Urban Heat Island Characterization in an Alpine Valley City Integrating Observations and Models in Bolzano's Complex Terrain

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Motivation

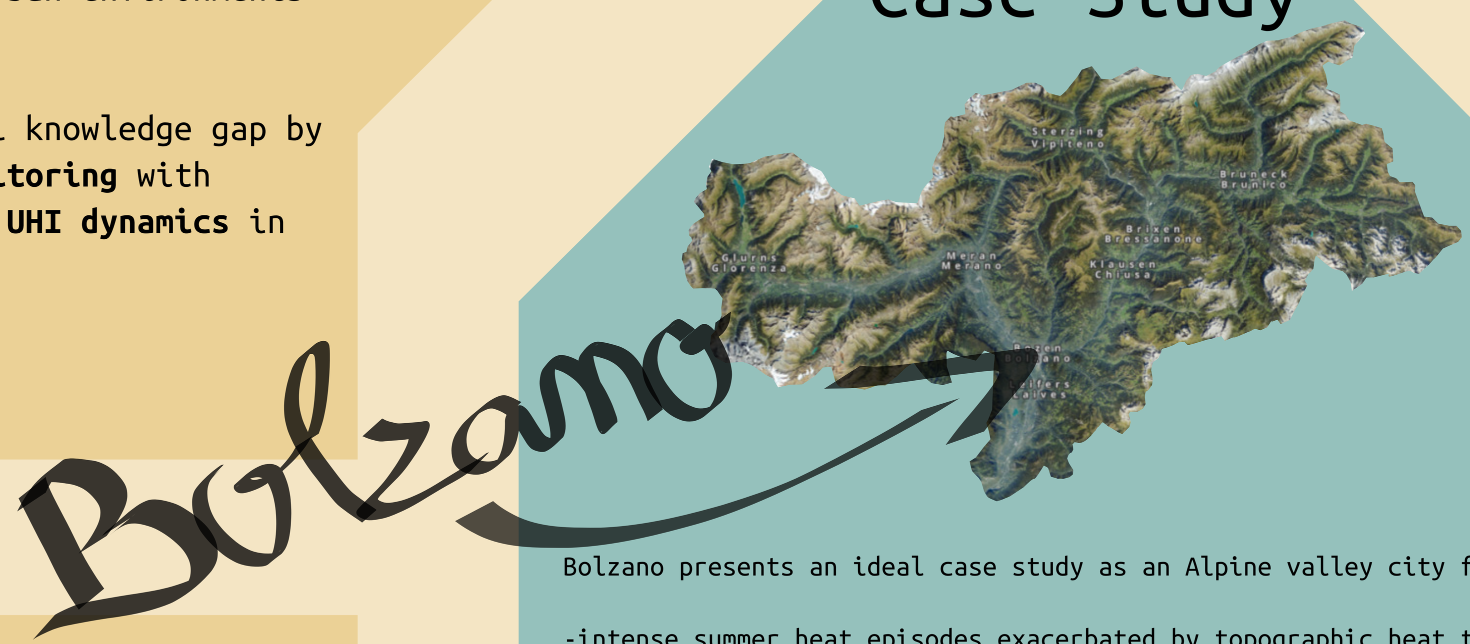
Urban Heat Islands (UHI) pose critical challenges for climate adaptation and heat stress mitigation, particularly in complex mountainous environments where standard approaches often fail.

Key Challenges in Alpine Cities
Complex terrain effects: Mountain-valley circulations create unique microclimate conditions that traditional UHI studies cannot adequately capture
Seasonal variations: Summer heat trapping vs. winter cold air drainage fundamentally alter UHI dynamics
Limited spatial coverage: Traditional fixed weather stations provide insufficient data density for complex topography

Research Imperative
Understanding these complex UHI patterns is essential for:
-Developing effective climate adaptation strategies
-Mitigating urban heat stress risks
-Planning resilient mountainous urban environments

This research addresses a critical knowledge gap by integrating innovative **mobile monitoring** with **advanced modeling** to characterize **UHI dynamics** in **complex Alpine terrain.**

Bolzano Case Study

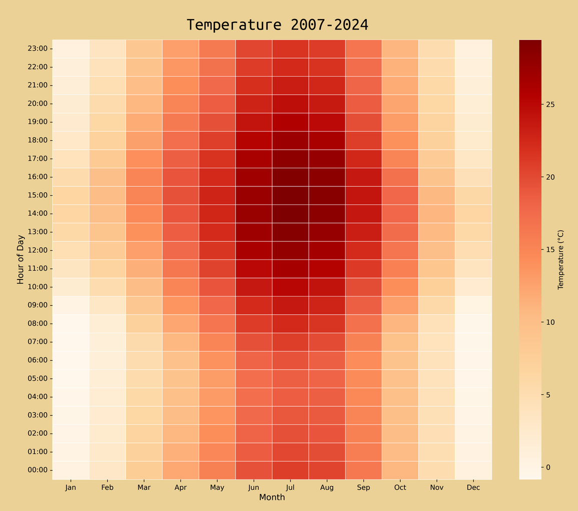


Bolzano presents an ideal case study as an Alpine valley city featuring:

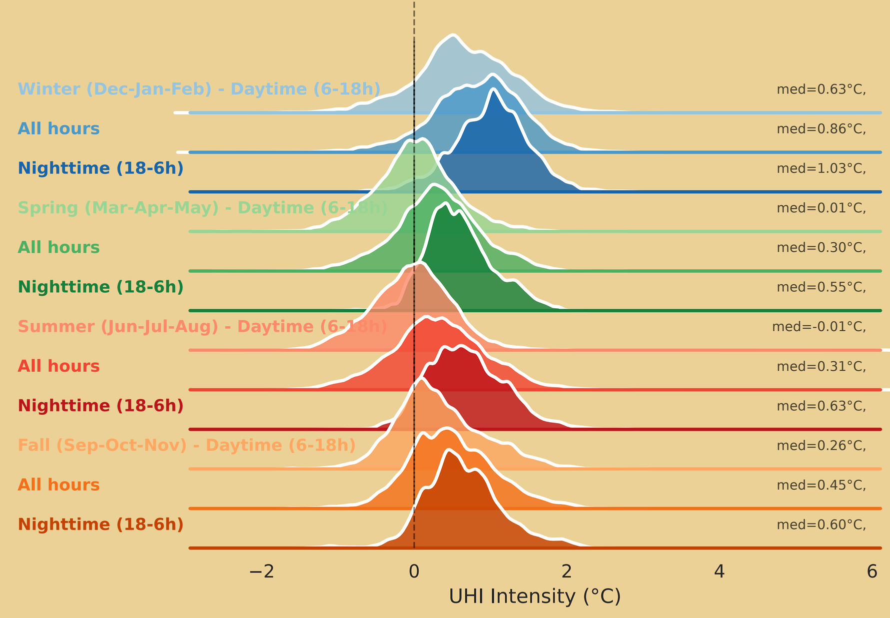
-intense summer heat episodes exacerbated by topographic heat trapping
-unique three-valley convergence creating complex thermal environments
-steep mountain slopes influencing local wind patterns and temperature distribution

Observations

AWS and NetAtmo



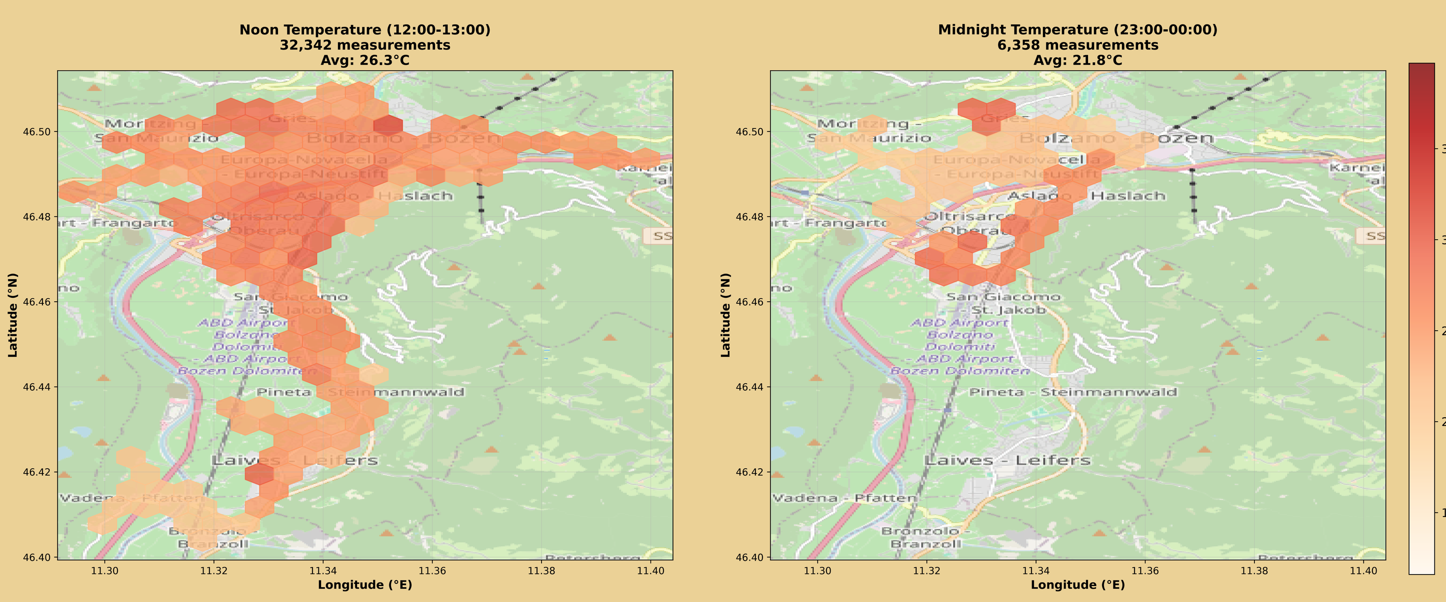
This heatmap shows official AWS temperature data for Bolzano (2007-2024), revealing clear diurnal cycles with afternoon peaks and seasonal variations from winter lows below 10°C to summer highs around 25°C.



Seasonal UHI Patterns (2022-2024): Comparing Daytime, Nighttime, and 24-Hour Averages from almost 100 NetAtmo stations.

UHI intensity in Bolzano varies seasonally and diurnally. Summer displays modest UHI intensities despite higher temperatures, likely due to enhanced valley ventilation in warmer months.

MeteoTrackers



Meteotracker measurements for July and August 2025.
Temperature measurements from individual trackers are aggregated into hexagonal grid cells and averaged over the same temporal periods (midnight and noon intervals). These hexagon-based maps provide comprehensive spatial visualization of thermal hotspots across day and night cycles, revealing the geographic distribution of heat patterns and allowing identification of persistent warm zones and areas with significant diurnal temperature variations during the peak summer months.

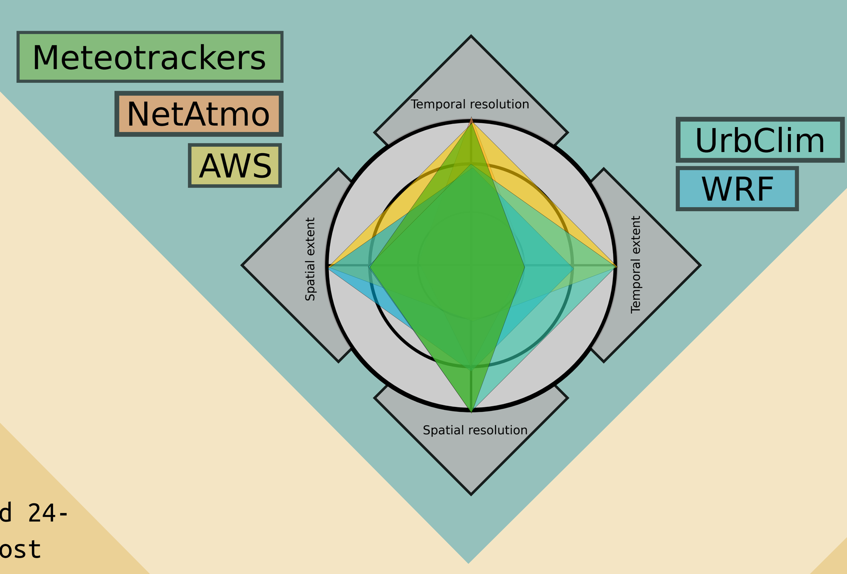
Methods

Models:

UrbClim: hydrostatic, 100m resolution, historical simulations (2003-2022) + future projections
WRF: non hydrostatic, no complex urban scheme, 1km resolution, detailed mountain-valley wind systems (2020-2024)

Observations:

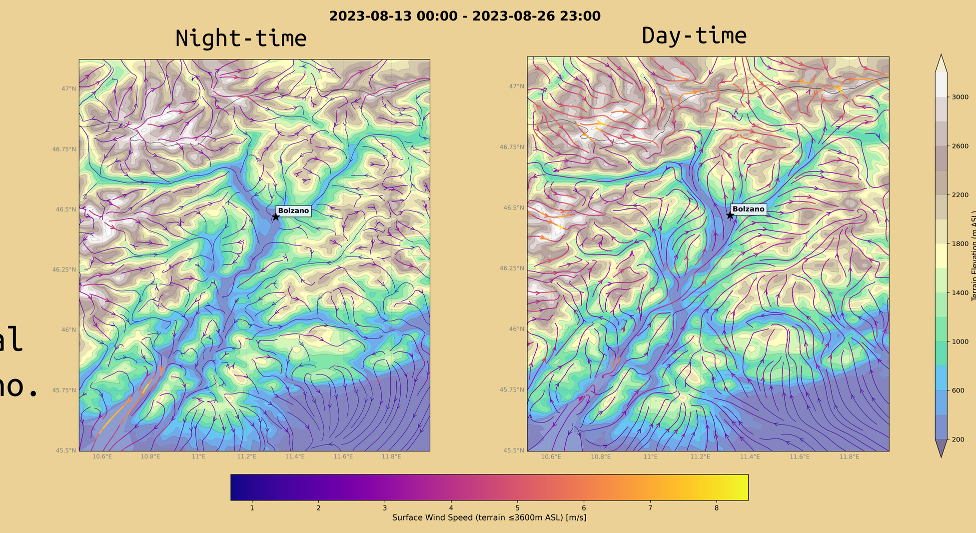
Mobile monitoring: 15 MeteoTracker sensors on public buses measuring at 1 Hz
Fixed stations: Provincial weather network + NetAtmo citizen stations
Parameters: Temperature, humidity, pressure, wind speed



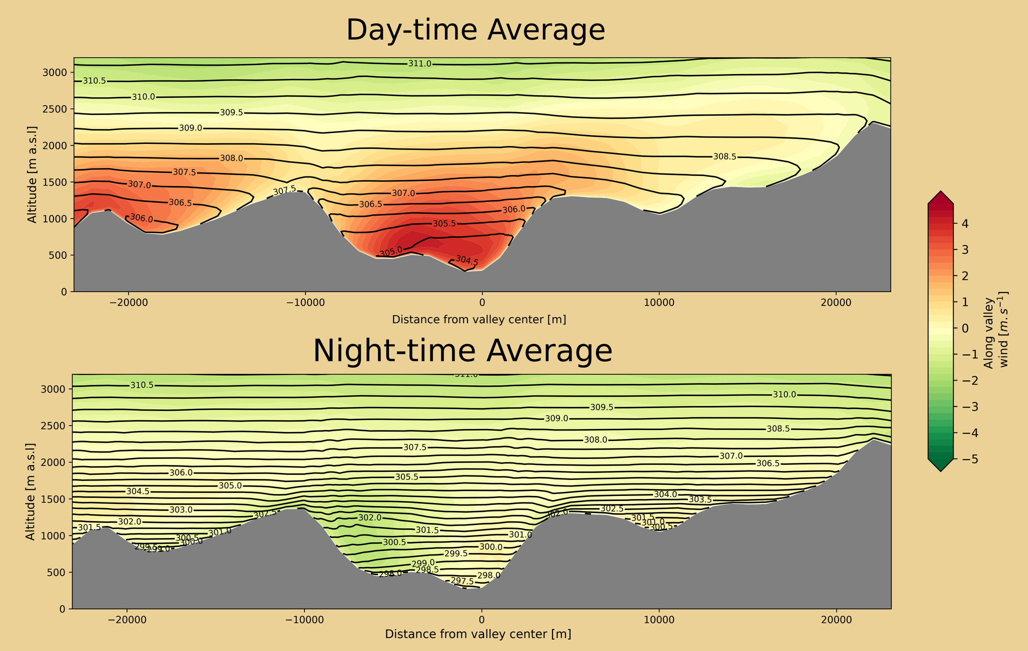
Models

WRF

Surface Wind average



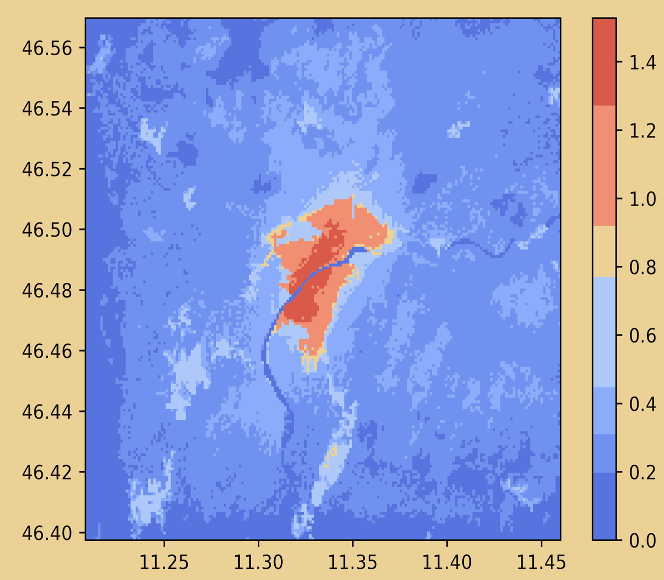
Surface wind circulation. Average during a 10-day heat wave event in August 2023 in the Adige Valley. And vertical cross section south of Bolzano.



Vertical cross-section of potential temperature (isopleths) and along-valley wind (colorbar) for the entire period, the daytime and the nighttime averages during the 10-day August 2023 heat wave

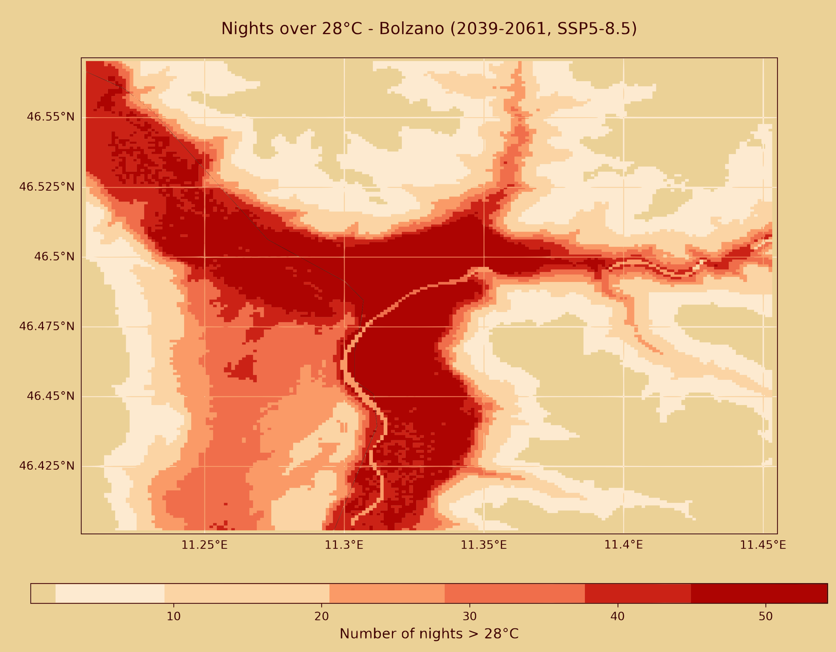
During day time, the ventilation effect might explain the the more homogenize temperature field over the city and between the rural and urban area. During night-time, with less wind, the UHI is more pronounced.

UrbanClim



Average daytime UHI SSp2-4.5 projection for 2069 - 2081 period

2001-2024
100-m horizontal resolution
SSP2-4.5 and SSP5-8.5 2050 and 2080 projections
Simple and fast model → allows for climate projections at 100-m resolution



SSP5-8.5 projections suggest that the number of nights per year where the temperatures don't drop below 28 degrees will last the major part of the summer in the future.

Take Home Message

From Valley to Street: Understanding Bolzano's Urban Heat Island.

Multiple scales: Valley-wide to street-level analysis
Multiple timeframes: Long-term projections to daily patterns
Various Observations and models: Mobile + fixed observations + climate models + local weather forecasting
Actionable outcomes: Support effective climate adaptation strategie