Unraveling Urban Heat and Moisture Anomalies Across the Continental U.S. Using Local Climate Zones and Earth Observation Data

Aashish Gautam[1], Saurav Bhattrai[1], Rocky Talchabhadel[1]

[1]Department of Civil and Environmental Engineering Jackson State University, Jackson, MS

Introduction

Urban climate anomalies pose significant challenges for public health, energy consumption, and sustainability.

Urban Heat Islands (UHI): Urban areas experience elevated temperatures compared to rural surroundings

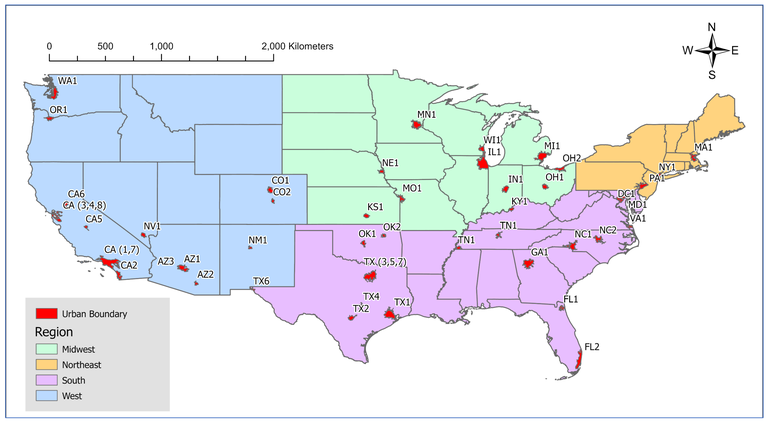
Urban Moisture Islands (UMI): Urban areas exhibit altered humidity patterns, creating moisture surpluses or deficits. If positive UMI and if negative UDI.

Knowledge Gap: Limited understanding of how different urban forms influence heat-moisture coupling across diverse North American climates

Why Local Climate Zones???

- Standardized classification of urban morphology (17 classes).
- Links physical form to thermal/hydrological function.
- Enables cross-city comparison at continental scale.

Study Area



- ✓ Top 50 cities by population across all states
- ✓ Four U.S. Census regions: Northeast, Midwest, West, South
- ✓ Urban boundaries defined using Global Urban Boundaries (GUB) dataset

Research Question

How do Local Climate Zones influence urban heat and moisture anomalies across the continental United States?

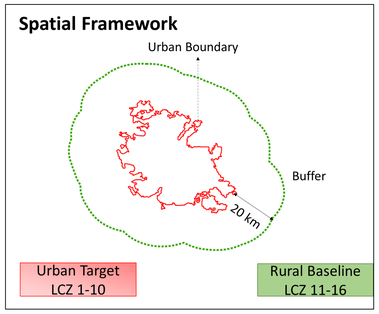
I. Which urban forms generate the strongest heat and moisture anomalies?
II. How do these patterns vary by season and time of day?
III. Are urban climate anomalies intensifying over time (2000-2020)?
IV. How are heat and moisture anomalies coupled in different urban forms?
V. Do regional climates modulate urban form-climate relationships?

Data and Methodology

Dataset	Source	Resolution	Temporal Coverage
Land Surface Temperature (LST)	MODIS Terra (MOD11A2)	1 km	2000, 2005, 2010, 2015, 2020 + 4 seasons
Humidity	Daymet-derived	1 km	Matching LST
Local Climate Zones (LCZ)	Qi et al. (2024)	100 m	All study years
Validation Data	Meteostat Weather Stations	Point (200 stations)	Hourly, all years

Validation Metrices

Variable	Pearson r	RMSE	Bias
LST Night	0.834	8.6°C	-8.119
LST Day	0.596	14.5°C	+13.785
Humidity D	0.644	38.0%	-37.216
Humidity N	0.495	39.1%	+36.181

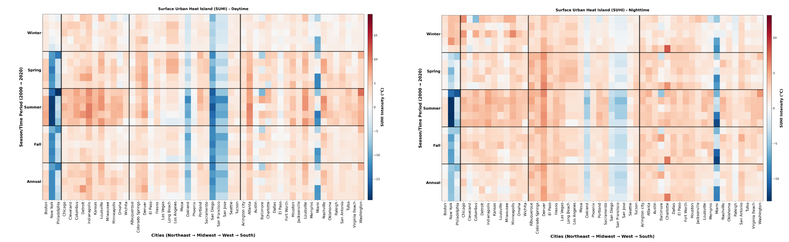


Key Formulas

SUHI= LST_Urban-mean(LST_rural)

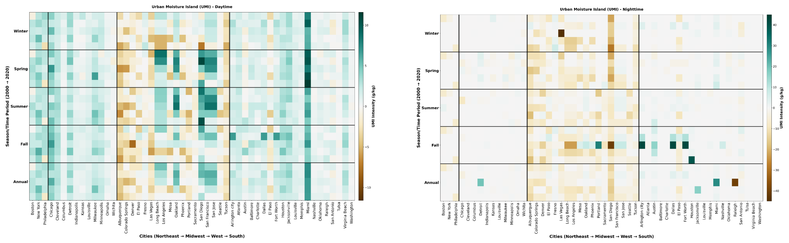
UMI= RH_urban-mean(RH_rural)

2. Surface Urban Heat Island (SUHI) Patterns



- ❑ SUHI intensities predominantly range 0-5°C across all seasons, with major Western cities showing urban cool island effects (negative SUHI) during summer and similar day-night patterns across most metropolitan areas.

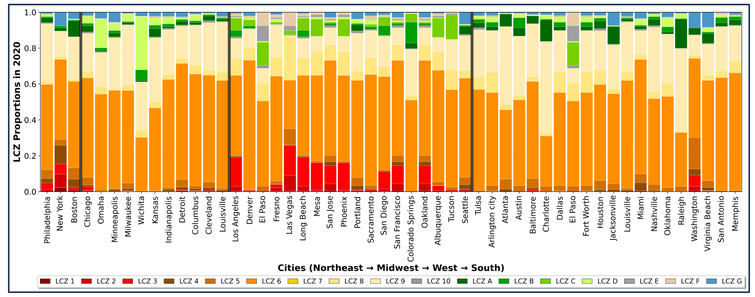
3. Urban Moisture Island (UMI) Patterns



- ❑ Urban Moisture Island (positive surplus, 0-10 g/kg) prevails during daytime especially in Northeast, Midwest & South, while nighttime exhibits Urban Dry Island (deficit -10 to -40 g/kg) most strongly in West cities during fall and winter.

Results

1. Urban Form Evolution (2000-2020)



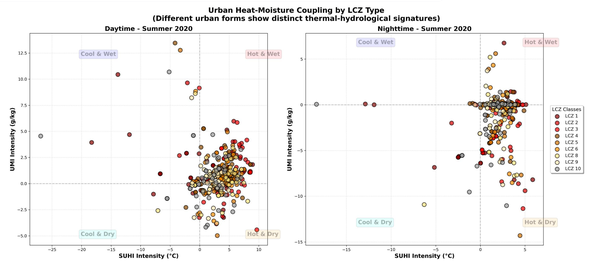
- ❑ U.S. cities are predominantly composed of open low-rise (LCZ 6, 50-70%) and open midrise (LCZ 5) urban forms, with Northeast and West cities exhibiting higher proportions of compact development (10-25%) compared to Midwest and Southern cities.

4. LCZ-Specific Heat and Moisture Island Performance

Rank	LCZ_Class	Mean_SUHI_Day	Mean_SUHI_Night	Mean_UMI_Day	Mean_UMI_Night
1	3	3.116	1.998	0.997	-1.007
2	5	2.74	1.927	0.913	-0.966
3	2	2.71	2.02	0.828	-1.66
4	8	2.56	1.414	0.349	-1.279
5	4	2.434	1.669	1.189	-0.911
6	6	2.267	1.517	0.421	-0.865
7	9	1.209	0.823	0.265	-0.783
8	10	0.99	1.168	0.572	-1.413
9	1	0.427	1.155	1.521	-1.415

- ❑ Compact low-rise (LCZ 3) exhibits the strongest daytime SUHI (3.12°C) with positive moisture surplus (+0.997 g/kg), while all urban forms transition to moisture deficits at night (-0.78 to -1.66 g/kg), and sparsely built areas (LCZ 9-10, 1) show minimal heating effects (<1.21°C daytime SUHI).

5. Heat-Moisture Coupling Analysis



- ❑ Urban areas predominantly exhibit hot-dry coupling during daytime (70% of observations in hot-dry quadrant, r ≈ -0.2), but nighttime patterns show decoupled heat-moisture dynamics (r ≈ -0.05) with quadrant shifts toward moisture surplus.

Key Findings

- ➢ Compact low-rise (LCZ 3) shows strongest SUHI (3.12°C daytime); sparsely built areas show minimal effects (<1.21°C).
- ➢ Summer daytime peaks at 5-10°C SUHI; nighttime is 30-50% weaker with moisture deficits.
- ➢ Minimal change over 20 years; only compact forms show slight warming (+0.3-0.4°C).
- ➢ Daytime shows weak hot-dry coupling (r ≈ -0.2); nighttime patterns are decoupled (r ≈ -0.05).
- ➢ West/South show highest SUHI (4.5-6.0°C); regional climate affects magnitudes but not LCZ rankings.

References

- ➢ **Chen, B.**, Wu, S., Song, Y., Webster, C., Xu, B., & Gong, P. (2022). Contrasting inequality in human exposure to greenspace between cities of Global North and Global South. *Nature Communications*, *13*, 4636.
- ➢ **Qi, M.**, Xu, C., Zhang, W., Demuzere, M., Hystad, P., Lu, T., ... & Hankey, S. (2024). Mapping urban form into local climate zones for the continental US from 1986–2020. *Scientific Data*, *11*, 195.

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