Remote & In-Situ Investigations of a Medium City Urban Heat Island

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Motivation

- It is estimated that up to 68% of the world's population will live in urban areas by the year 2050[1].
- Urban areas contain high concentrations of impervious surfaces (i.e. roads and buildings) and often have a higher heat capacity than the surrounding environment. Additionally, waste heat from HVAC, vehicle exhaust, and industrial emissions lead to the ***Urban Heat Island*** (UHI) effect[2].
- The UHI effect for large cities (>1 million people) is well-documented, however, there is less research on medium and small cities.
- In Georgia, the very strong UHI in Atlanta has been extensively studied[3], but there are currently few studies on the UHI in Augusta, which is Georgia's second largest metropolitan area (approx. 615,000 people).

Background on the Urban Heat Island

Four main types of UHI's have been described:

1. **Surface UHI: Elevated land surface (skin) temperatures in urban areas.**
2. **Canopy Layer UHI: Elevated air temperatures from near-surface to top of building height in urban areas.**
3. Boundary Layer UHI: Elevated air temperatures from above building tops to the height of the planetary boundary layer.
4. Hydrologic UHI: Elevated stream and water temperatures following rain events due to runoff heating over impervious surfaces.

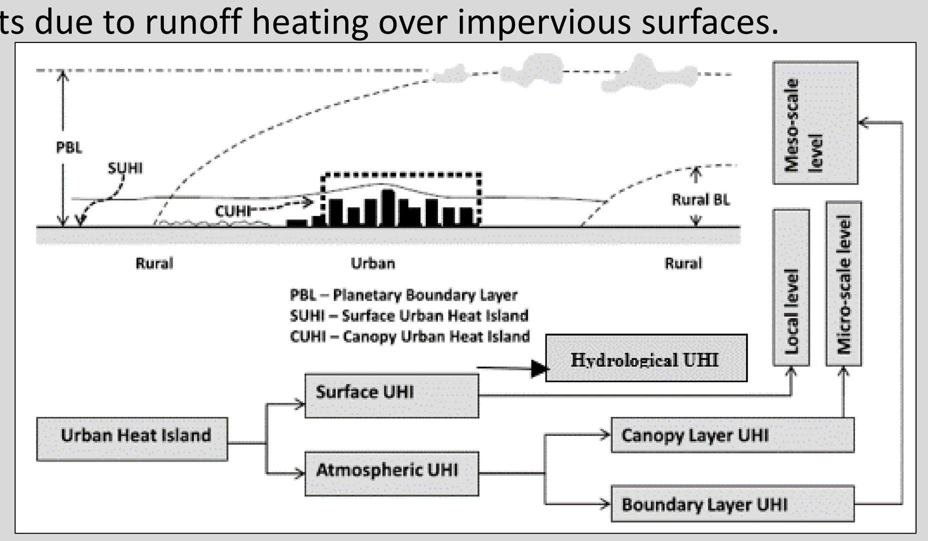

Figure 1: Hierarchy and structure of UHI types, and corresponding spatial scales. Hydrologic UHI spatial scale is currently undecided in the literature and therefore not included. (Adapted from Kotharkar & Surawar, 2016)[4]

Study Area & Research Objectives

- The Augusta GA-SC Metropolitan Statistical Area (Augusta MSA) covers seven counties across Georgia and South Carolina with a total area of 3,408.7 mi² (Figure 2).
- Augusta-Richmond Consolidated County is the urban center (pop. 202,000 people) and is majority Black or African American with a 22% poverty rate.
- Augusta is considered to be a medium city, and studying its UHI will expand our knowledge of UHI's at different city scales.

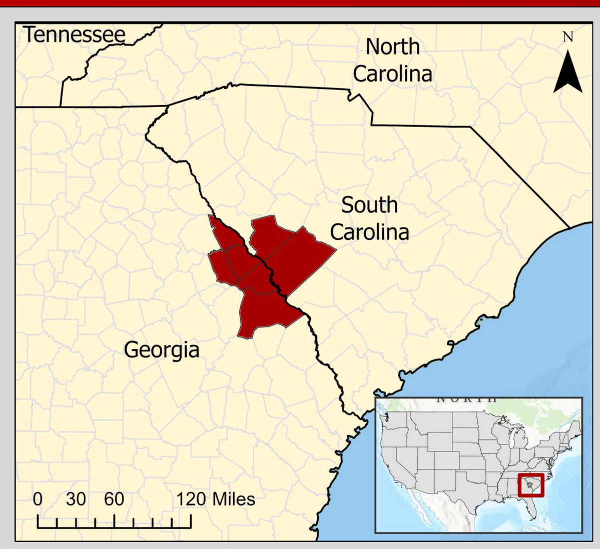

Figure 2: Augusta GA-SC MSA (Red)

Main Objective: *Use thermal infrared remote sensing of the SUHI to inform field campaign planning to use established vehicle-based and novel unmanned aerial system (UAS)-based methods of atmospheric data collection via low-cost sensors.*

References & Acknowledgements

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2. U.S. Environmental Protection Agency. (2023, August 16). Heat island effect. EPA.gov. https://www.epa.gov/heatislands
3. Shepherd, J. M. (2005). A review of current investigations of urban-induced rainfall and recommendations for the future. Earth Interactions, 9(12). https://doi.org/10.1175/ei156.1
4. Kotharkar, R. & Surawar, M. (2016). Land use, land cover, and population density impact on the formation of Canopy Urban Heat Islands through traverse survey in the Nagpur Urban Area, India. Journal of Urban Planning and Development, 142(1). https://doi.org/10.1061/(asce)up.1943-5444.0000277
5. Samad, A.; Alvarez Florez, D.; Chourdakis, I.; Vogt, U. Concept of Using an Unmanned Aerial Vehicle (UAV) for 3D Investigation of Air Quality in the Atmosphere—Example of Measurements Near a Roadside. Atmosphere 2022, 13, 663. https://doi.org/10.3390/atmos13050663

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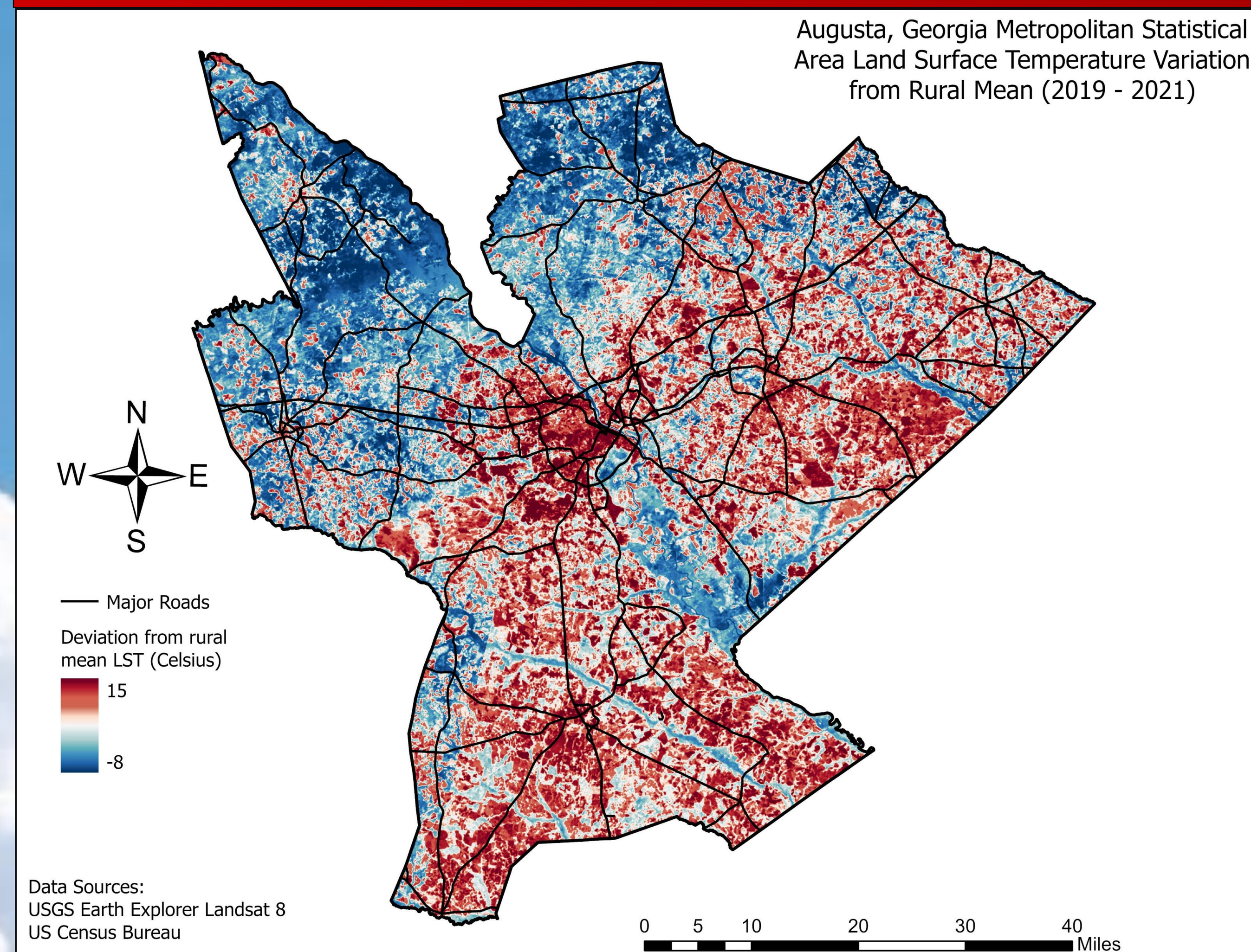
Surface UHI Data & Methods

Preliminary analysis for field planning:

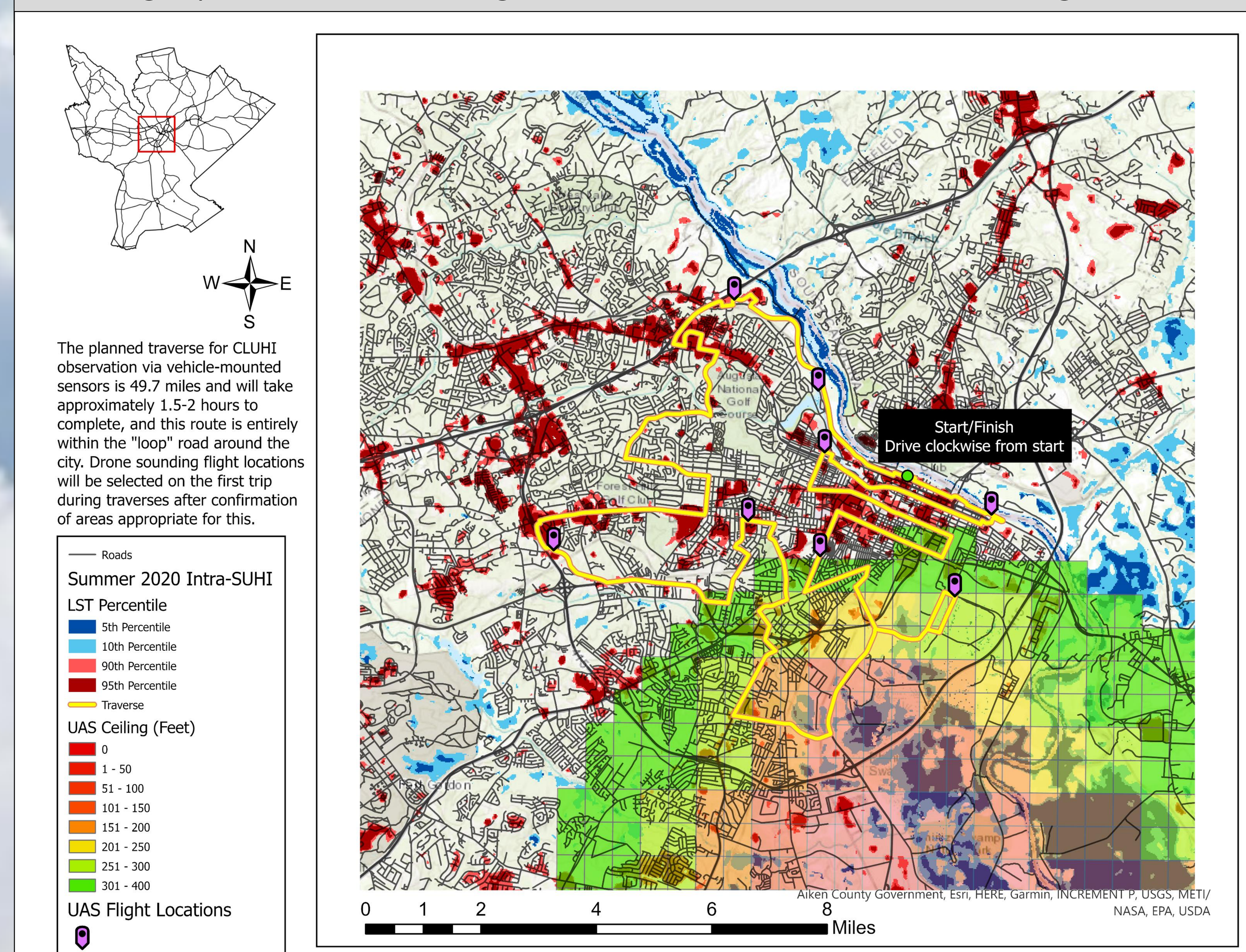
- Satellite Data: Landsat 8/9 Surface Temperature Bundle
- Cloud-free images from 2019-2021 for entire study area coverage, and from 7/11/2020, 7/27/2020, and 6/16/2022 for local-scale, high-accuracy planning.
- ArcGIS Pro used for rescaling satellite data, creating cloud and QA mask, mosaicking imagery from multiple dates and footprints, and visualization.

2019-2021 Surface UHI



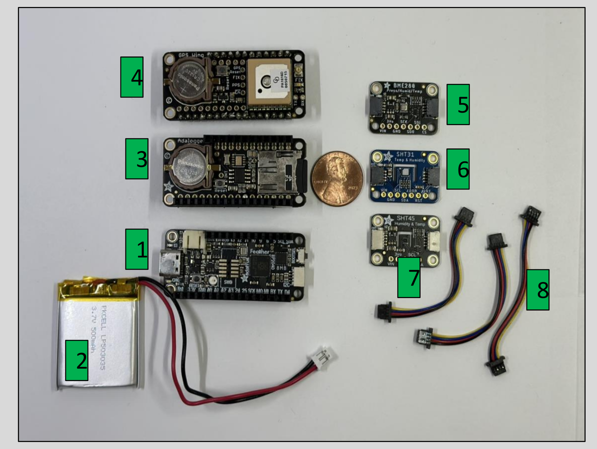
Summer 2020 Intra-SUHI & Route Delineation

- Hotspot analysis for significantly hot (90th & 95th percentile) and cold (5th & 10th percentile) areas inform traverse delineation and UAS flight points to observe the canopy layer UHI (CLUHI).
- FAA controlled airspace ceiling restrictions for drones are included. Maximum drone altitude is restricted to 400 feet AGL outside of controlled airspace.
- The route was planned to be less than 2 hours, and cover as much variation in SUHI intensity as possible.
- Eight public locations along the traverse were selected for UAS flights.



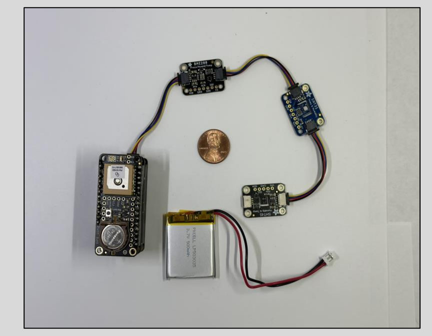
Low-Cost Sensor Hardware

- **Controller:** [1 - $11.95] Adafruit Feather RP2040 (RaspberryPi)
- **Battery:** [2 - $ 7.95] Lithium-Ion Polymer 3.7V, 500mAh
- **Data Logger:** [3 - $ 8.95] Adafruit Adalogger FeatherWing – RTC + SD
  [$ 4.95] 512mb microSD Card
- **GPS Unit:** [4 - $24.95] Adafruit Ultimate GPS FeatherWing
- **Temperature + Humidity Sensors:**
  [5 - $14.95] Bosch BME280 (+ pressure)
  [6 - $13.95] Sensirion SHT31-D
  [7 - $12.50] Sensirion SHT45
- **Accessories:** [8 - $0.95 x 3] STEMMA QT/Qwiic JST SH 4-Pin Cable – 50mm



Sensor Components - Disassembled

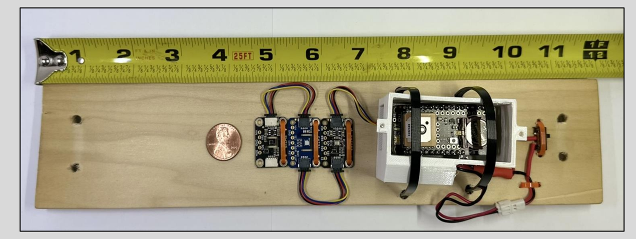
Total Cost per Sensor Unit: $103.00



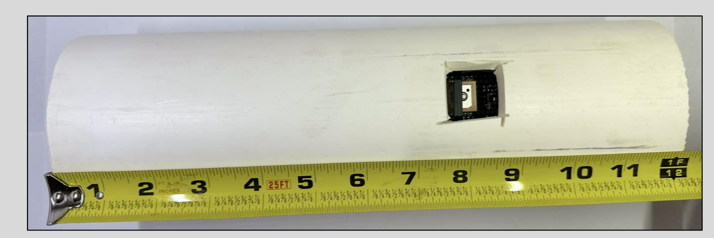
Sensor Components – Assembled Unit

Vehicle-Borne Sensor Housing

- Sensors and controller unit are mounted to a 12″ x 2″ x 0.25″ wood plank with plastic zip ties. The controller is placed in a 3D-printed housing for protection.
- The assembled wood plank slides into a 12″ long piece of 3″ Schedule 40 PVC pipe to isolate the sensors from wind while driving.
- The assembled tube is secured to a milk crate on the roof of the collection vehicle to be elevated from the vehicle's boundary layer while driving.
- Mounting height is approximately 8 feet above the ground (≈ 2.5 meters).



Assembled sensor unit PVC tube insert

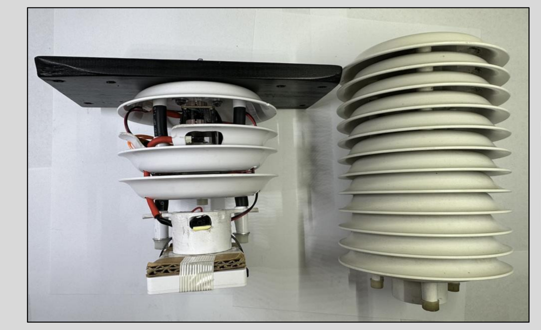


Assembled roof-mounted sensor unit with cutout for GPS receiver to have clear sky view

UAS-Borne Sensor Housing

- Based on a weather station thermometer multi-plate radiation shield that was disassembled and heavily modified to be carried by a DJI Matrice 600 Pro.
- A small fan is employed to provide active ventilation to the sensors to avoid stagnant air under the UAS affecting the observations.
- The modified radiation shield is attached to an 8″ x 4″ x 0.5″ wood plank that attaches to rails on the underbody of the UAS.

Side Views



UAS Housing and radiation shield it is based on

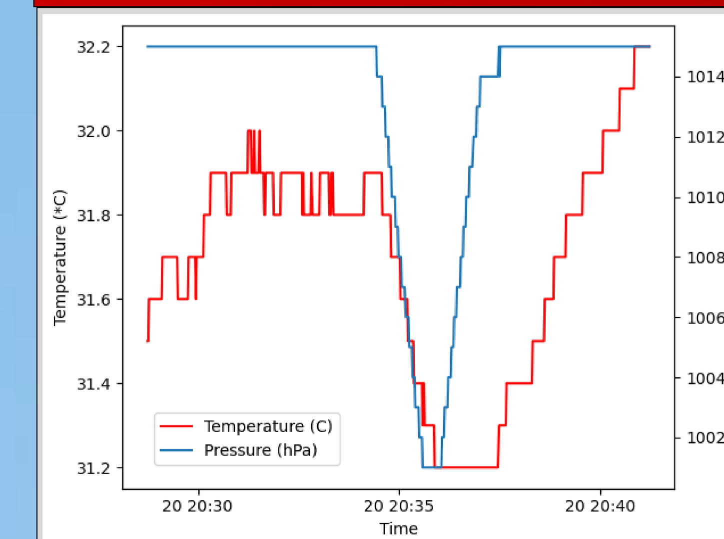
Vehicle-Borne Observation Methods

- Temperature, pressure, and relative humidity observations were recorded at a frequency of 1 Hz.
- The planned traverse was driven four times/day for each day of data collection, starting at 7:00AM, 11:00AM, 3:00PM, and 9:00PM.
- Field collections took place as three two-day trips, and the traverse was driven in opposite directions on each day.
- The traverse was driven at the posted speed limit to not impede traffic, and the typical speed limit along the traverse was 35 miles/hour.

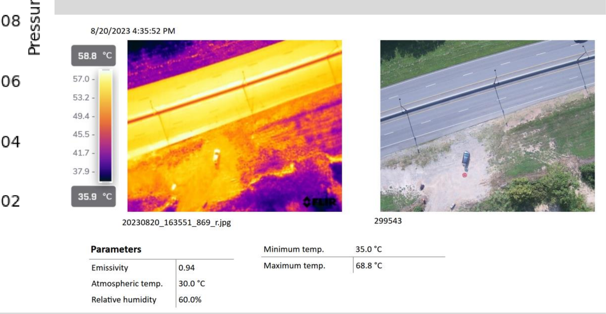
UAS-Borne Observation Methods

- The sensor payload was mounted directly underneath the UAS body. This is an area where air is mostly undisturbed by rotor wash, demonstrated by Samad et al. (2022)[5] on an identical DJI Matrice 600 Pro.
- The UAS payload was complemented with a radiometric thermal imager (FLIR Duo Pro r) to record surface temperature at the flight locations every 15 seconds.
- The UAS was flown vertically to 400 feet (122 meters) at a vertical speed of 6.6 ft/s (2 m/s).
- At the FAA-mandated 400-foot ceiling, the UAS hovered for 15 seconds before descent to allow the imager to capture the full ground scene.

Field Observation Visualizations



Vertical profile and thermal imagery for drone flight conducted at 4:30PM EDT on August 20, 2023, at the point marked on the map by a green arrow.

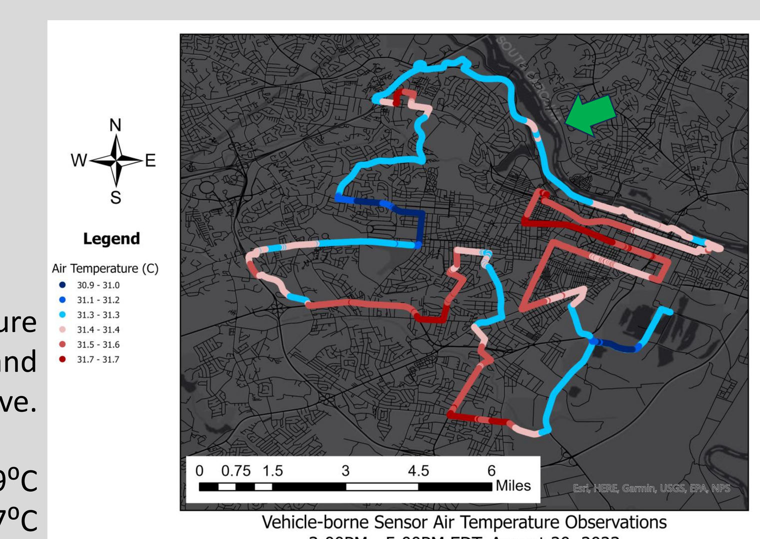


A lapse rate of approximately 5.7°C/km is observed.

Ongoing work is correcting the offset response in temperature and pressure.

Vehicle-borne air temperature observations for the same time and date as the plot above.

Maximum: 30.9°C
Minimum: 31.7°C



Low-Cost Sensor Benefits & Challenges

Benefits:

- Low-cost sensor systems are, as the name implies, very cheap compared to traditional off-the-shelf sensors.
- The researcher or team can have full customizability in terms of the observations recorded and observation frequency, as well as full control of how the system is encased and deployed.
- For the price of one off-the-shelf sensor, several identical units can be made to enable low-budget projects or large-scale field deployments.

Challenges:

- The researcher or team is wholly responsible for controller and sensor selection, assembly, testing, calibration, and maintenance.
- Technical skills such as soldering, 3D design, fabrication, and machine programming are required.
- Calibration against a trusted weather station is needed to ensure measurement accuracy, and correction factors may be required.