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

Professor Vivek Shandas

November 17, 2020
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

<table>
<thead>
<tr>
<th>Author name</th>
<th>Year of publication</th>
<th>Language of publication</th>
<th>City or region studied</th>
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<td>F. Ludwig</td>
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<td>Y. Goldreich</td>
<td>1970</td>
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<td>Johannesburg (South Africa)</td>
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<td>S. Shams</td>
<td>1972</td>
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<td>Kuala Lumpur (Malaysia)</td>
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<td>C. Daniel &amp; K. Krishnamurthy</td>
<td>1973</td>
<td>English</td>
<td>Pune, Mumbai (India)</td>
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<td>E. Jauregui</td>
<td>1973</td>
<td>English</td>
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<td>T. Oke</td>
<td>1973</td>
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<td>St. Lawrence Lowland (Canada)</td>
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<td>T. Oke &amp; G. Maxwell</td>
<td>1975</td>
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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 $T_{\text{max}}$, $T_{\text{min}}$, $T_{\text{mean}}$
- 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
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)

NASA’s Applied Remote Sensing Training Program

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.

2. Establish

- Get to know the Heat Watch process and begin volunteer engagement.
  - Begin recruiting volunteers using provided outreach material.
  - Schedule a kickoff meeting with CAPA program managers to ask questions and review next steps.

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.

4. Activate

- Finish pre-campaign steps by finalizing a campaign date, notifying volunteers and distributed CAPA provided equipment.
  - Using forecasts, confirm the ideal high heat, 10-day Campaign Day.
  - Confirm availability with volunteers and organize backup teams if needed.
  - Receive equipment from CAPA and organize a central meeting time and location to distribute equipment.

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 Organizer ships back the equipment to CAPA.

6. Analyze

- CAPA analyzes provided data to 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 CAPA Team.

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 interpretation.
  - CAPA and City Team meet virtually to explore future possibilities.
  - Next steps are determined and planned for action.

CAPA Heat Watch
Organizer Timeline

- 10-12 weeks pre-campaign: 4-5 hours by Organizer
- 6-10 weeks pre-campaign: 4-5 hours by Organizer
- 2-6 weeks pre-campaign: 6-8 hours by Organizer: 5-7 hour by Volunteer
- 1-2 weeks pre-campaign: 4-5 hours by Organizer: 5-7 hour by Volunteer
- Campaign Day: 4 hours by Organizer: 4 hours by Volunteer
- 6-8 weeks post-campaign: 4 hours by Organizer: 4 hours by Volunteer
- 6-10 weeks post-campaign: 4 hours by Organizer: 4 hours by Volunteer

Weighted Multi-Model Mean

0 10 20 30 40 50 60 70

Campaign Planning

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Campaign Day

HEAT WATCH PROGRAM

“The Rhode Island Heat Watch Program will build on the work of our Health Equity Zones and be an important part of Rhode Island’s efforts to promote equity and health at the community level.”

Dr. Nicole Alexander-Scott
Director, RIDOH

NASA’s Applied Remote Sensing Training Program
Campaign Outputs & Impacts

Executive Summary

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.

Study Date
6/27/20

21 Volunteers
9 Routes
60,234 Measurements
93.7° Max Heat Index
10.6° Heat Differential
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

<table>
<thead>
<tr>
<th>Traverse</th>
<th>Temperature</th>
<th>Heat Index</th>
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<tbody>
<tr>
<td></td>
<td>MIN</td>
<td>MAX</td>
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<tr>
<td>6 - 7 am</td>
<td>71.8 F</td>
<td>82.7 F</td>
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<td>3 - 4 pm</td>
<td>87.3 F</td>
<td>102.3 F</td>
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<tr>
<td>7 - 8 pm</td>
<td>78.7 F</td>
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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

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<th>LOCATION</th>
<th>LandSat LST DATE/TIME</th>
<th>AVERAGE TEMP LST</th>
<th>LOW/HIGH/AVG LST</th>
<th>NSAT SURVEY DATE</th>
<th>AVERAGE DAILY NSAT</th>
<th>LOW/HIGH/AVG NSAT</th>
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<td>64/85/75</td>
<td>08/30/18</td>
<td>92°F</td>
<td>78/93/86</td>
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<td>85°F</td>
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<td>84°F</td>
<td>57/84/72</td>
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<td>59/89/74</td>
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<td>74/97/86</td>
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Satellite and Mobile Temps – Effects of Land Cover

LST-NSAT

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<td>Herb Weigands</td>
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Map showing LST_NSAT values with color legend and map scale.
District of Columbia (8/28/2018)

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<td>Weather Underground</td>
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<td>1.73</td>
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Boston
(7/29/2019)

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Sacramento (8/14/2019)

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<tr>
<td>Weather Underground</td>
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<td>2.57</td>
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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
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

Greenleaf Hot spot: UTCI (°F)

Greenleaf Cool Spot: UTCI (°F)

NASA’s Applied Remote Sensing Training Program
Contact

Vivek Shandas

vshandas@pdx.edu