

Integrating In-situ Observations with Satellite Imagery for Mapping Urban Heat

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November 17, 2020



Portland
State

Urban Heat Assessments: A 137 Year History

- Research motivations have changed over time.
 - i. Historically: Observe differences between city and surrounding areas
 - ii. Current: Describe the causes for differences within and across cities
- Measuring Progress
 - i. Development and use of methodological standards
 - ii. Effective application of findings to planning tools and design guidelines for mitigation
 - iii. Ops for climate change adaptation

Author name	Year of publication	Language of publication	City or region studied
L. Howard	1833	English	London (U.K.)
É. Renou	1868	French	Paris (France)
J. Hann	1885	German	Europe, India, USA
M. Moreno	1899	Spanish	Mexico City (Mexico)
W. Hammon & F. Duenckel	1902	English	St. Louis (USA)
W. Schmidt	1927	German	Vienna (Austria)
A. Treibich	1927	German	Berlin (Germany)
A. Pepler	1929	German	Karlsruhe (Germany)
C. Brooks	1931	English	Springfield (USA)
L. Besson	1931	French	Paris (France)
K. Sasakura	1931	Japanese	Tokyo (Japan)
A. Budel & J. Wolf	1933	German	Munich (Germany)
H. Berg & H. Metzler	1934	German	Hanover (Germany)
W. Middleton & F. Millar	1936	English	Toronto (Canada)
E. Fukui & N. Wada	1941	Japanese	Tokyo, Osaka, Nagoya (Japan)
W. Balchin & N. Pye	1947	English	Bath (U.K.)
Å. Sundborg	1951	English	Uppsala (Sweden)
F. Duckworth & J. Sandberg	1954	English	San Francisco (USA)
E. Einarsson & A. Lowe	1955	English	Winnipeg (Canada)
H. Shitara	1957	Japanese	Hiroshima (Japan)
M. Takahashi	1959	Japanese	Ogaki, Kumagaya (Japan)
T. Chandler	1960	English	London (U.K.)
I. Kayane	1960	Japanese	Tokyo (Japan)
T. Sekiguti	1963	Japanese	Ogaki (Japan)
T. Kawamura	1964	Japanese	Kumagaya (Japan)
T. Chandler	1965	English	London (U.K.)
S. Nieuwolt	1966	English	Singapore
K. Nakamura	1966	Japanese	Nairobi (Kenya)
E. Fukui	1968	Japanese	Japan
F. Ludwig	1970	English	Dallas (USA)
Y. Goldreich	1970	English	Johannesburg (South Africa)
S. Sham	1972	English	Kuala Lumpur (Malaysia)
C. Daniel & K. Krishnamurthy	1973	English	Pune, Mumbai (India)
E. Jáuregui	1973	English	Mexico City (Mexico)
T. Oke	1973	English	St. Lawrence Lowland (Canada)
T. Oke & G. Maxwell	1975	English	Vancouver, Montreal (Canada)

Source: Stewart I., 2019. The relevance of history in contemporary urban heat island research. *Urban Climate News*, 74.



Examining the Sun's Heating of Earth

Short Wave Radiation Budget



Warms the Surface



Ground Heat (G)

Warms the Air



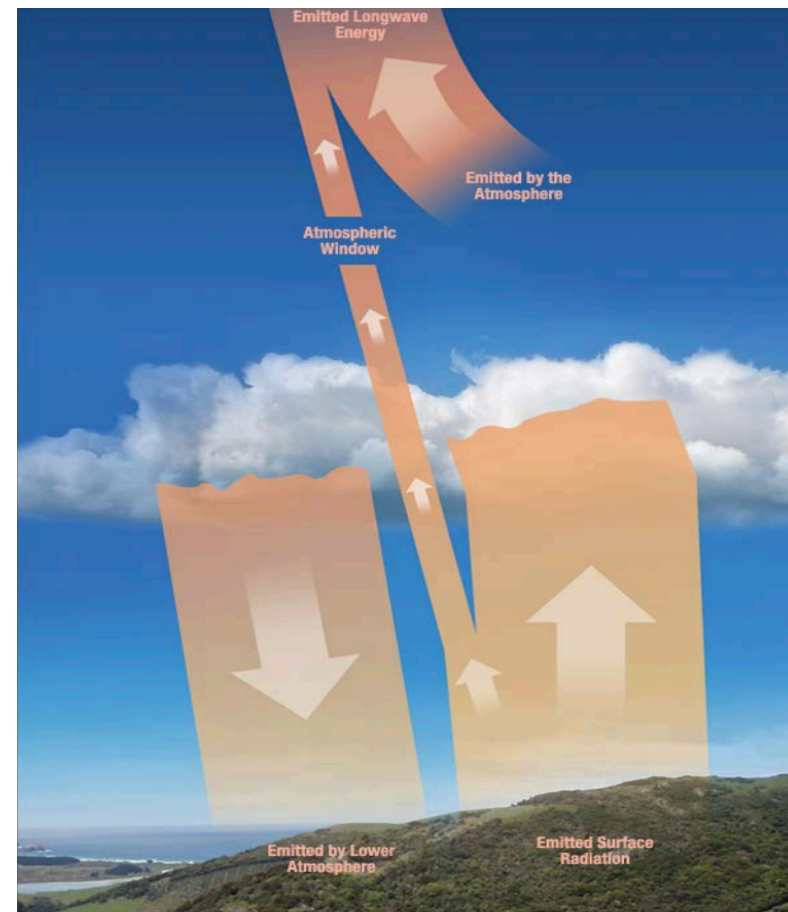
Sensible Heat (H)

Evaporates Water



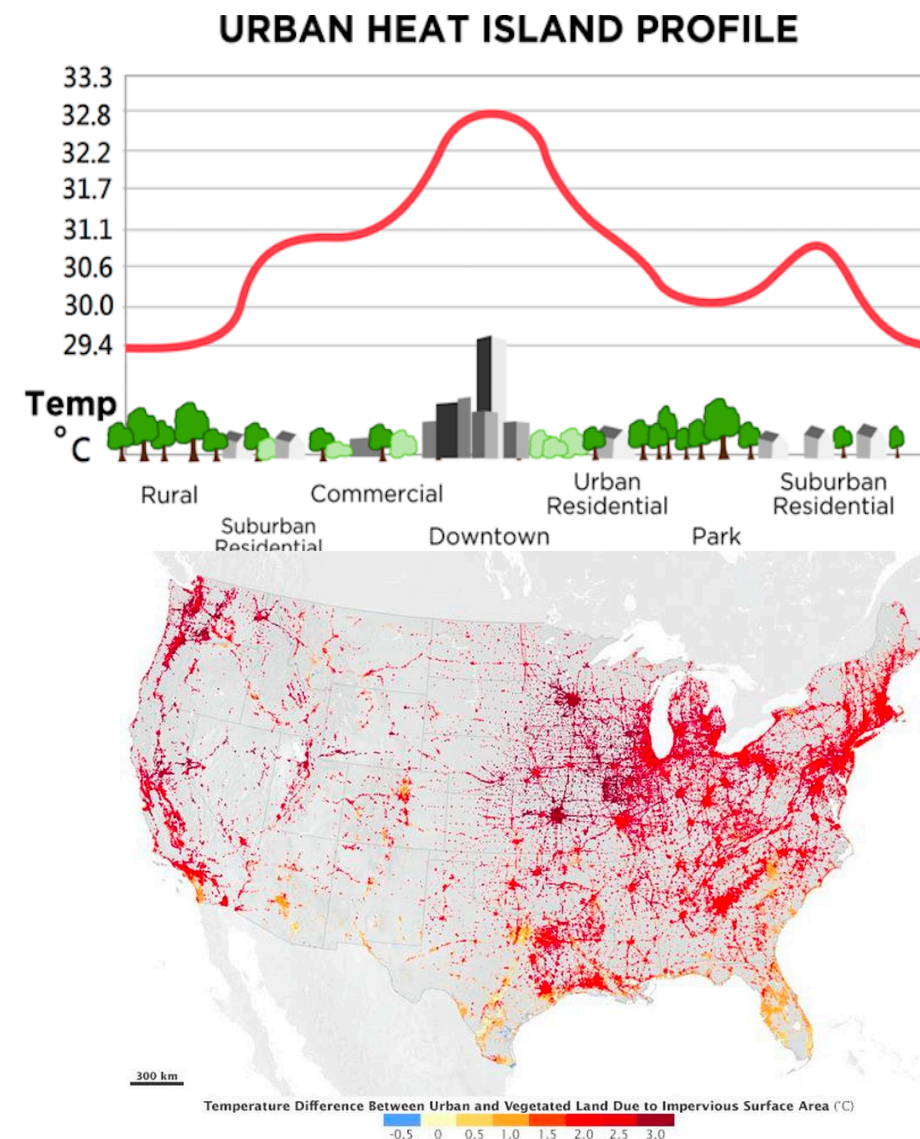
Latent Heat (L)

Long Wave Radiation Budget



Common Descriptions of the UHI

1. Traditional use of a 'reference site' to assess urban temps (Chandler, 1965; Landsberg, 1979)
 - Use of weather stations (spatial)
 - Nighttime differences (temporal)
2. Satellite description of the land surface temperature (LST)
 - Atmospheric brightness & emissivity
3. Integrating satellite with ground-based measurements
 - Aim of developing a predictive model for air temperatures



Opportunities for Integration: *Satellite and Ground Based Methods*

- Limited number of in-situ data, which is obtained from weather stations to validate the model
 - In order to collect appropriate number of data, data are collected for multiple days/years and/or large study area
- Predict only Tmax, Tmin, Tmean
- MODIS is the most widely used imagery to obtain LST and other auxiliary variables.
 - High temporal resolution (Daily), but low spatial resolution (1km)
 - Four times a day (Terra-10:30am, Aqua-1:30pm, Terra-10:30pm, Aqua-1:30am)
- Other studies use Landsat LST or BT
 - Native resolutions of the thermal bands are:
 - Landsat 4-5 Thematic Mapper (TM): 120m
 - Landsat 7 Enhanced Thematic Mapper Plus (ETM+): 60m
 - Landsat 8 Thermal Infrared Sensor (TIRS): 100m



Ground-Based Assessments

- No need for LST data (thermal band)
- High spatial resolution (10m)
- Large number of in-situ data (the number of points of vehicle traverses) to validate and calibrate
- Able to predict a specific time period (6 am, 3 pm, and 7 pm) - diurnal temperature pattern



Heat Watch Engagement Model

Engage communities in describing and localizing climate-induced hazards

Develop analytical tools for examining scenarios of adaptation actions

Support capacity building efforts through engagement of decision makers and community groups

How it Works

Engage Locally

Identify organizations and individuals to support heat action

Complete Campaign

Use materials provided to engage volunteers in Heat Watch campaign

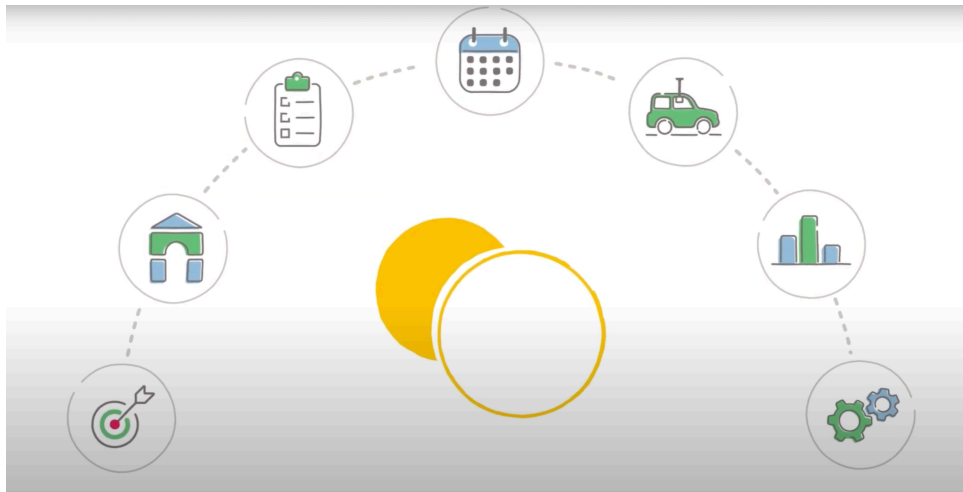
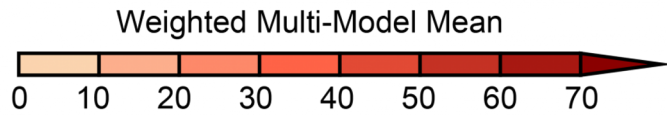
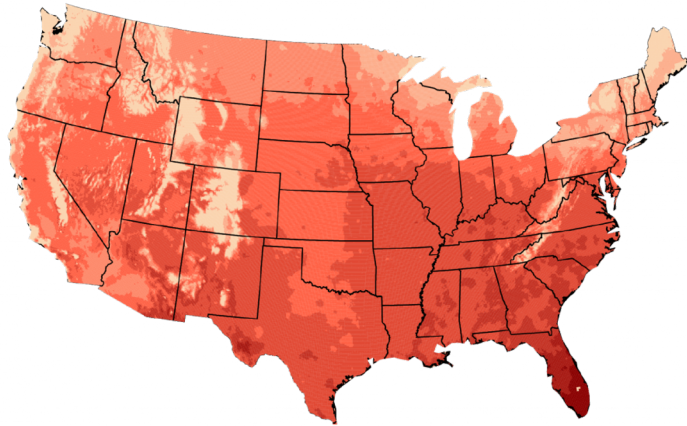
Review Results & Identify Actions

Deepen engagement through active involvement in heat planning



Campaign Planning

Projected Change in Number of Days Above 90°F
Mid 21st Century, Higher Scenario (RCP8.5)



CAPA Heat Watch

Organizer Timeline

2. Establish

Get to know the Heat Watch process and begin volunteer engagement.

- Review customized "starter kit", including materials for volunteer recruitment & training, step-by-step guides, and a document road-map
- Begin recruiting volunteers using provided outreach material
- Schedule a kickoff meeting with CAPA program managers to ask questions and review next steps

4. Activate

Finish preparatory steps by finalizing a campaign date, notifying volunteers and distributing CAPA-provided equipment.

- Using forecasts, confirm the ideal high-heat, no-rain Campaign Day
- Confirm availability with volunteers and organize backup teams as needed
- Receive equipment from CAPA and organize a central meeting time and location to distribute equipment

6. Analyze

CAPA analysts process data and produce heat map outputs.

- Analysts download, clean, and process raw data files
- Using satellite imagery to inform land-cover variables, analysts produce predictive temperature and heat index surfaces
- Maps and datasets are shared with the City Team



Graphic format from freepik.com



KEY
Timing relative to campaign
Avg. Organizer time commitment
Avg. Volunteer time commitment

1. Set Goals

Determine the timing of your Heat Watch campaign and set up your team.

- Identify a target campaign date with high temperatures and clear skies based on historical weather patterns
- Partner with local organizations (e.g. science museums, universities, and non-profits) to combine resources and increase action potential
- Designate a lead, or "Organizer", who will act as the main point of contact

3. Prepare

Ensure volunteers are ready for their important role as data collectors.

- Schedule comprehensive volunteer training sessions
- Volunteers attend the live training or complete an at-home module, covering logistics to equipment usage
- Assign polygons and routes to volunteers in teams of 1 to 3 people
- Detail next steps for volunteers leading towards Campaign Day

5. Execute

Conduct a successful campaign, mapping the distribution of heat across your city at morning, afternoon and evening.

- Volunteers arrive at starting points and install equipment
- Following prescribed routes, volunteers collect ambient temperature and humidity data at every second
- Volunteers return and Organizers ship back the equipment to CAPA

7. Implement

Heat Watch results are reviewed and interpreted by participants, with a meeting to discuss next steps.

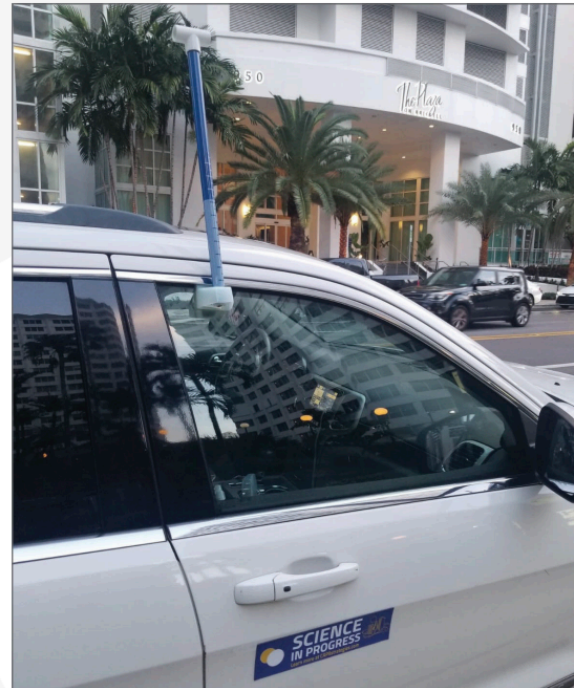
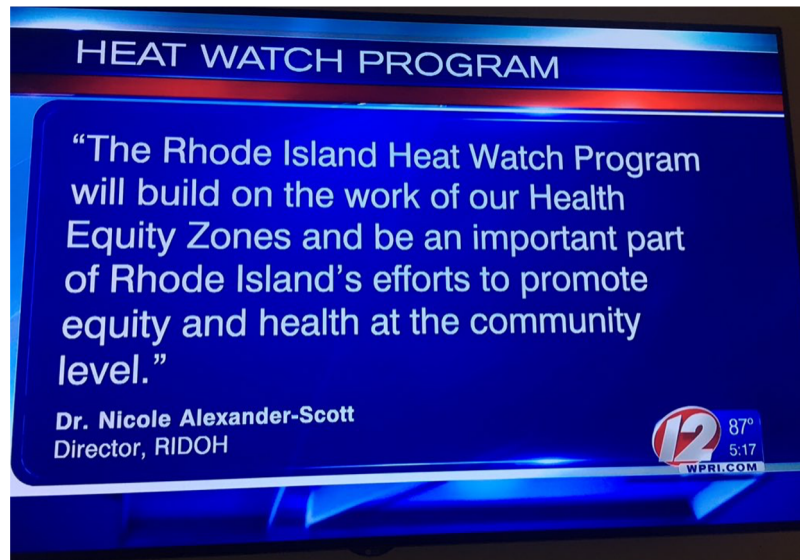
- Surveys are distributed to participants to gather feedback on experience and interpretations
- CAPA and City Team meet virtually to explore future possibilities
- Next steps are determined and planned for action



Campaign Day

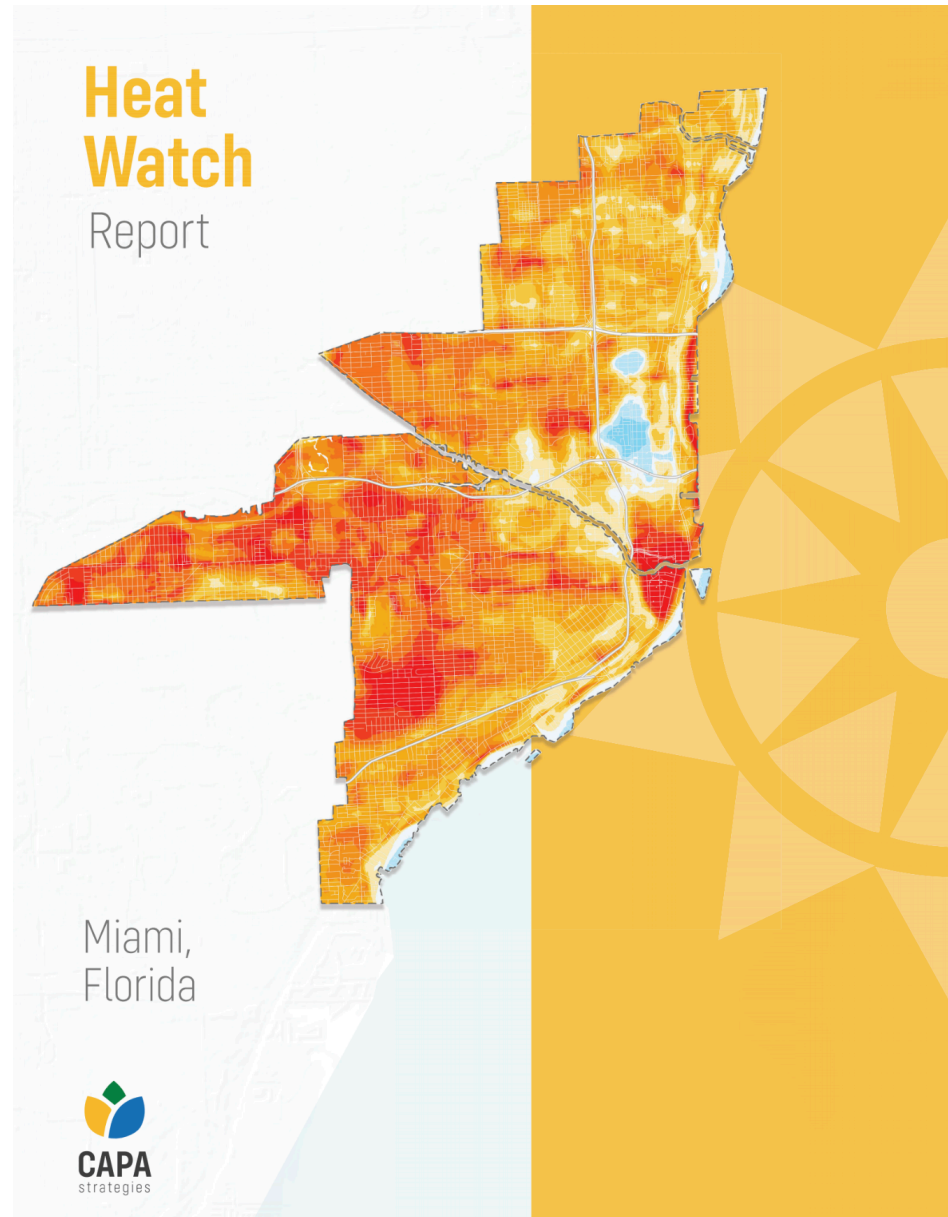


Extreme heat impacts everyone.



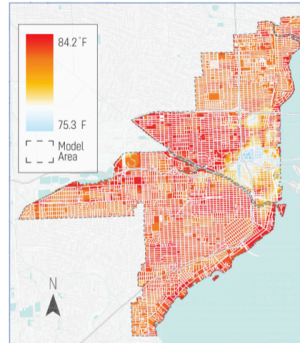
so it's good to have this data and also it'll give us some kind of scope to see

Campaign Outputs & Impacts

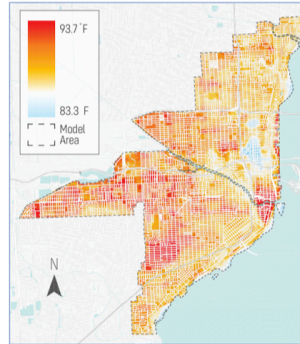


Executive Summary

Morning Area-Wide Predictions (6 - 7 am)

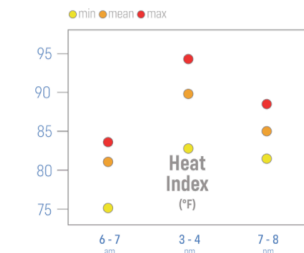
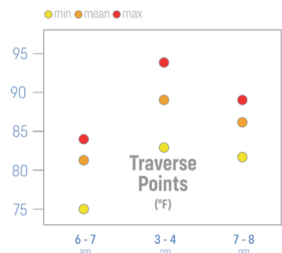
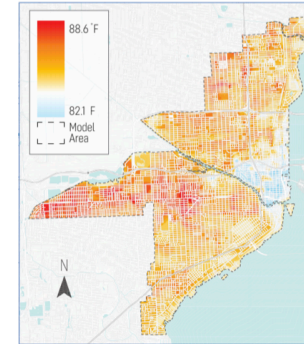


Afternoon Area-Wide Predictions (3 - 4 pm)



Major thanks to all of the participants and organizers of the Urban Heat Watch program in Miami, Florida. After months of collaboration and coordination, local organizers and volunteers collected thousands of temperature and humidity data points in the morning, afternoon, and evening of a long, hot campaign day on June 27th, 2020.

Evening Area-Wide Predictions (7 - 8 pm)



Study Date

6/27/20

21
Volunteers

9
Routes

60,234
Measurements

93.7°
Max Heat Index

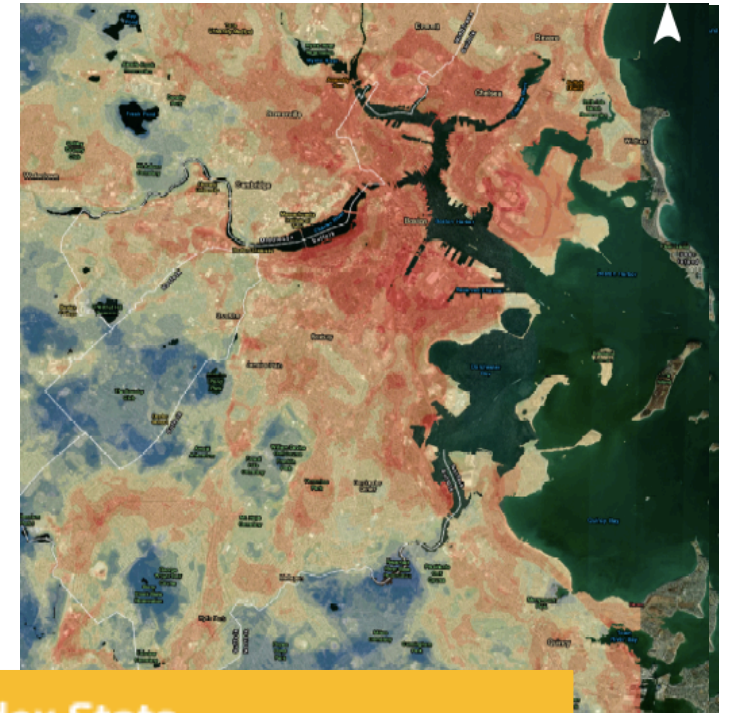
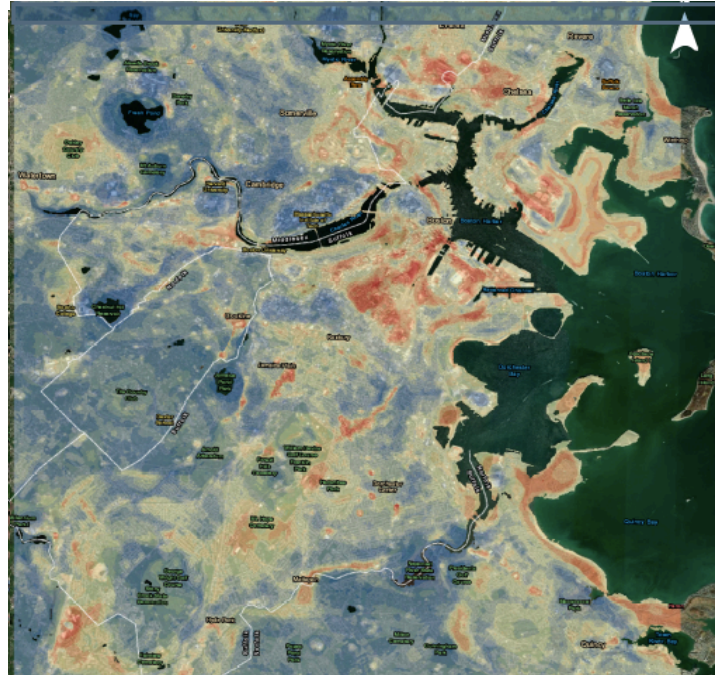
10.6°
Heat Differential



Learn more about the background and goals of each Heat Watch 2020 campaign city at <https://nihhis.cpo.noaa.gov/Urban-Heat-Is->



Outputs: City of Boston, MA (2019)



On July 29th and 30th, 2019, volunteers traversed ten study areas across Boston, Cambridge, and Brookline. The maximum heat measured during the traverses was 102.3 degrees Fahrenheit (near Boston Harbor), with a highest concurrent heat differential of 15 degrees.

Temperature and Heat Index Stats

Traverse	Temperature			Heat Index		
	MIN	MAX	MEAN	MIN	MAX	MEAN
6 - 7 am	71.8 F	82.7 F	74.5 F	73.0 F	87.7 F	75.8 F
3 - 4 pm	87.3 F	102.3 F	90.8 F	91.0 F	108.9 F	96.1 F
7 - 8 pm	78.7 F	91.1 F	84.0 F	80.5 F	97.7 F	88.9 F



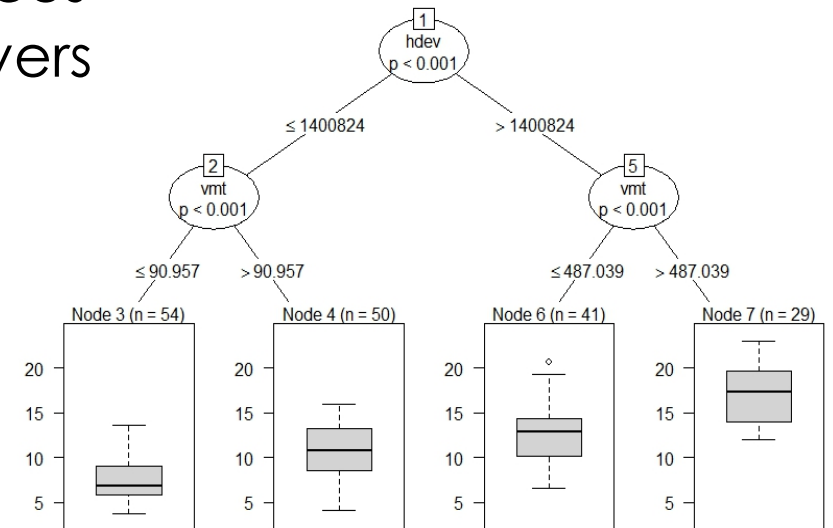
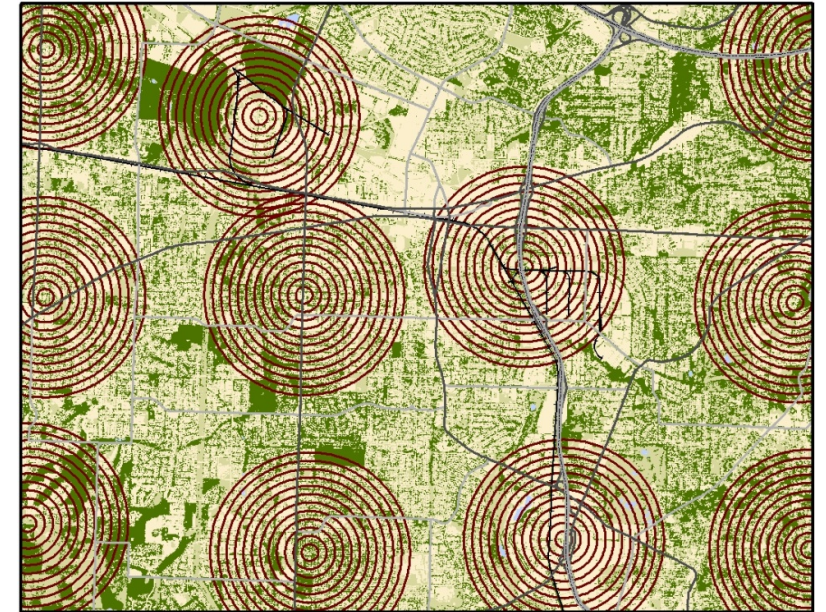
Approaches to Validation

- Assess differences between satellite-derived and ground-based mobile temperature measurements (exhaustive)
- Compare ground-based stations with mobile temperature measurements (selective)
- Conduct repeat measurements of mobile temperatures in one region and compare across days (TBD)



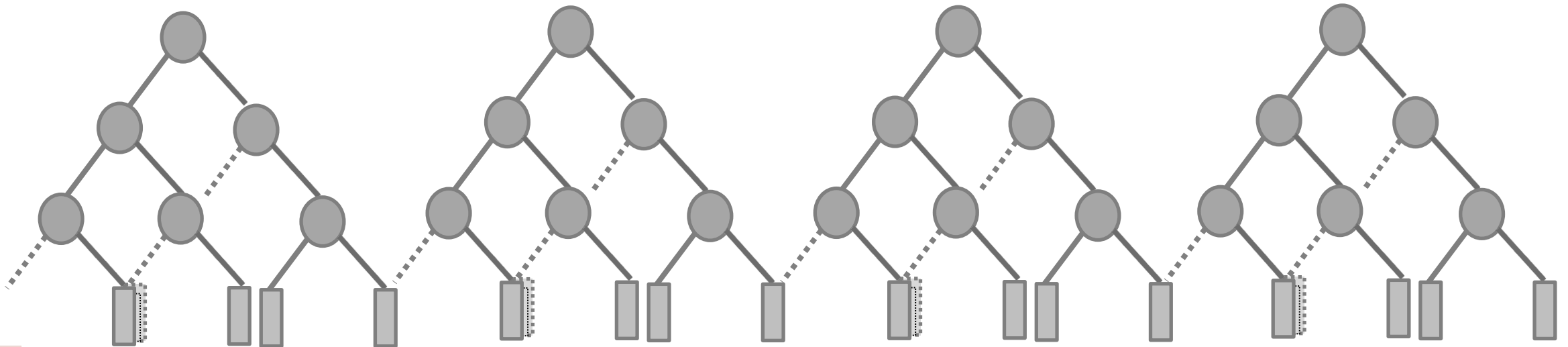
Machine Learning: Random Forest

- Integrate ground-based measurements with satellite imagery
 - i. Satellite bands provide descriptions for land cover
 - ii. Diversity of land covers accounts for variation in temperature measurements
- Identify best predictors of temperatures across all land covers
 - i. Use predictors to develop temperature surfaces
 - ii. Temperature estimation is based on land covers traversed
- Advantages over geospatial interpolation
 - Takes into account what is on the ground, as opposed to strictly statistical estimation



Ensemble of Regression Trees

- Developed by Breiman (2001)
- Combine many “weak learners” into a “strong learner”
- Use bootstrap aggregation or **bagging**
- Each tree uses only a **random** subset of predictors
- Highest accuracy for predicting air temperature

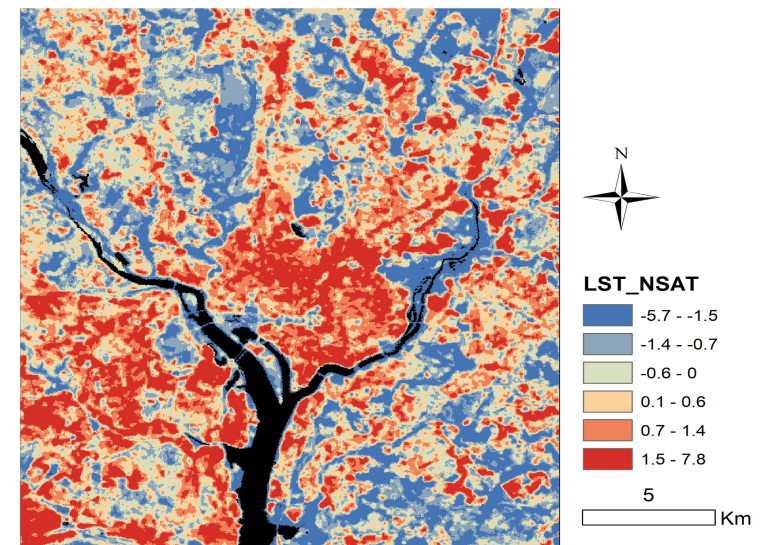
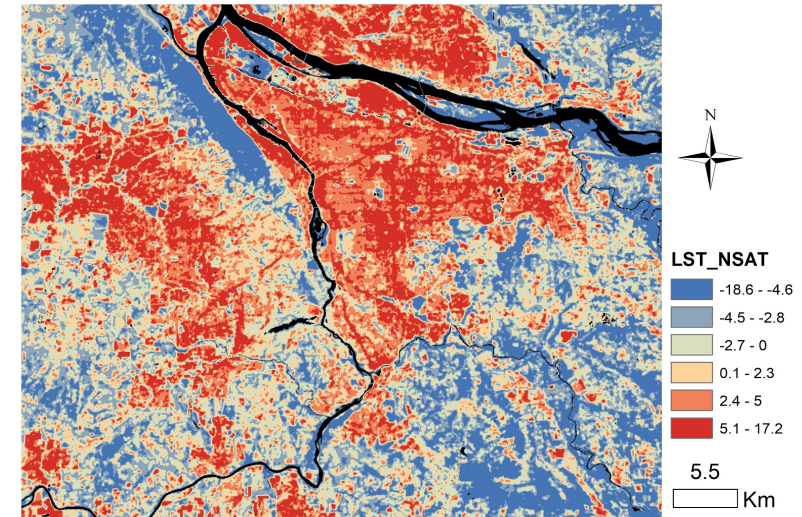
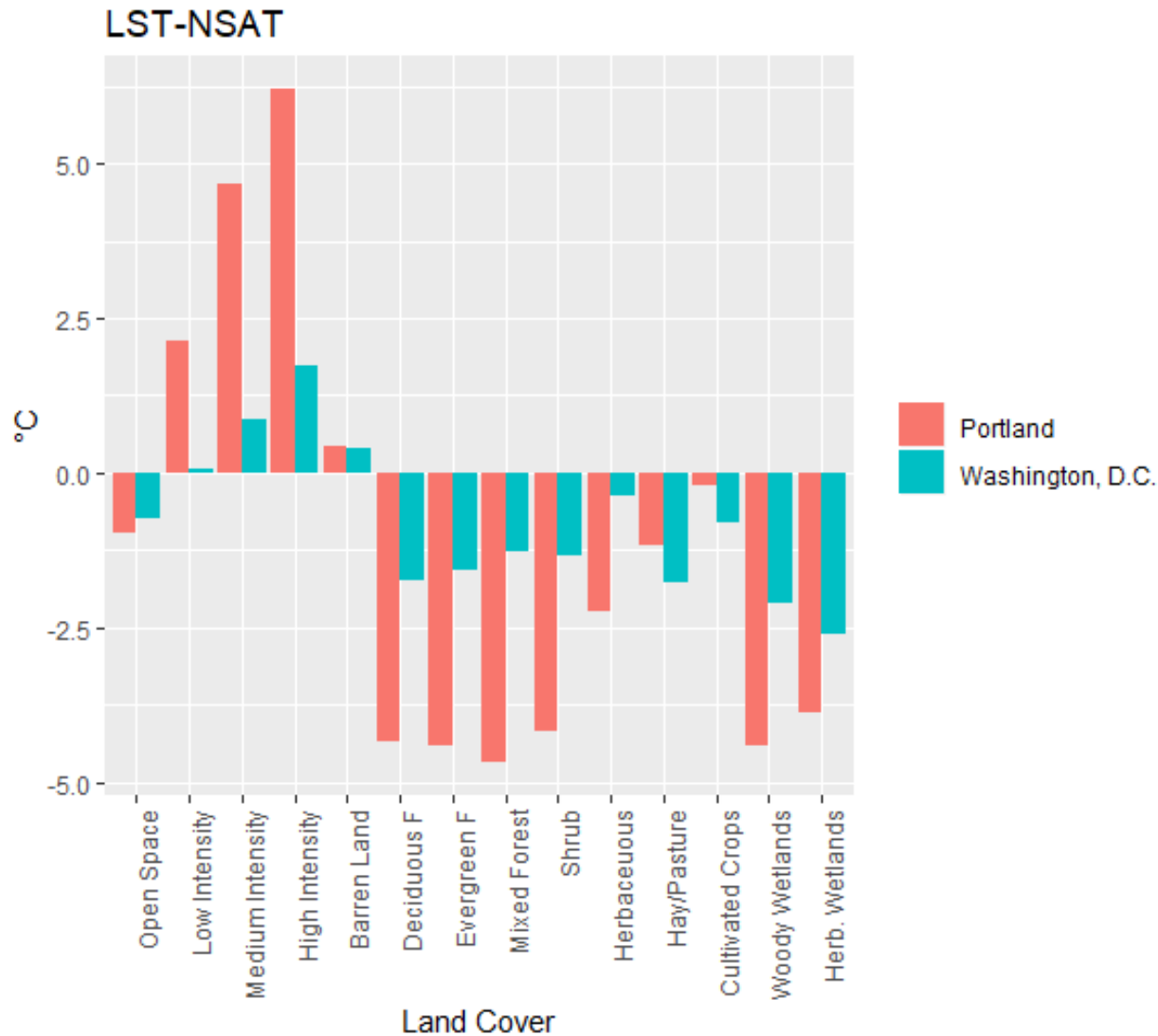


Comparing Satellite with Mobile Temps

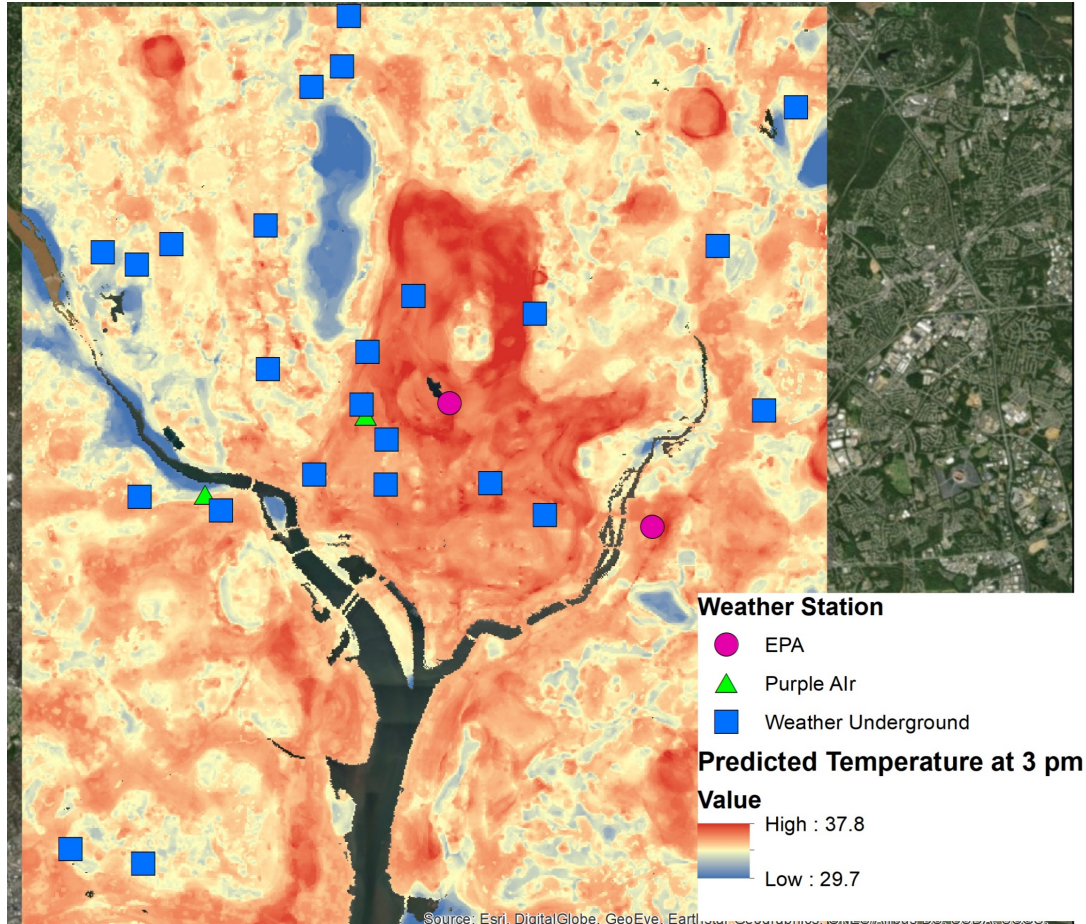
LOCATION	LandSat LST DATE/ TIME	AVERAGE TEMP LST	LOW/ HIGH/ AVG LST	NSAT SURVEY DATE	AVERAGE DAILY NSAT	LOW/ HIGH/ AVG NSAT
Washington D.C. Elevation: 150'	07/08/18 3:45 PM	84°F	64/85/ 75	08/30/18	92°F	78/93/ 86
Albuquerque, NM Elevation: 5,312'	07/27/18 5:43 PM	85°F	63/87/ 75	06/23/18	97°F	65/98/ 82
Portland, OR Elevation: 50'	08/28/16 6:56 PM	84°F	57/84/ 72	08/25/16	91°F	60/95/ 78
Richmond, VA Elevation: 166'	08/06/17 3:46 PM	85°F	59/89/ 74	07/23/17	94°F	74/97/ 86
Tacoma, WA Elevation: 243'	07/24/18 7:00 PM	83°F	55/86/ 70	07/26/18	86°F	57/89/ 73



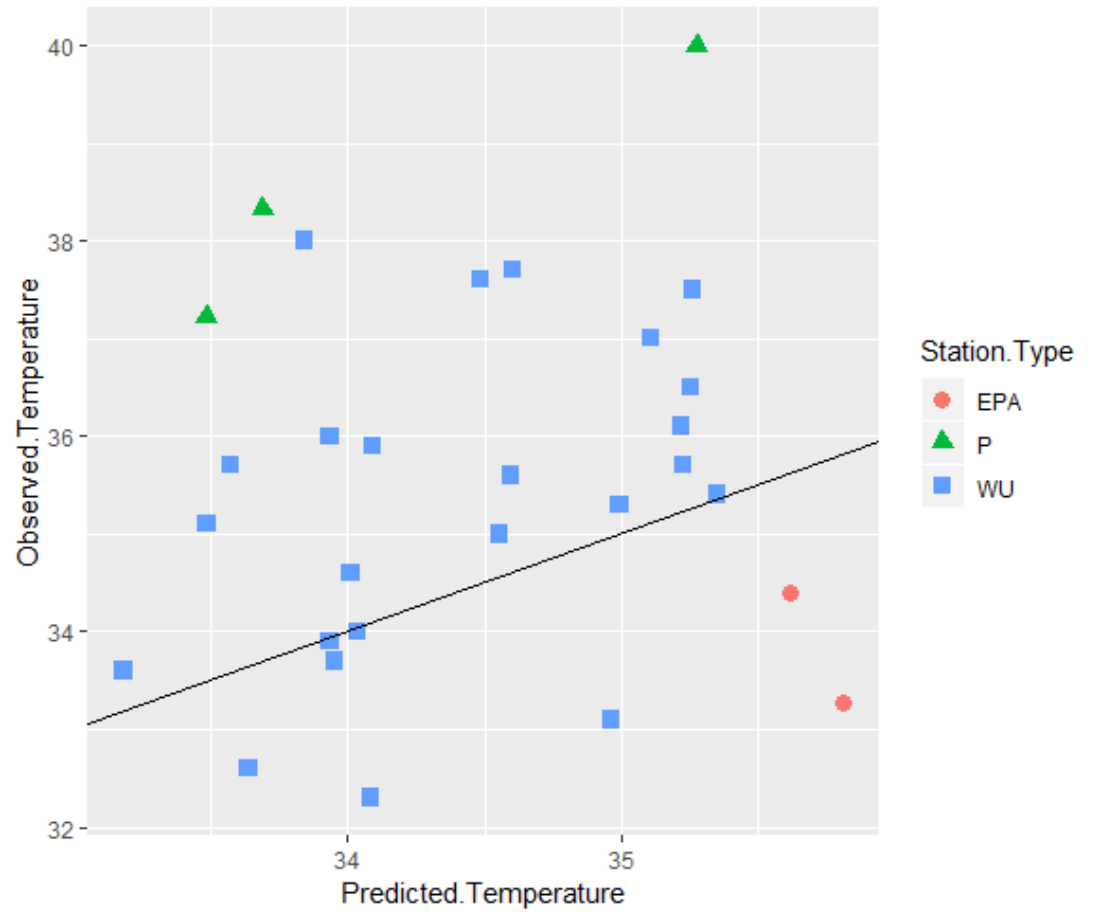
Satellite and Mobile Temps – Effects of Land Cover



District of Columbia (8/28/2018)



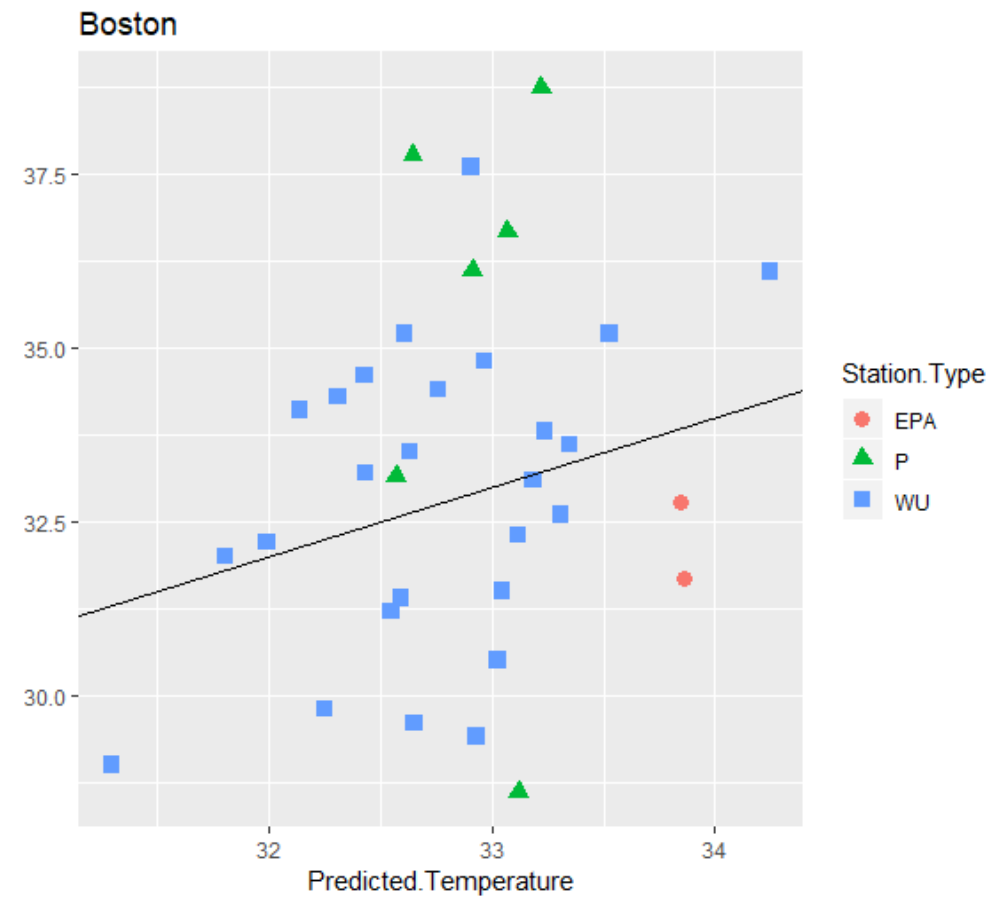
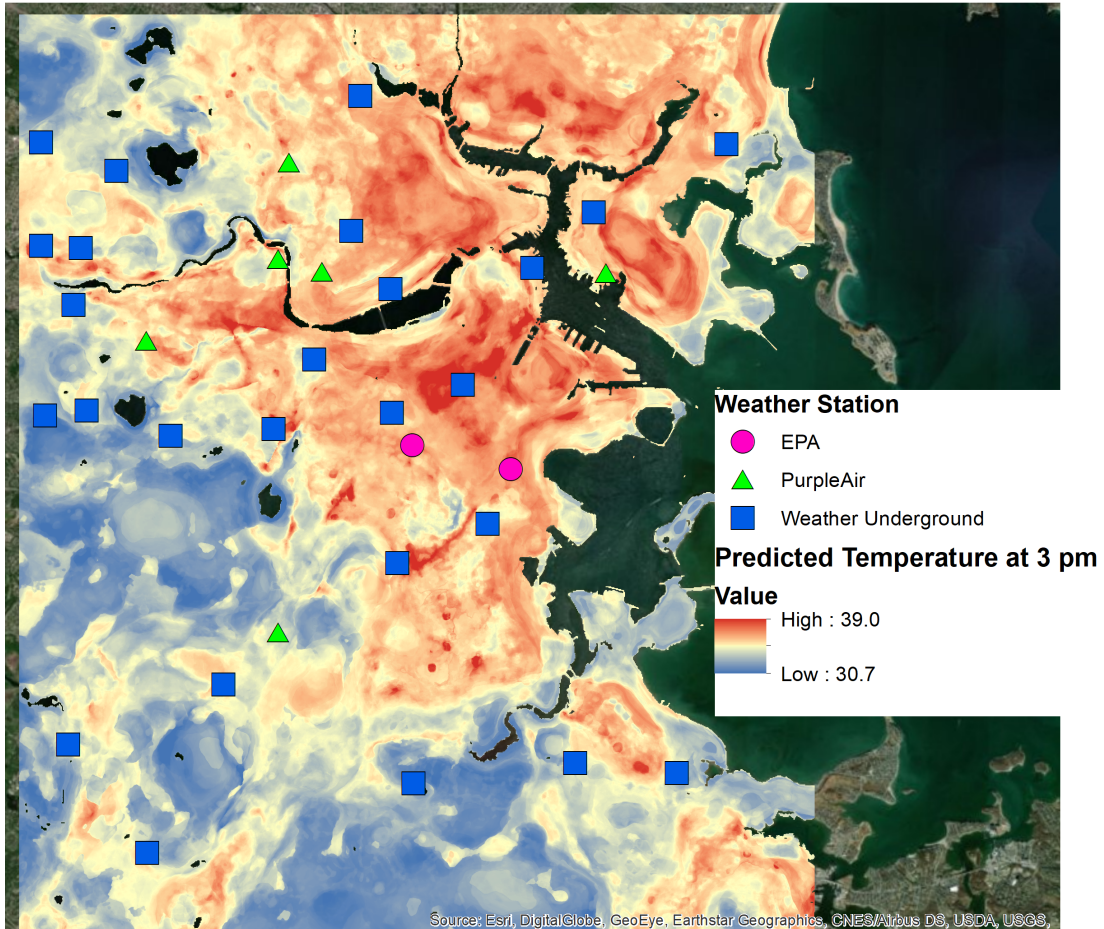
Washington, D.C.



	Number of Stations	RMSE (°C)
EPA	2	1.99
Purple Air	3	4.39
Weather Underground	24	1.73



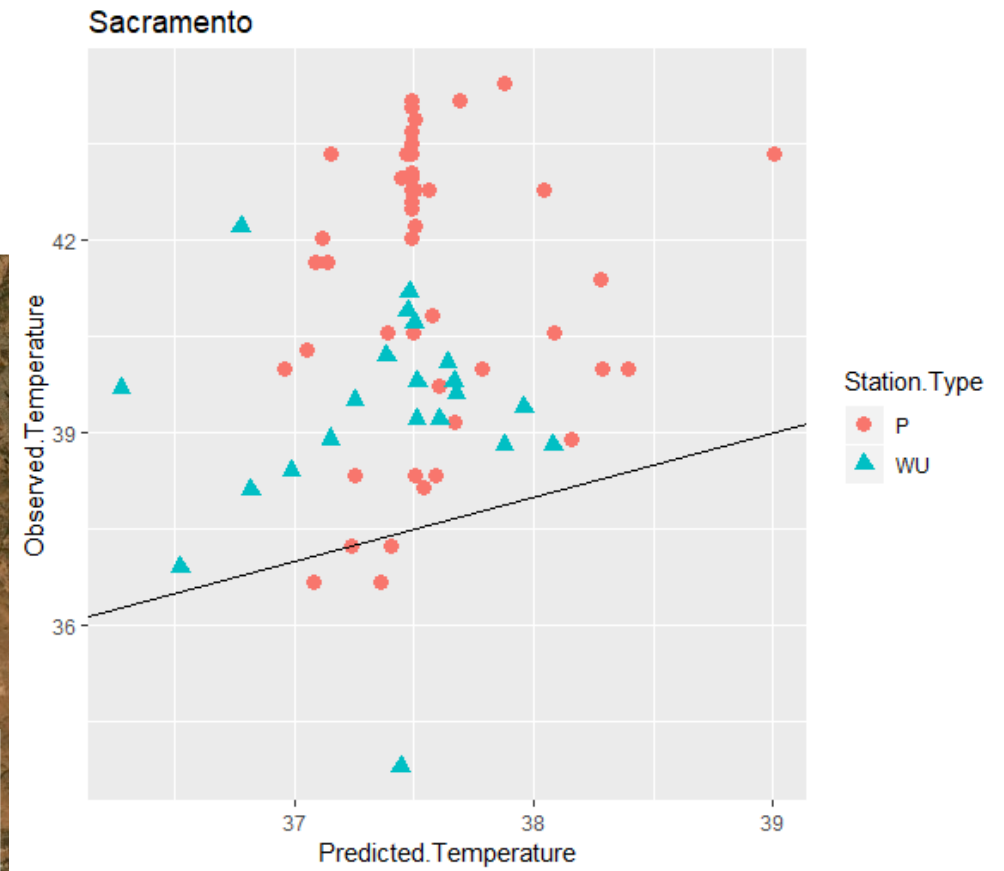
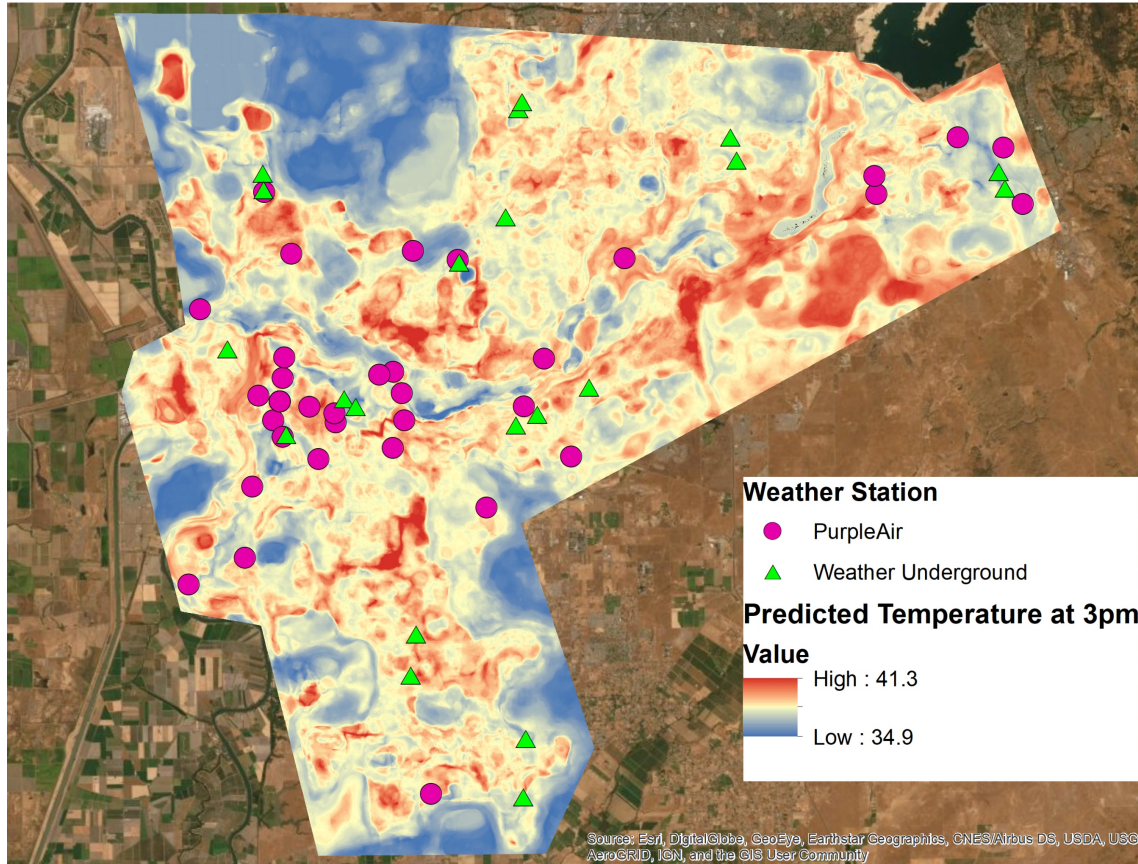
Boston (7/29/2019)



	Number of Stations	RMSE (°C)
EPA	2	1.72
Purple Air	6	4.10
Weather Underground	26	1.98



Sacramento (8/14/2019)



	Number of Stations	RMSE (°C)
Purple Air	53	4.45
Weather Underground	21	2.57



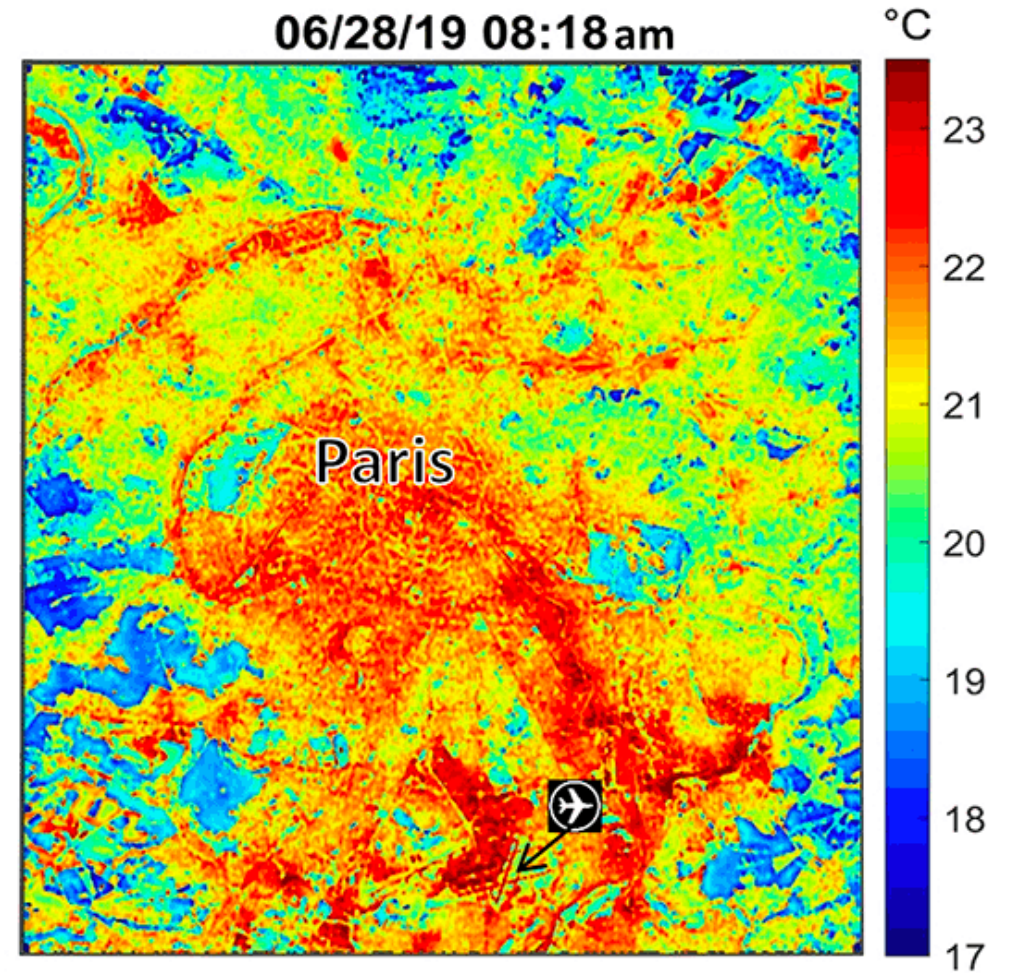
Satellite-Based Measurements

Strengths

1. Freely available across the world
2. Seasonal availability
3. Intra-urban variation detectable
4. Extensive literature and research
5. Potential connections to land use

Weaknesses

1. Exaggerates temperature ranges
2. Coarse pixel size (30m, 90m, 1km...)
3. Rooftops as opposed to street-level
4. Discrete differences between land covers
5. Translation to policy remains unclear



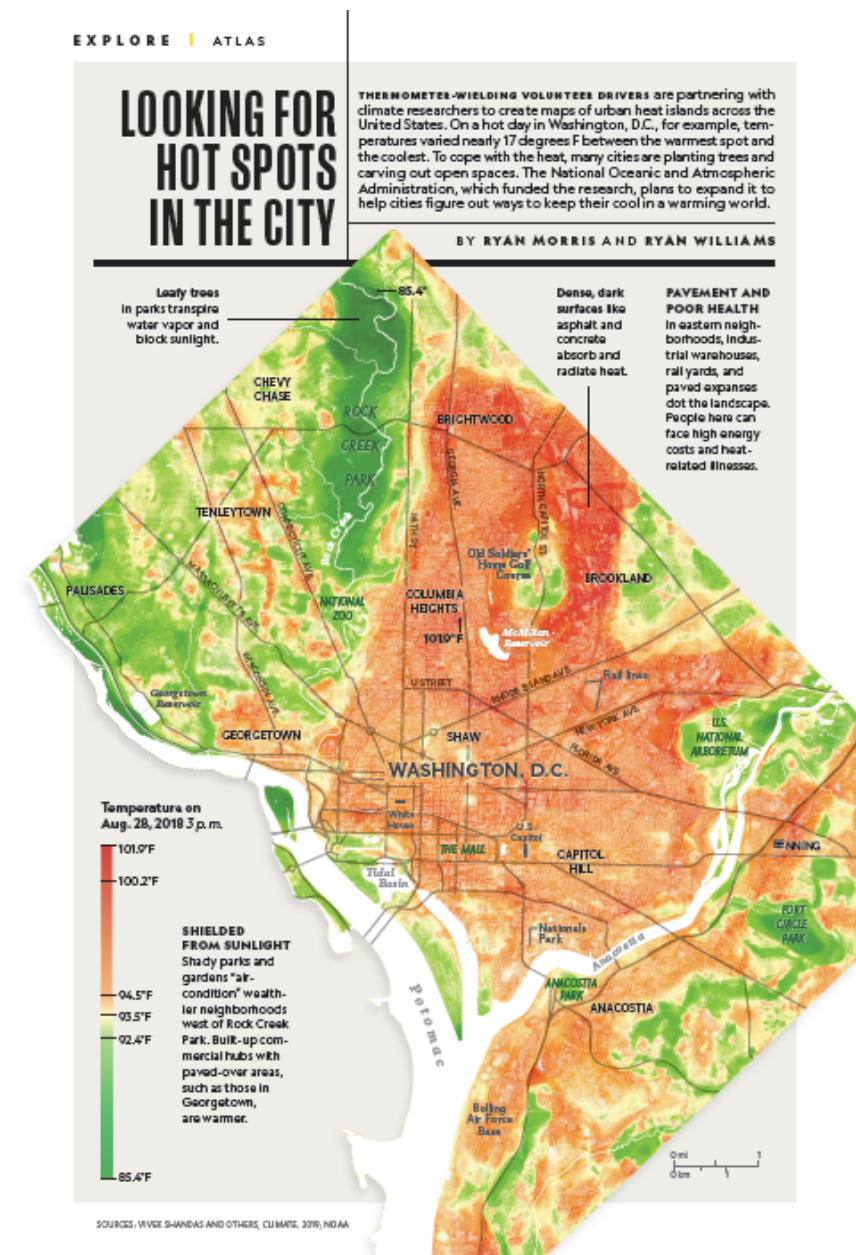
Ground-Based Measurements

Strengths

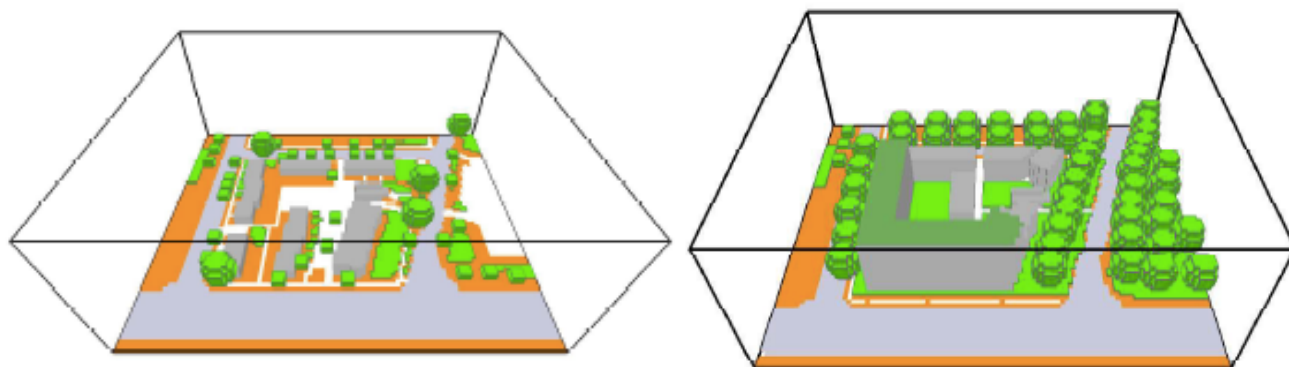
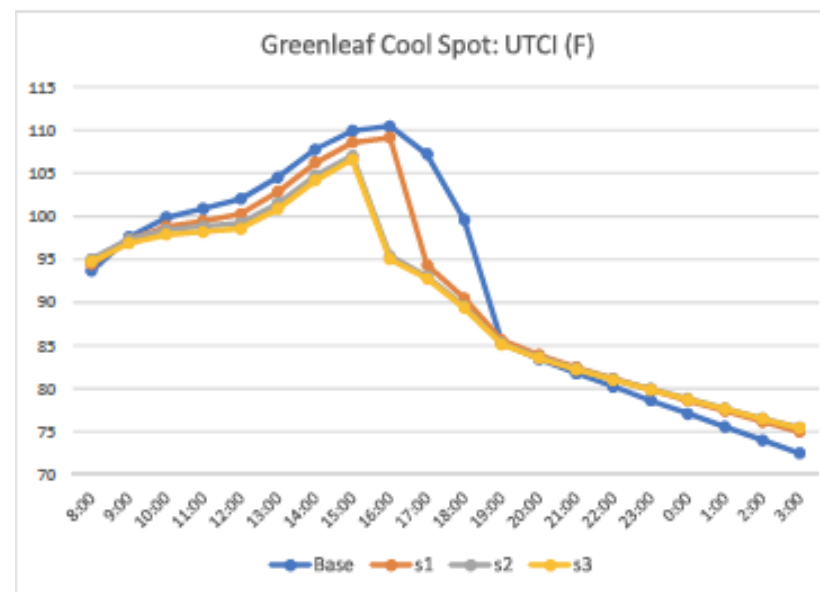
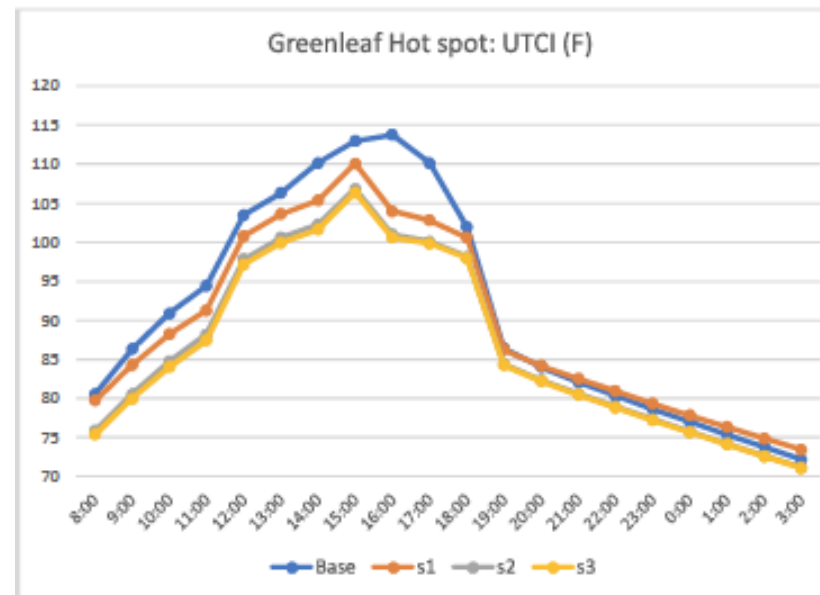
1. Engages community in their place
2. Established 'civic legitimacy' of scientific process and results
3. High resolution outputs (1m, 10m)
4. Diurnal profile of air temperatures
5. Policy applications are evident

Weaknesses

1. Coordination of local community groups requires time and strategy
2. Not free due to engagement and analysis
3. Seasonal differences not [yet] available
4. Clouds or rain can create delays
5. Generalizable models are still forthcoming



District of Columbia Extensions: Land Use Change



Contact

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