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

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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

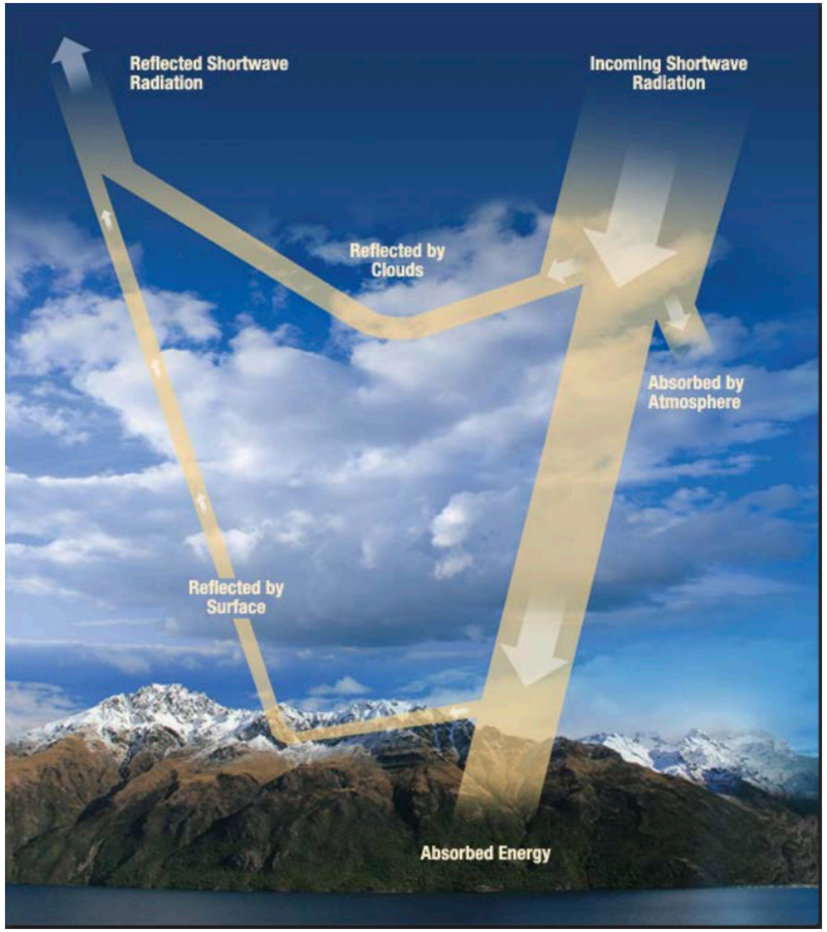
- Measuring Progress
  i. Development and use of methodological standards
  ii. Effective application of findings to planning tools and design guidelines for mitigation
  iii. Ops for climate change adaptation

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. Peppler	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.

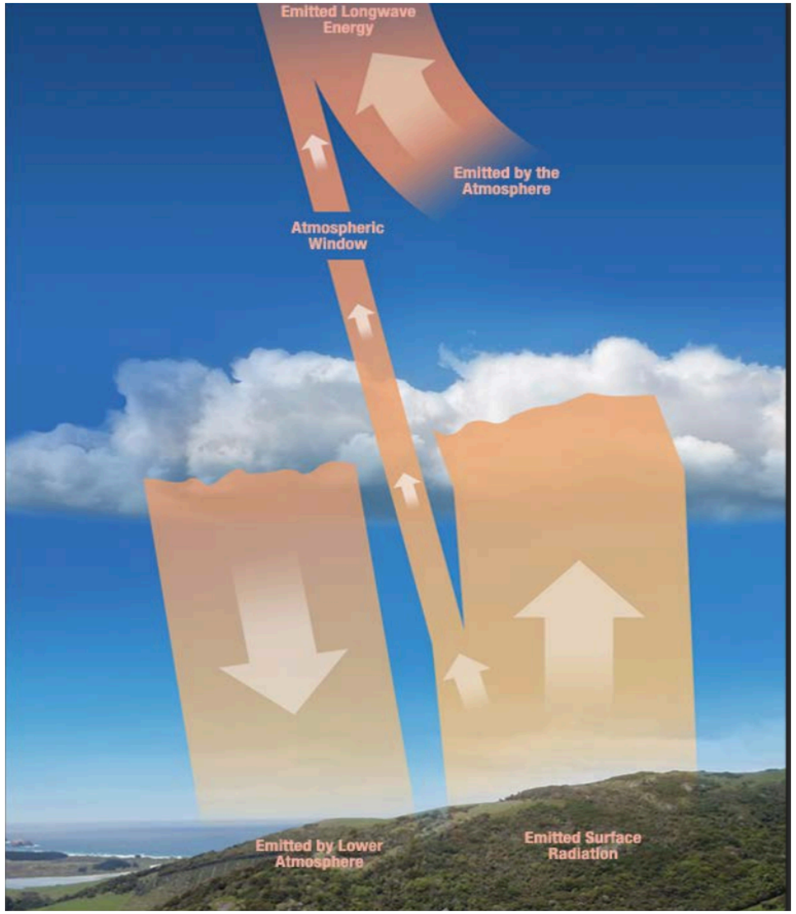
Examining the Sun’s Heating of Earth

Short Wave Radiation Budget



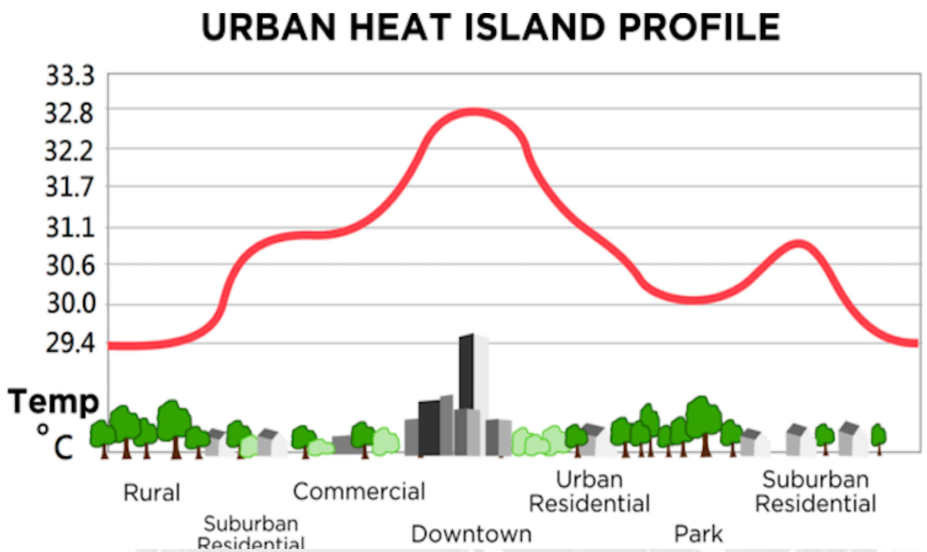
Warms the Surface ↓ Ground Heat (G)
Warms the Air ↓ Sensible Heat (H)
Evaporates Water ↓ Latent Heat (L)

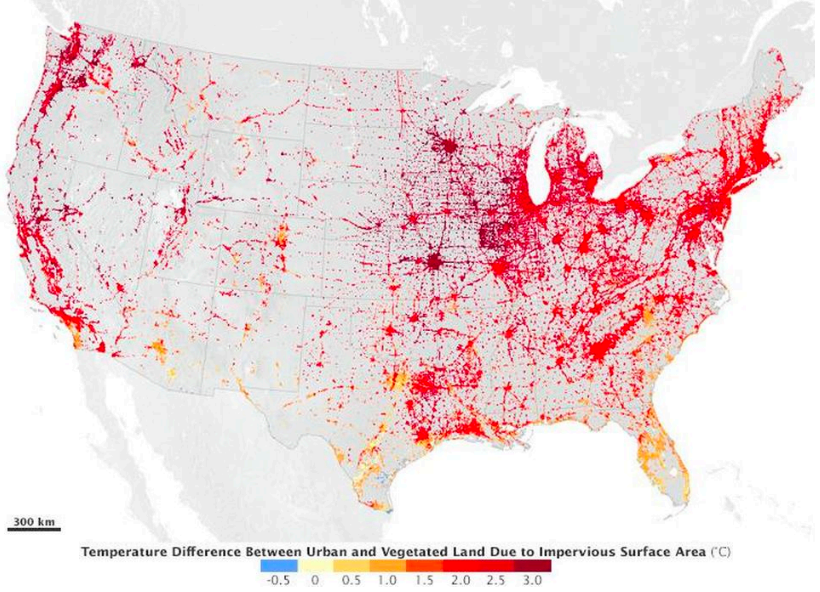
Long Wave Radiation Budget



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

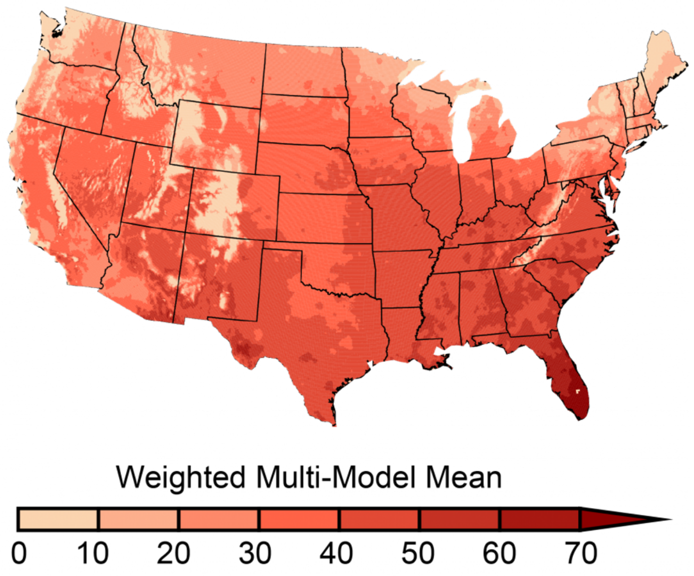
Use materials provided to engage volunteers in Heat Watch campaign

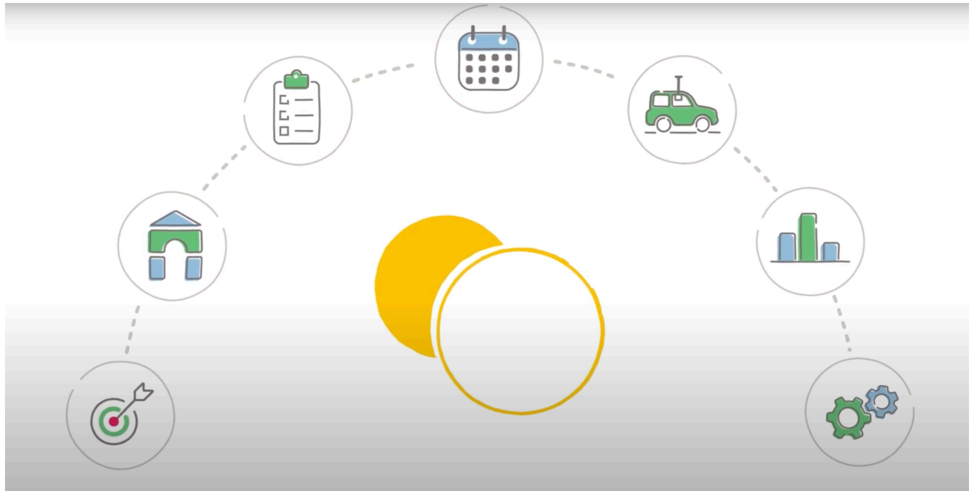
Review Results & Identify Actions

Deepen engagement through active involvement in heat planning

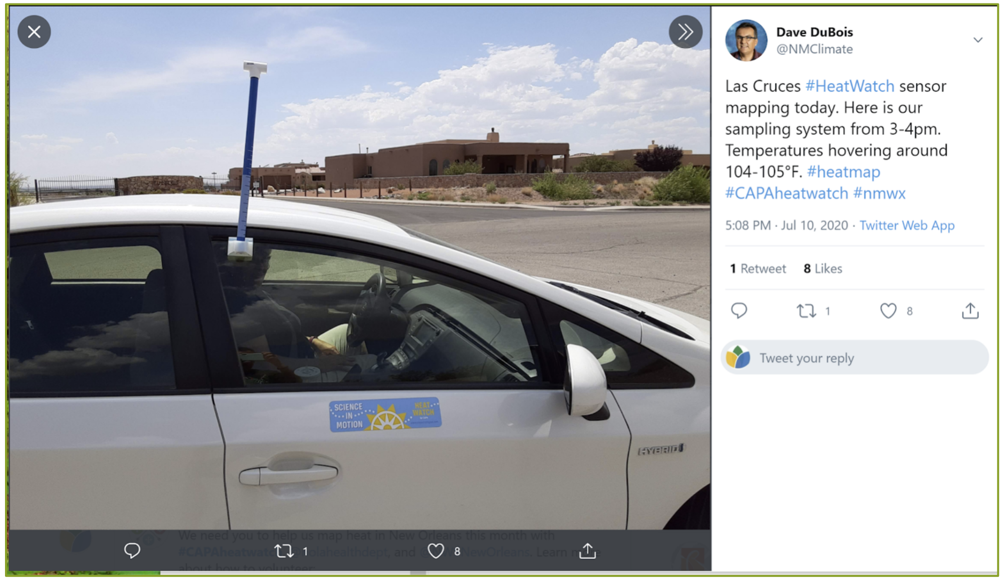
Campaign Planning

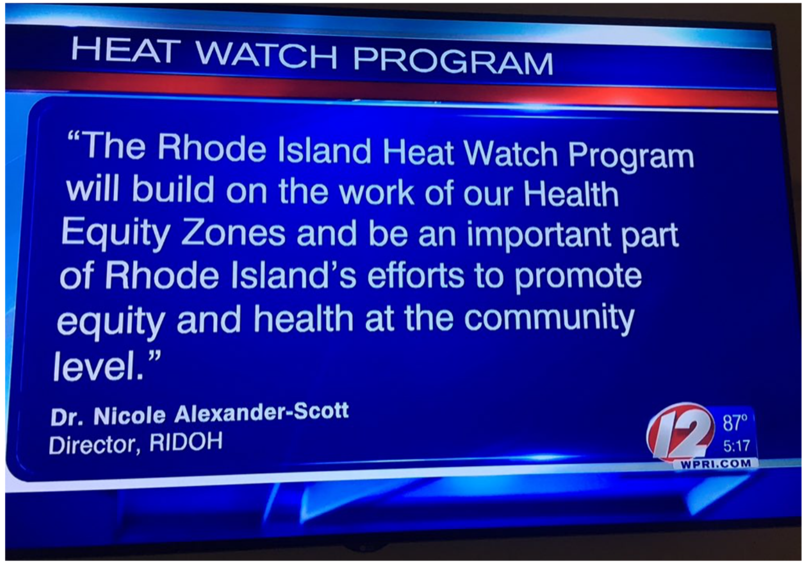
Projected Change in Number of Days Above 90°F
Mid 21st Century, Higher Scenario (RCP8.5)

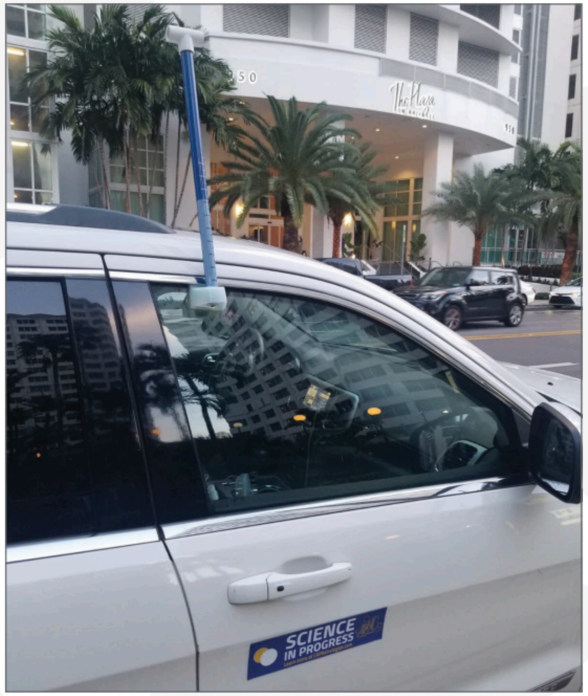




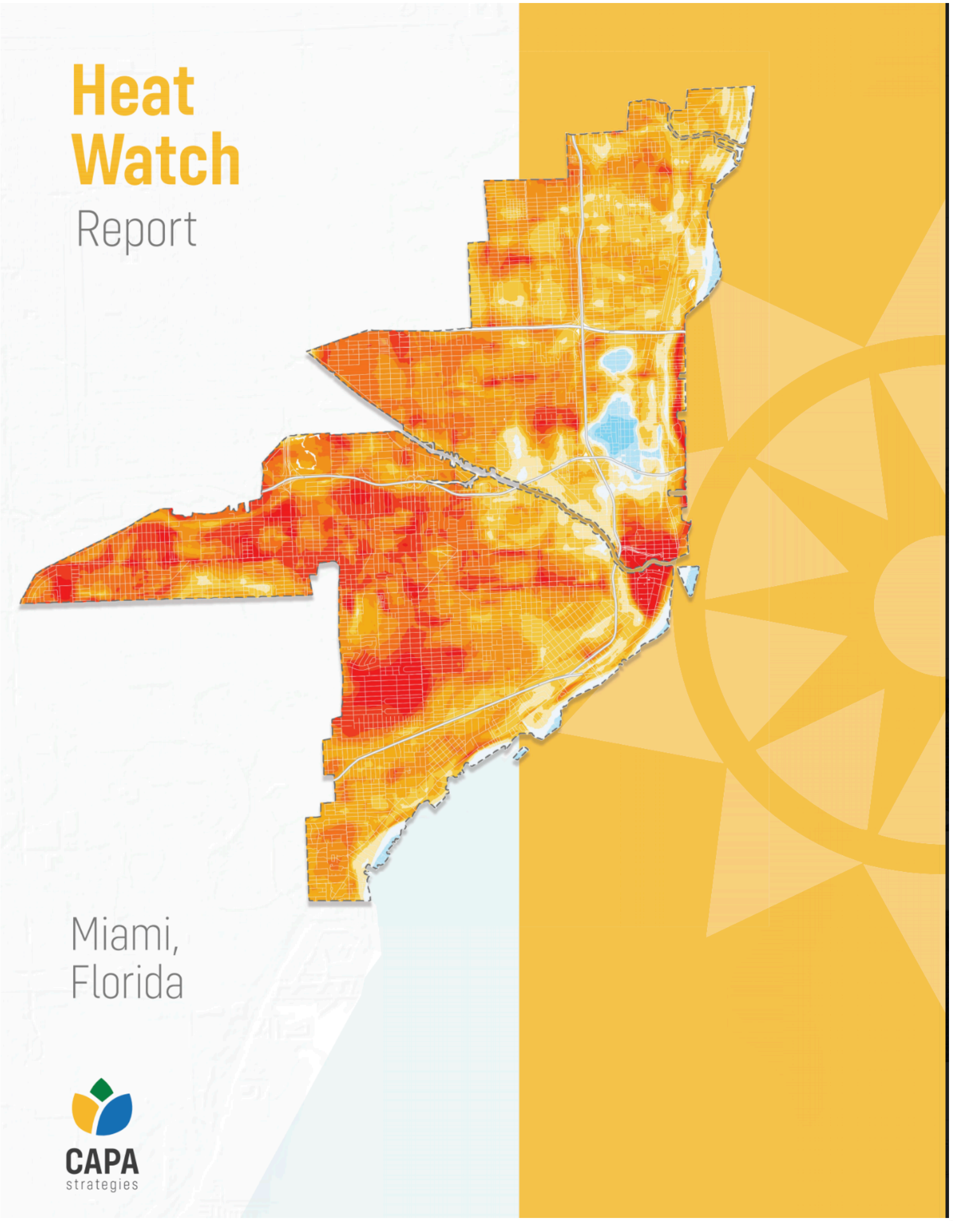
Campaign Day

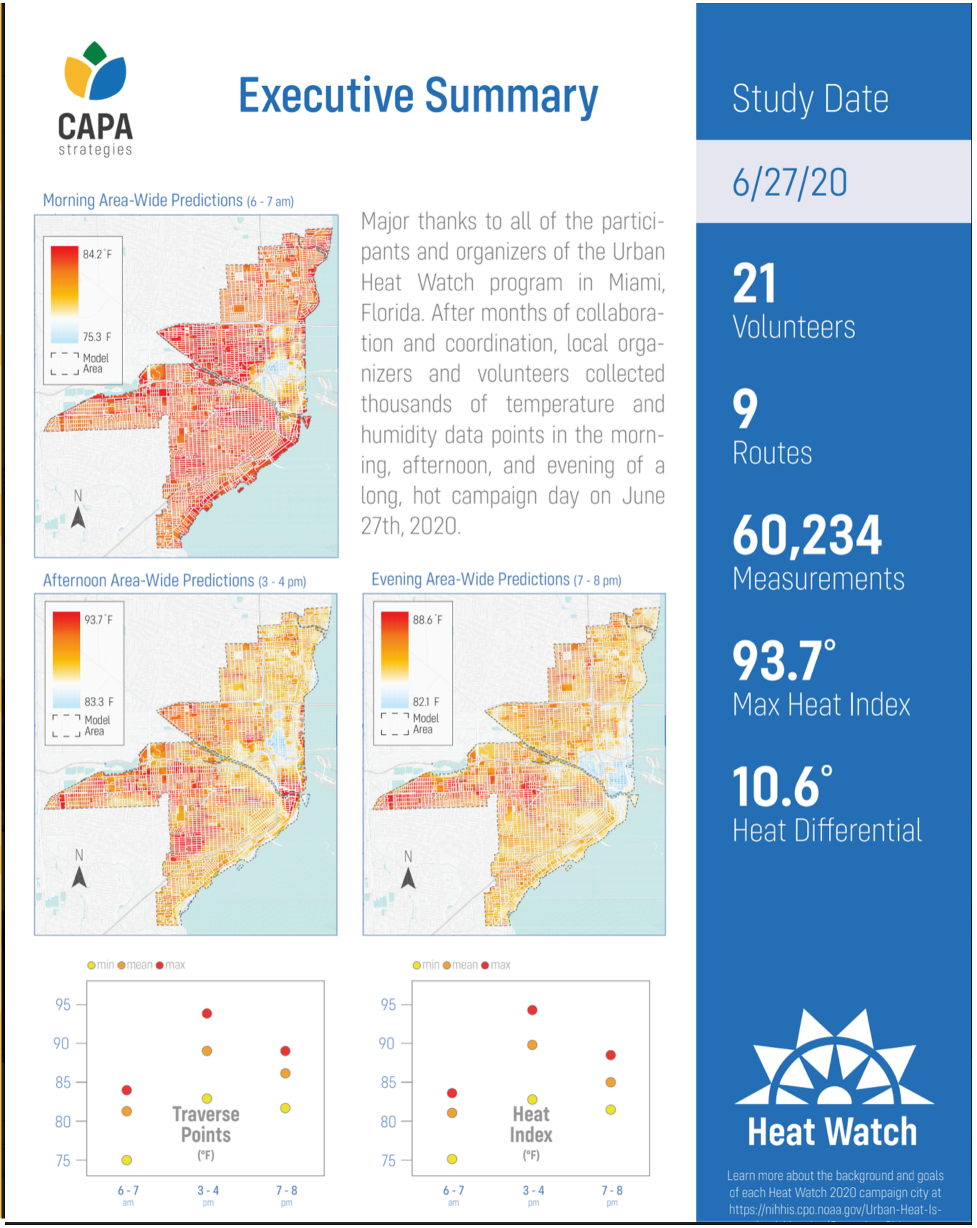




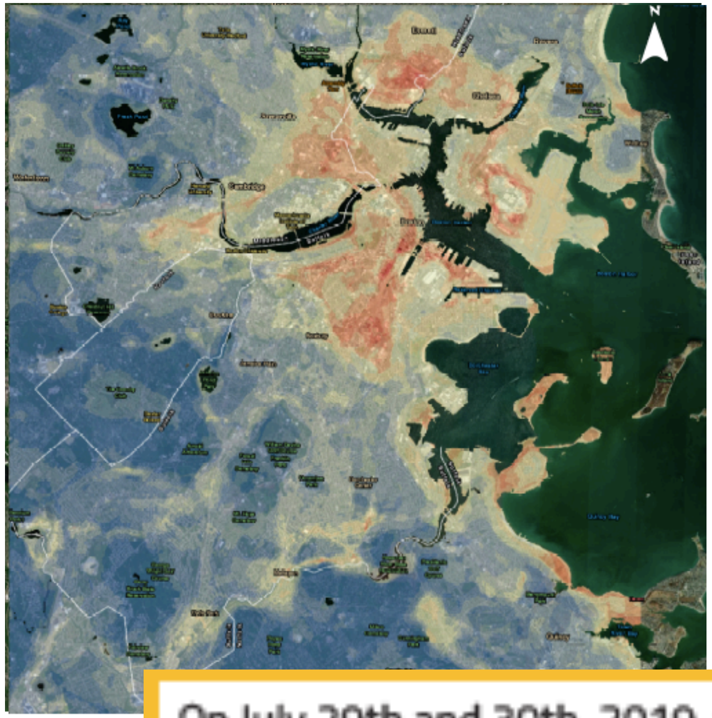


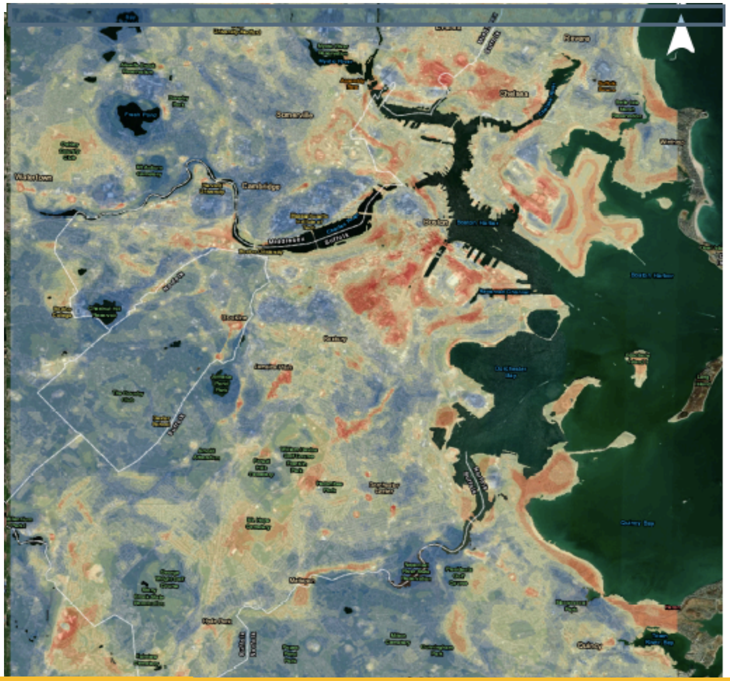
Campaign Outputs & Impacts





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

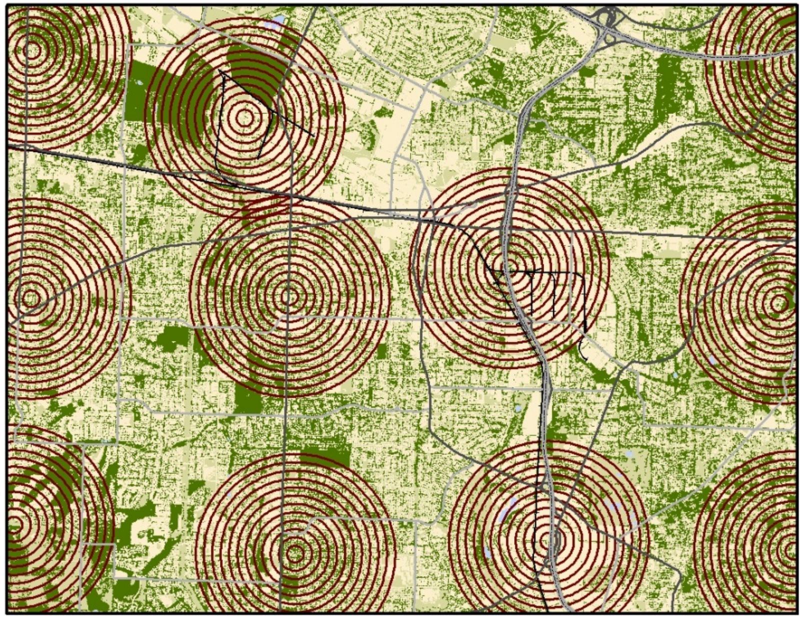
Traverse	Temperature			Heat Index		
	MIN	MAX	MEAN	MIN	MAX	MEAN
6 - 7 am	71.8 F	82.7 F	74.5 F	73.0 F	87.7 F	75.8 F
3 - 4 pm	87.3 F	102.3 F	90.8 F	91.0 F	108.9 F	96.1 F
7 - 8 pm	78.7 F	91.1 F	84.0 F	80.5 F	97.7 F	88.9 F

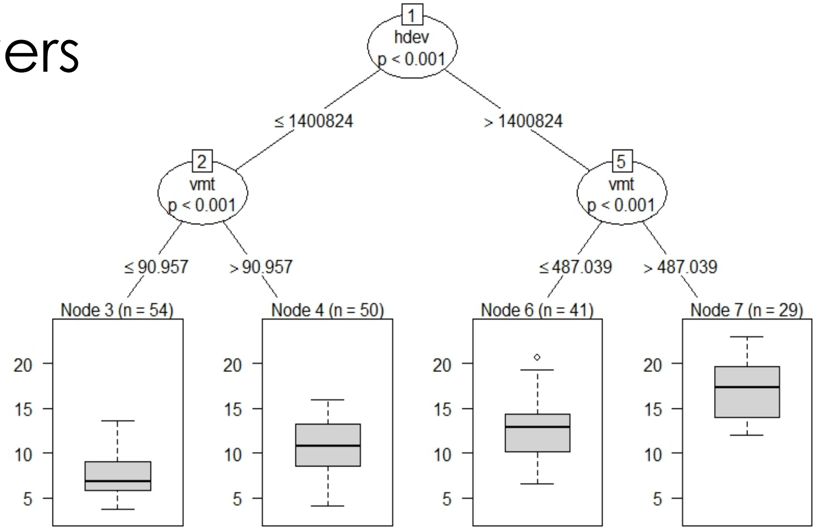
Approaches to Validation

- 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

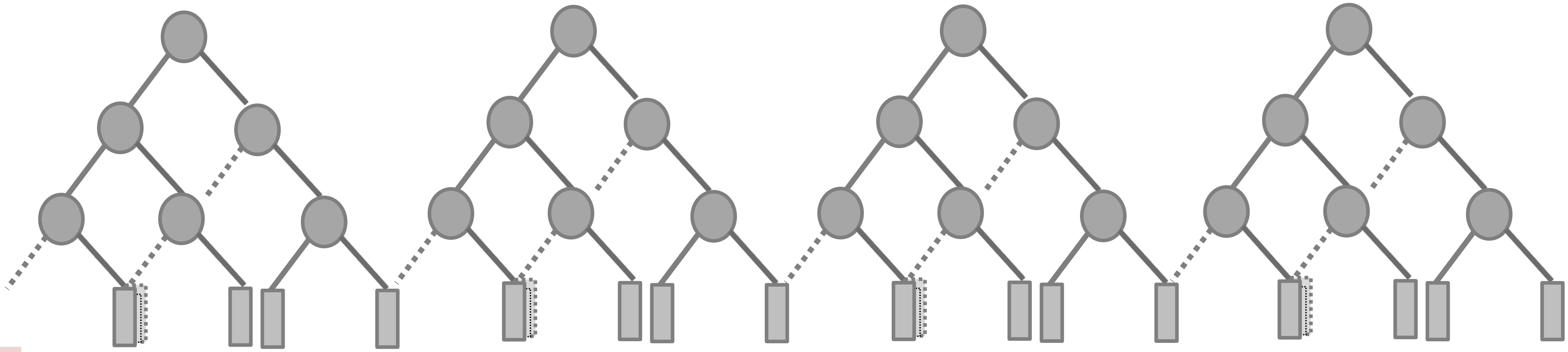
- Integrate ground-based measurements with satellite imagery
  i. Satellite bands provide descriptions for land cover
  ii. Diversity of land covers accounts for variation in temperature measurements
- Identify best predictors of temperatures across all land covers
  i. Use predictors to develop temperature 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

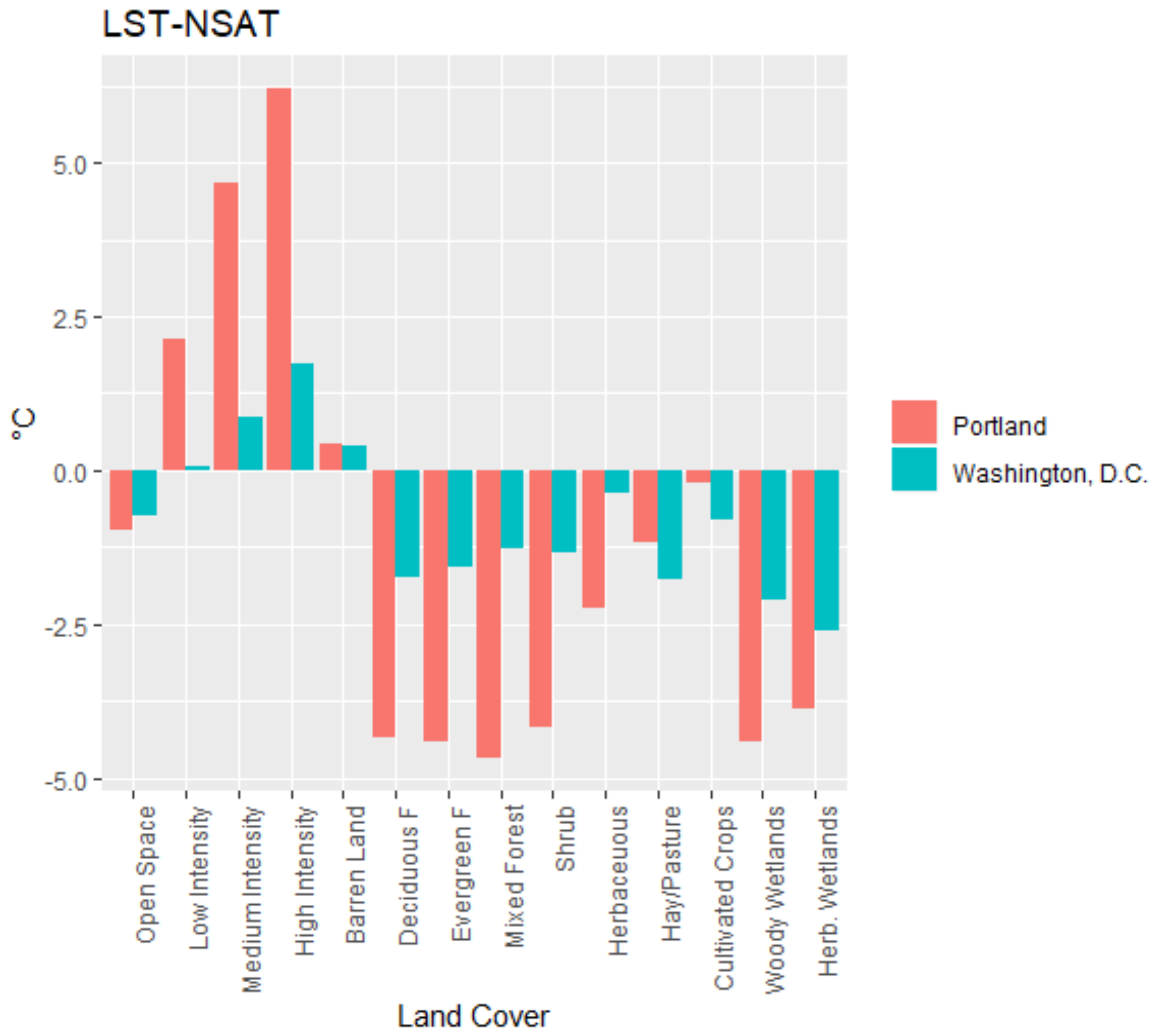
- Developed by Breiman (2001)
- Combine many "weak learners" into a "strong learner"
- Use bootstrap aggregation or **bagging**
- Each tree uses only a **random** subset of predictors
- Highest accuracy for predicting air temperature

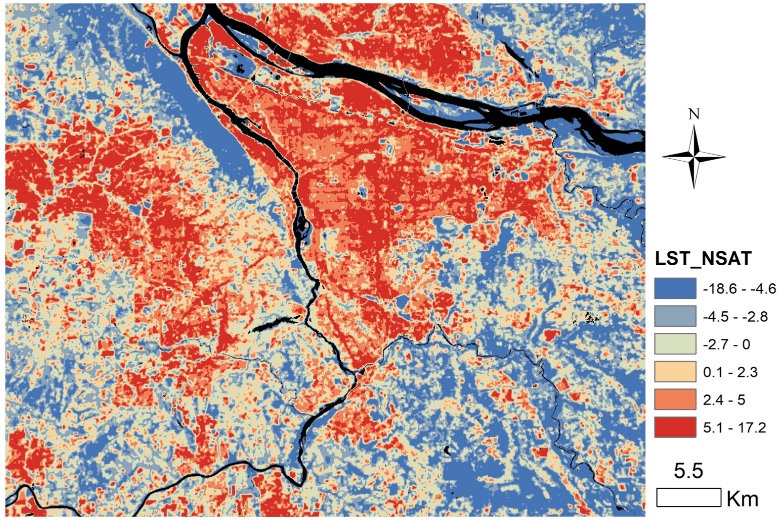


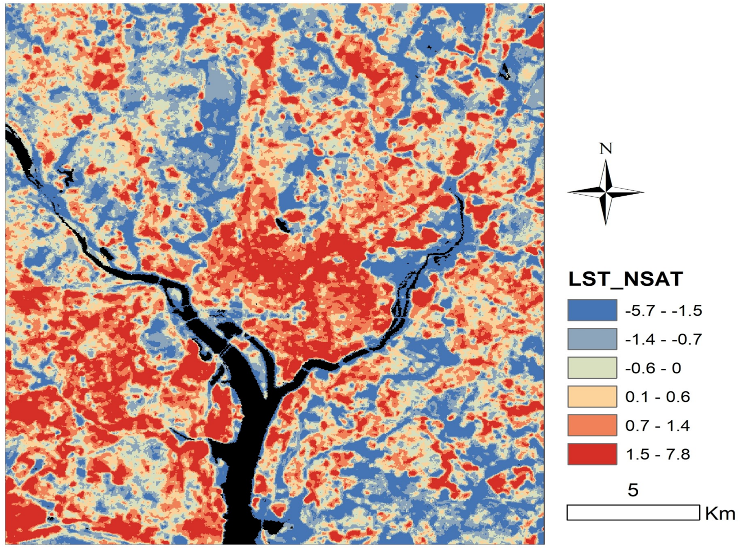
Comparing Satellite with Mobile Temps

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**

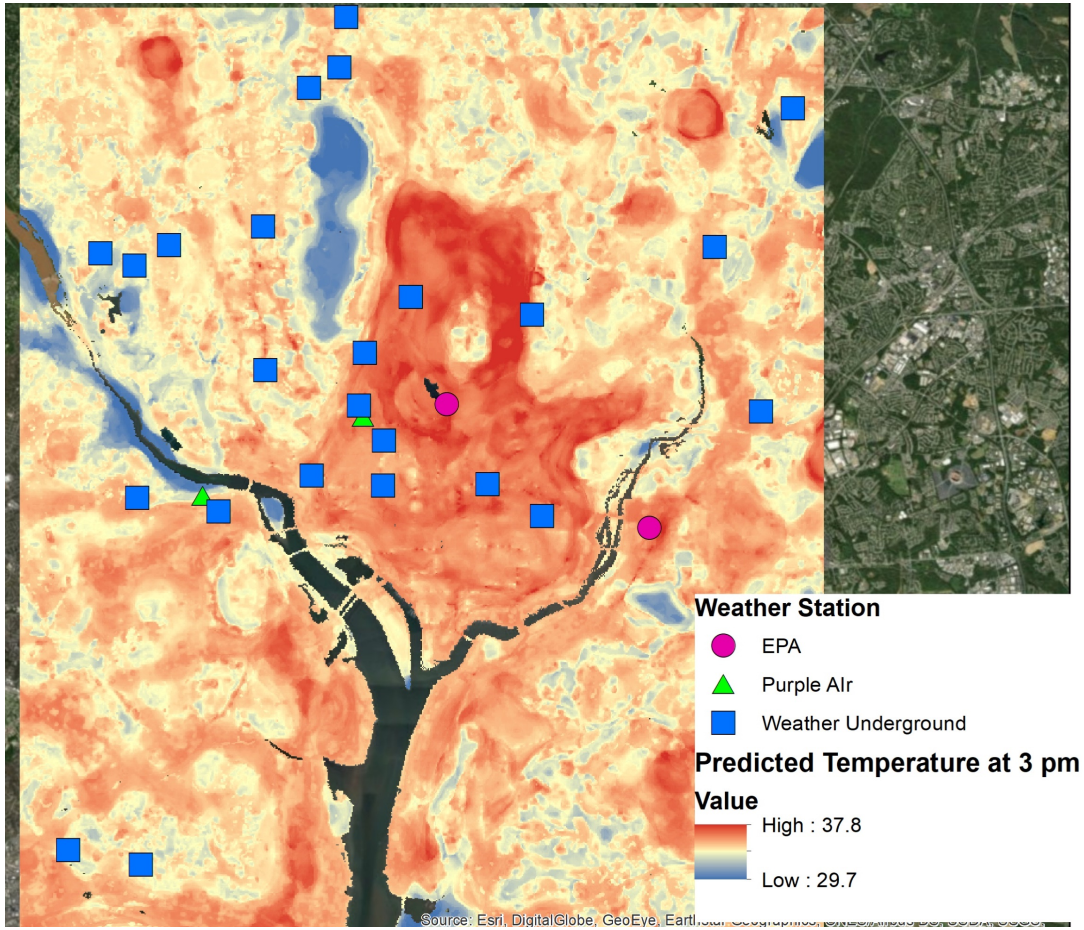
Satellite and Mobile Temps – Effects of Land Cover

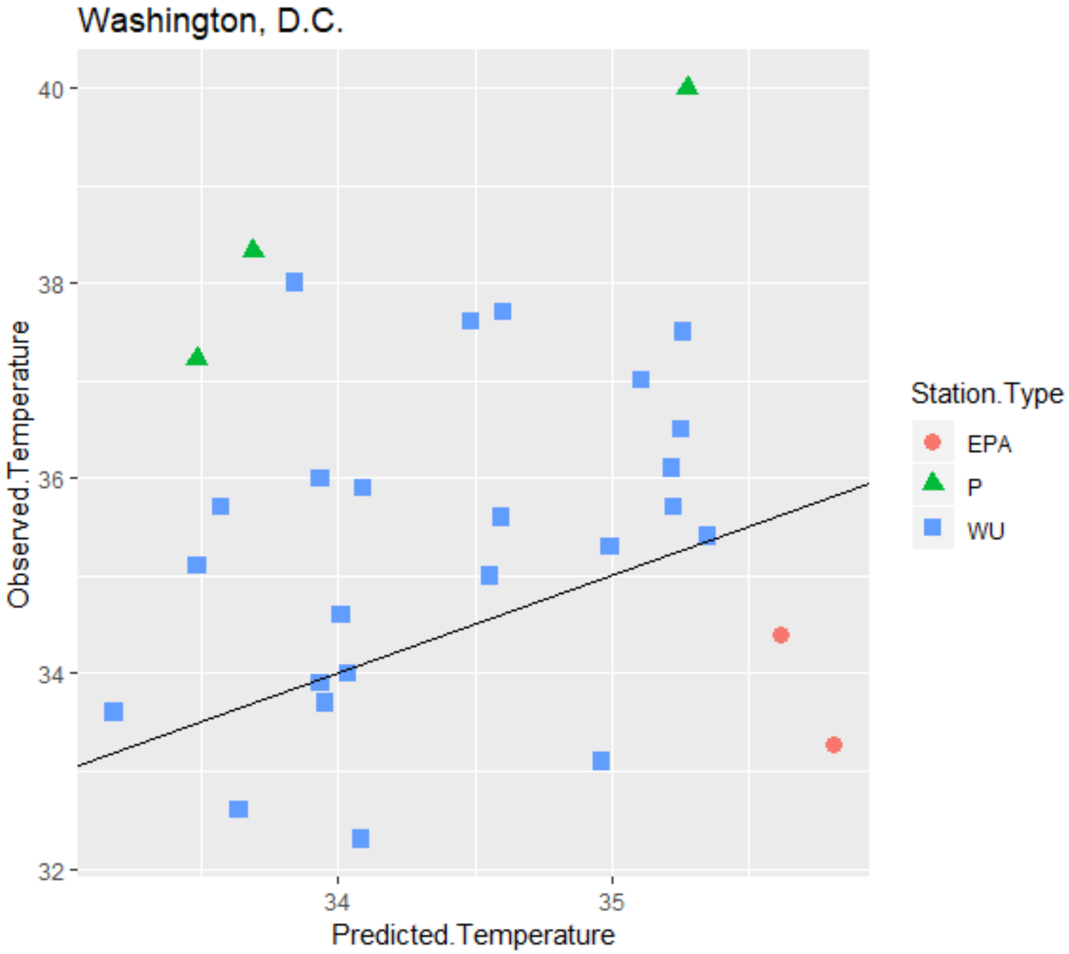






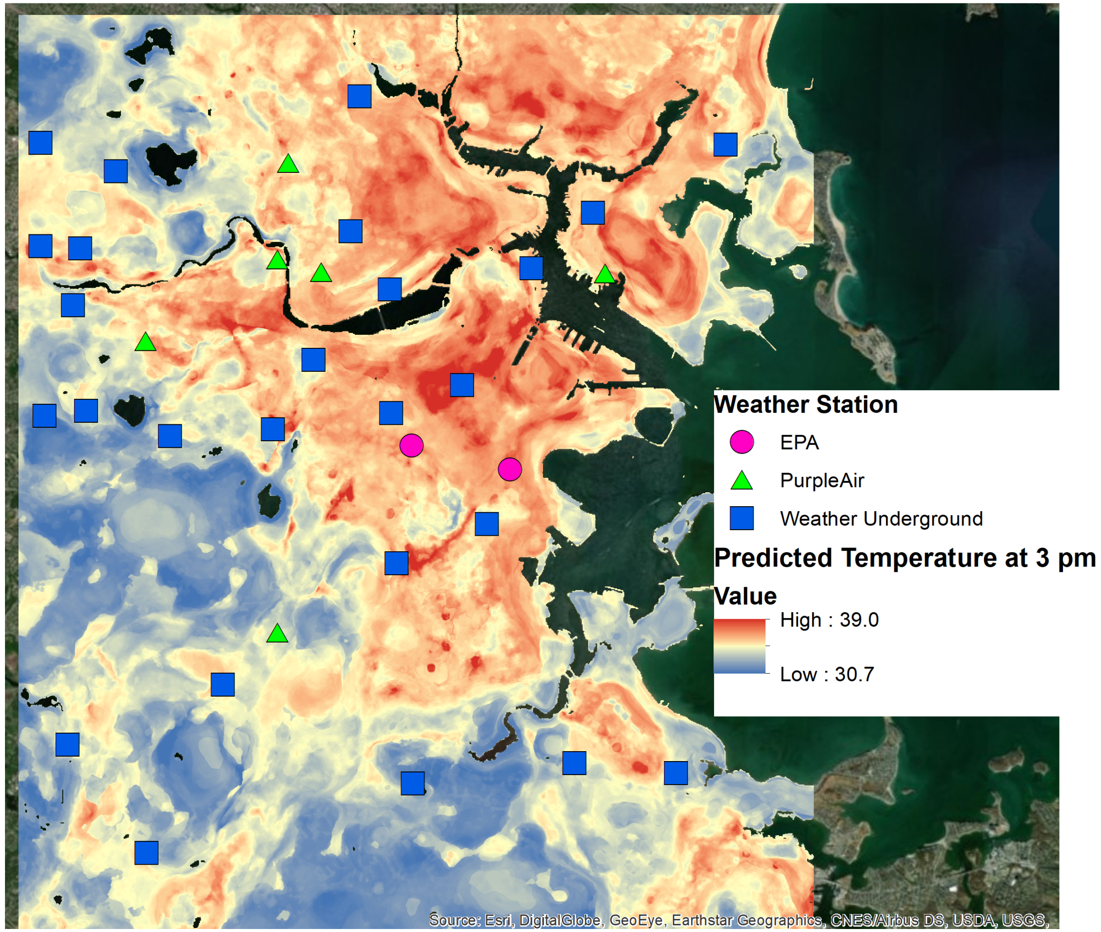
District of Columbia (8/28/2018)

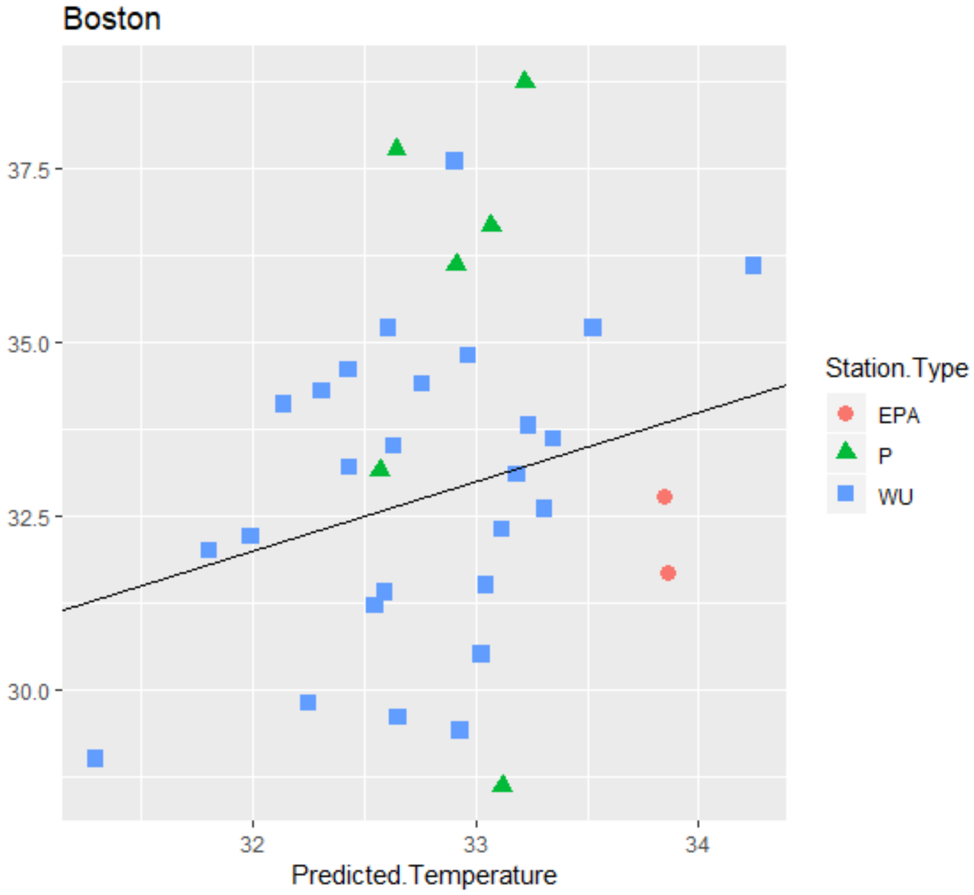




	Number of Stations	RMSE (°C)
EPA	2	1.99
Purple Air	3	4.39
Weather Underground	24	1.73

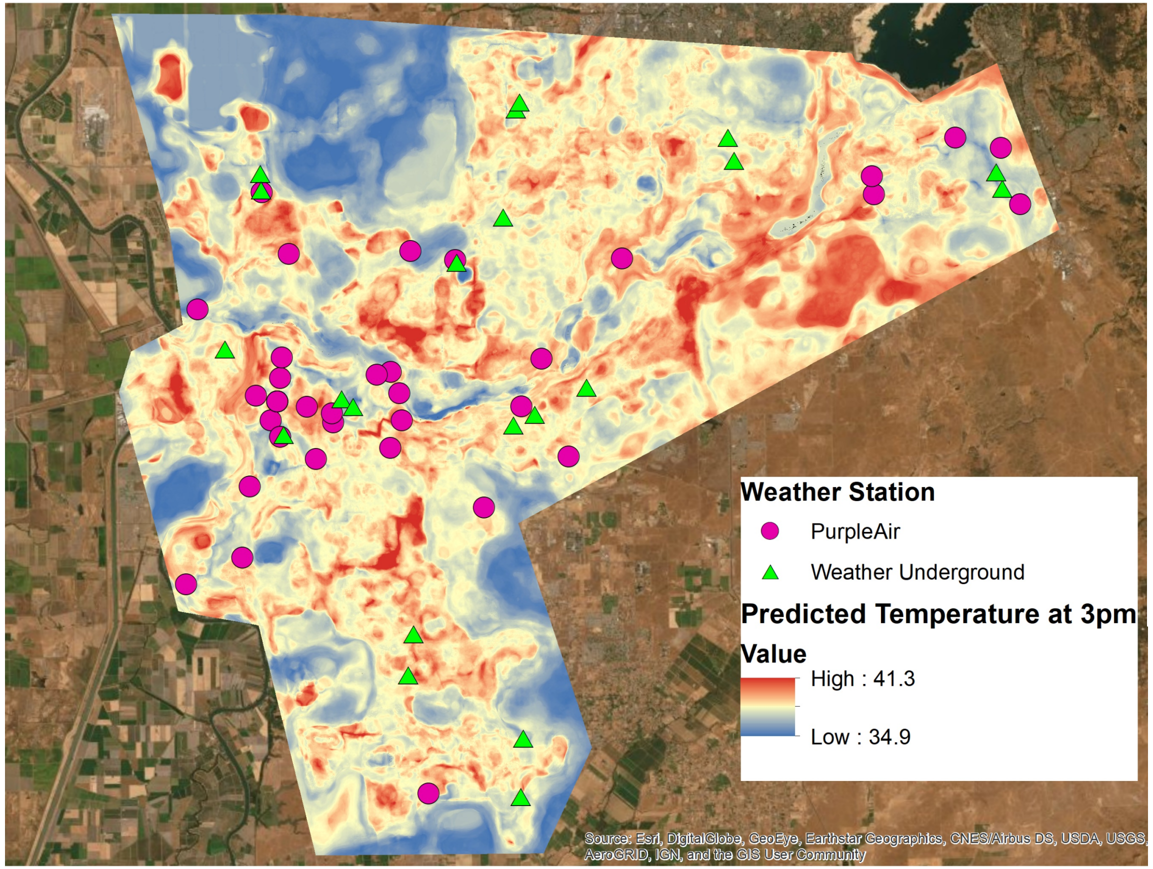
Boston (7/29/2019)

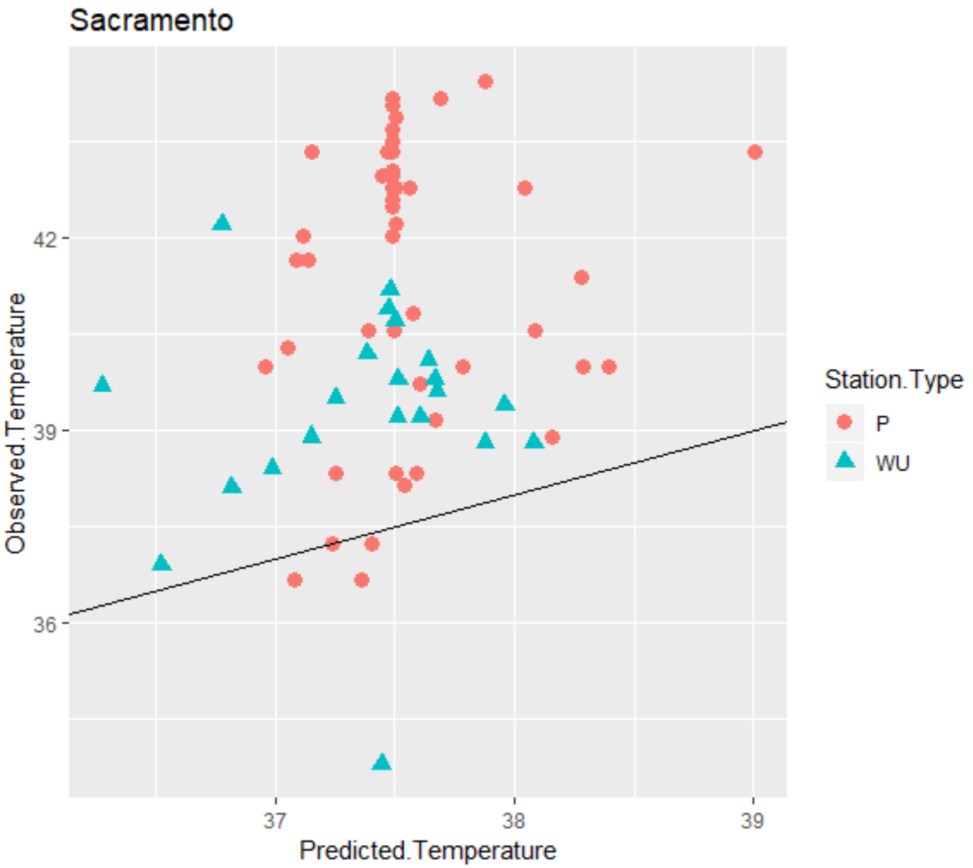




	Number of Stations	RMSE (°C)
EPA	2	1.72
Purple Air	6	4.10
Weather Underground	26	1.98

Sacramento (8/14/2019)





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

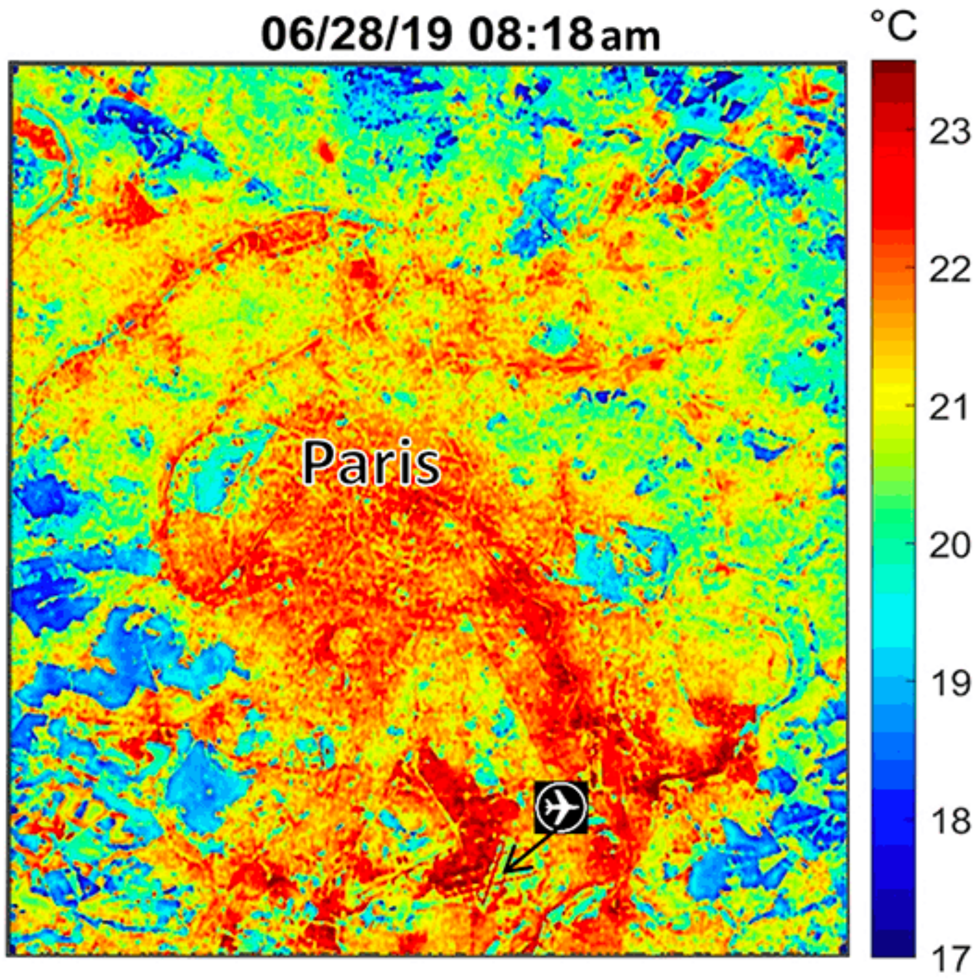
Satellite-Based Measurements

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



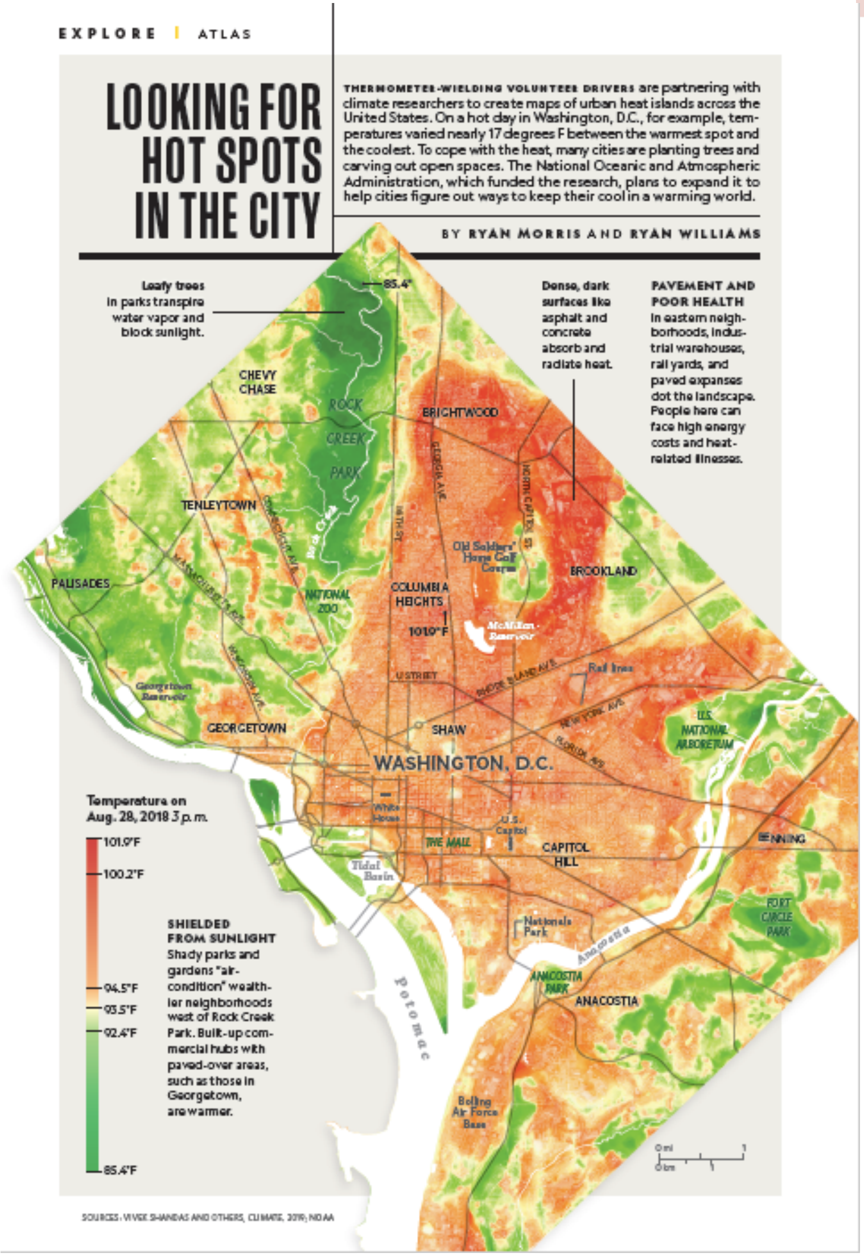
Ground-Based Measurements

Strengths

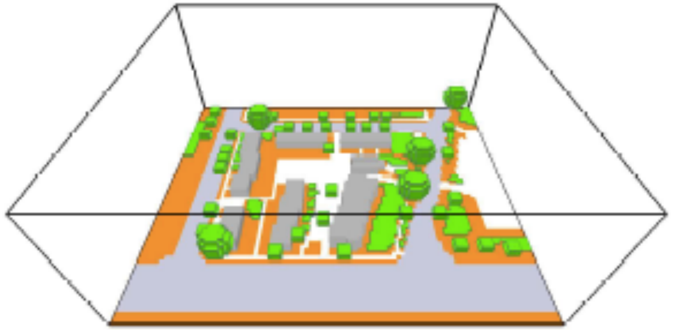
1. Engages community in their place
2. Established 'civic legitimacy' of scientific process and results
3. High resolution outputs (1m, 10m)
4. Diurnal profile of air temperatures
5. Policy applications are evident

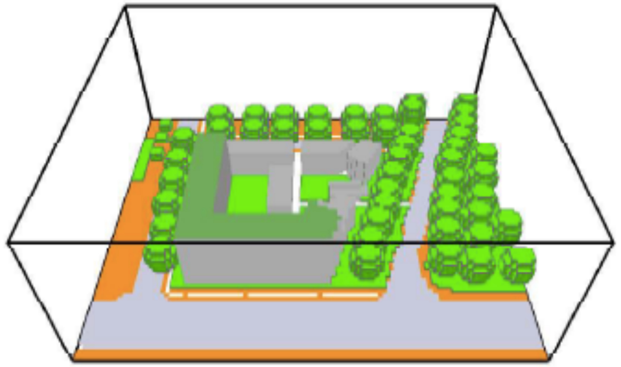
Weaknesses

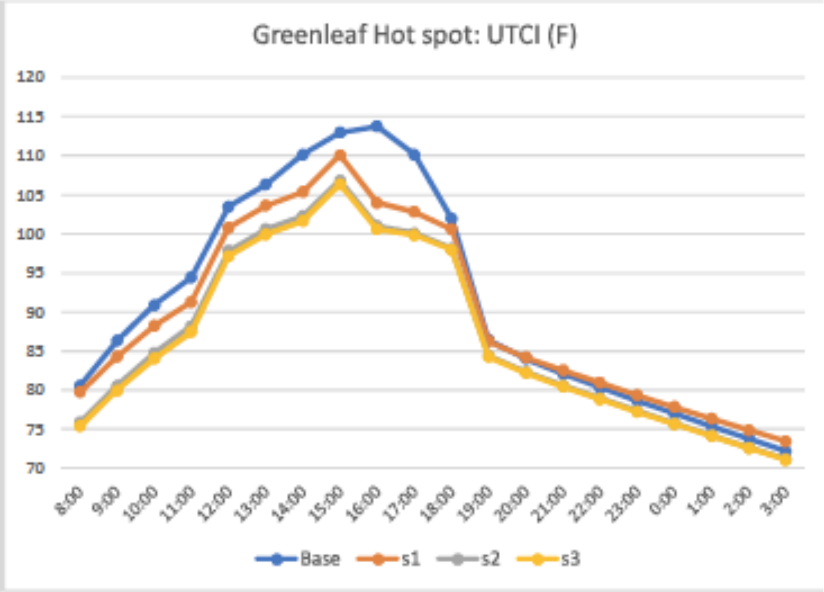
1. Coordination of local community groups requires time and strategy
2. Not free due to engagement and analysis
3. Seasonal differences not [yet] available
4. Clouds or rain can create delays
5. Generalizable models are still forthcoming

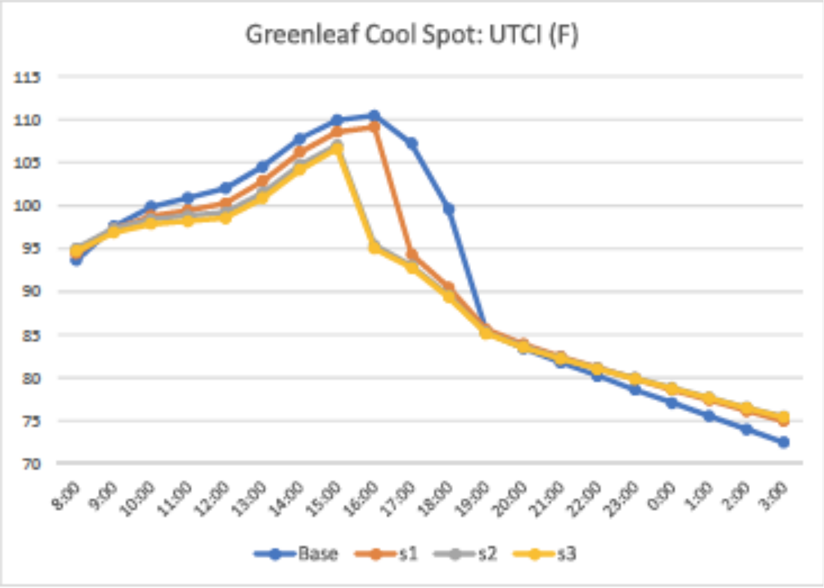


District of Columbia Extensions: Land Use Change









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