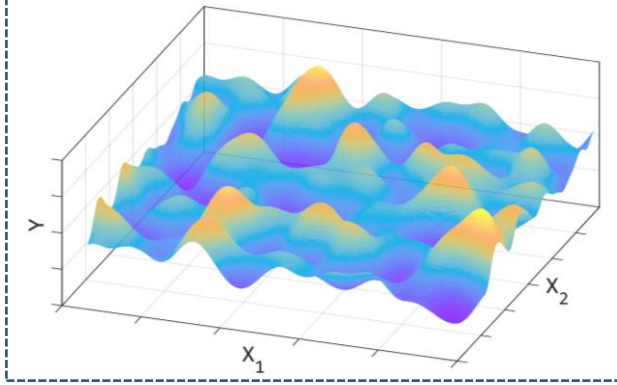
Urban Weather Forecast

WRF/urban modeling framework



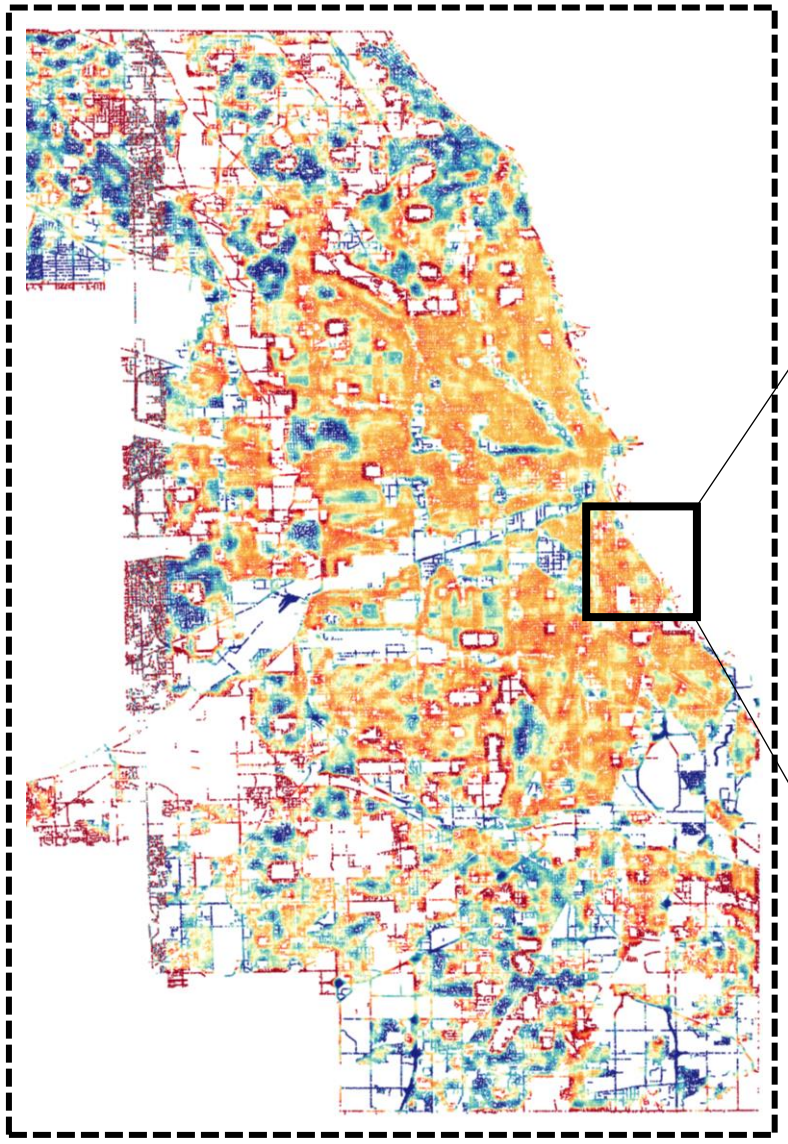
Machine Learning

Gaussian Process Regression



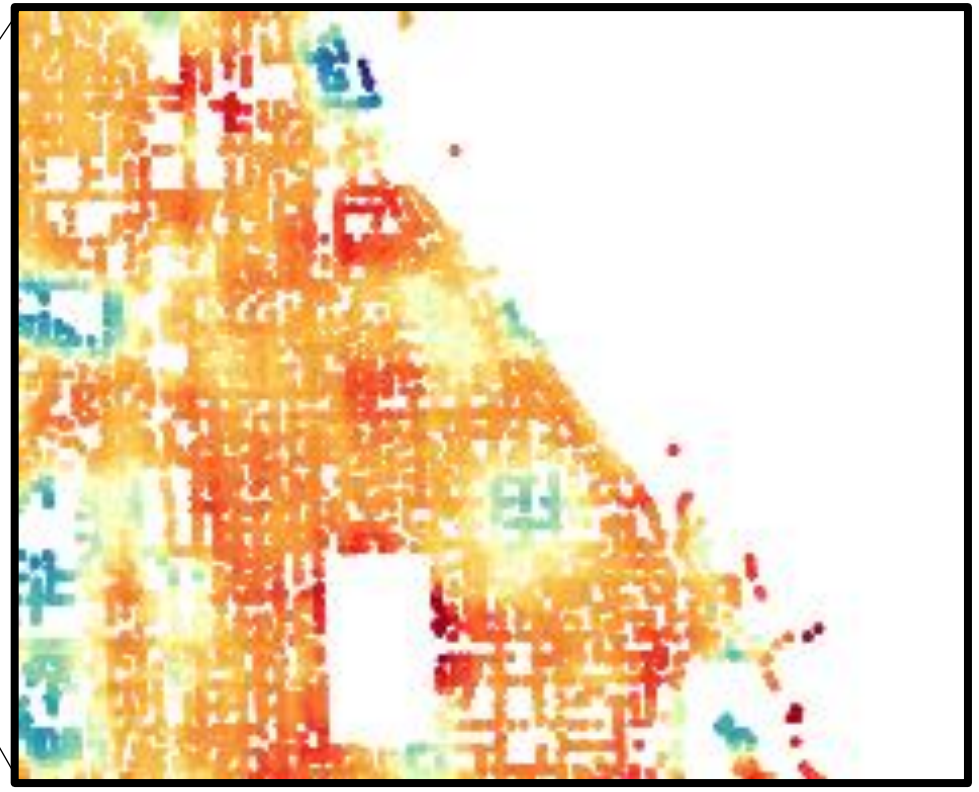
- Forecasting street-level temperature via data fusion of urban informatics

Street-level temperature estimation



Li and Sharma (in review)

Street-level air temperature at resampled locations

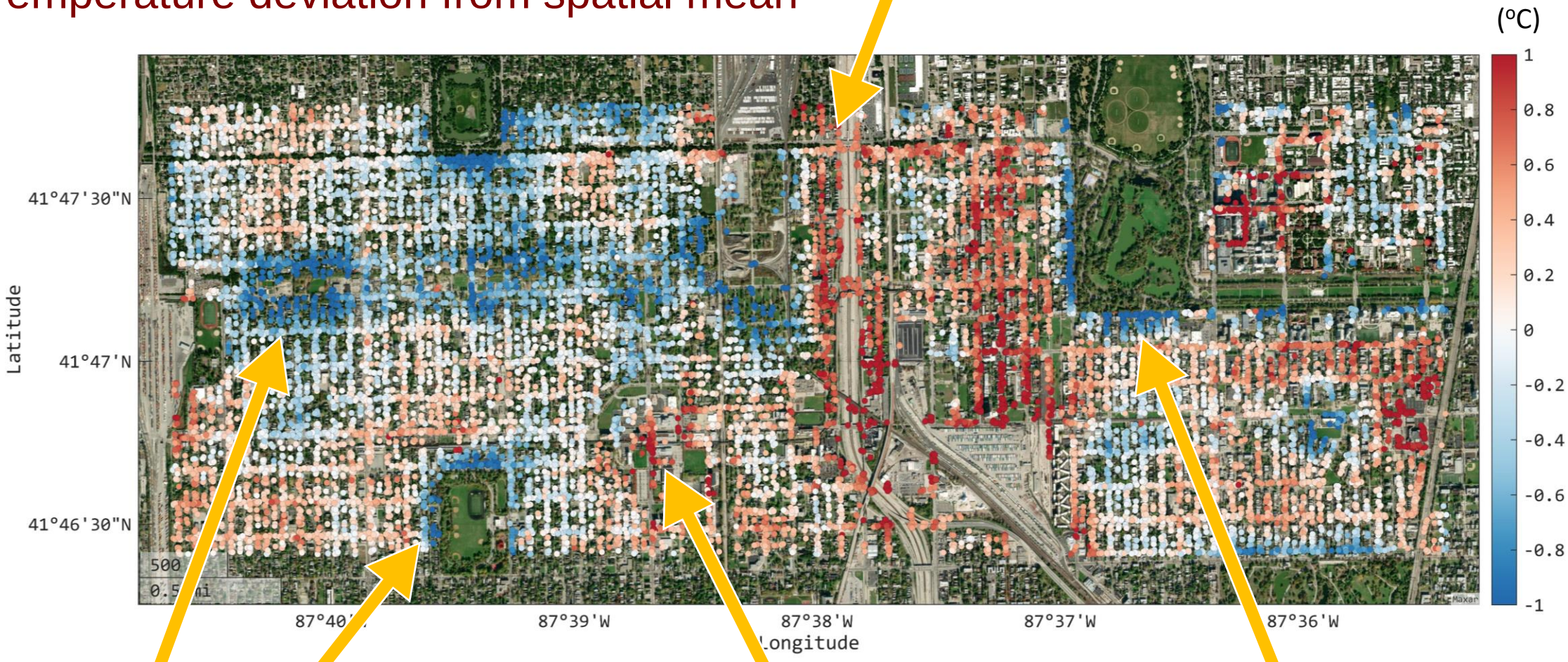


- Downscale 1-km climate prediction to sub-meter street-level air temperature using machine learning.

Address Urban Planning issues at street scales

Area along the freeways, no shading, is hotter

Temperature deviation from spatial mean



Area with dense vegetation is cooler.

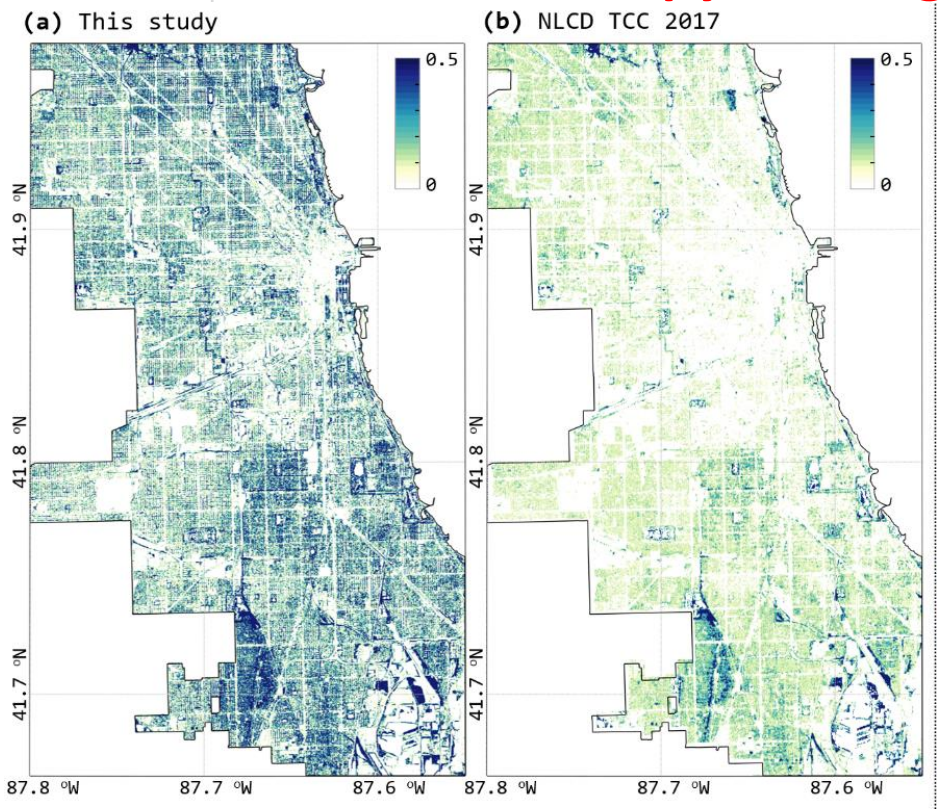
Commercial corners are hotter

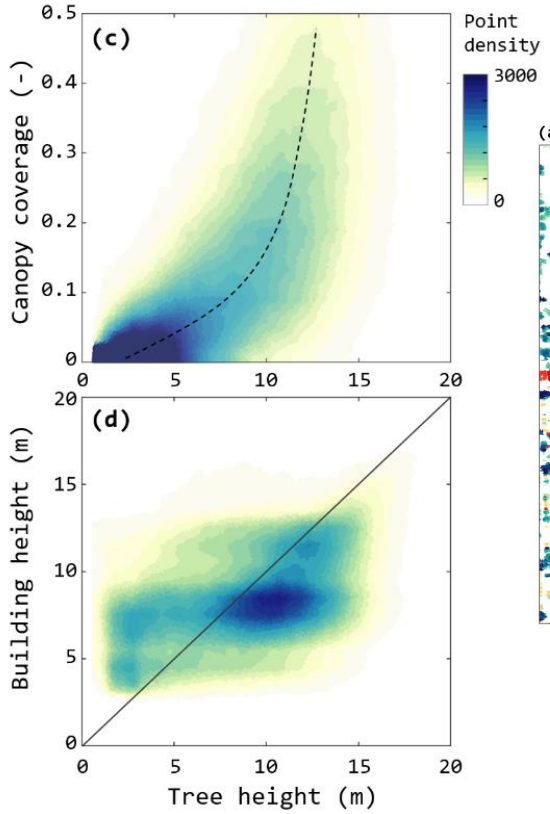
Li and Sharma (in review)

Street near large urban parks is cooler

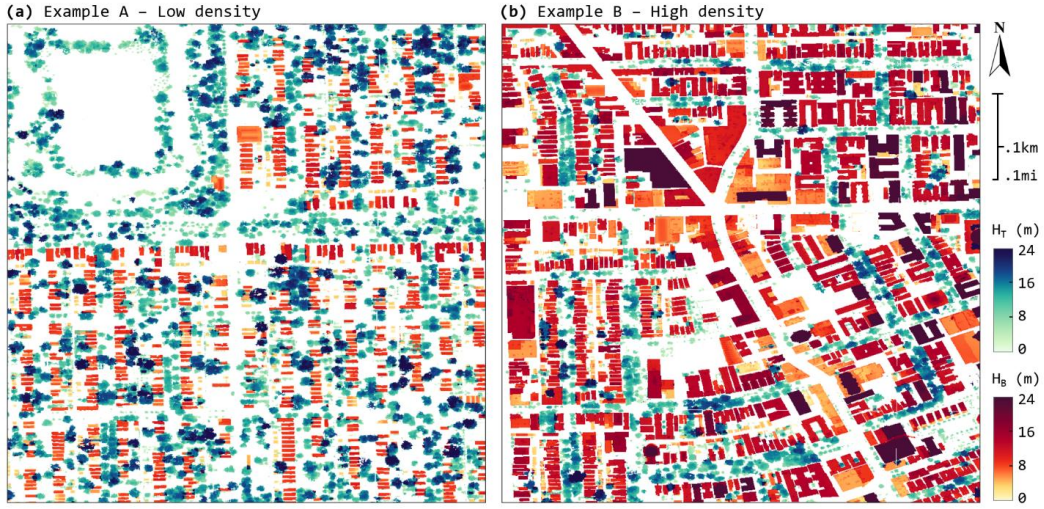
HiTAB-Chicago:
HeIght map of Trees And Buildings for the City of Chicago

Tree canopy coverage





Building height

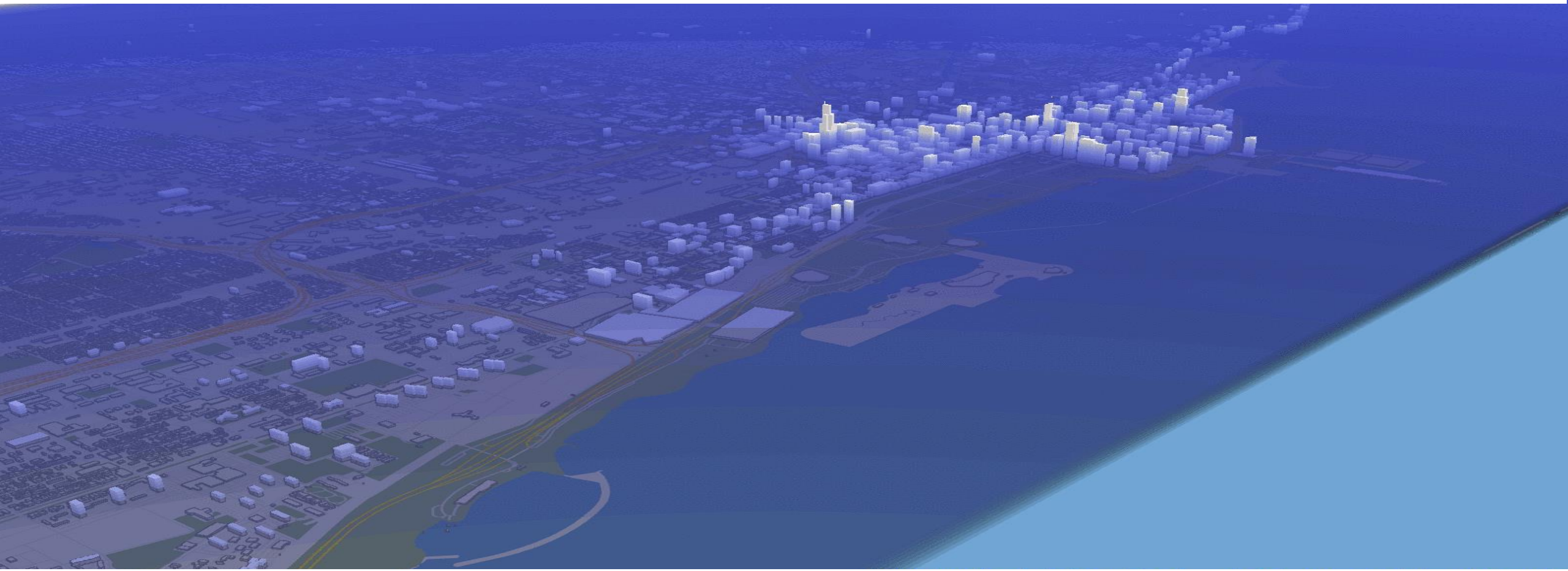


Open source data available at:
https://doi.org/10.5281/zenodo.10463648

Li and Sharma (in review)

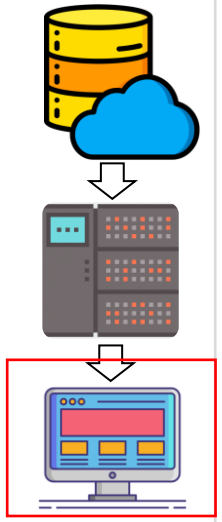
Urban products/tools

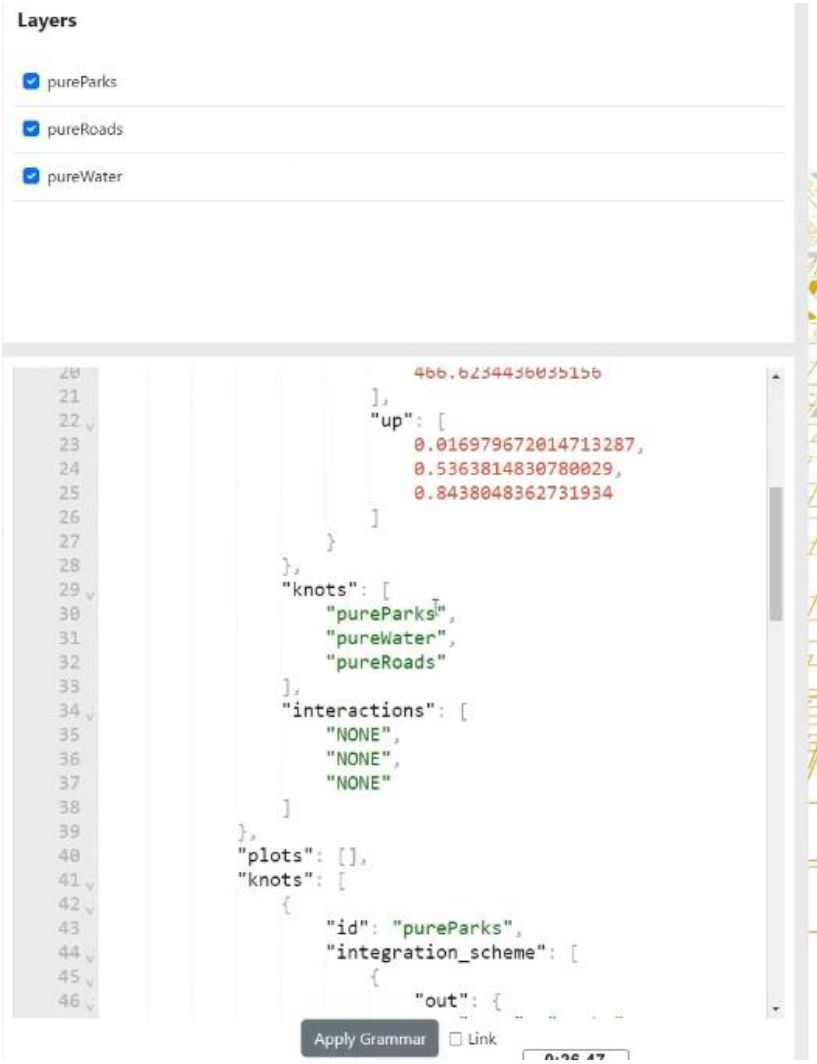
3D visualization



Applications

- Shadow impact of two buildings on Millennium Park (3-5 pm)





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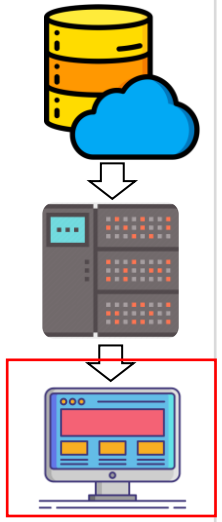

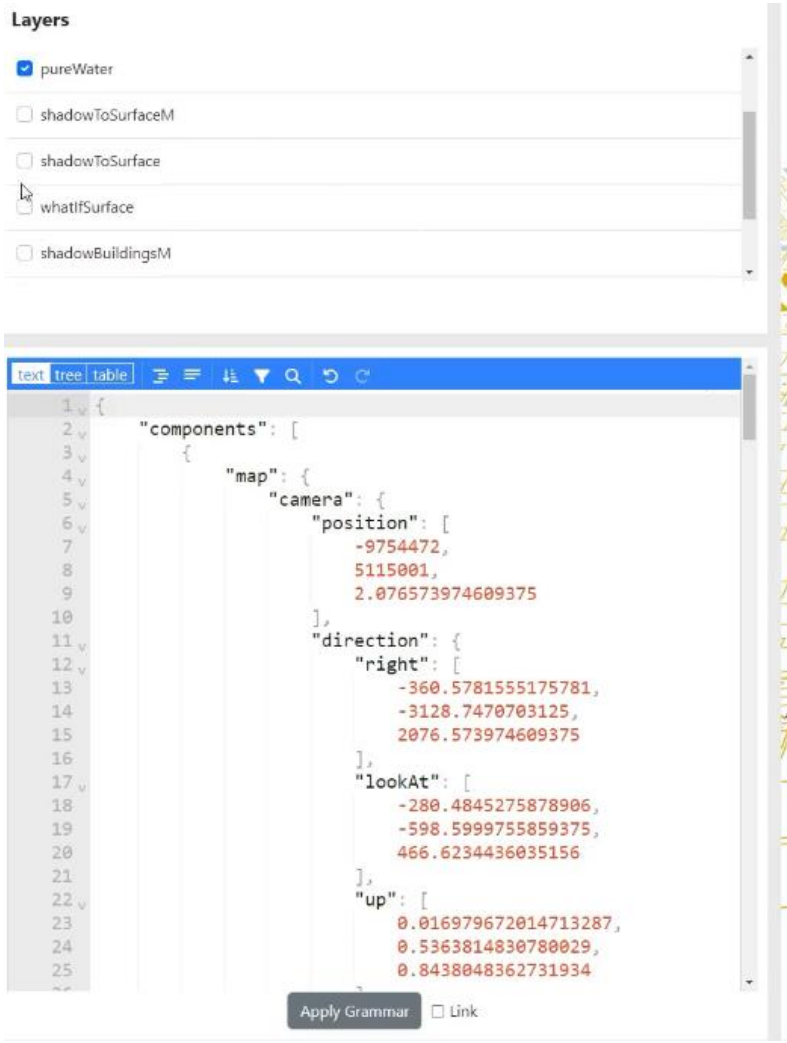

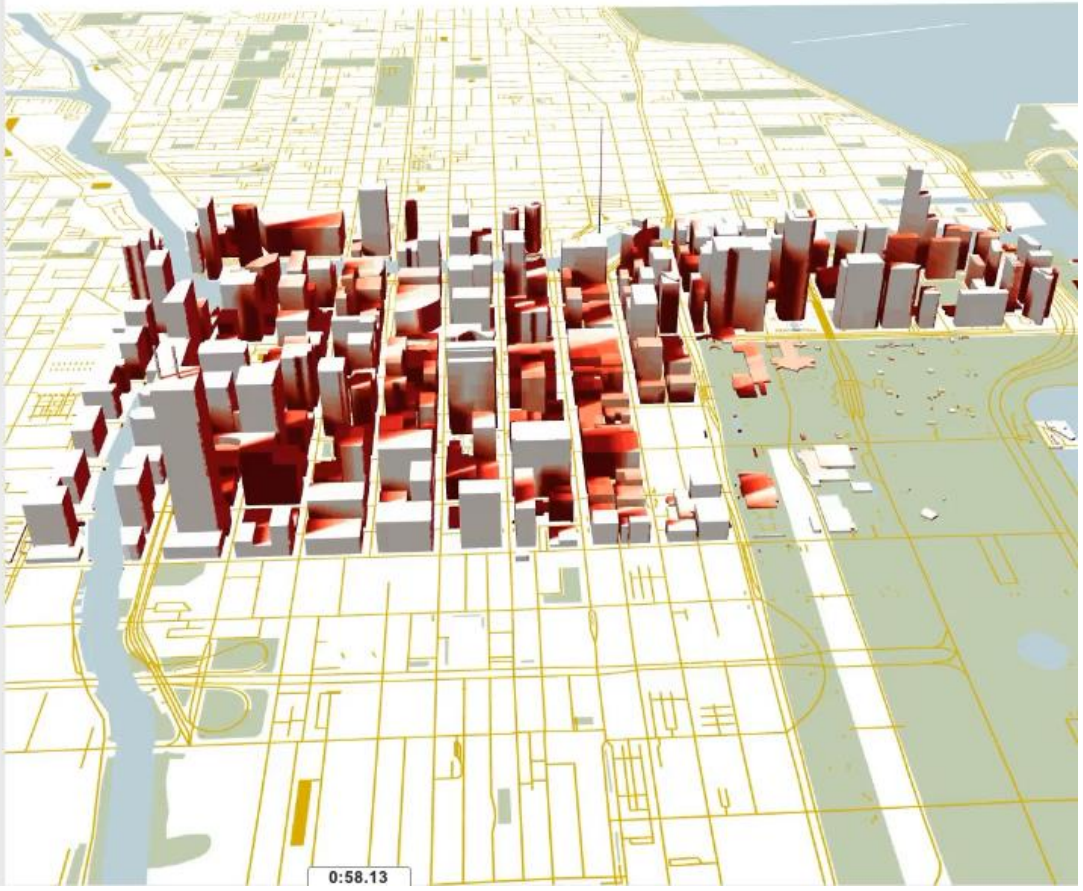

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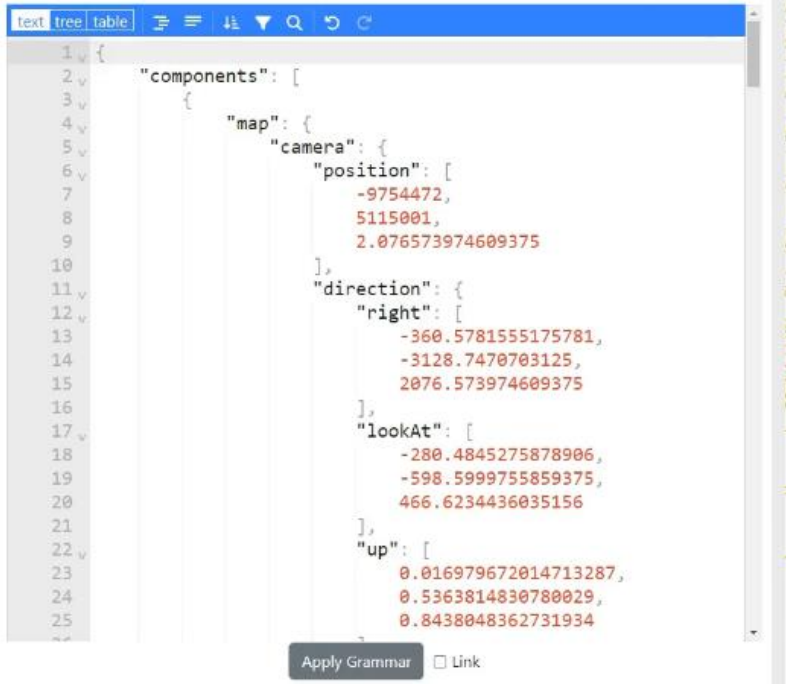
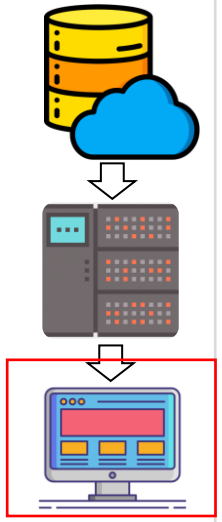
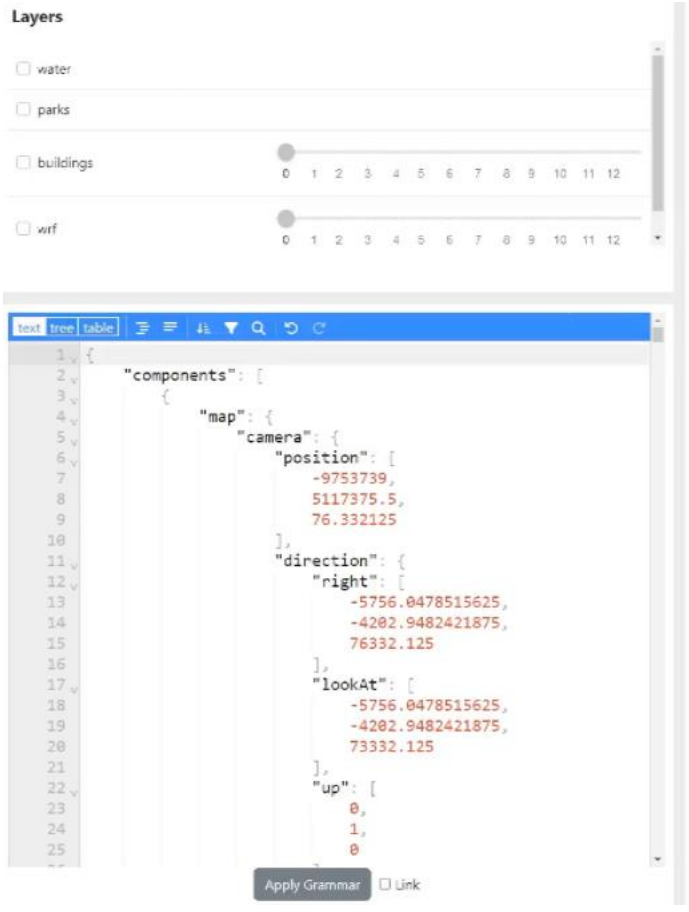


Applications

- WRF temperature data at the street and building levels.
- Combining 1 km and 250 m resolution climate simulation data





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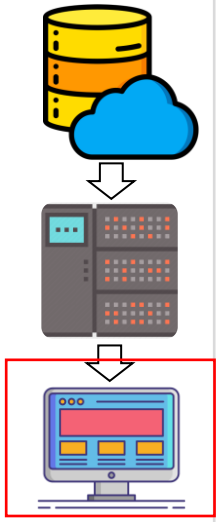

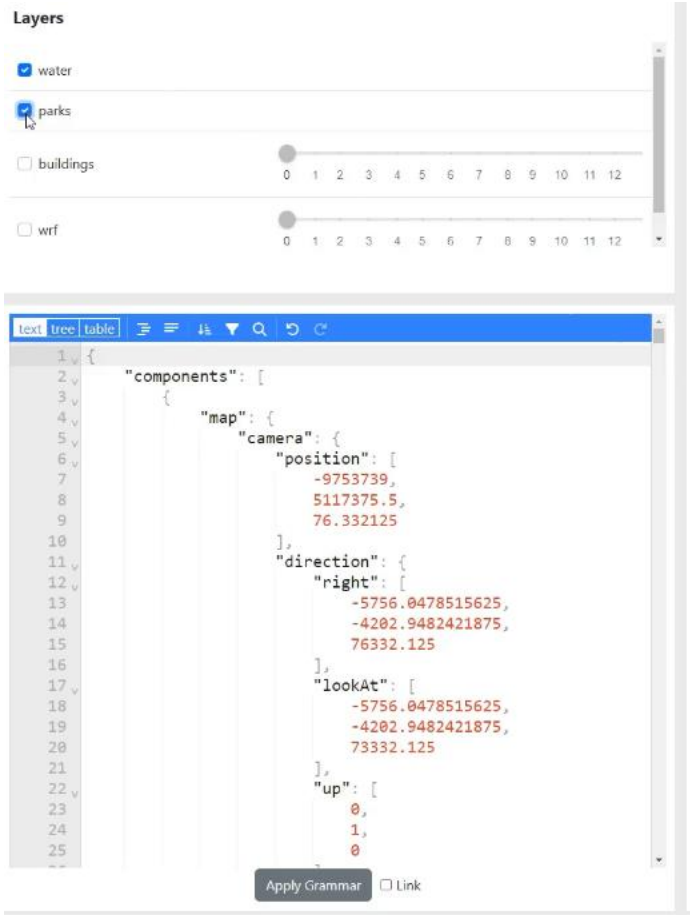

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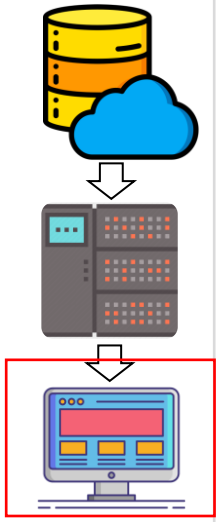

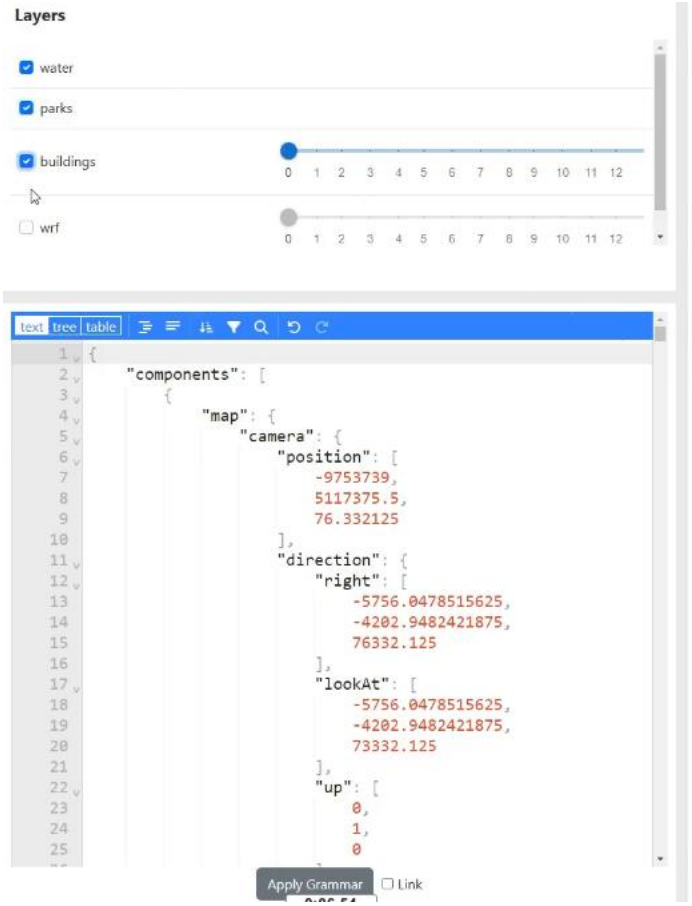

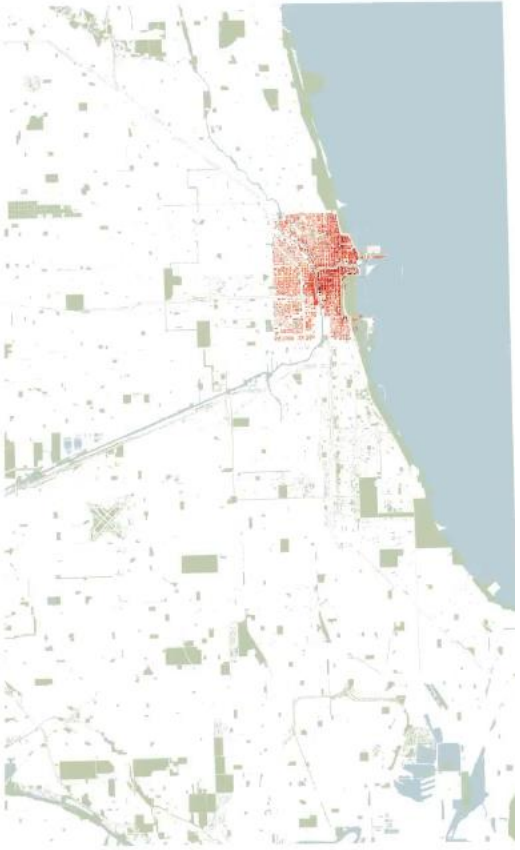

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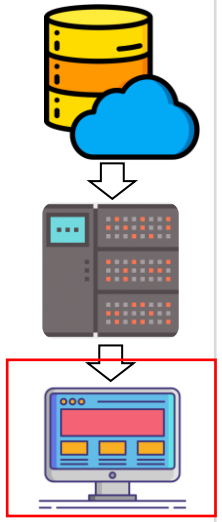

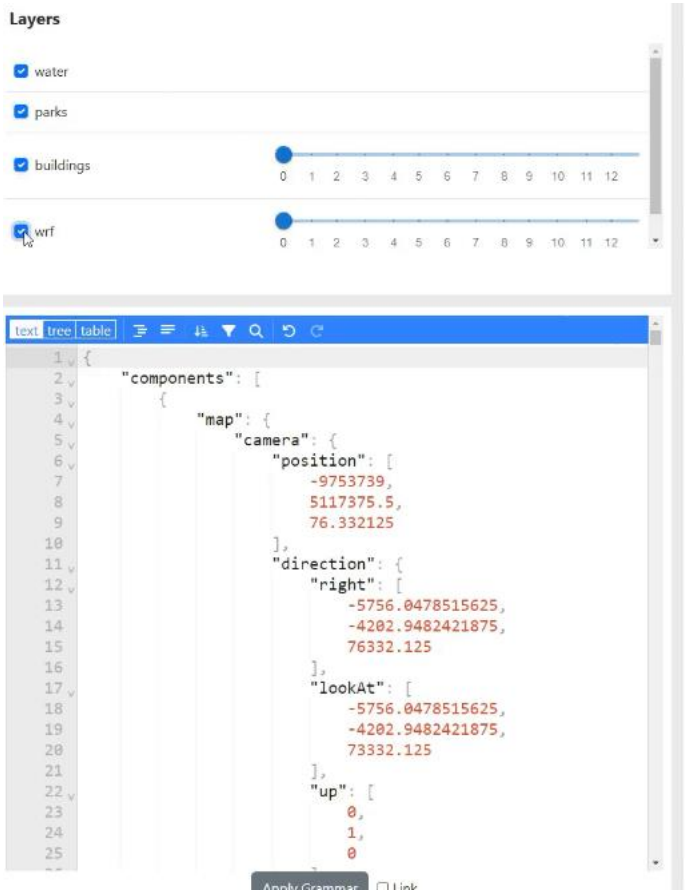

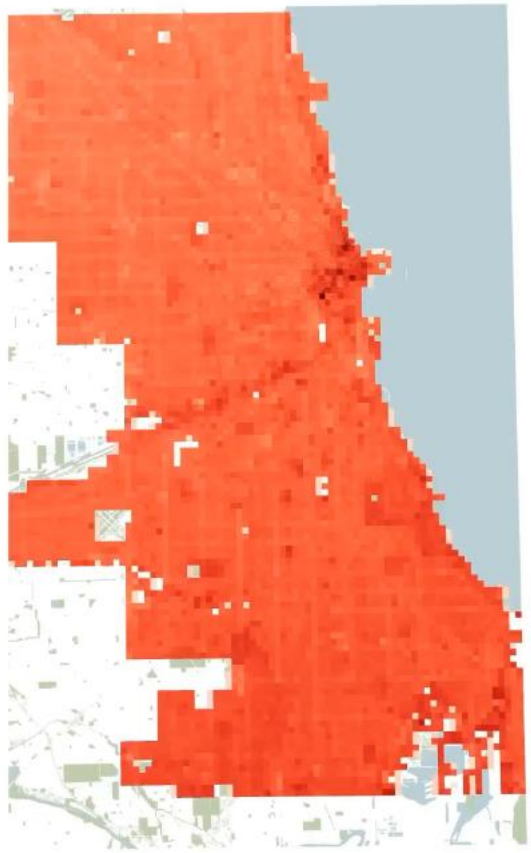

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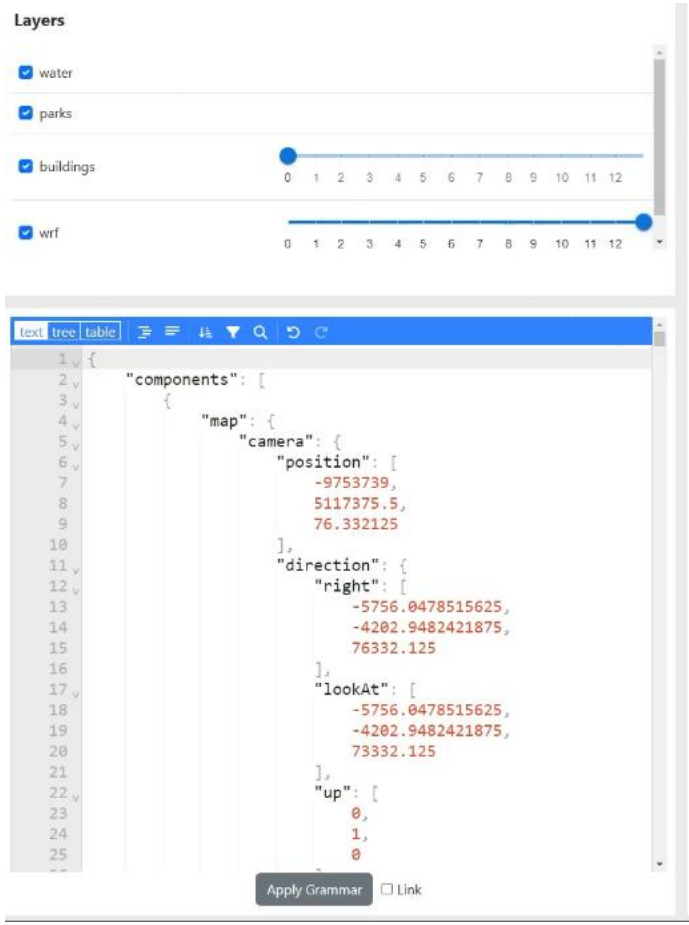

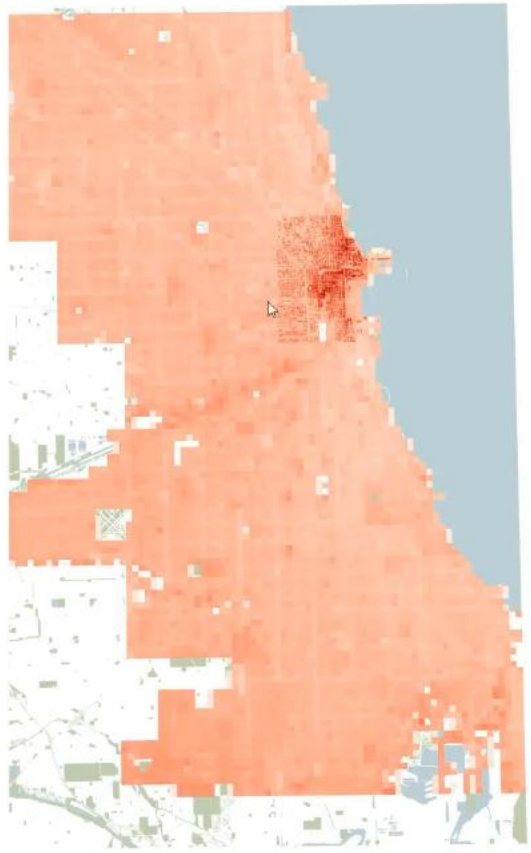

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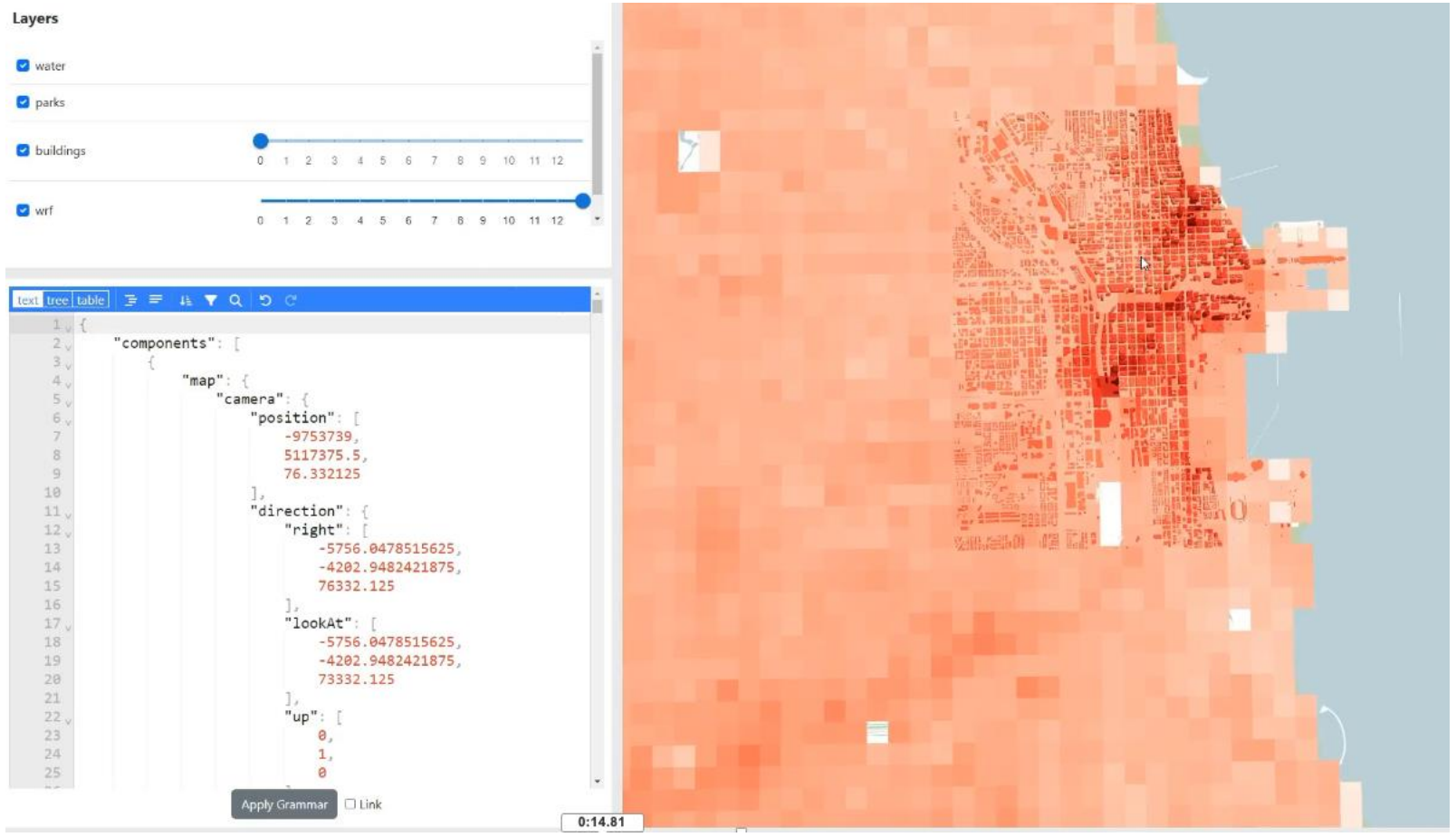

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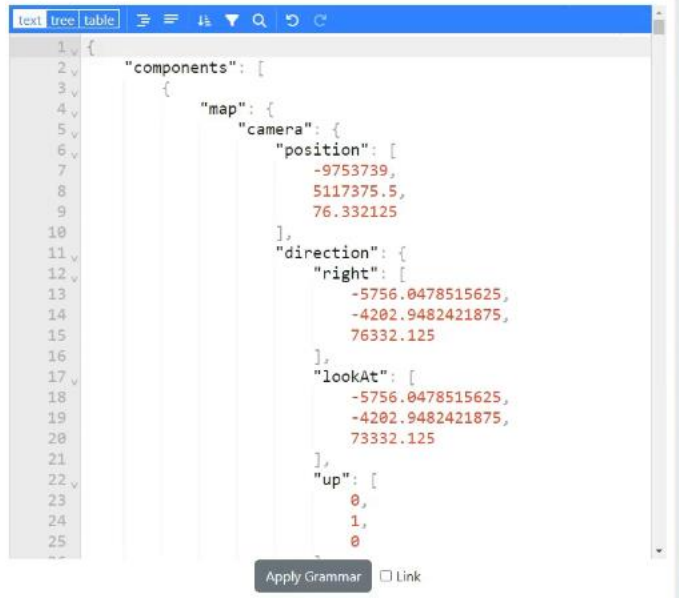

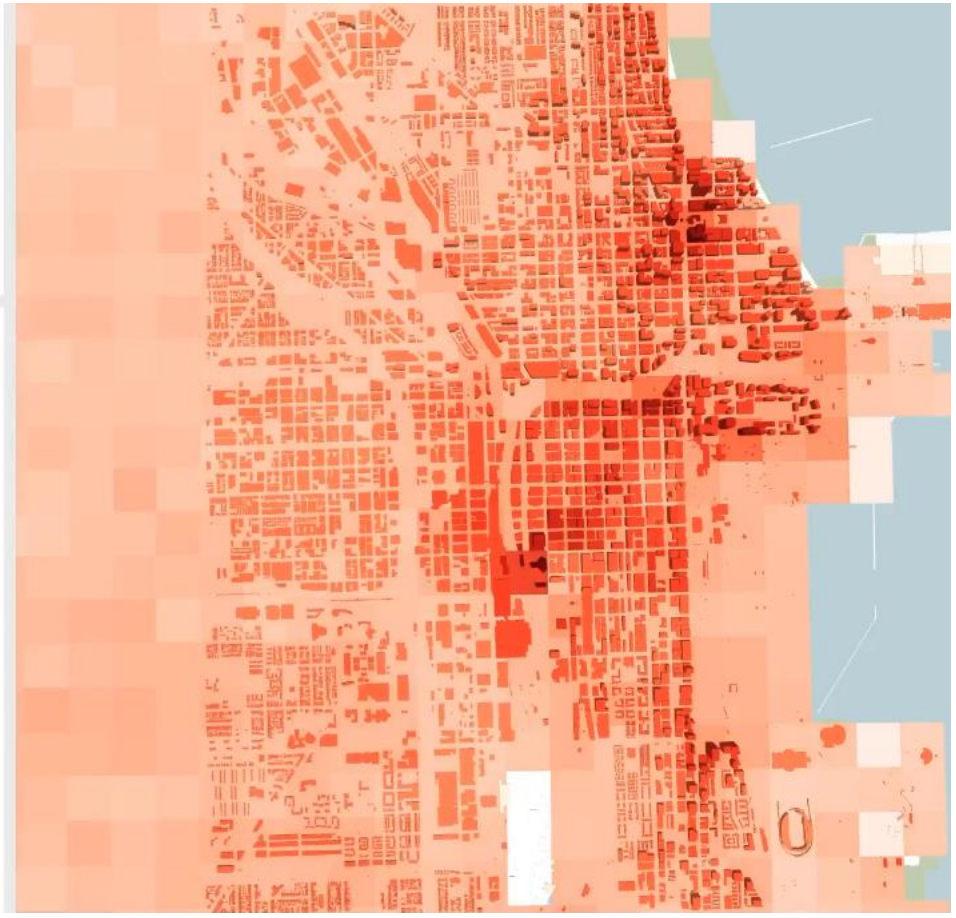

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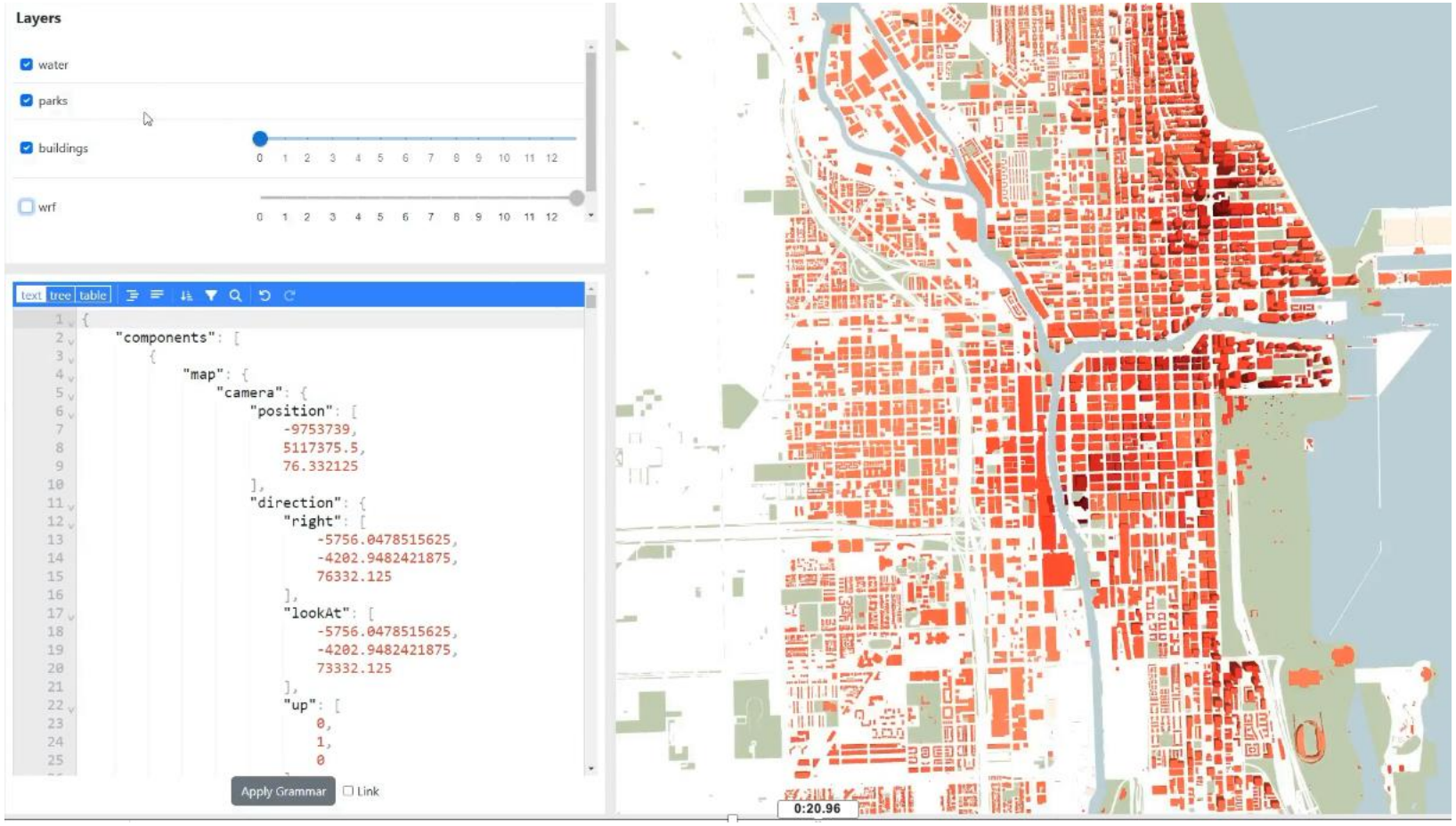

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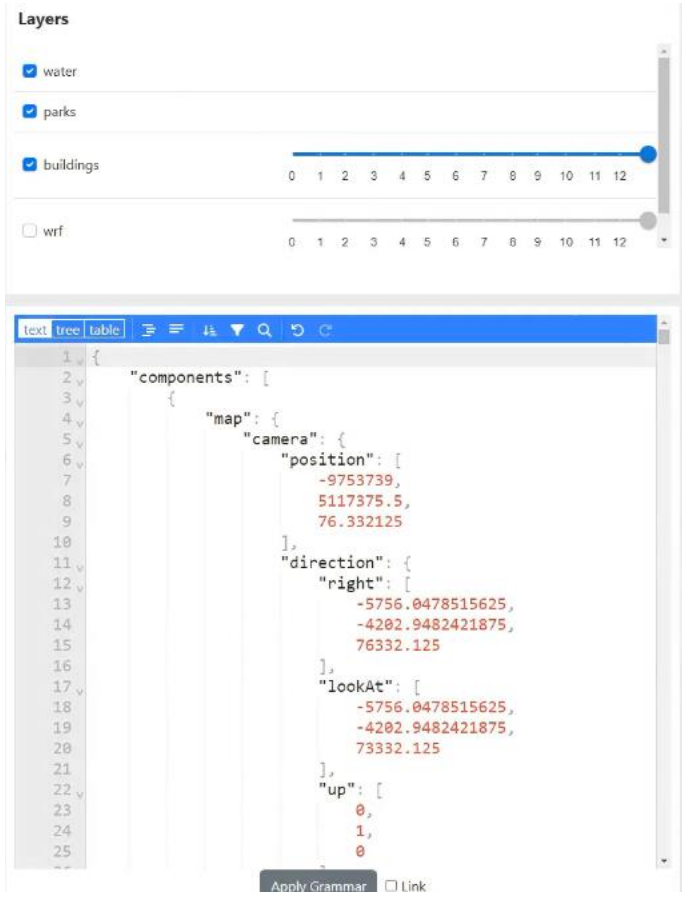

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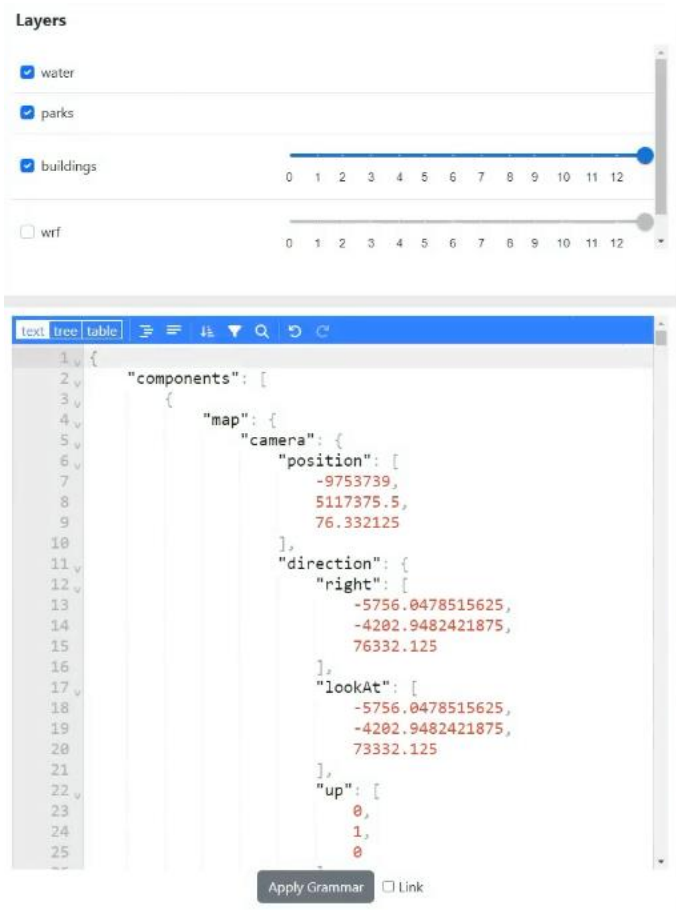

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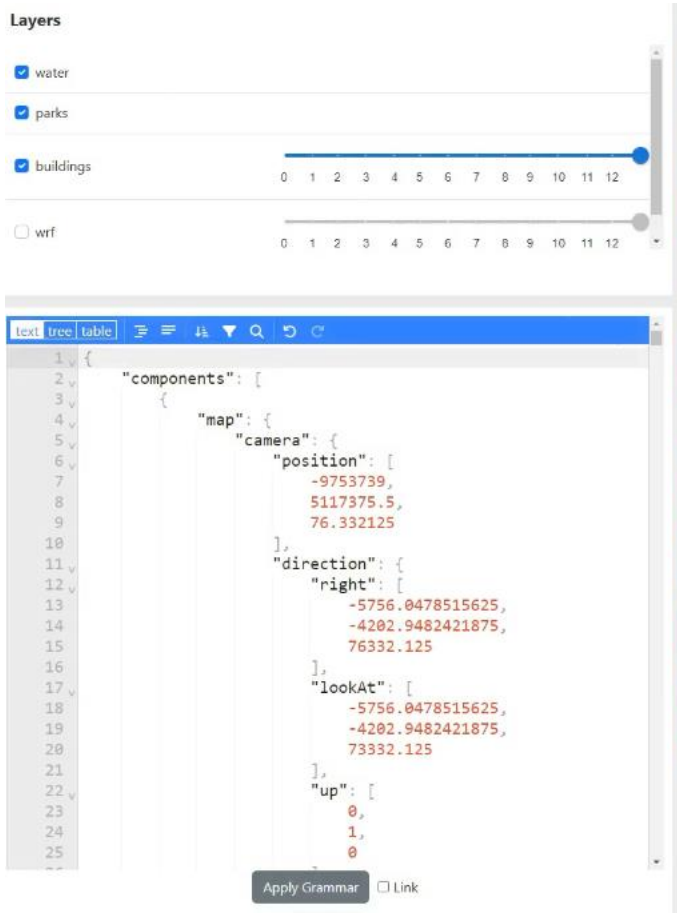
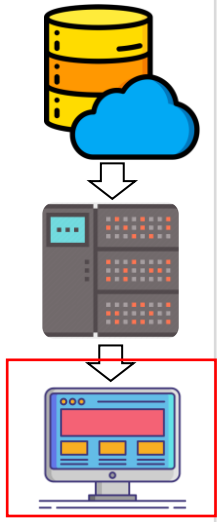
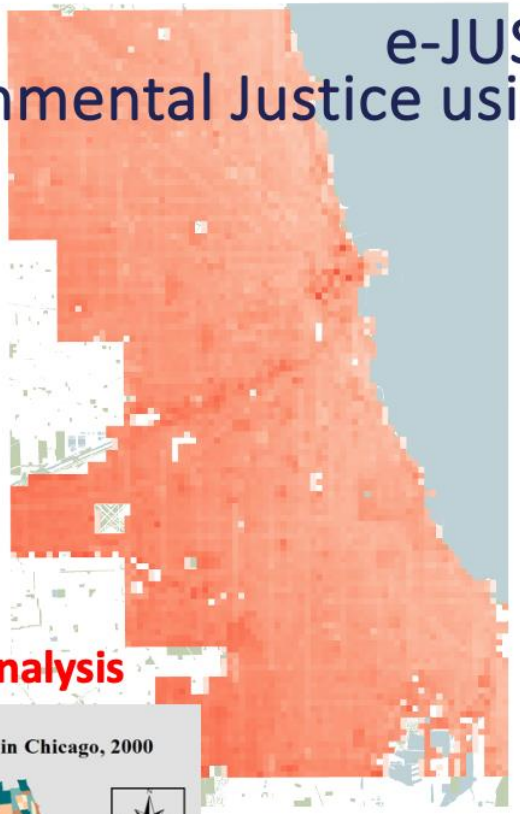
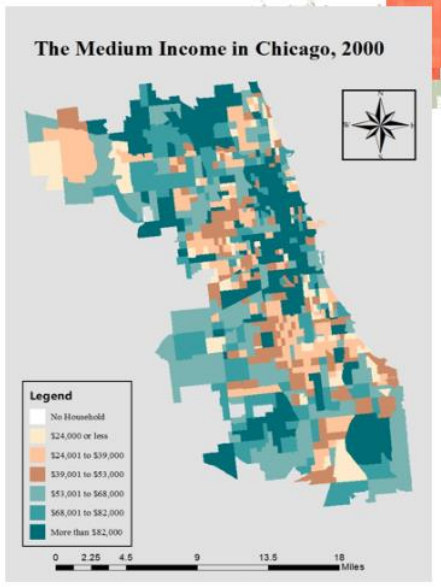


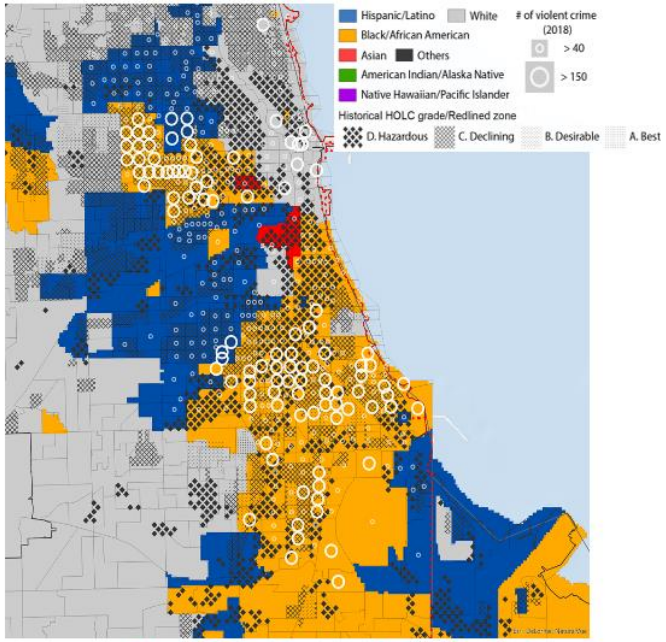
e-JUST — Environmental Justice using Urban Scalable Toolkit



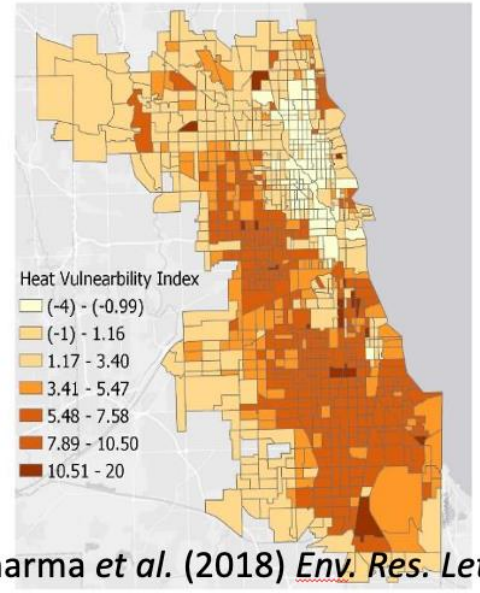


Income analysis



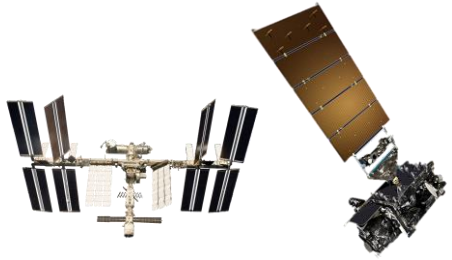


Heat Vulnerability Index



Sharma *et al.* (2018) *Env. Res. Lett.*

Observed Data



Urban Climate Models

WRF

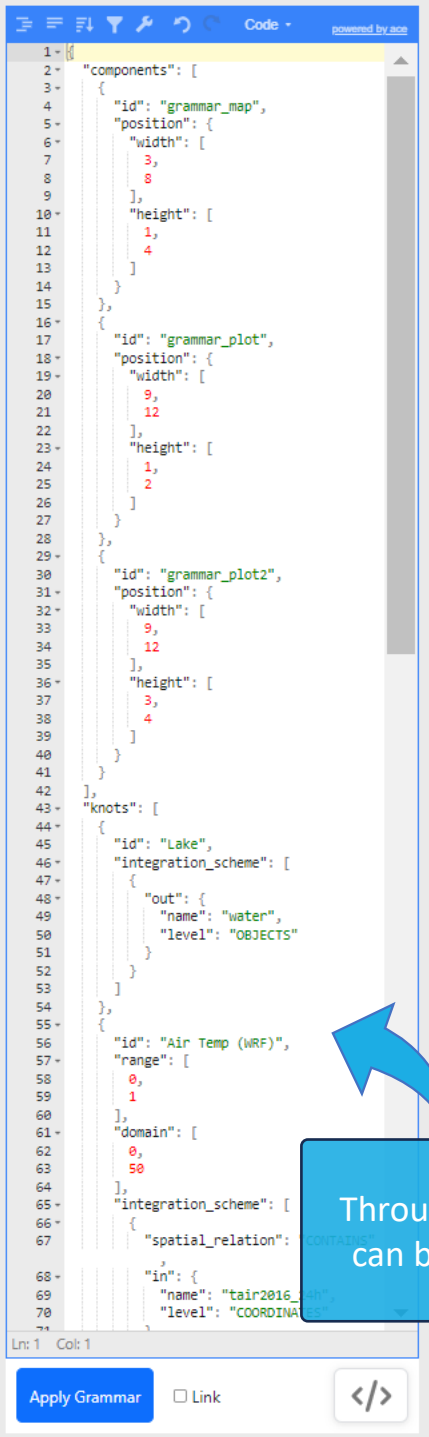
WRF-Chem

Demographic Dataset

2020 US Census

e-JUST

Decision-Making



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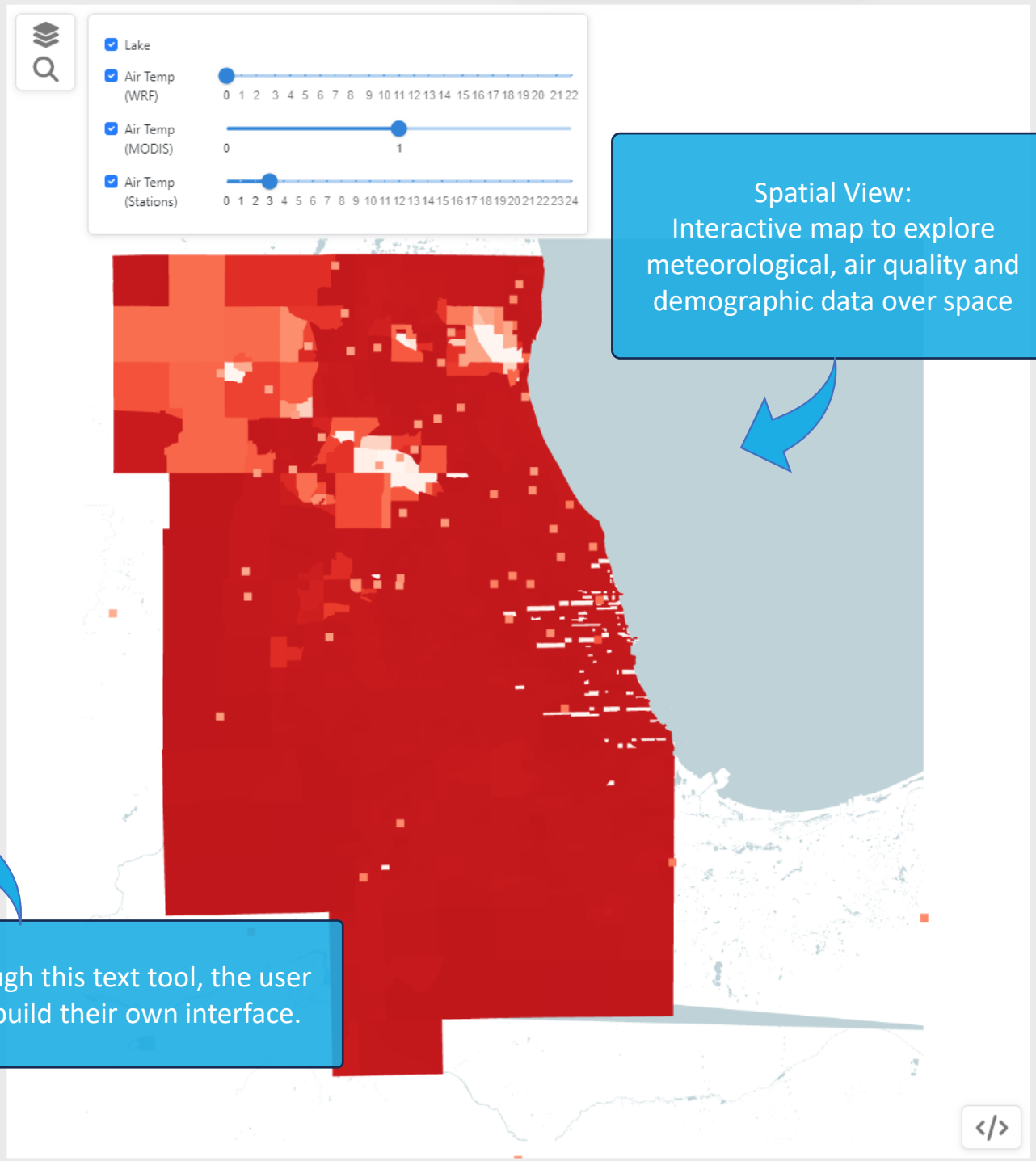
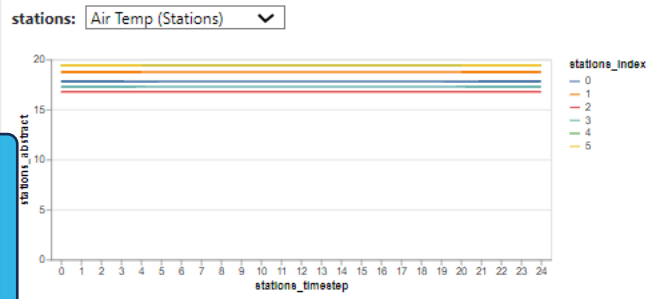
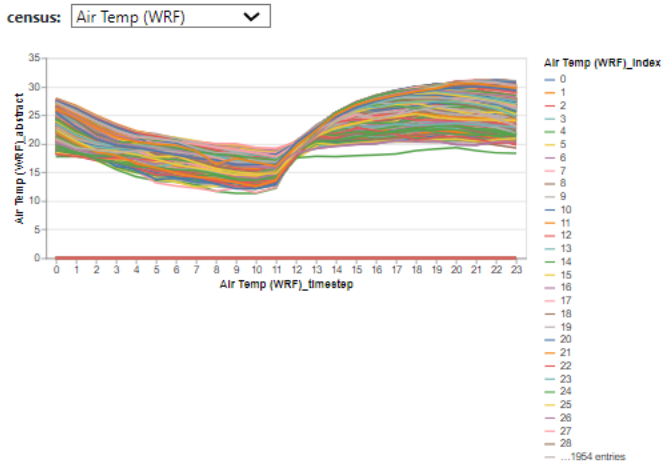


Spatial View:
Interactive map to explore meteorological, air quality and demographic data over space





Code

powered by ace

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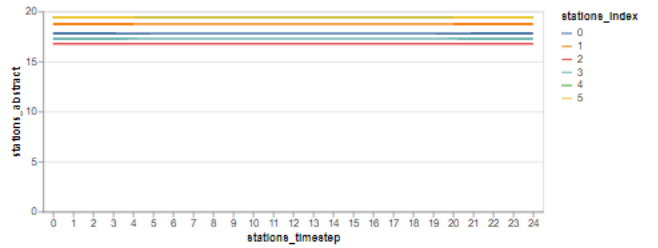
Apply Grammar

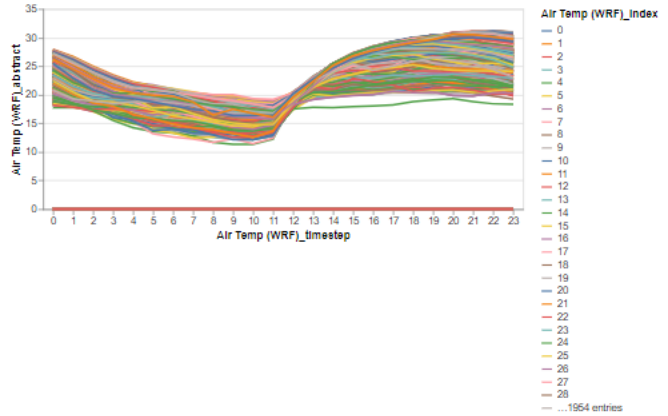
Link

The user can zoom in and zoom out, choose the field to be explored, and click on an area on the map to explore the other views.

stations: Air Temp (Stations)



census: Air Temp (WRF)

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powered by ace
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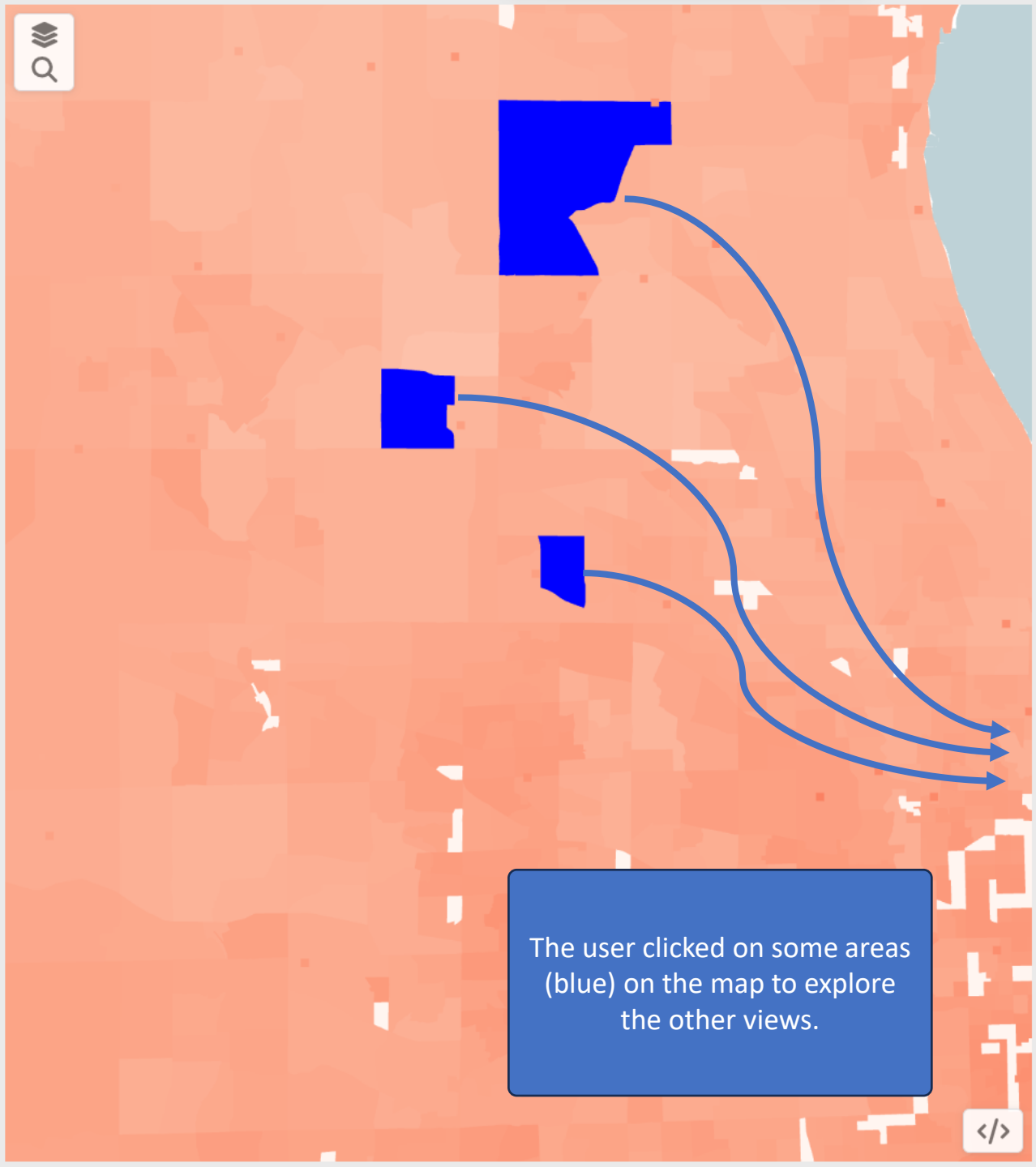
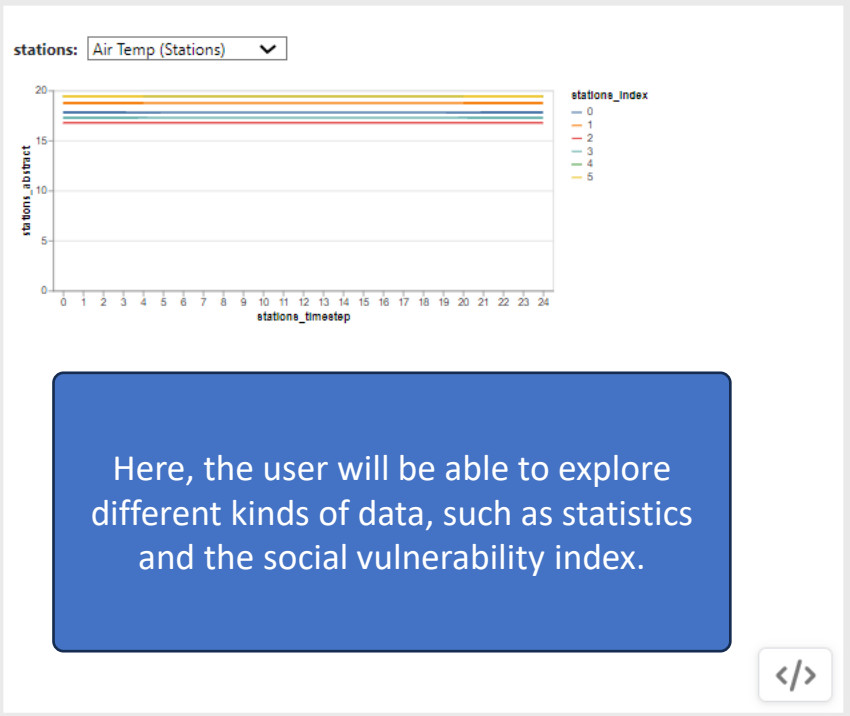
Link


The user clicked on some areas (blue) on the map to explore the other views.


stations:
Air Temp (Stations)
stations_abstract
stations_timestep
stations_index
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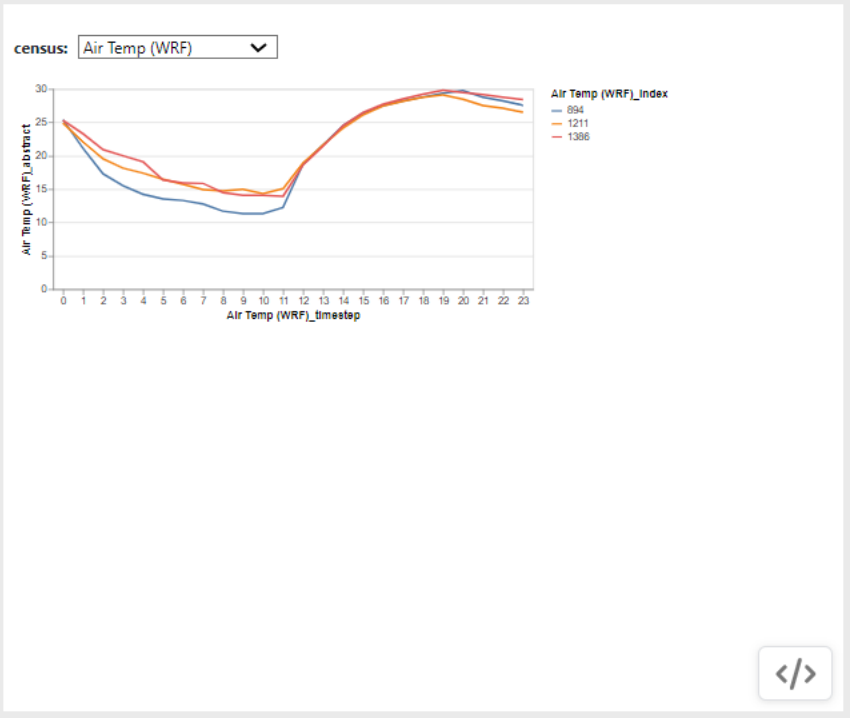
2
3
4
5
Here, the user will be able to explore different kinds of data, such as statistics and the social vulnerability index.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Air Temp (WRF)
Air Temp (WRF)_abstract
Air Temp (WRF)_timestep
Air Temp (WRF)_index
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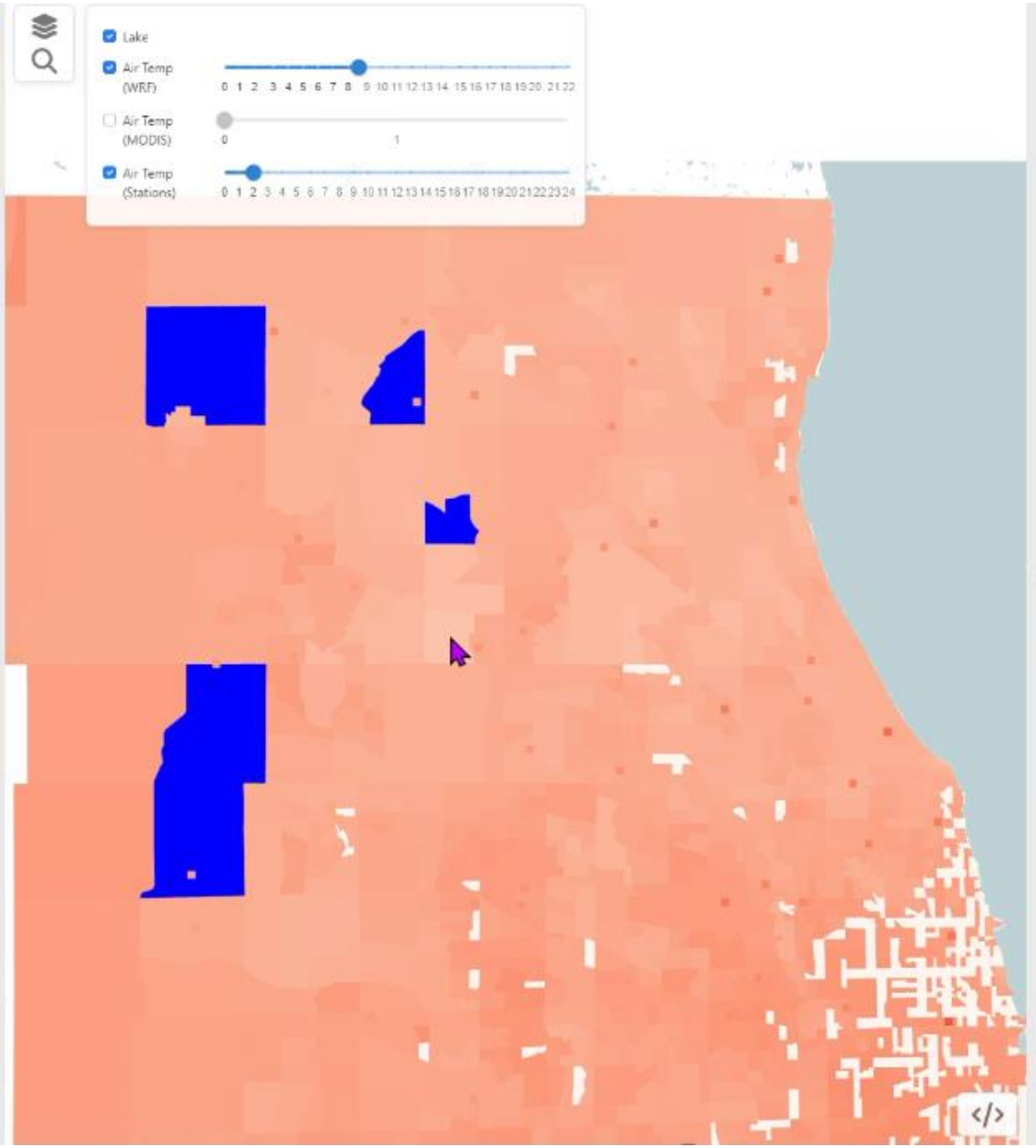
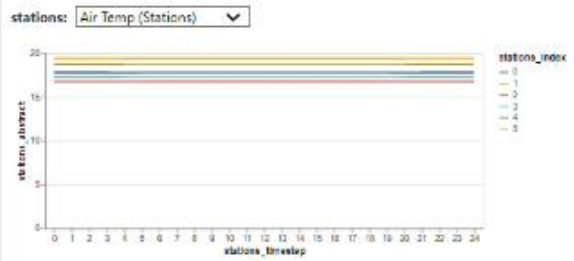
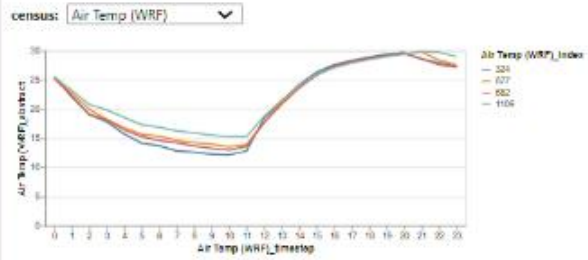
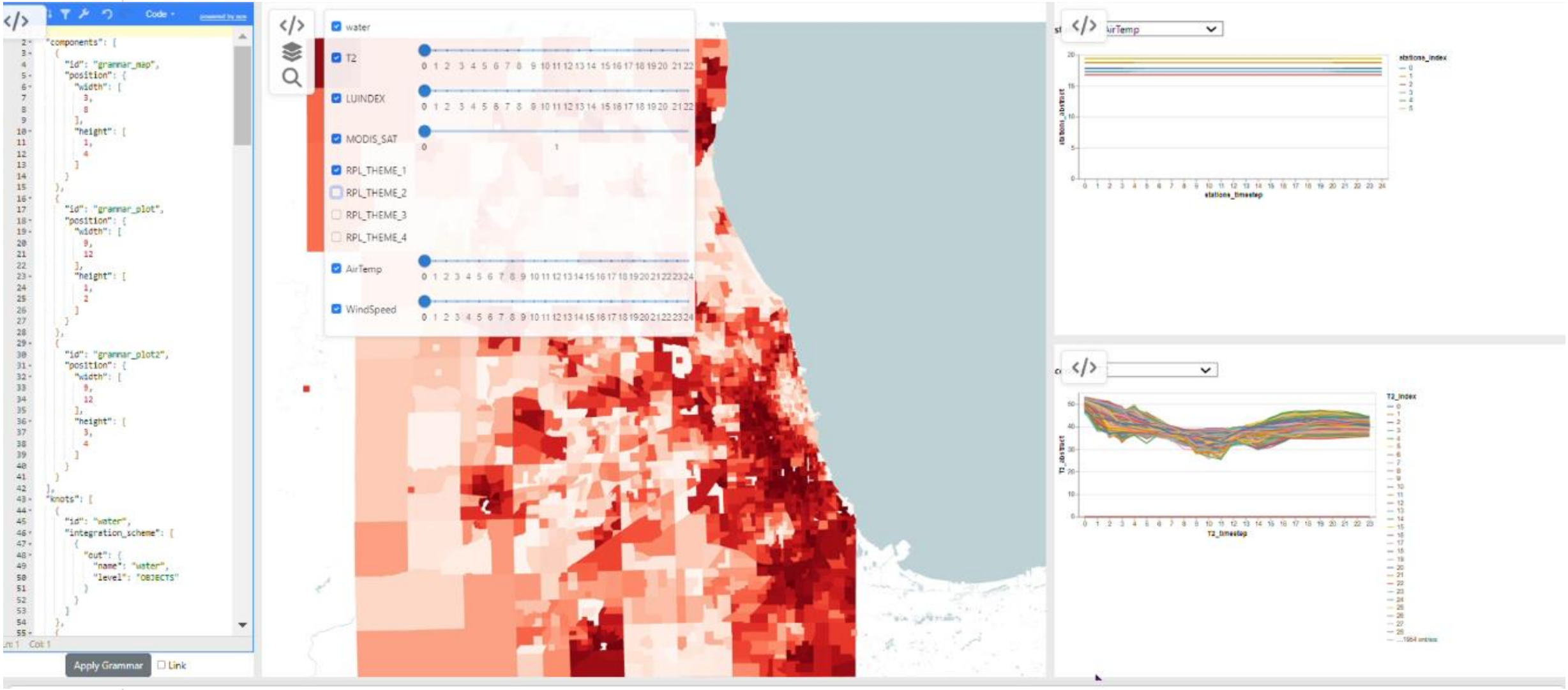
Example of interactivity (1)



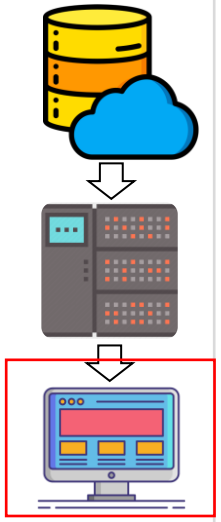




Example of interactivity (2)



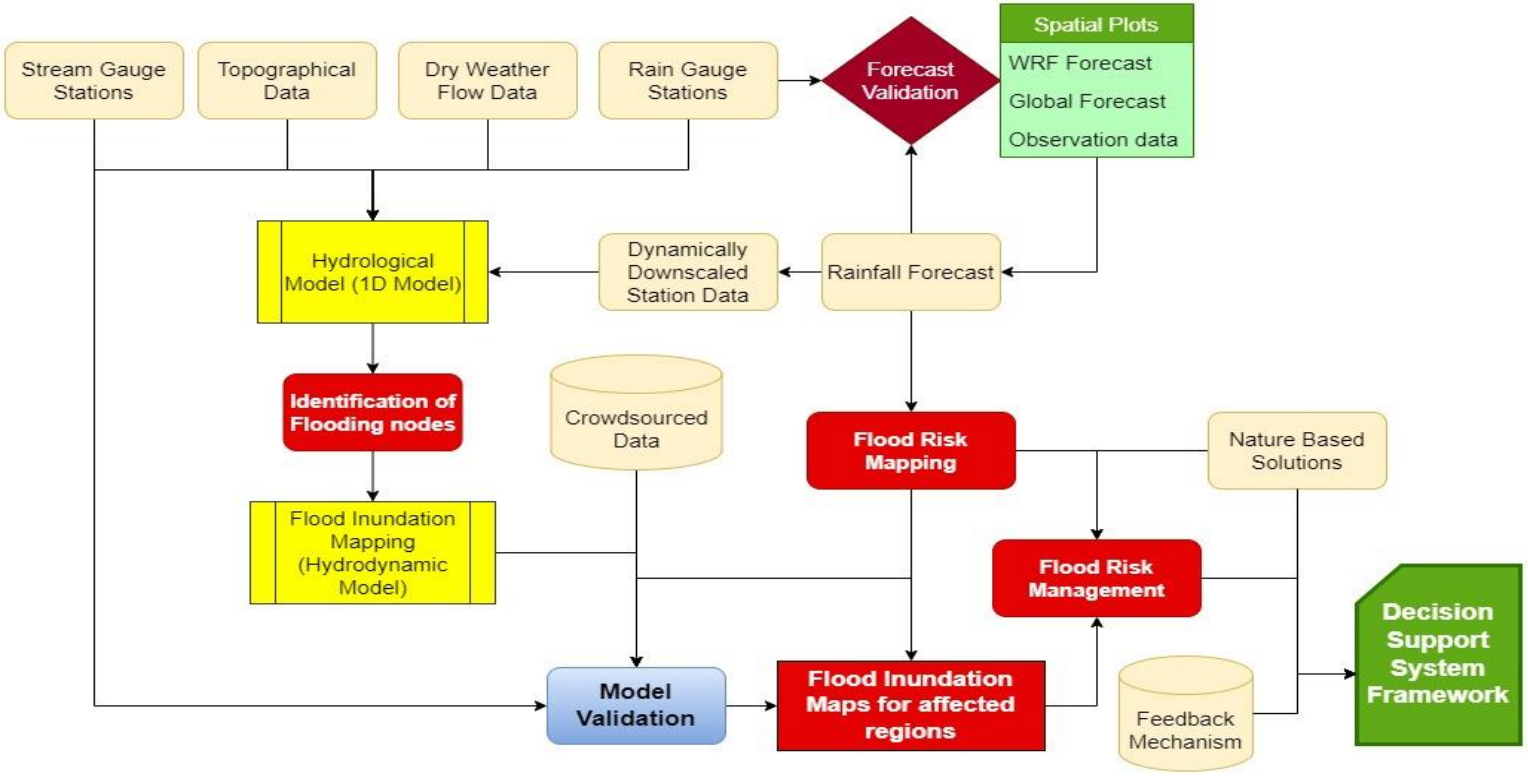
Near Real-time (NRT) Climate/weather products/tools



- Weather and Air Quality forecasting
  - 3 to 1 km regional scale
  - 250 m to 100 m to street-level forecasting (~m scales)
- Environmental justice (EJ) toolkit
- EJ toolkit + machine learning street-scale weather and air quality forecasting

Urban Flood Forecasting Model

- Develop a high-resolution coupled hydrodynamic model to visualize flood propagation, identifying fine-scale flooding scenarios.
- Decision support system for early warning flood forecast system
- Engineered and nature-based solutions to mitigate flooding in urban cities.

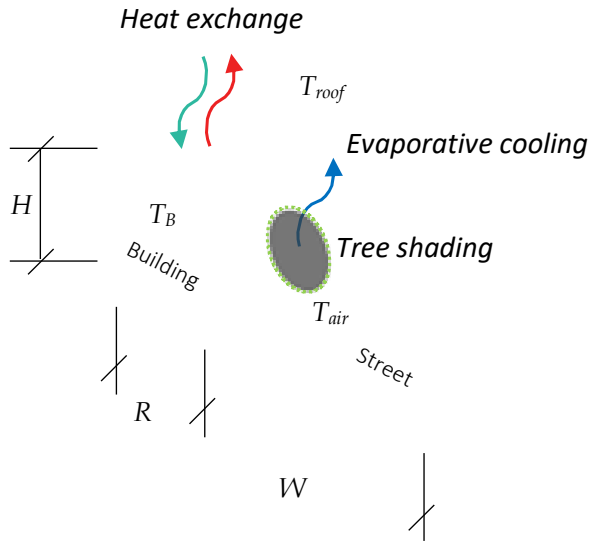


Early simulation of flood inundation maps – flood propagation in the Chicago Region

Few flagship projects!

Helping utilities plant trees and avoid grid failures

Modeling sketch



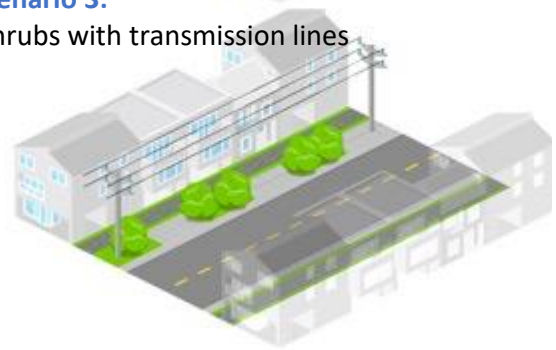
Metrics

- Cooling/heating degree days
- Heat mitigation efficiency
- PMV thermal comfort index

Scenario 1:
Two row
Densely vegetated

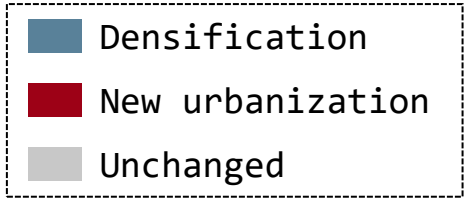
Scenario 2:
One row
Tall trees

Scenario 3:
Shrubs with transmission lines

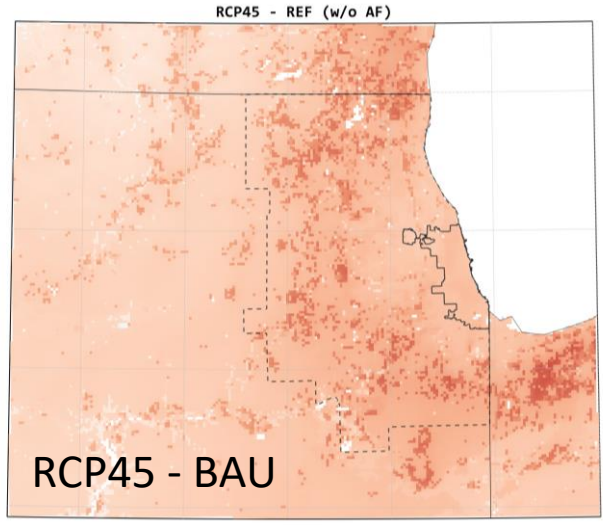


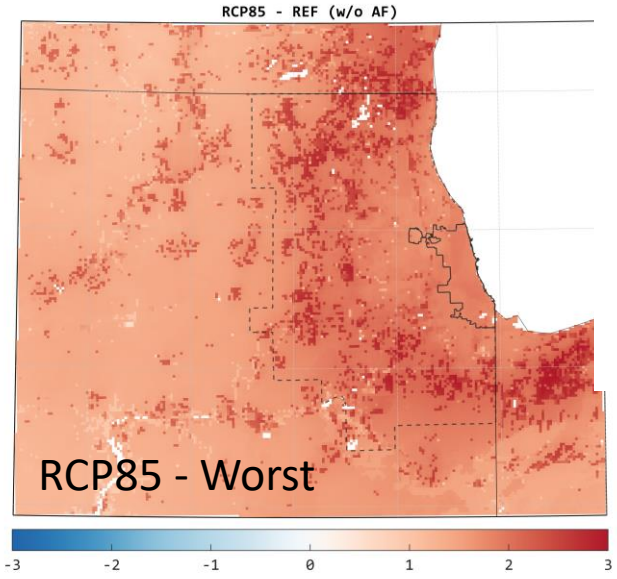
Year 2030 minus year 2020

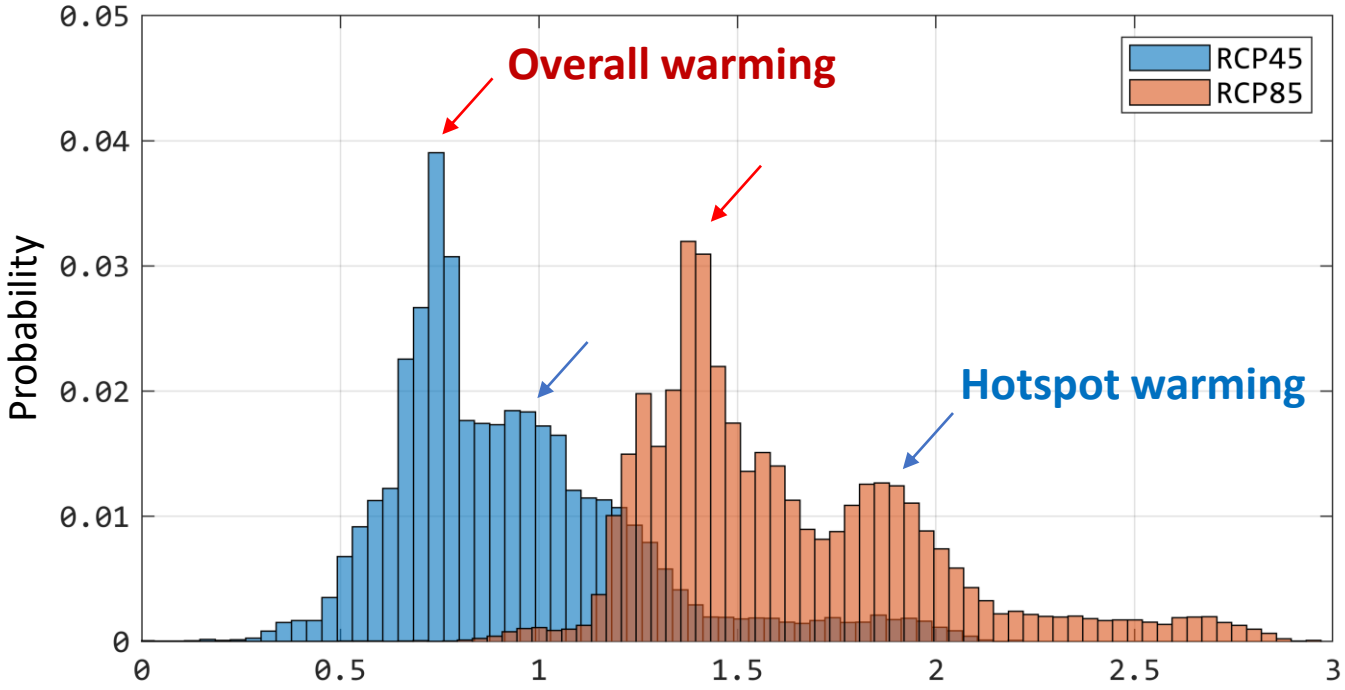
Development intensity



comed℠
AN EXELON COMPANY







- Afforestation will mitigate or offset hotspot warming.

Urban science is not just modeling **environmental topics and issues**

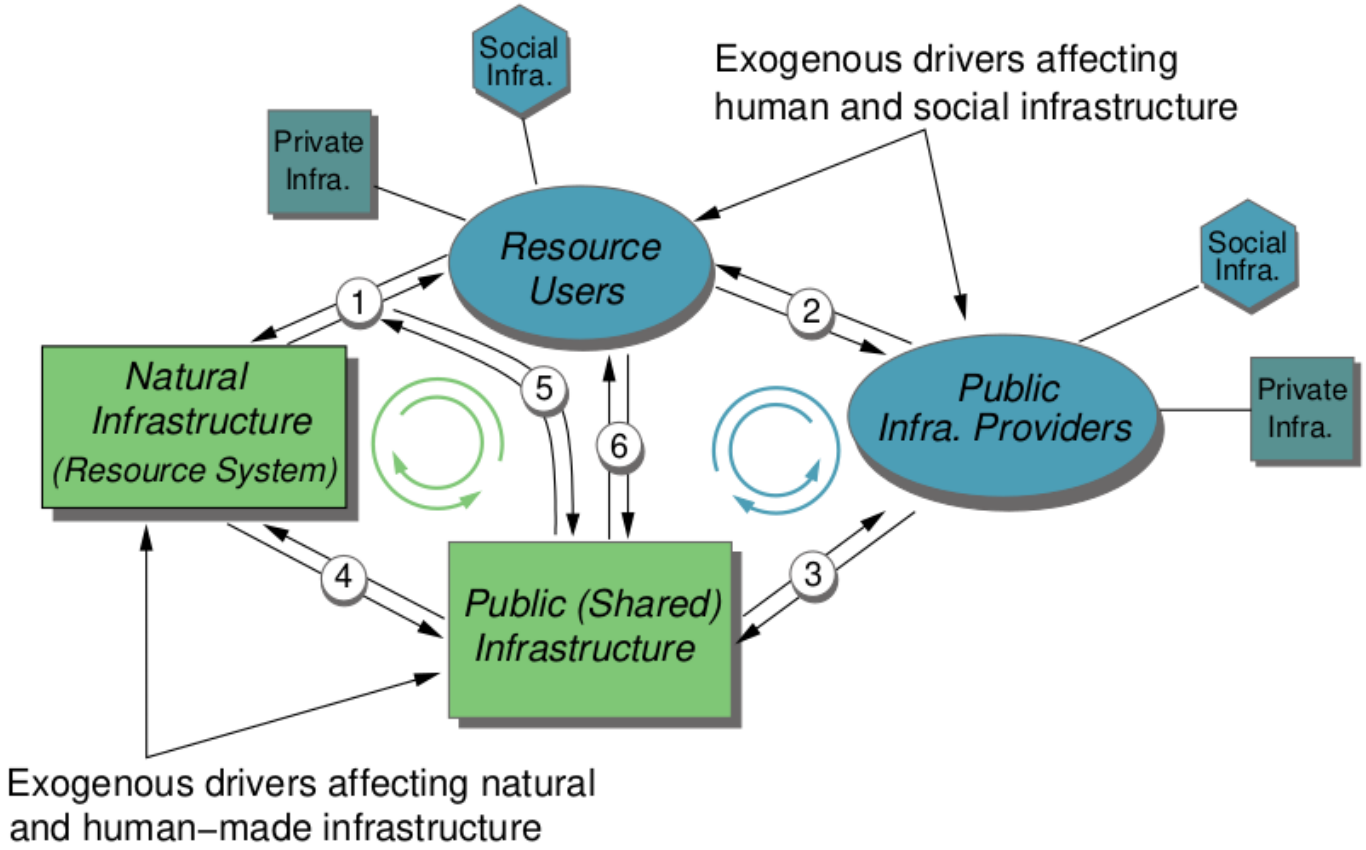
It is also about

other complexities related to societal & infrastructure issues.

We need to address them in an integrated fashion!

Let’s see few examples…

Urban Coupled Infrastructure System framework



RU: People who rely on the natural infrastructure to generate livelihoods and well being.

PIP: People who make decisions about how to allocate shared financial resources (e.g. taxes, user fees, etc.) to fund shared infrastructure

PI: Facilities and systems that are collectively owned that transform materials/information. *Hard:* Built environment, e.g. roads, dams, canals. *Soft:* Instituions (formal regulation), norms, legal structures, codified knowledge

NI: Abiotic+Biotic elements and their interactions create ecosystems that support populations of desired species, resource flows (e.g. water, air, minerals etc.).

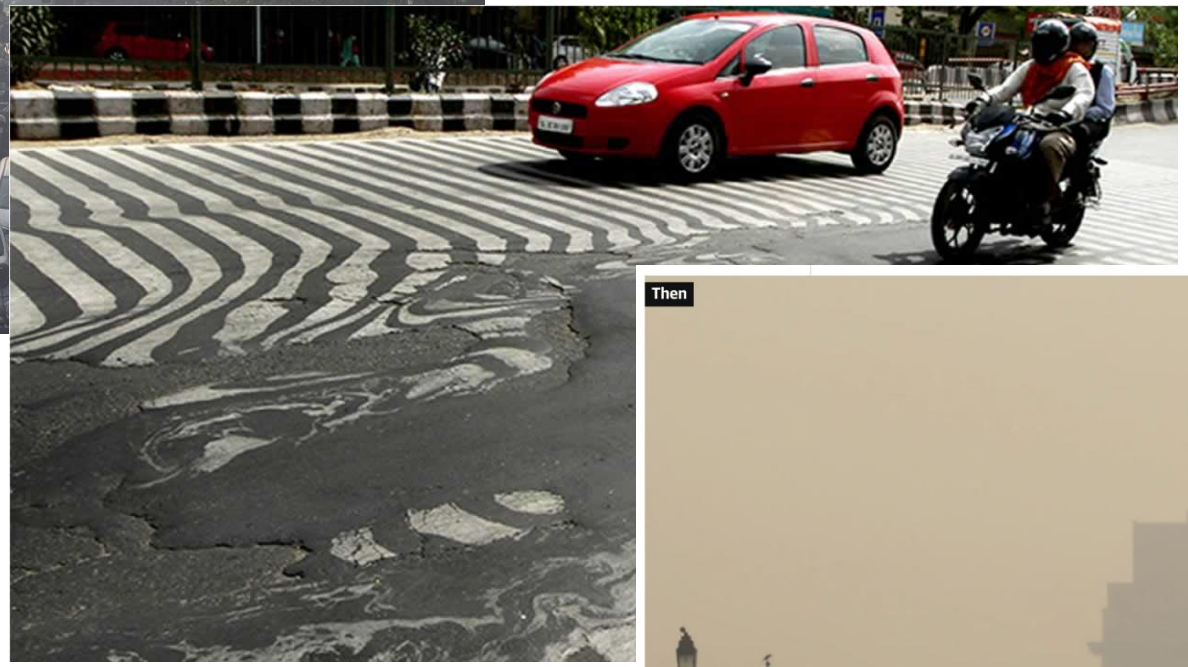
Working with interdisciplinary scientists…

NSF Partnerships for International Research and Education (PIRE)

How can decarbonizing the transportation sector make cities sustainable and resilient?

Traffic congestion

Heatwave

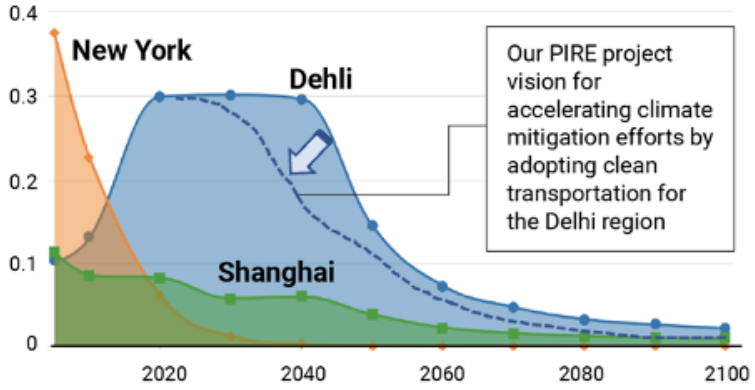


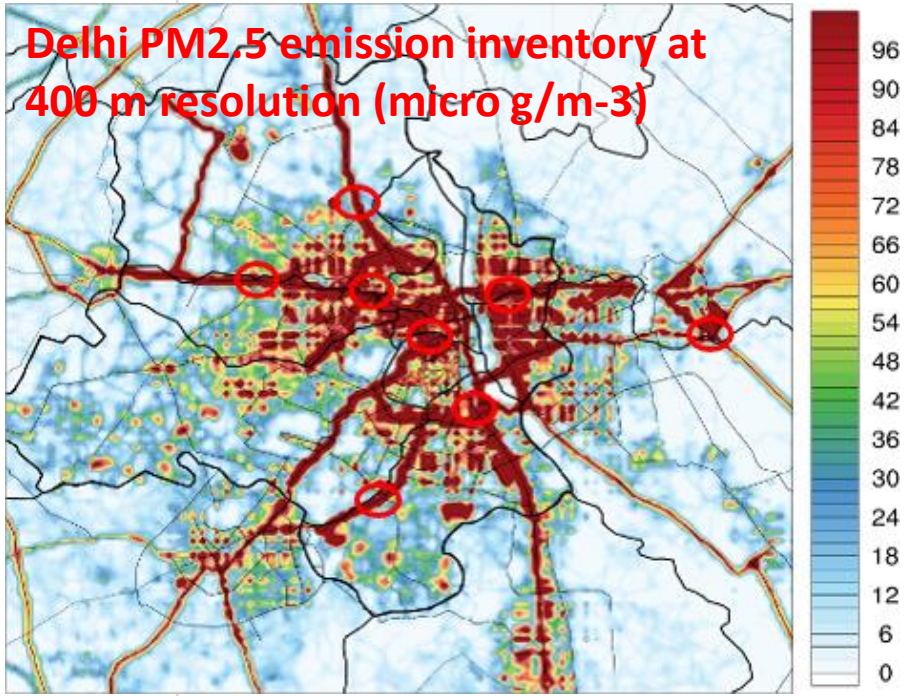
Air quality

Delhi, Bhuvneshwar, Pune as a testbed

Urban transportation CO emissions (yearly)

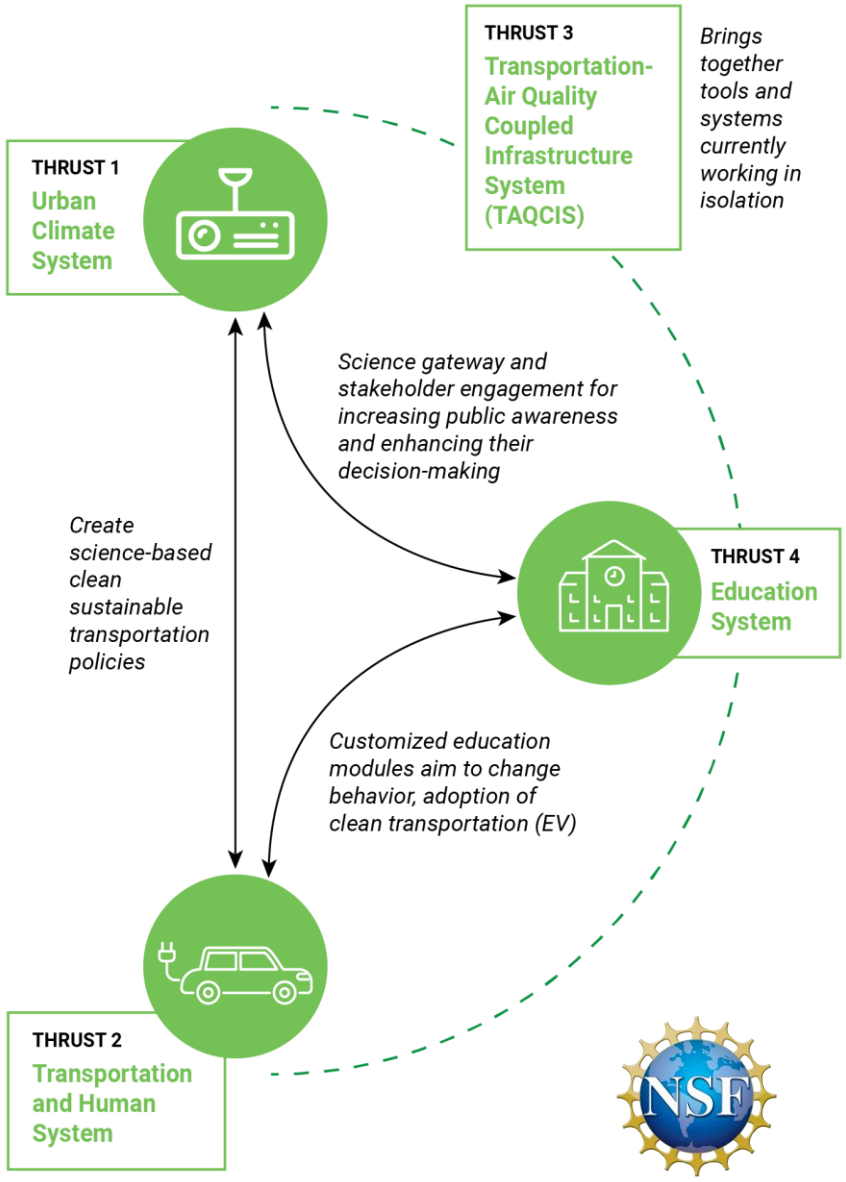
Carbon monoxide emissions for RCP8.5 in teragram (Tg) [b]





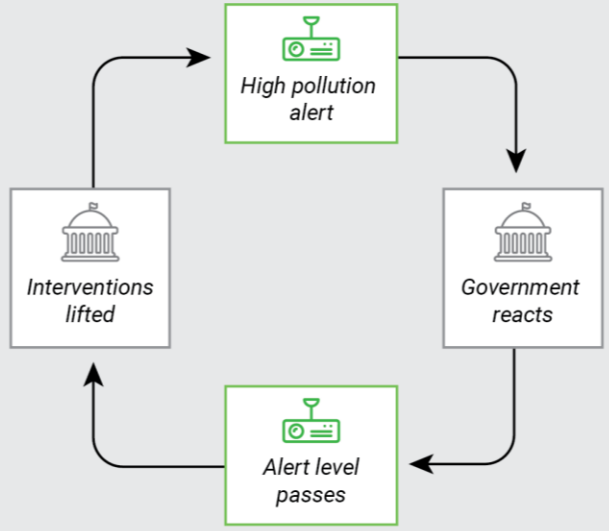
PIRE vision for Convergence Sustainable Urban Research

Accelerating clean transportation and mitigating climate change

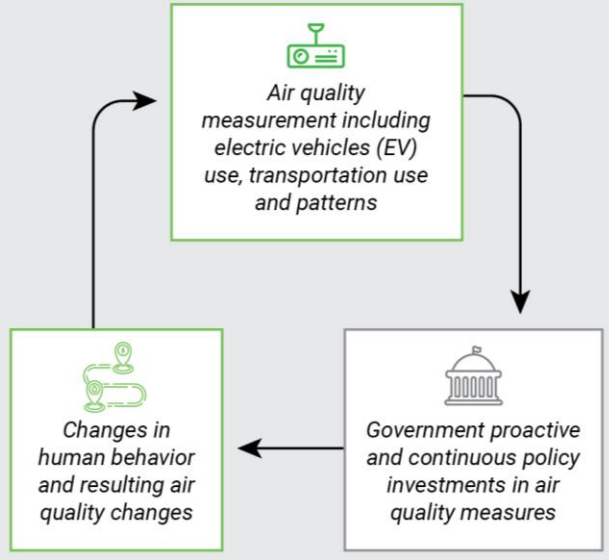


Current: Air quality management approach

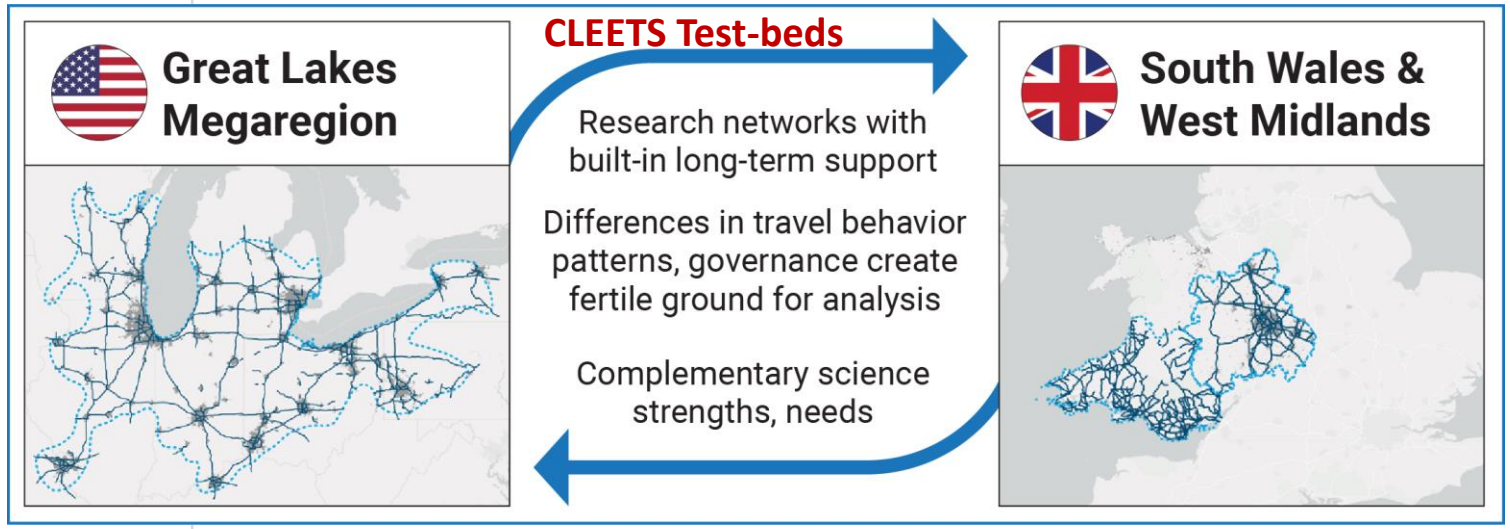
Graded Response Action Plan (GRAP)



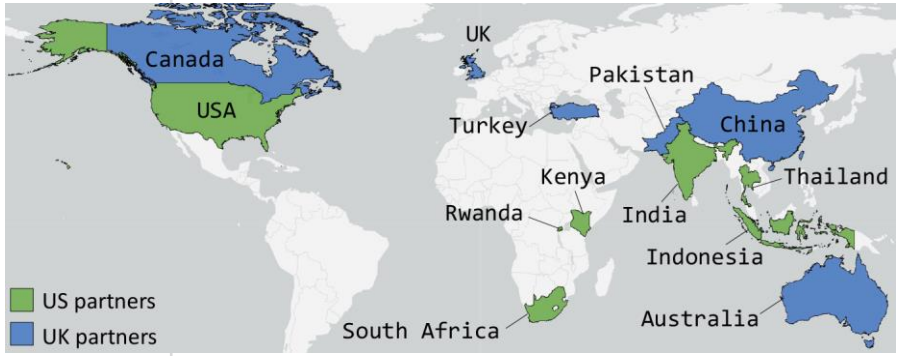
Proposed: PIRE-based proactive system



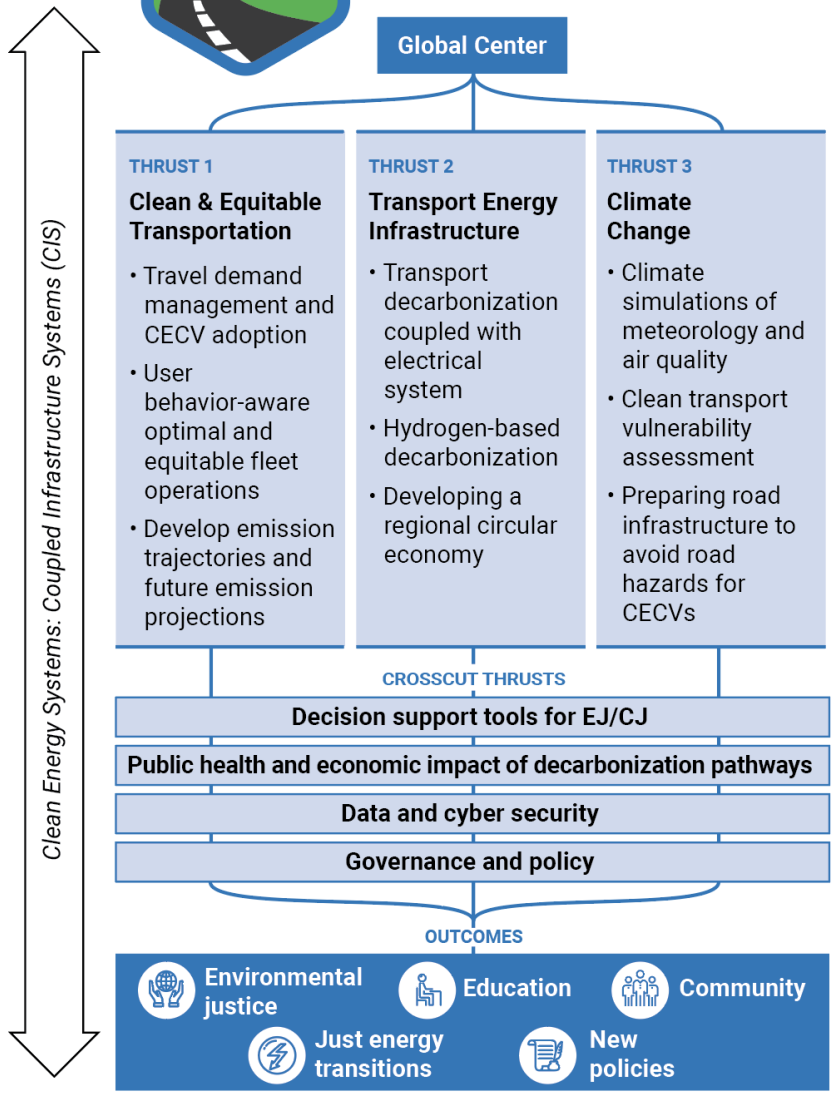
Clean Energy and Equitable Transportation Solutions (CLEETS) NSF-UKRI Global Center



CLEETS potential to scale with partners



For more information, visit:
https://www.cleets-global-center.org/
@CleetsGlobal and @DPI_Climate

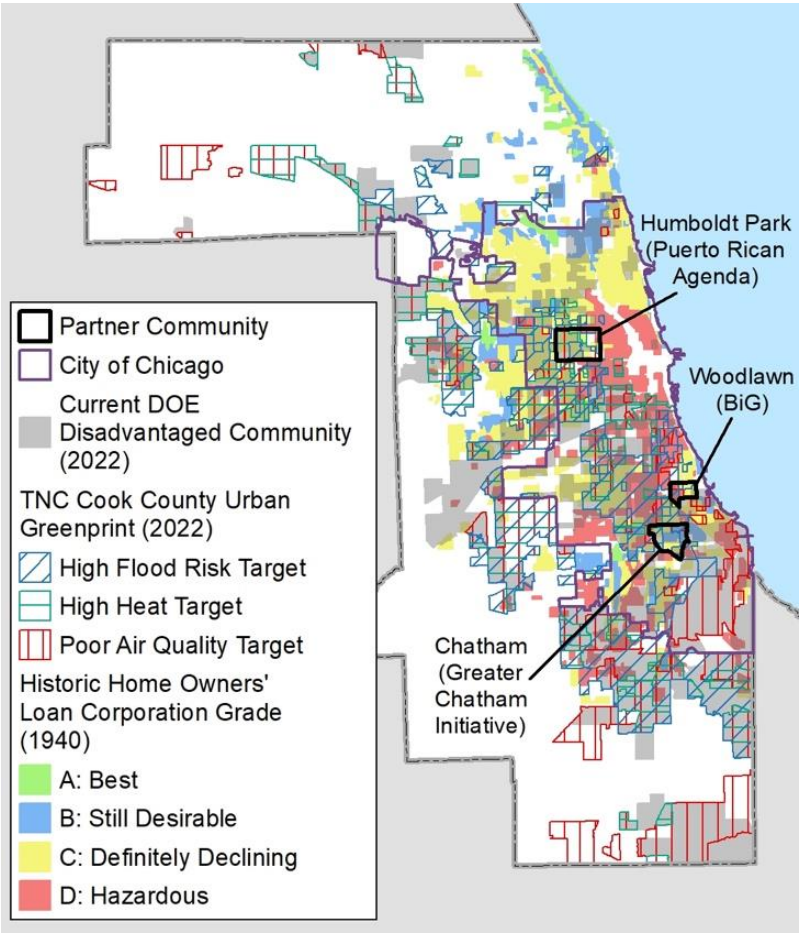


DOE Office of Science: urban integrated field laboratory

CROCUS
Community Research on Climate & Urban Science

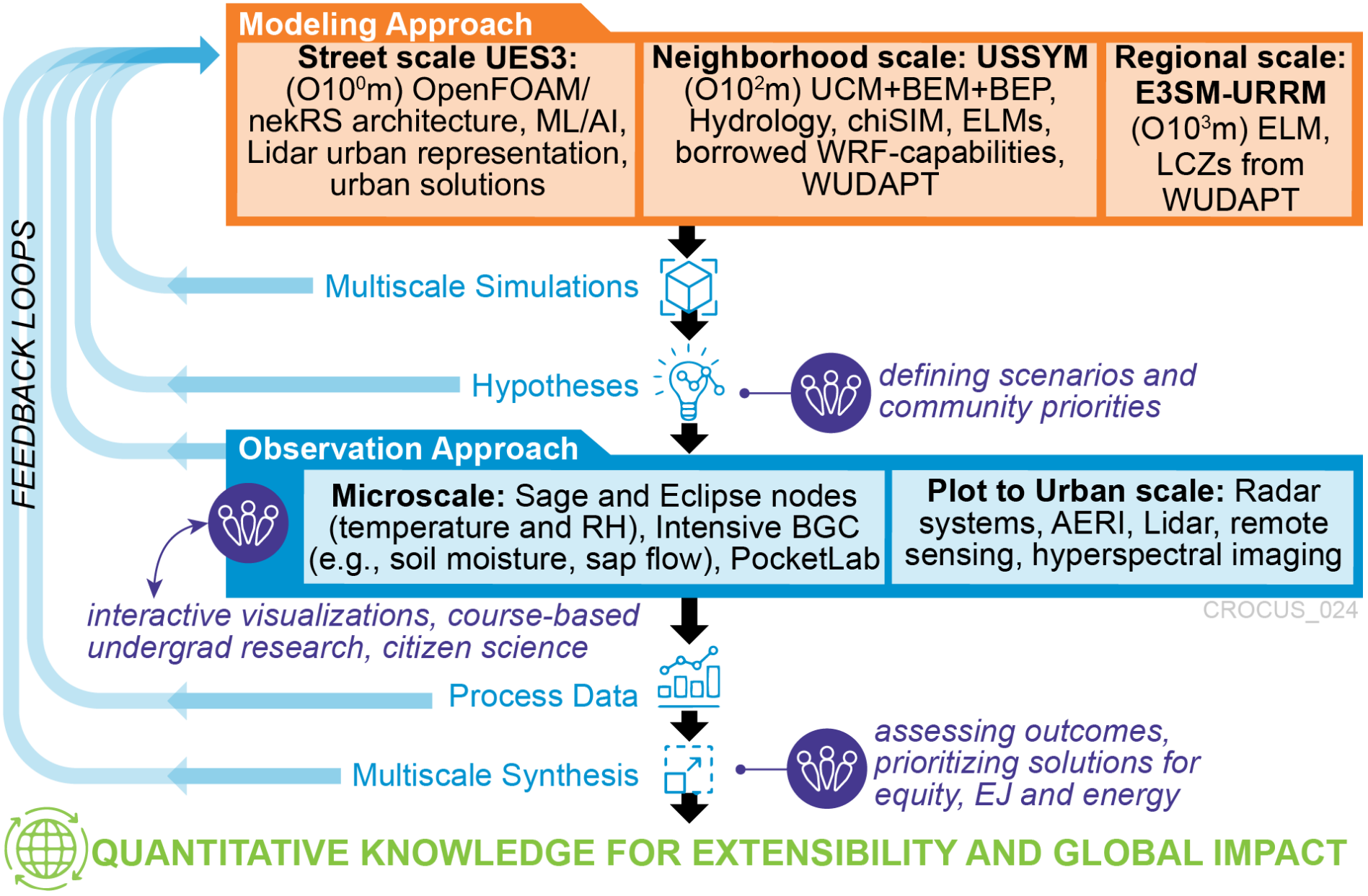
https://www.anl.gov/crocus

- Led by Argonne, with 12 academic and 4 community partners
- 16-County wide study region around Chicago, in three states
- Results specific to the region plus methods that can be used elsewhere
- $25 million over five years

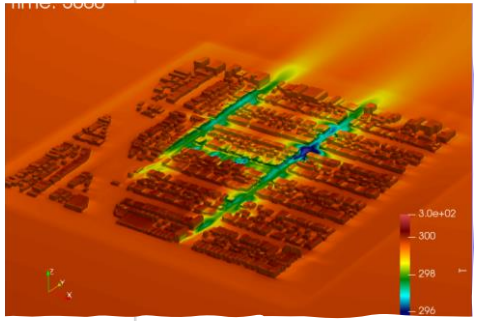


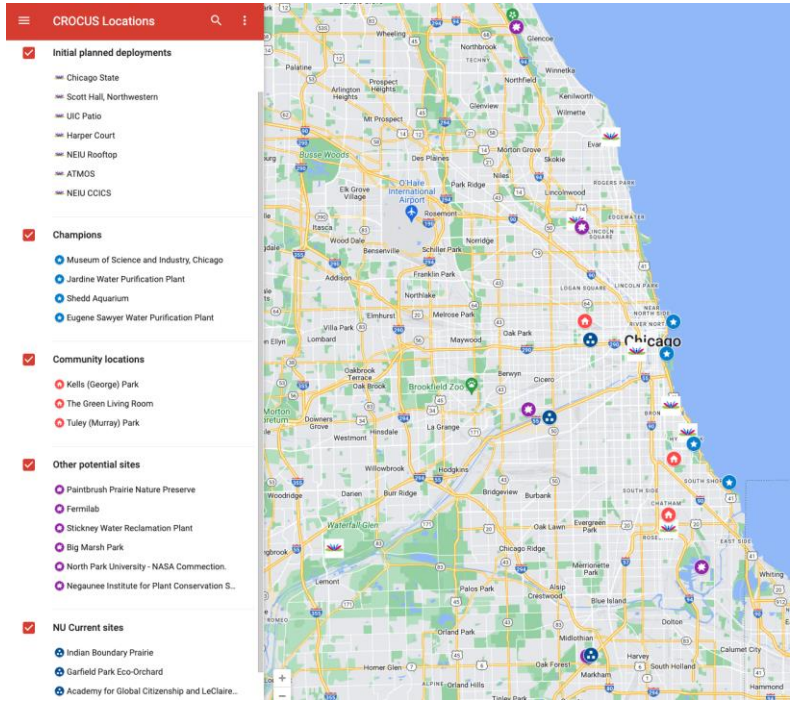
Climate Science Through the Lens of Community

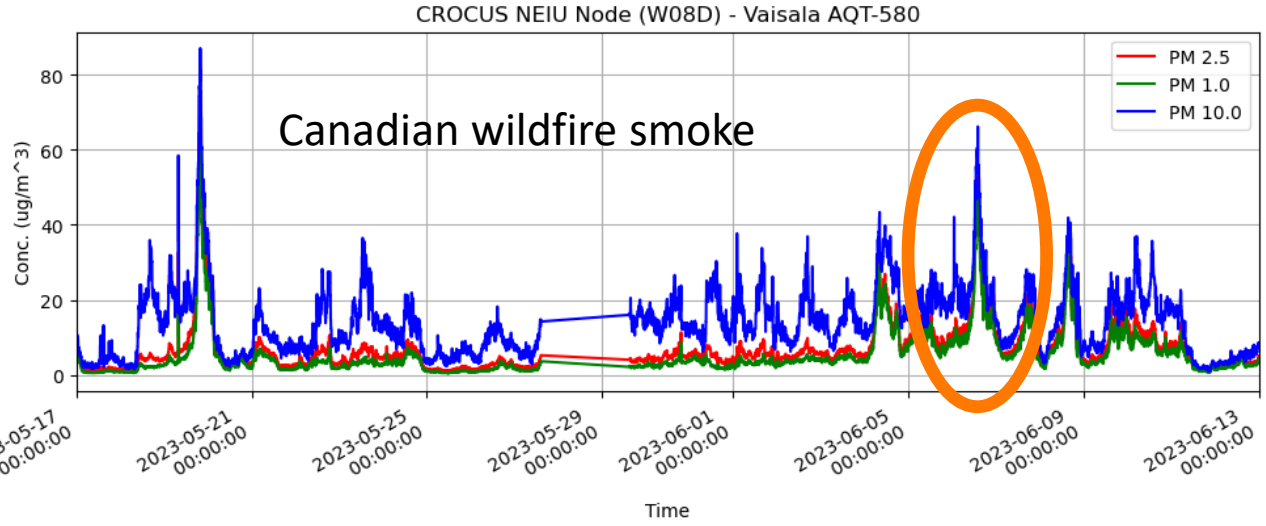
Addressing Scales in modeling and observations



CROCUS Deployment







Takeaways:

Making cities and communities resilient!!!

Fundamental → Applied → Translational → Collaborative research

- Climate change impacts are **disproportional** in cities.
- **Bridge scale gaps**: regional <—> local <—> hyper-local
- Design tools for **specific science questions** and research needs.
- One solution can't fit all → Need a **mix of solutions**.
- Multi-disciplinary and multi-stakeholder engagements for **actionable research-based**, cost-effective, sustainable solutions.

Thank you!

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Twitter: @A_Sharma007; @DPI_Climate

https://www.climate-dpi.org/