Elucidating Urban Geomorphological Drivers of Heat Islands Using a Geographically Weighted Random Forest Framework

Orhun Aydin, PhD

Assistant Professor. Earth, Environmental and Geospatial Science

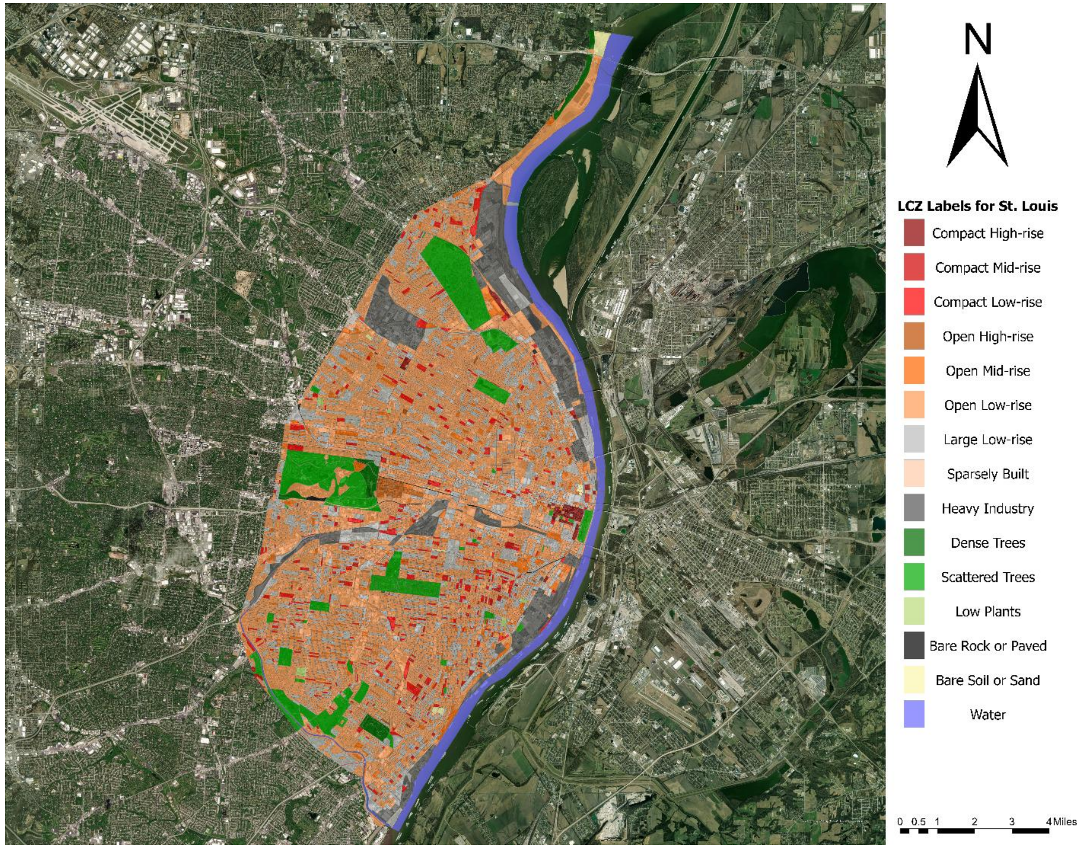
Assistant Professor. Computer Science

Director, ADAPT-STL

What is ADAPT-STL?

- Department of Energy-funded Resilience Center at SLU
- Regional hub of scientific and operational research to mitigate
  - Urban Heat Islands
  - Urban Flooding
- Interface between research, implementation, and community

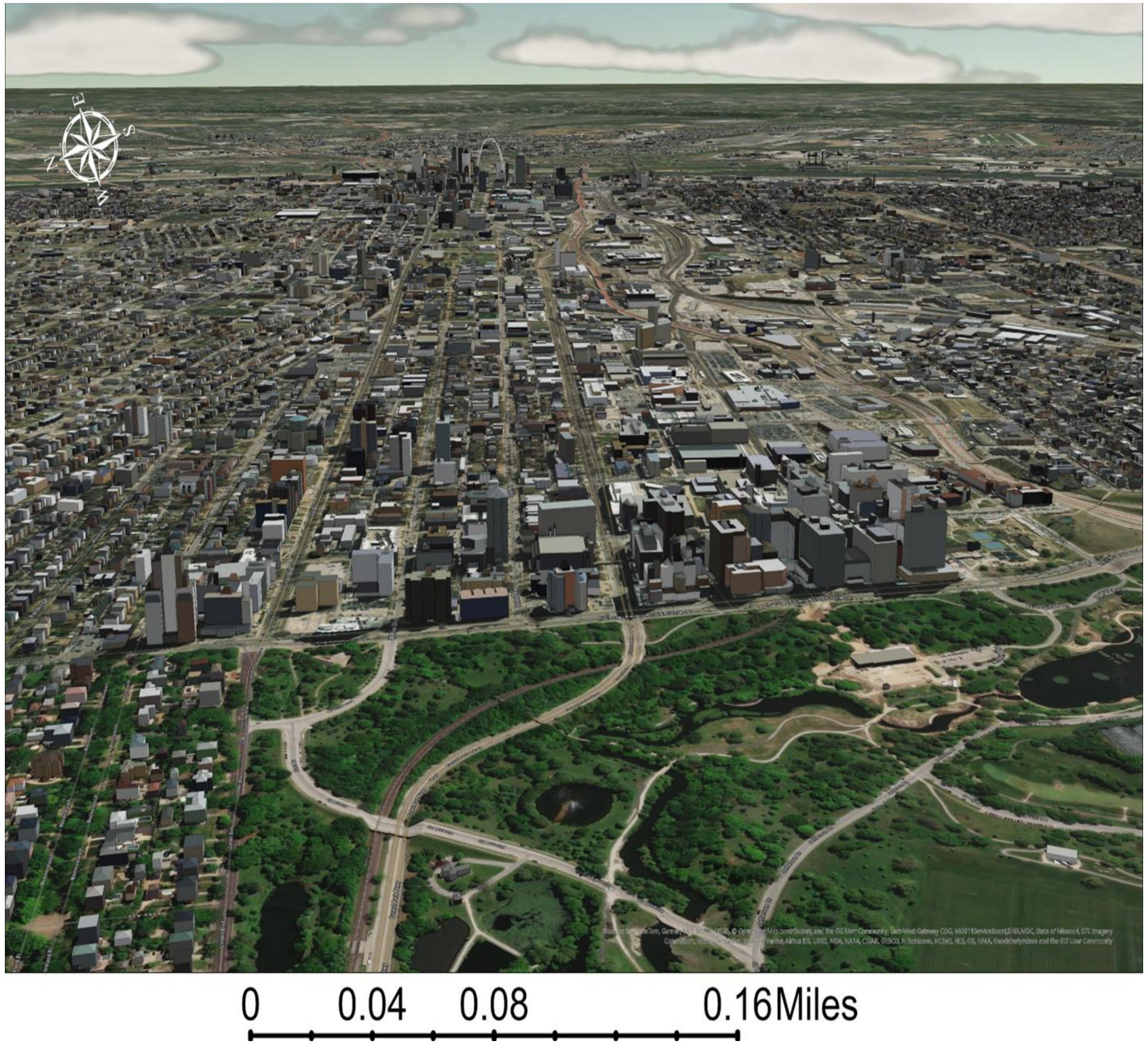
Research Questions



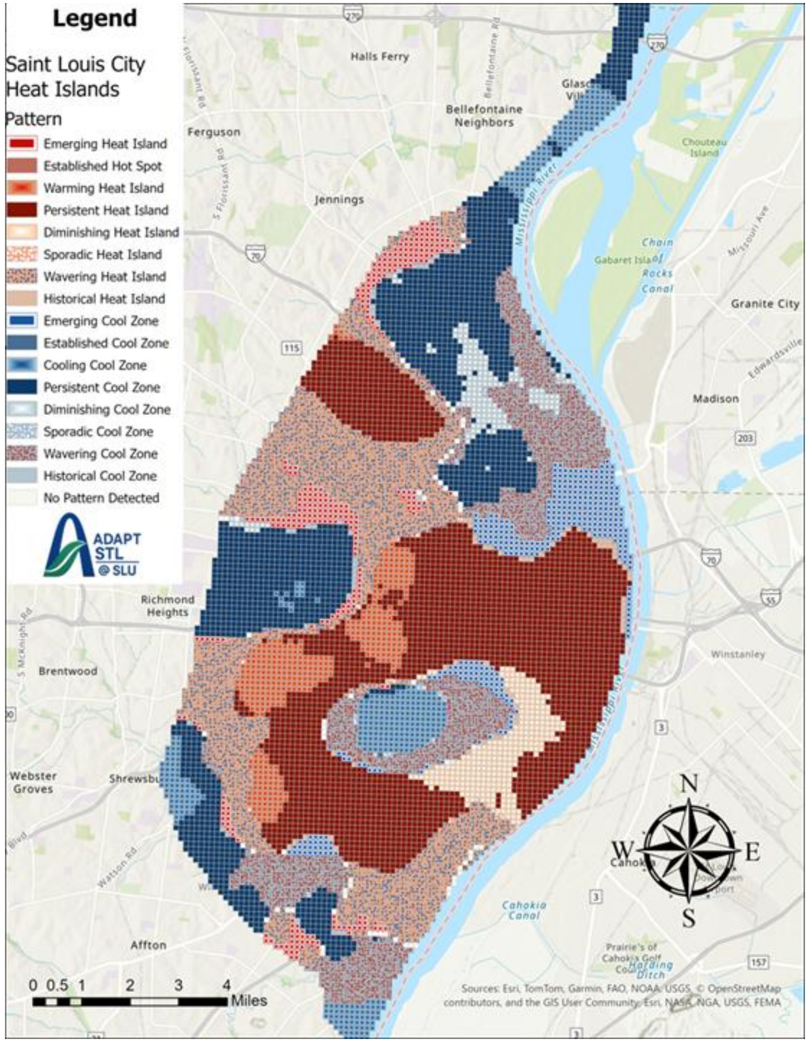
- What are the urban morphological drivers of urban heat in Saint Louis, MO?
- Which built environment factors are
  - Modulating factors
  - Direct control factors

Data Sources

- Landsat 8 Collection 2 Level-2 imagery at 30-meter resolution
- 8,020 individual census blocks, acquired from the U.S. Census Bureau.
- An Urban Digital Twin is built using a 2022 Aerial LiDAR Survey to define:
  - Any structure larger than 10 sq-ft footprint
  - All trees in the city
- Digital elevation model (DEM) was obtained from the U.S. Geological Survey (USGS).



Spatio-temporal Patterns of LST 2015-2025



- Large parks and their surrounding are getting cooler over the city average
- Lack of shade causing new temperature peaks outside of greenspaces
- A persistently warm area is forming

Target Variable

- We define the z-score of the G_i^*, statistic as the target

$$G_i^* = \frac{\sum_{j=1}^{n} w_{i,j} x_j - \bar{X} \sum_{j=1}^{n} w_{i,j}}{S \sqrt{\frac{n}{n-1} \sum_{j=1}^{n} w_i^2 - \left(\sum_{j=1}^{n} w_{i,j}\right)^2}}$$

$w_{i,j}$: Geographic weight

x_j: Block-level average temperature

$\bar{X}$: Citywide average temperature

S: Standard deviation of average temperature

n: Number of blocks

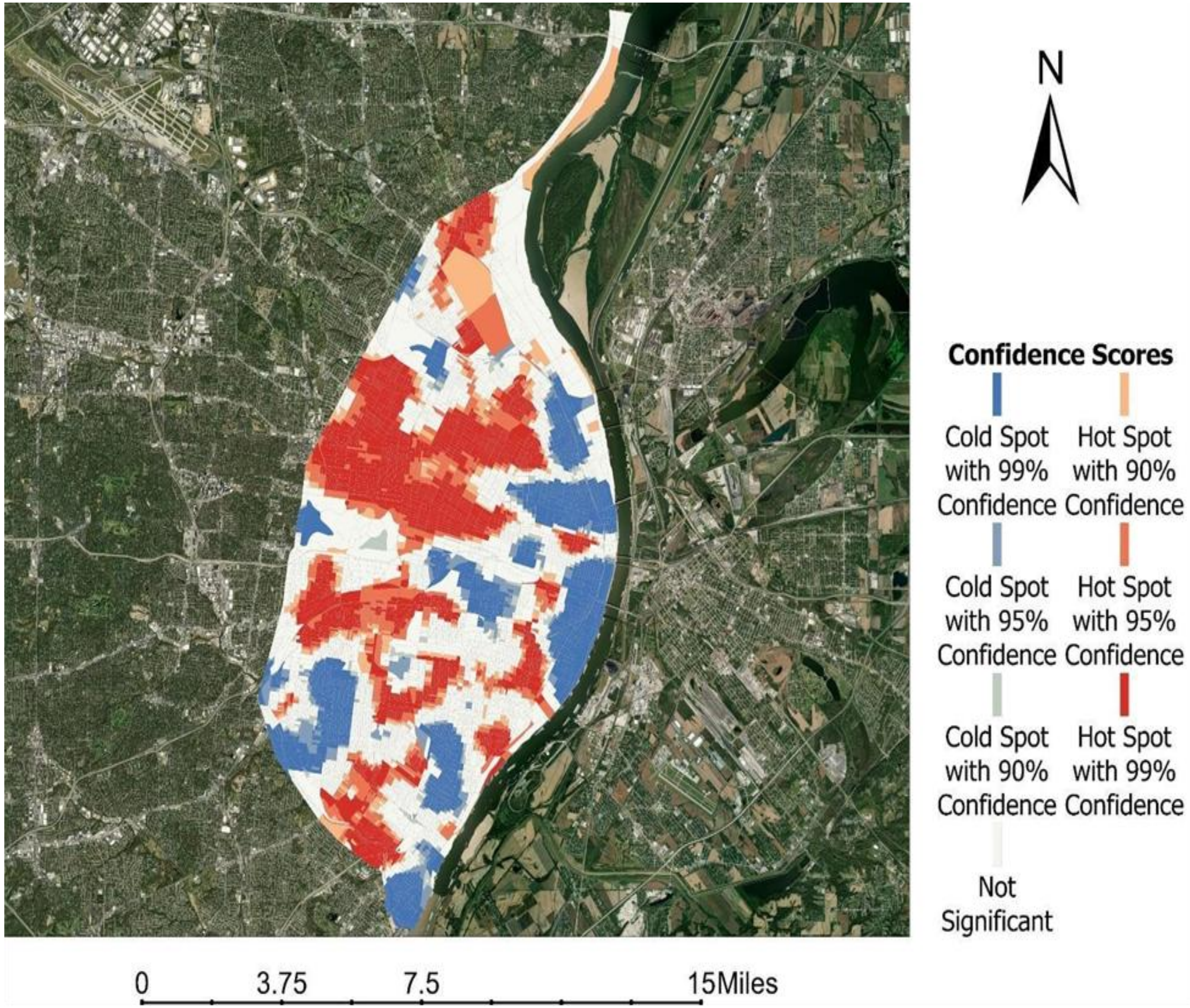


Fig. 1. Hot spot map of St. Louis.

ADAPT STL @ SLU

ADAPT-STL

Geomorphology Variables

Variable	Description
BLDGHEIGHT	Building heights within each census block
EAVEHEIGHT	Building eave heights within each census block
ROOFDIR	Rooftop direction in degrees. Mode value per census block
NEAR_DIST	Buildings distances to the nearest greenspace
SVF	Building's sky view factor per census block
Shape_Length_Build	Building lengths per census block
Shape_Area_Build	Building areas per census block
BlockType	Mode value of each census block type
RoofForm	Rooftop direction in degrees. Mode value per census block

Regression Model Comparison

- Geographically-weighted (GW) models outperform global models
- Top models are GW CART models, GWBRF and GWRF
- Out of sample accuracy for MGWR is low

Model	Training Score	Testing Score
MGWR	• R^2 = 99.06%	• R^2 = 78.1%
Forest-based regression	• R^2 = 74.4%	• R^2 = 16.3%
Boosted random forest regression	• R^2 = 84.2%	• R^2 = 9.1%
GWBRF	• R^2 = 99.67%	• R^2 = 96.1%
GWRF	• R^2 = 99.66%	• R^2 = 97.0%
OLS	• R^2 = -4.42%	• R^2 = 6.65%

GW Random Forest
(Georganos et al., 2018)

Models Standardized Residual Patterns

- Global nonlinear models, such as RF, show extensive clusters of negative residuals.
- Overall spatial residual is low with insignificant clustering (wrt. Moran's I)
- Global models have strong spatial bias

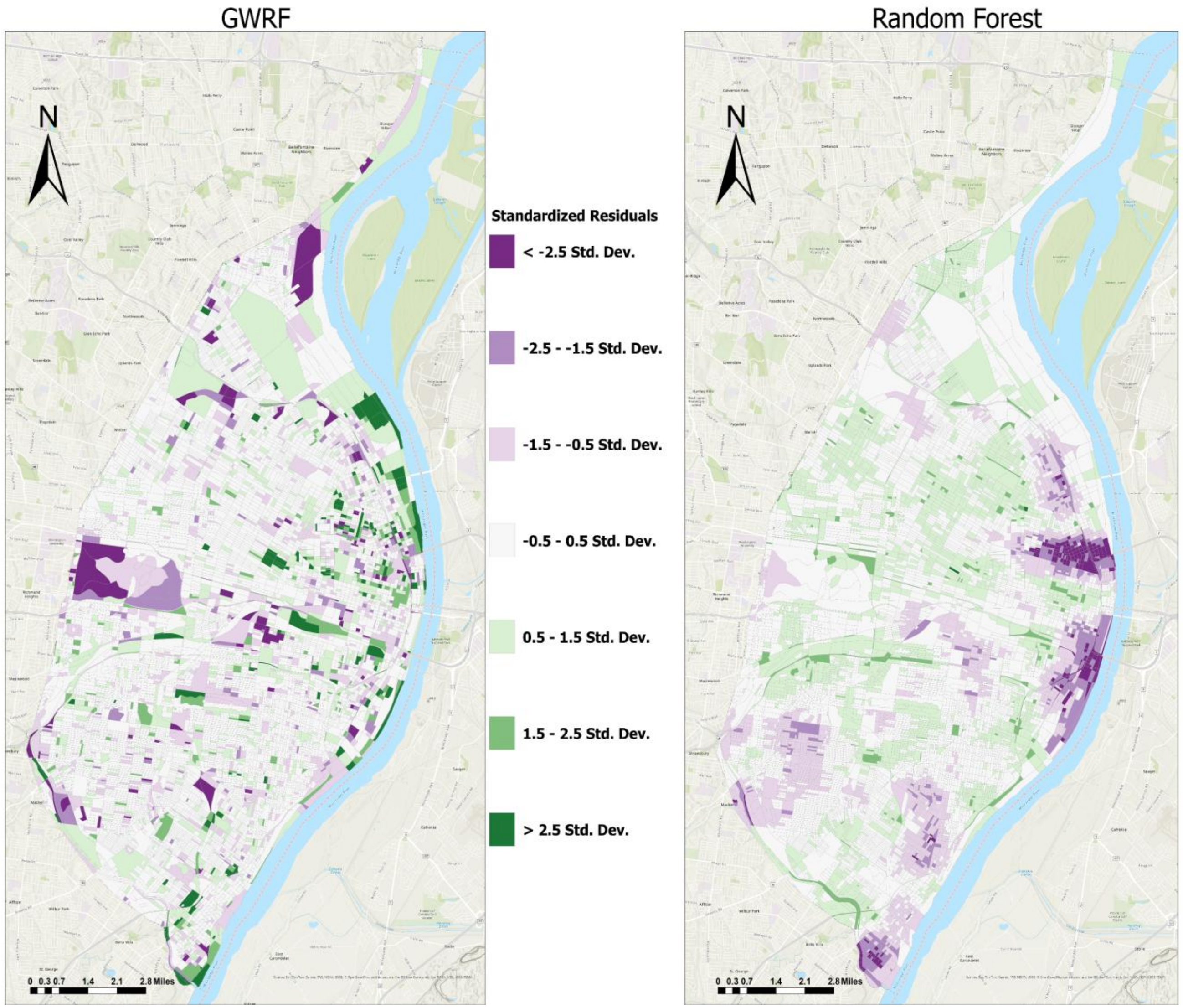


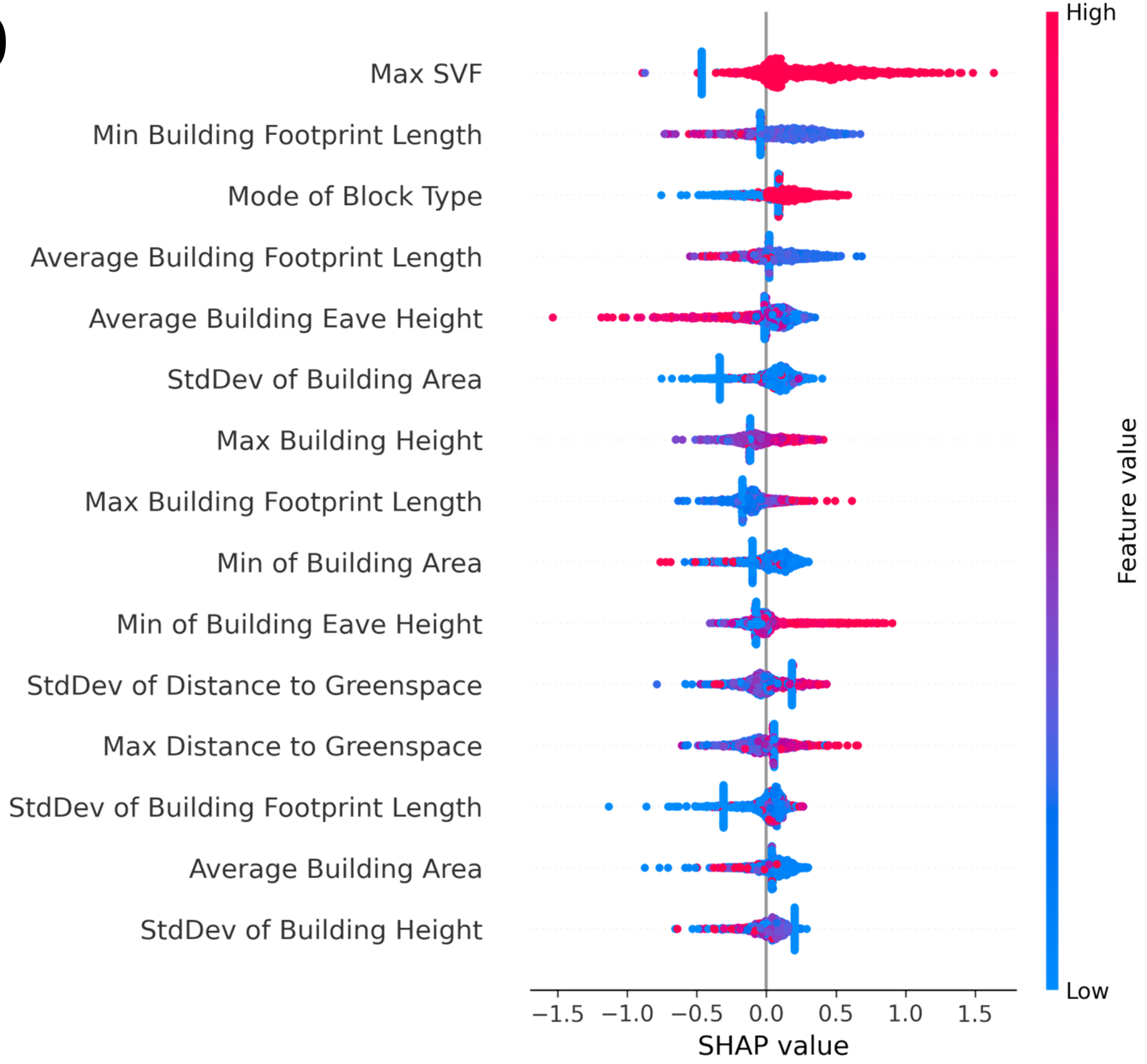
Fig. 6. Global RF vs Local GWRF Residuals

ADAPT STL @ SLU

ADAPT-STL

Urban Controls on Temp

- Sky View Factor (shade metric) has a direct impact
  - SVF increase maximum temps
- Buildings have a complex control on temperature
- Greenspace is important as a modulating variable

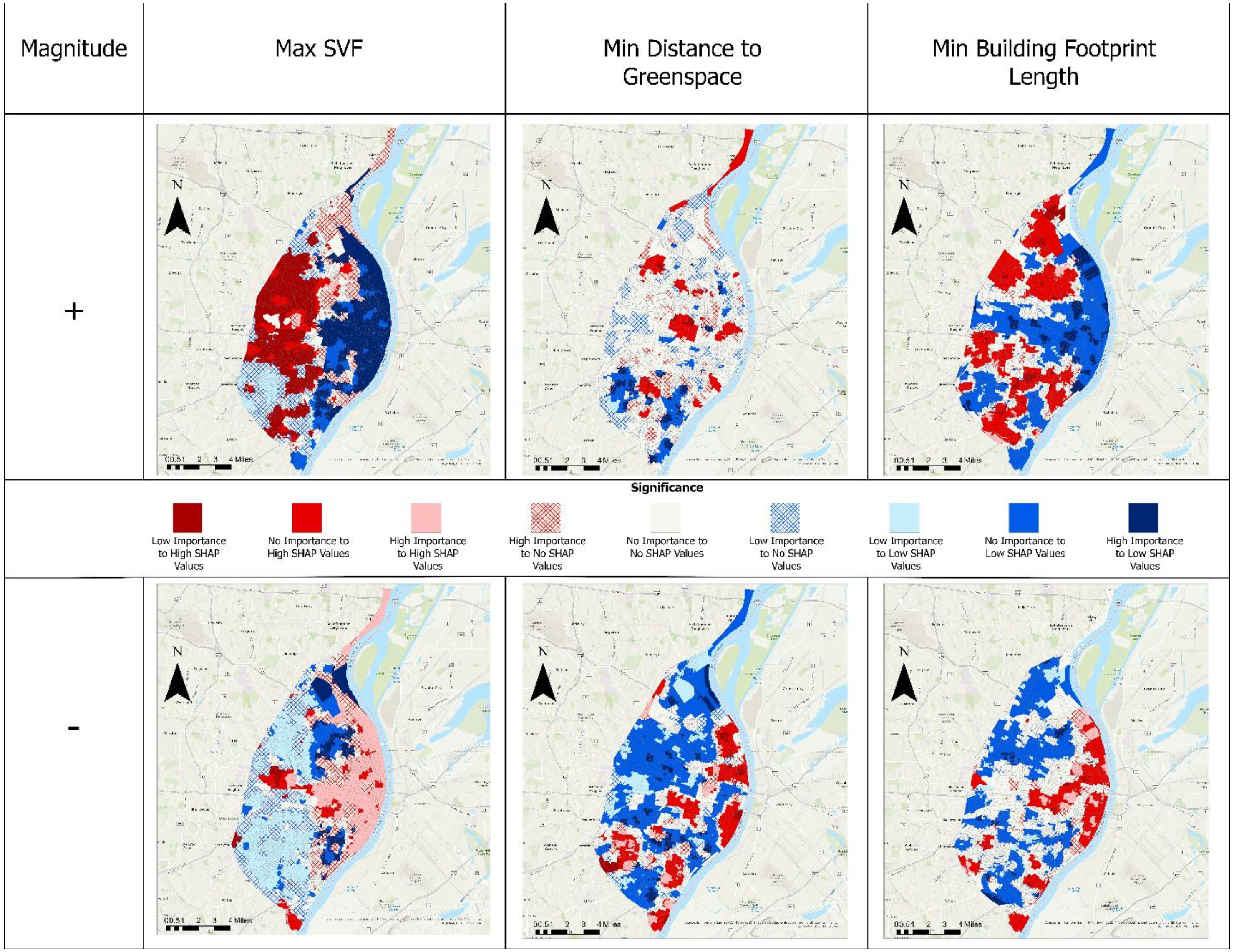


ADAPT STL @ SLU

ADAPT-STL

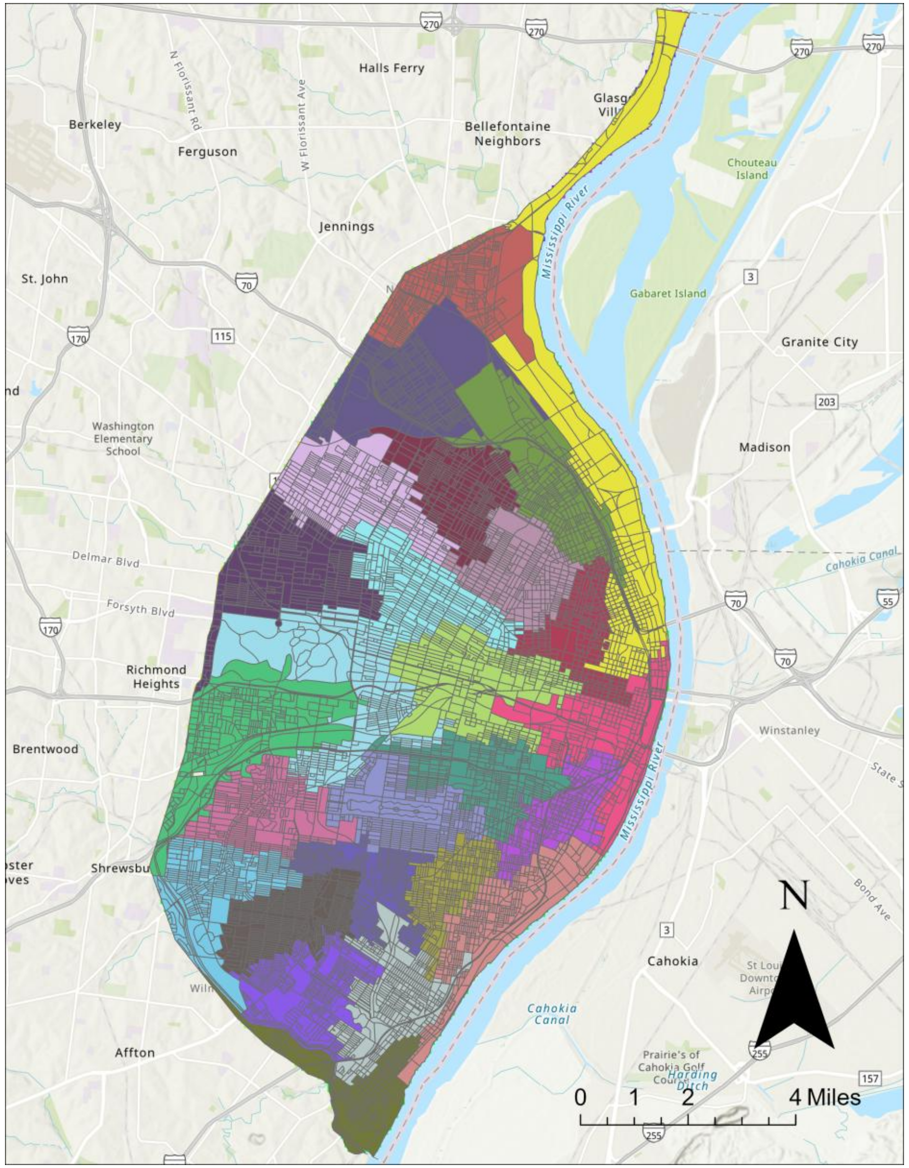
GeoSHAP Profiles

- Built environment factors such as SVF and the length of building footprints, have significant contributions to excessive heat within neighborhoods north and south of Forest Park.
- SHAP maps confirm that drivers of UHI/UCI are spatially heterogenous, which supports the use of geographically weighted machine learning models.



Spatial Jacknifing for LOOCV

- R2 values range between 0.21-0.92
  - Average R2 is 0.86
- Lowest R2 are obtained downtown with clustered high-rises
- High R2 for
  - Mixed housing
  - Zones with greenspaces
  - Low and mid-rise houses



Balanced Zone Building
(Gu and Aydin, 2021)

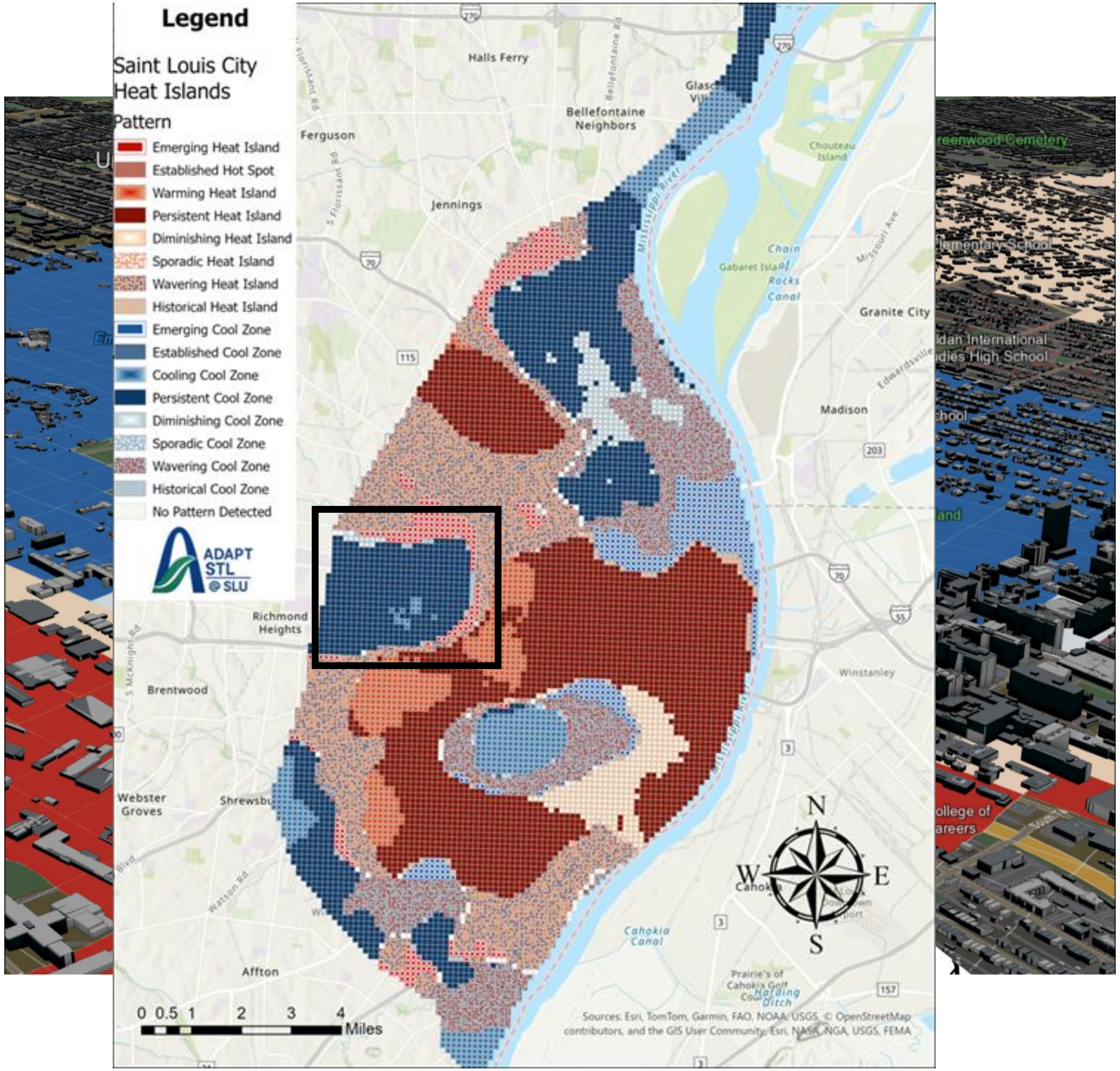
ADAPT-STL

Greenspace Modulation

- Urban morphology around a greenspace determines its heat reduction benefit

- Tall and dense buildings reduce the cooling intensity and extent

- Scatter shorter buildings promote a wider cooling area

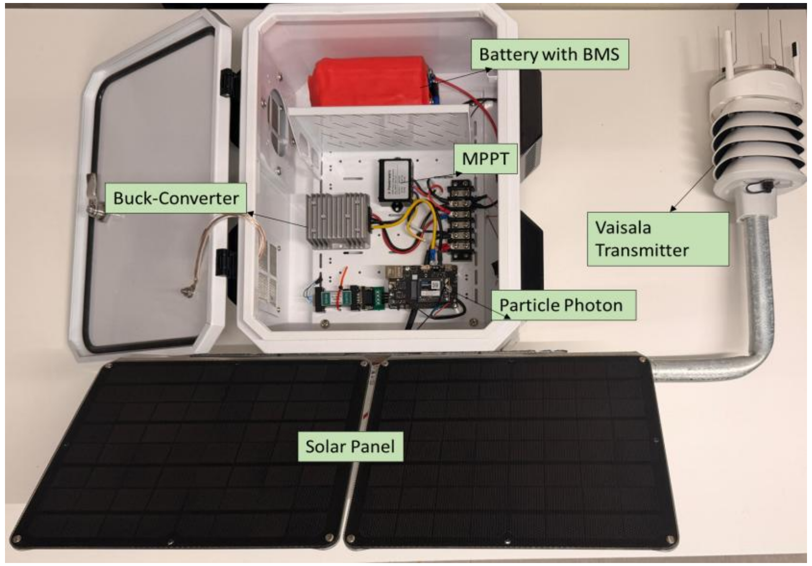


ADAPT-STL

Conclusions

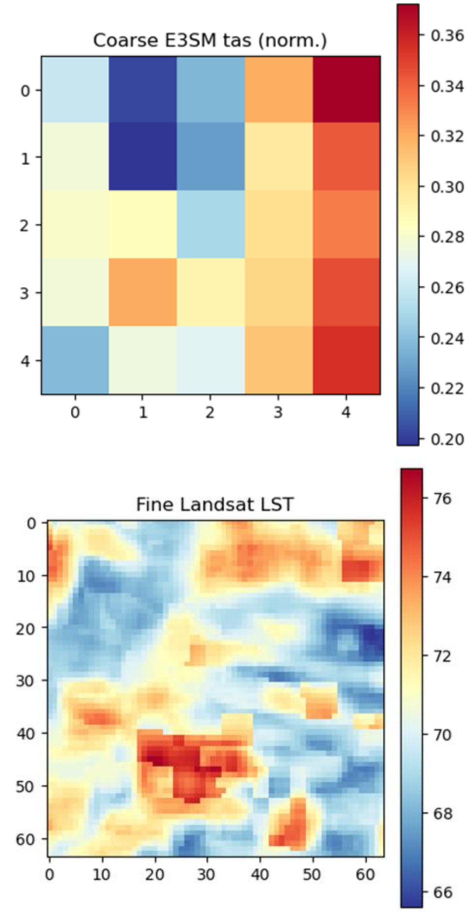
- Building height has a direct impact on urban heat islands
  - East part of the city, contiguous shade from downtown reduces heat proximally
- Greenspace distance is a modulating variable
  - Location of greenspaces modulate the impact of building footprint Large and tall buildings diminish the cooling effect of greenspaces
- In UHI modeling randomized R2 overinflate accuracy
  - GWRF R2 was 0.9966
  - Spatial jacknifing resulted in R2 between 0.21-0.92

Ongoing Work



Hybrid weather station network of 300 in Saint Louis City (66 sq-mi)

Diurnal thermal profile mapping with fixed-wing drone



Physics-Based Generative Temperature Modeling

AGU Session – AI for Methane

GC014 - AI for Methane: Physics-Informed and Data-Driven Approaches to Emissions Modelling across Natural and Anthropogenic Systems

Submit an Abstract to this Session

Deadline: August 4th, 2026

Methane is a potent greenhouse gas source attribution and emission quantification of which are critical to address managing natural and anthropogenic emissions. Substantial emissions arise from natural sources such as wetlands, thawing permafrost, gas hydrates, and various other large and diffuse areal sources. Methane is emitted from anthropogenic sources, including landfills and wastewater treatment facilities, and agricultural and industrial activities that are high-rate point sources. The convergence of multi-scale data sources and advances in data-driven methods provides a unique opportunity for using artificial intelligence for methane emission detection, quantification, and forecasting. Topics include, but are not limited to:

- Remote sensing of methane emissions (including hyperspectral imaging)
- Geospatial AI methods for source identification and characterization
- Physics-informed AI methods for hybrid methane modelling
- Anthropogenic methane emission quantification
- Natural methane emission quantification
- Seasonal and spatiotemporal analysis of methane emissions
- Source attribution from mixed sources
- Validation studies against flux tower, aircraft, mobile measurement campaigns

AI for Methane
Call for Abstracts

ADAPT STL @ SLU

Acknowledgements

- This research is funded by US Department of Energy Award # DE-SC0025226

- Results and findings are presenters' and do not reflect the view of DoE

ADAPT STL @ SLU

ADAPT-STL

Conclusions

- Sky View Factor has a direct impact on urban heat islands
- Greenspace distance is a modulating variable
- In UHI modeling randomized R2 overinflate accuracy

GW Random Forest
(Georganos et al., 2018)

Balanced Zone Building
(Gu and Aydin, 2021)

AI for Methane
Call for Abstracts

ADAPT STL @ SLU

ADAPT-STL