Ground Urban Heat Island (GUHI):
Strengthening the Connection between Spaceborne Thermal Observations and Urban Heat Risk Management

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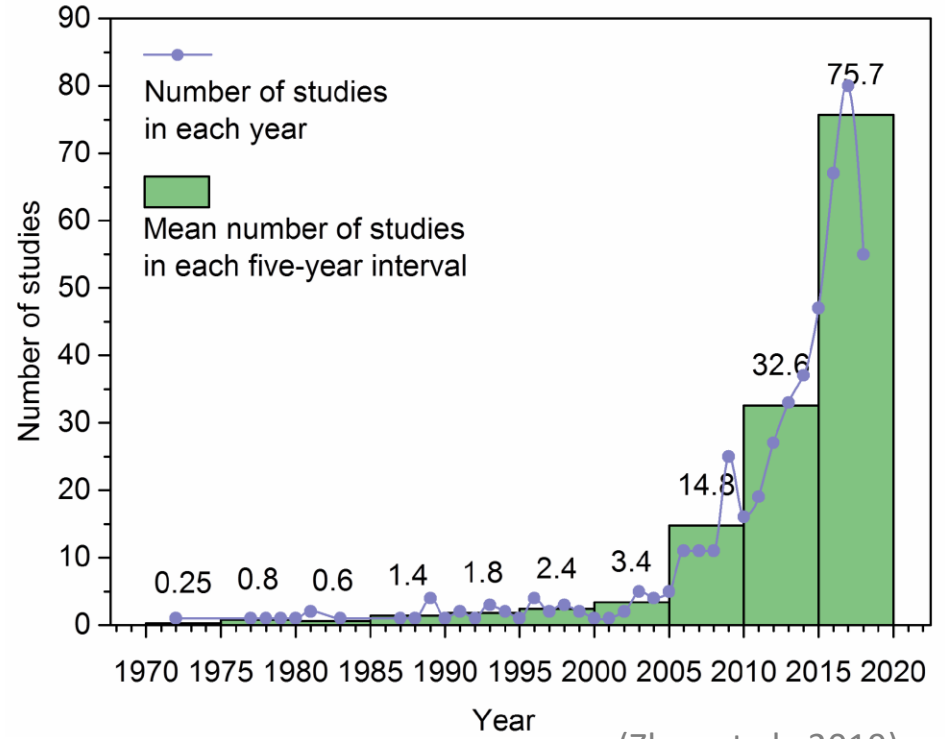
A birdseye view of St. Paul, a city which is reconnecting with a greener and cleaner Mississippi River. Image courtesy Ken Greenberg.

Dramatic Growth in Thermal Remote Sensing Applications on Urban Heat Islands.

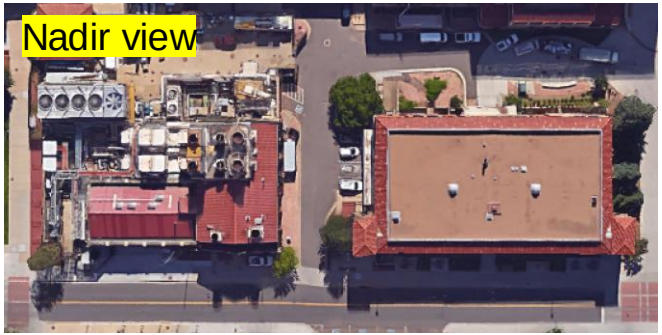


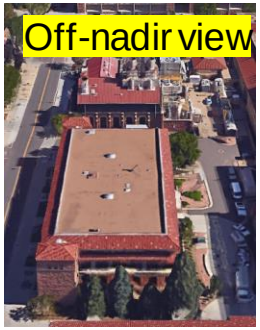
(Zhou et al., 2019)

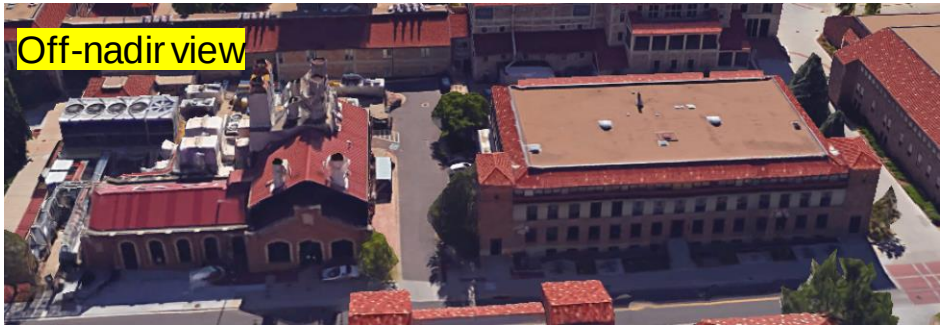
- High accessibility and the fast-growing volume of spaceborne thermal products at various frequencies and spatial resolutions
- Instantaneous scan over a relatively large spatial domain offers indisputable **spatial advantages** to capture the complex temperature structure over heterogeneous urban landscapes (versus T_{air}).

Uncertainties in Thermal Observations for Urban applications

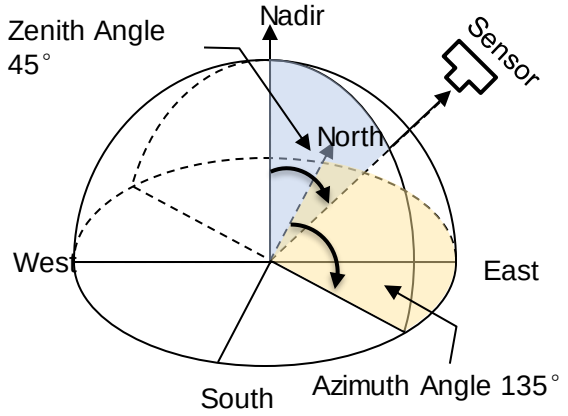
(1) Thermal anisotropy from wide-swath sensors







CU-Boulder, from Google Earth



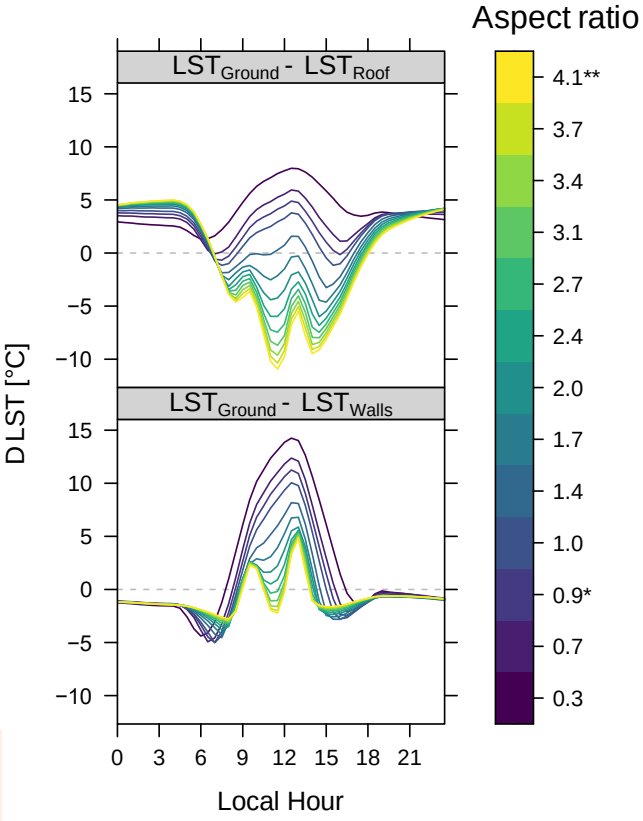
- The daytime LST can vary up to **10K** due to the anisotropy (Lagouarde et al., 2004 RSE)
- MODIS anisotropy possibly contributes an uncertainty of **25%-50%** surface urban heat island effect (SUHI) (Hu et. al., 2016, RSE).

Uncertainties in Thermal Observations for Urban Applications

(2) Overrepresentation of roofs and tree canopies

Marseille, France

New York City, USA

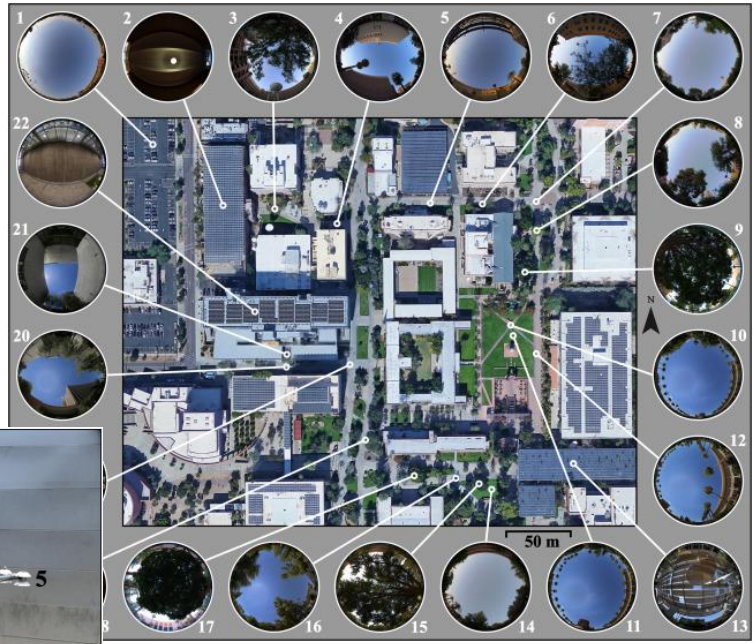


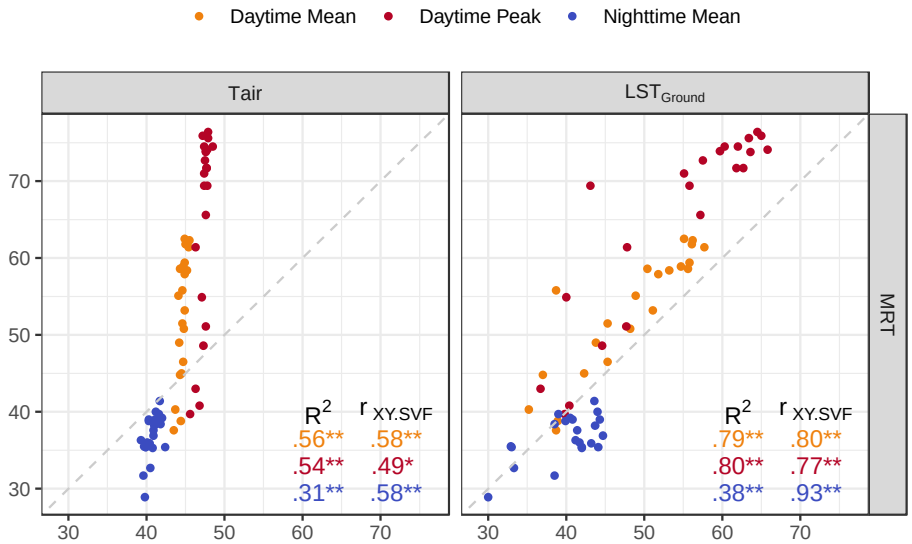
- Roof temperature exhibits significant contrasts with ground temperature depending on street morphologies, showing distinct diurnal patterns.

(Hu & Wendel, 2019, Hu & Uejio, 2024, in review)

Thermal Comfort and LST (Better than Air Temperature)

Tempe, AZ, USA (Middel & Krayenhoff, 2019)





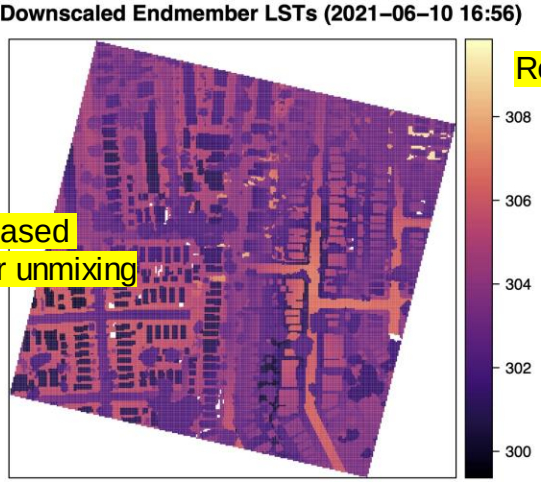
At the human (touch) scale, **LST** (LST_{Ground}) **outperforms** air temperature in characterizing **spatial** thermal comfort (MRT, PET & UTCI).

GUHI: Solution to Improve Thermal Obs. for Heat Applications

Very-high resolution LCLU

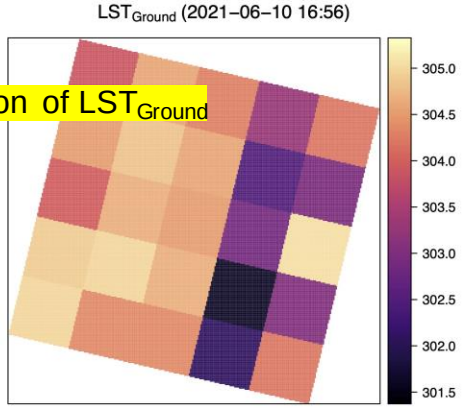
Tree C
Grass/
Building
Roads
Other impervious

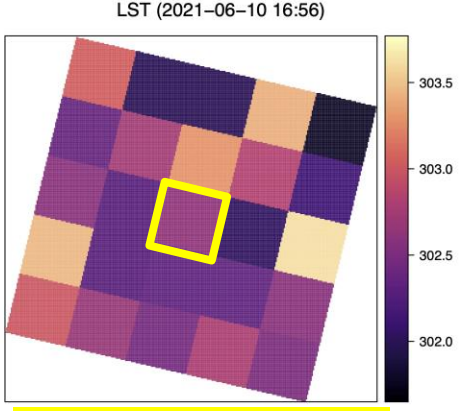
Radiation-based endmember unmixing



Grass/Shrub
Roads
Other impervious

Reconstruction of LST_{Ground}



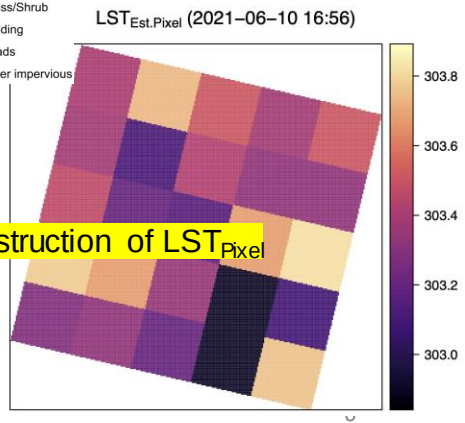


5 x 5 convolutional window

- Similar materials and properties for each element at a neighborhood scale
- Representing the mean status that does not distinguish different illumination conditions
- Spatially well realigned and temporally representative.

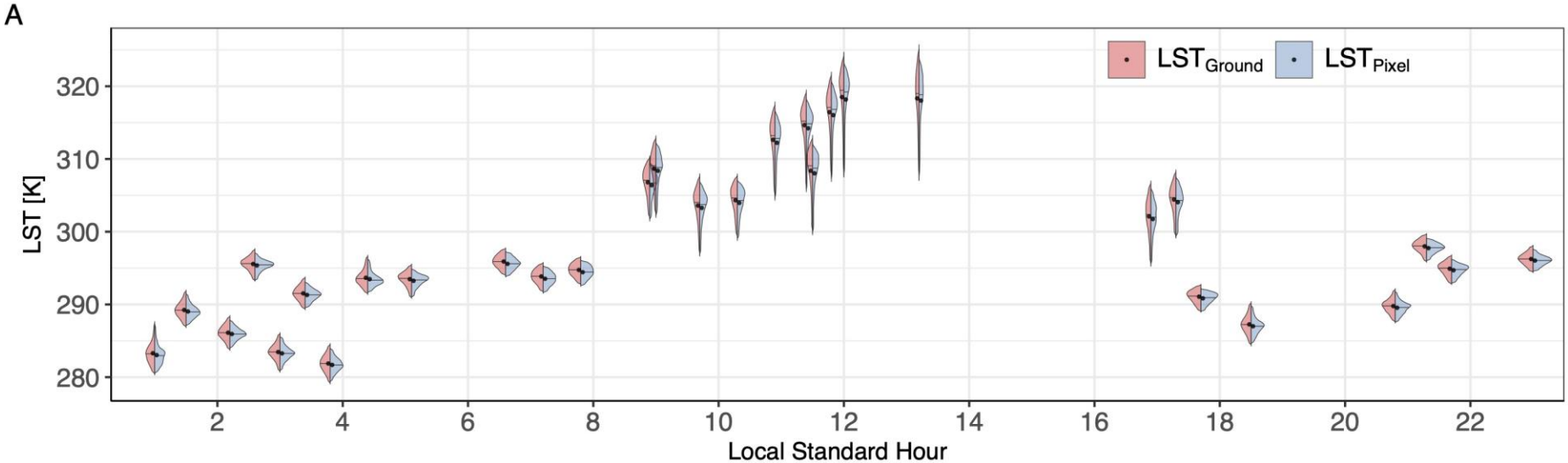
Tree Canopy
Grass/Shrub
Building
Roads
Other impervious

Reconstruction of LST_{Pixel}



Temporal and Spatial Patterns of GUHI

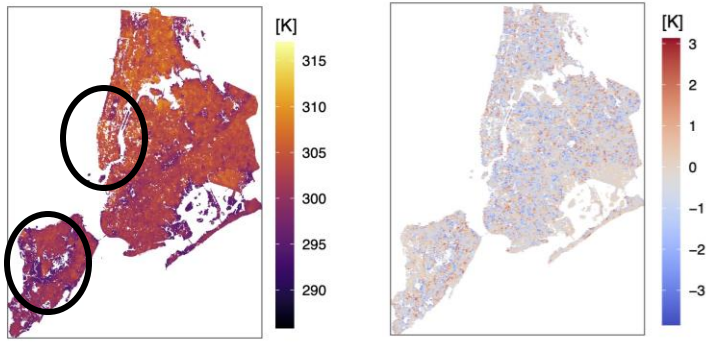
Data: **35** clear-sky summer ECOSTRESS LST images were analyzed, representing spatial LST variations diurnally.

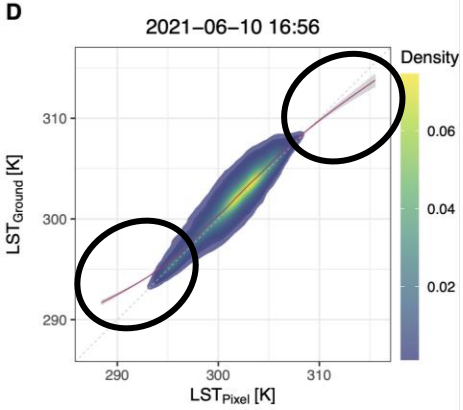


The diurnal change of GUHI is similar to SUHI but generally exhibits **larger intra-urban spatial variations** with slightly **higher mean** temperatures.

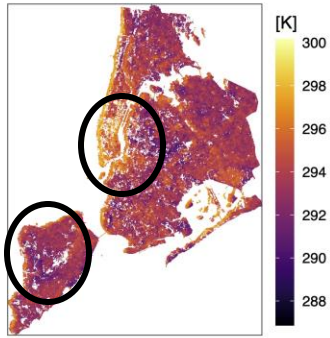
Temporal and Spatial Patterns of GUHI

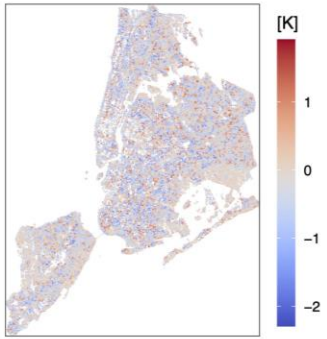
Day

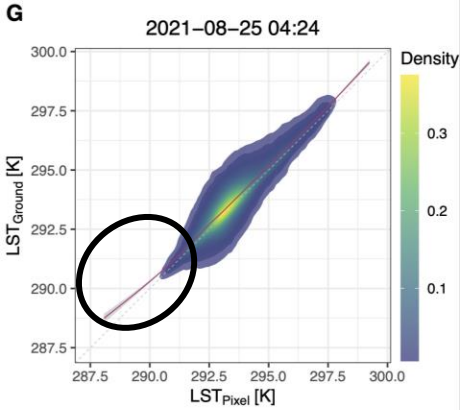




Night

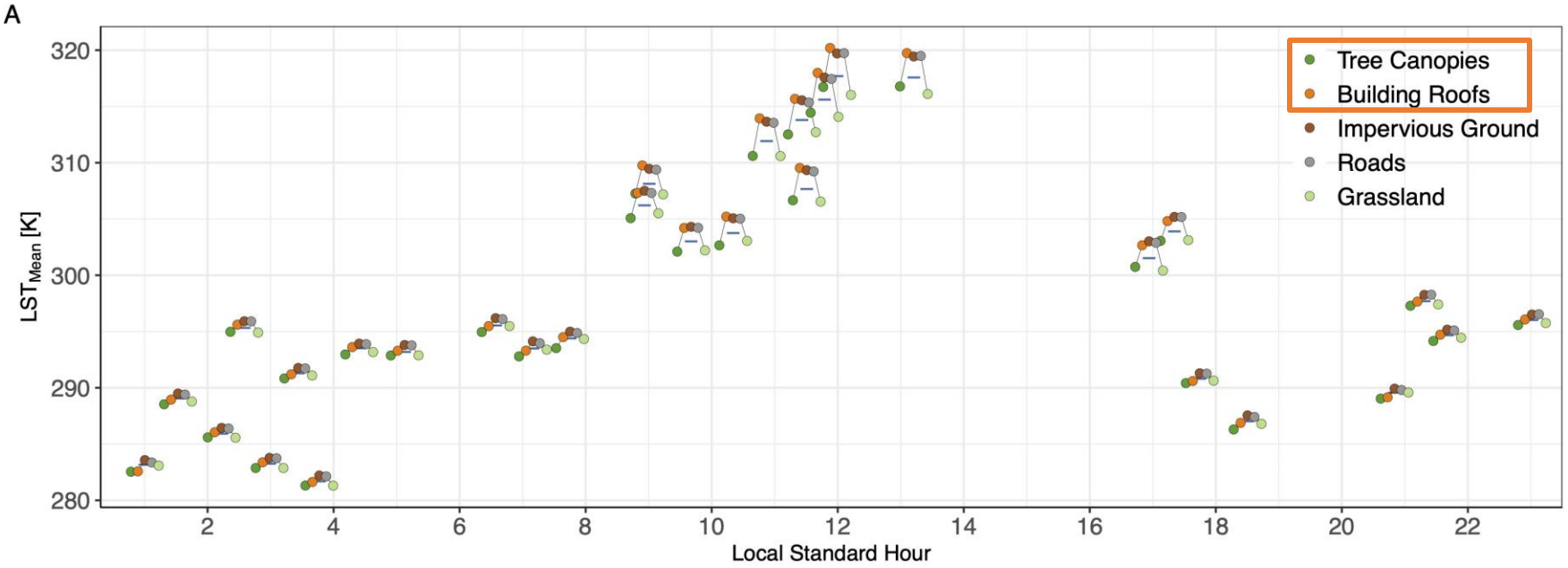






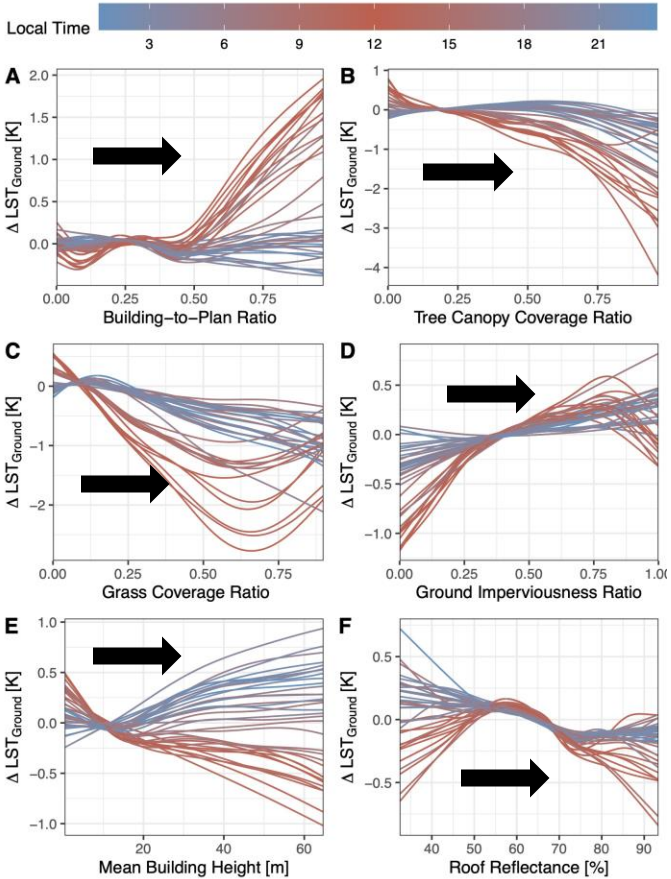
- The overall diurnal GUHIs **generally resemble** the typical patterns observed in SUHI.
- **Significant contrasts are evident at the local scale**, showing a rather random salt-and-pepper pattern in their differences.
- Daytime LST_{Ground} tends to be **cooler** (**warmer**) than LST_{Pixel} over the **hottest** (**coolest**) regions.

Drivers for Intra-urban Variations of GUHI



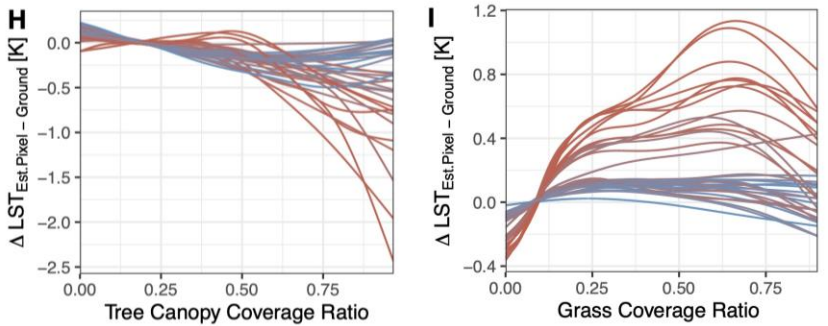
City-wide: Roofs and tree canopies are **warmer** (**cooler**) than human-made and natural **ground components** during the **daytime** (**nighttime**)

Drivers for Intra-urban Variations of GUHI



Generalized additive models unveil local impacts on LST_{Ground}:

- **Building density and mean building height** have strong influence
  Trapping effects > Shading effects
- **Roof reflectance** is mostly negatively correlated with LST_{Ground}
- **Ground imperviousness** is mostly positively correlated with LST_{Ground}
- **Vegetation cooling** is considerably on LST_{Ground}:
  Trees: shading and lower ambient air temp.
  Grass: cooler surfaces

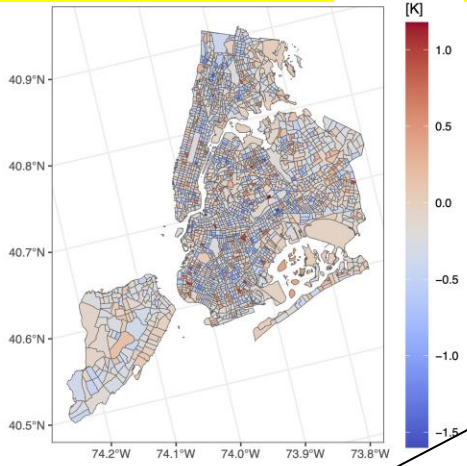


- **Local contrast** between LST_{Ground} and LST_{Pixel} is primarily driven by the **coverage of vegetation** components (**daytime > nighttime**)

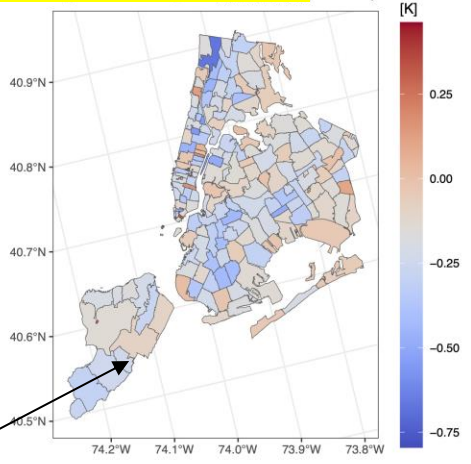
Implications

- Fast-growing literature using LST for regional to global applications for urban heat risks, heat adaption/mitigation, environmental justice, etc.
- Potential stronger uncertainties are using direct LST from EO at the local scale.
- Spatial aggregation reduces some uncertainties.

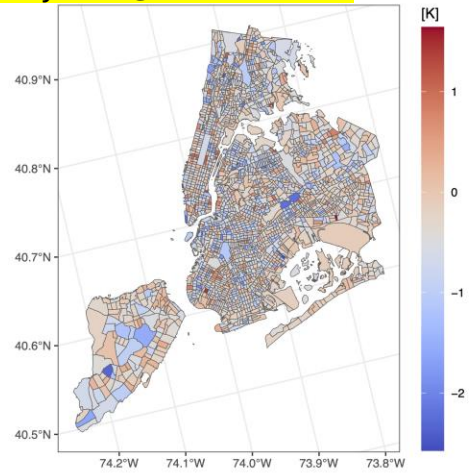
Nighttime @ Census Tract (@04:24)



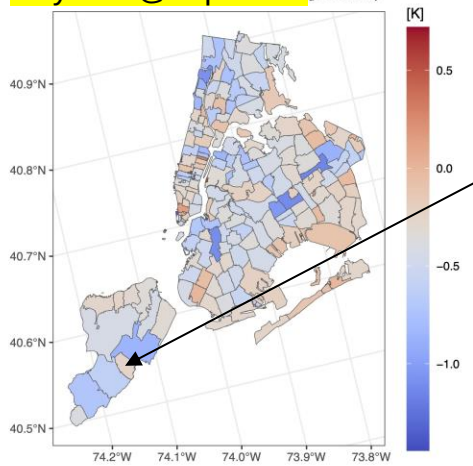
Nighttime @ Zip Code (@04:24)



Daytime @ Census Tract (16:56)



Daytime @ Zip Code (@16:56)



$LST_{Pixel} - LST_{Ground}$

- Clearly, due to some diverging diurnal forcing from urban surface properties, the spatial uncertainties are not consistent over time.
- Estimation LST_{Ground} requires representative higher resolution land cover information and geospatially aligned thermal observations.
- LST resolution, angular variation, and urban landscape features determine the statistical robustness and physical meaningfulness of downscaling estimates.