Improving the Urban Heat Island estimate through satellite imperviousness data

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ARIANET MODELLISTICA ATMOSFERICA

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Università di Roma Tor Vergata

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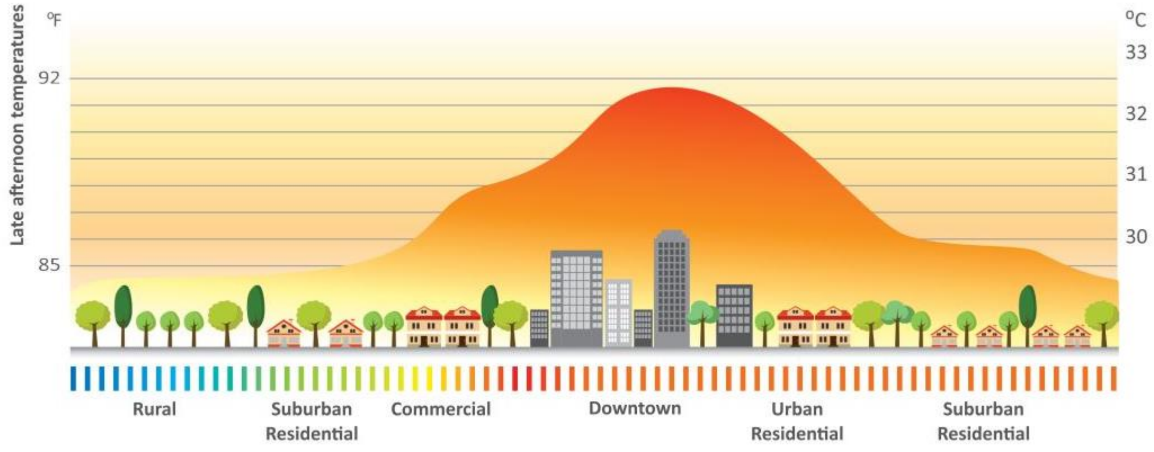
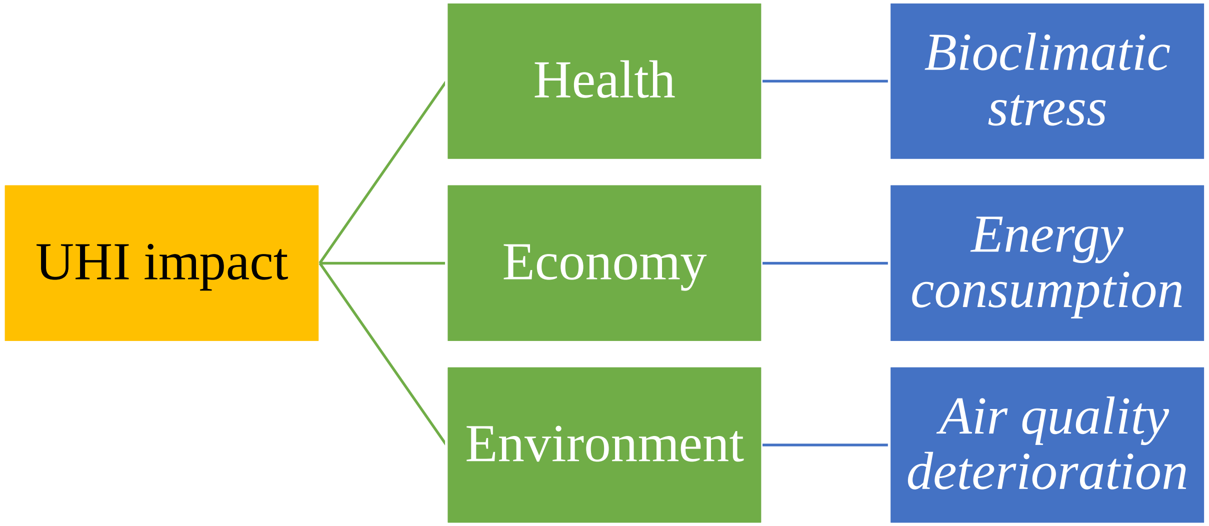
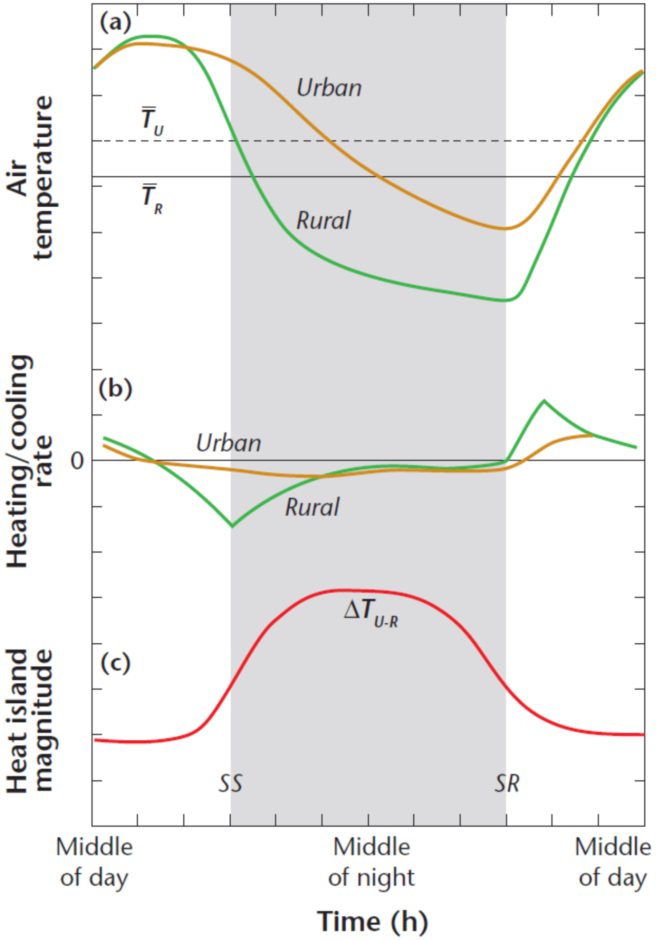
The Urban Heat Island (UHI)

The Urban Heat Island (UHI) is a **local** phenomenon caused by urbanization, which leads to a **warmer** microclimate within cities than in the surrounding rural.





Canopy layer urban heat island (UHI_{CL})



Ideal condition for its development: **clear sky** and **weak wind**.

Main urban characteristics

- Geometry and materials
- Anthropogenic heat sources

Timing

- The UHI_{CL} is a **nocturnal** phenomenon: the urban areas, after sunset, do not cool as fast as the surrounding rural ones.

Main atmospheric factors

- Clouds
- Wind

$$\Delta T = \frac{\Delta T_{\text{pot}}}{\sqrt{U}(1 - qn^2)} \quad n \in [0,1] \quad q \in [0,1]$$

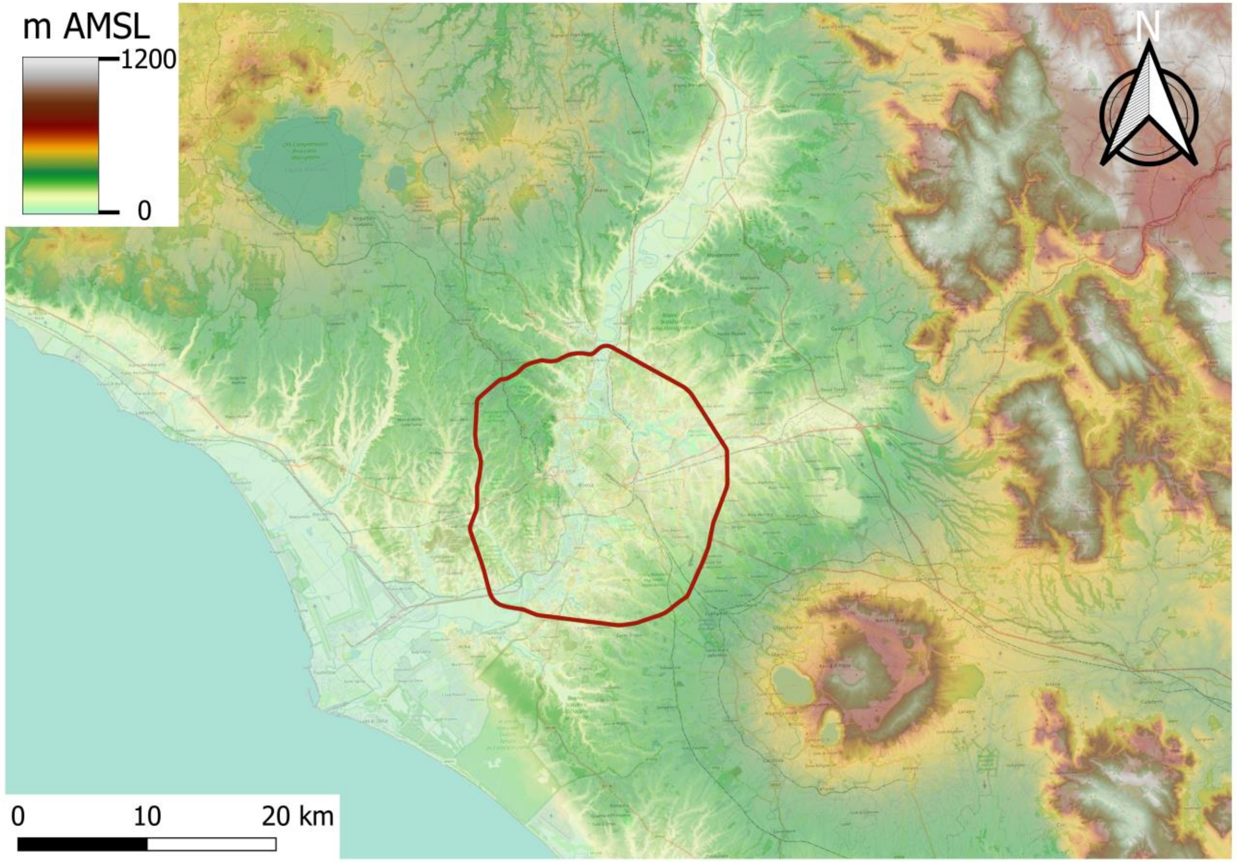
Observation methods

- **Fixed** temporal dynamic
  - **Rooftop** High measurements comparability
  - **In canyon** measurements are influenced by local factors
- **In motion** spatial dynamic

Characterizing the summer UHI of Rome

Objectives

- **Temporal and spatial characterization** of the UHI during summer, using a new method based on imperviousness satellite data
- **Comparation** with the traditional LCZ-based method
- Influence of **sea breeze**
- UHI behavior during summer **heat waves**



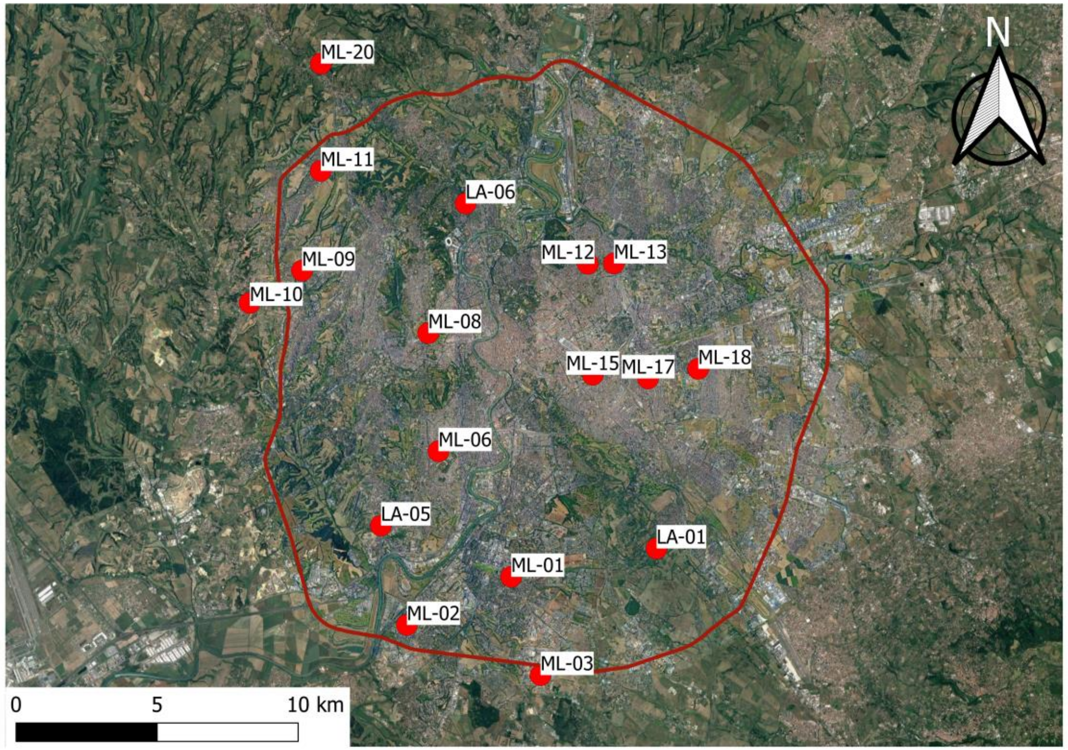
Measuring instruments

17 ASTI-Network stations

(8 LIFE-ASTI + 11 Meteo Lazio)

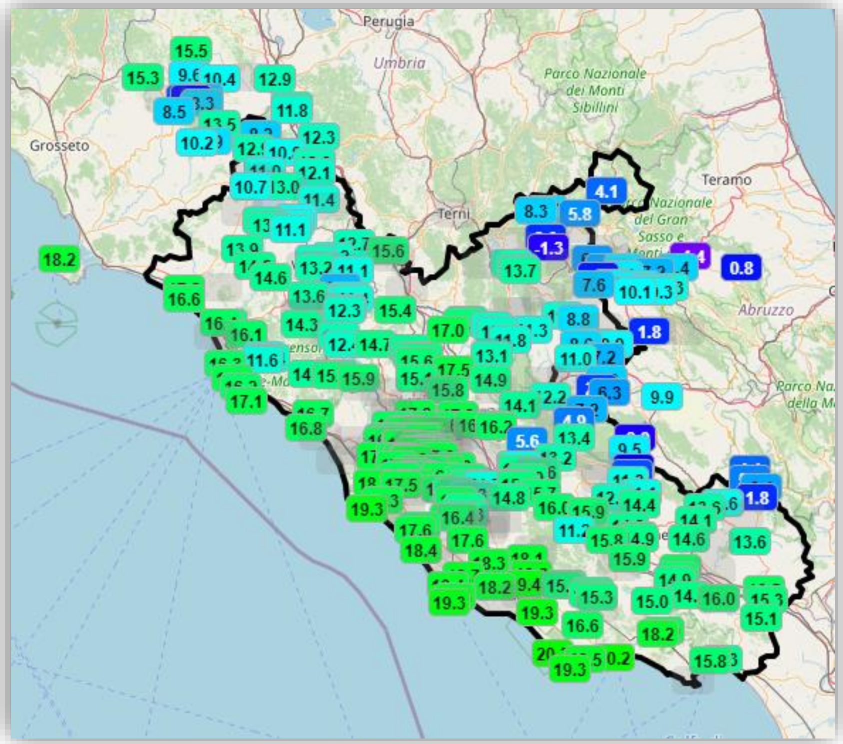
Rooftop measurements

Study of the *Canopy Layer* top UHI



Meteo Lazio

Amateur weather network → Citizen science



412 weather stations

Quality check before acquiring data → 27 stations in the area of Rome

METEO LAZIO

The weather stations

Davis Vantage Pro 2

+

Raspberry Pi3 + Antenna

- Temperature
- Relative Humidity
- Wind speed and direction
- Rainfall: intensity and cumulated

- Data sampling
- Data storage
- Data transmission

Dataset

Air temperature data

- **Study period:** JJA 2019-2020, considering only 138/184 days with anticyclonic conditions
- **Data aggregation:** 1 hour average for each of the $N = 17$ *in situ* stations
- **Quality check:** climatic, spike filter, spatial filter

Imperviousness satellite data

- **Description:** presence of artificially sealed surface as a percentage for each pixel (0% = rural, 100% = dense urban)
- **Source:** Copernicus Land Monitoring Service
- **Year:** 2015
- **Resolution:** 20 m

Methods

Hypothesis: at fixed time, linear relationship between air temperature T and imperviousness IMP
(Schatz and Kucharik, *Urban climate effects on extreme temperatures in Madison, Wisconsin, USA*. Environmental Research Letters, 2015)

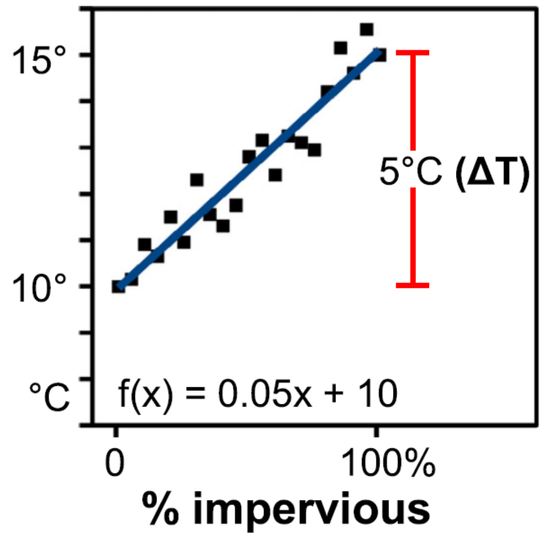
$$T = T_0 + aIMP, \qquad IMP \in [0,100]\%,$$

The present study **firstly** reproduces this approach

the **UHI intensity** is defined as

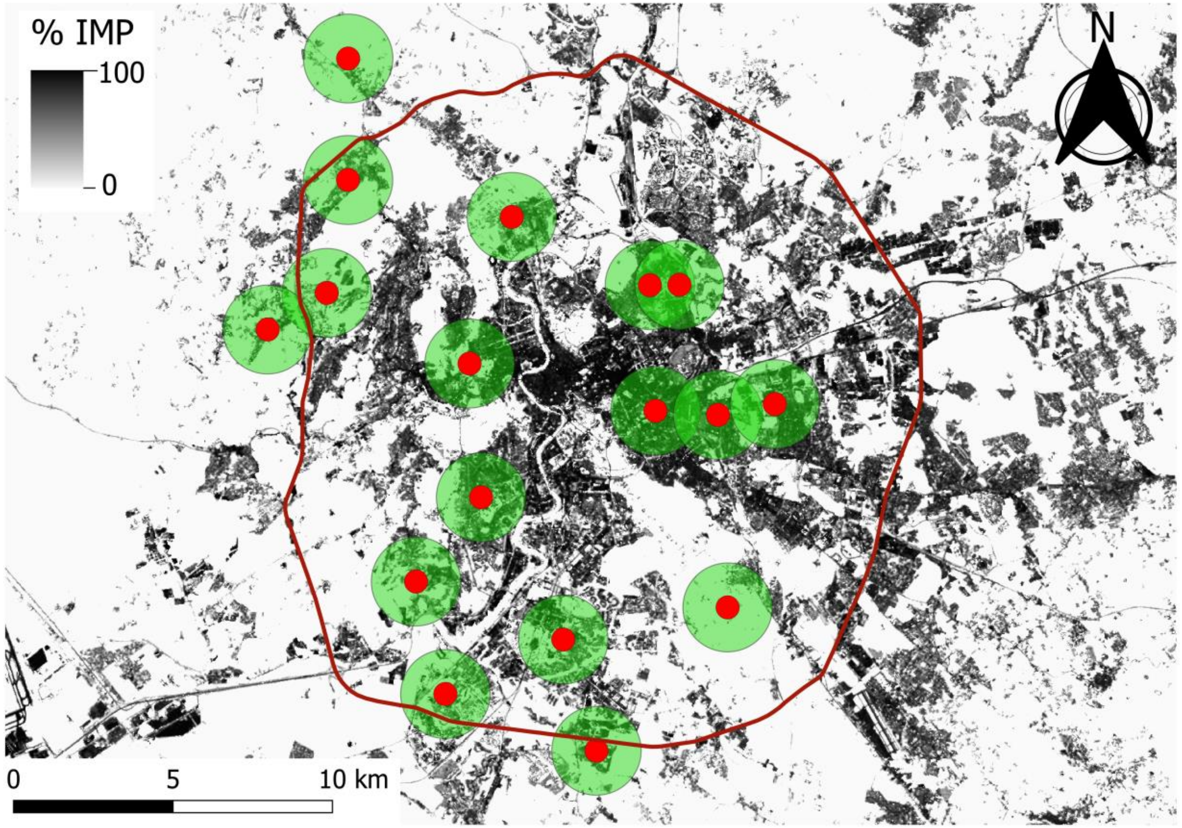
$$\Delta T \doteq T(100) - T(0) = 100a.$$

To calculate it, a **linear fit** is performed every hour between the temperatures detected by the N stations and the associated IMPs.

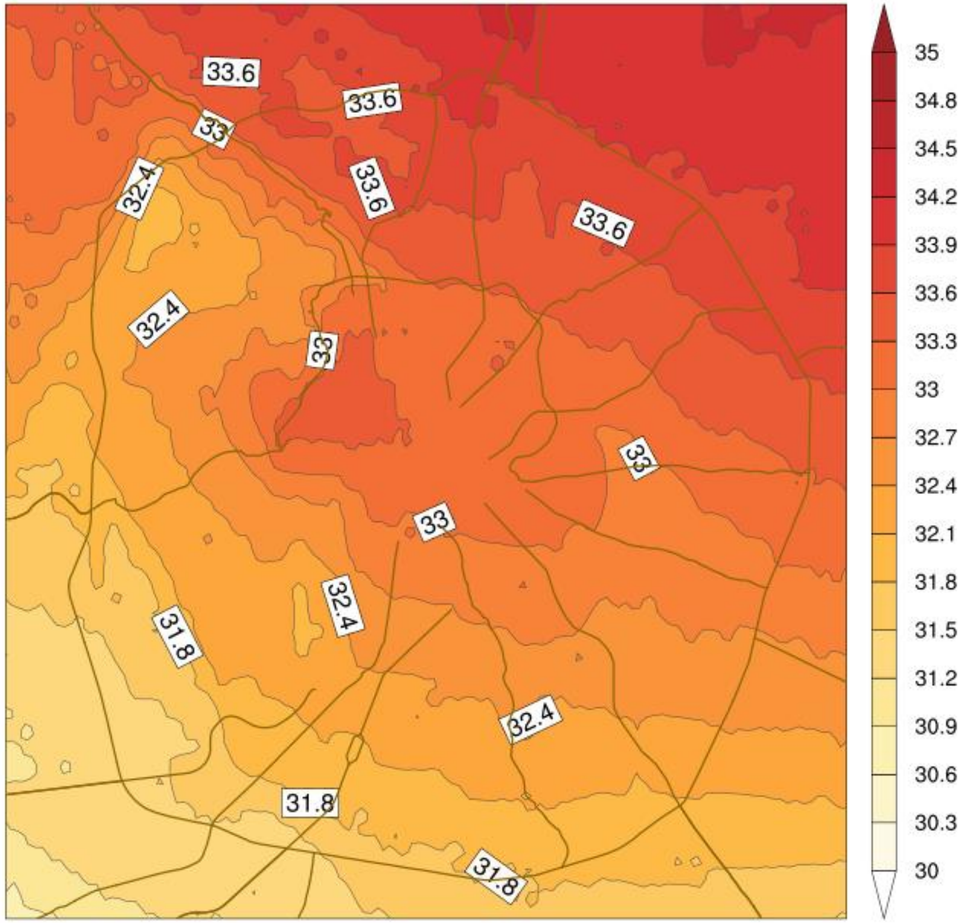


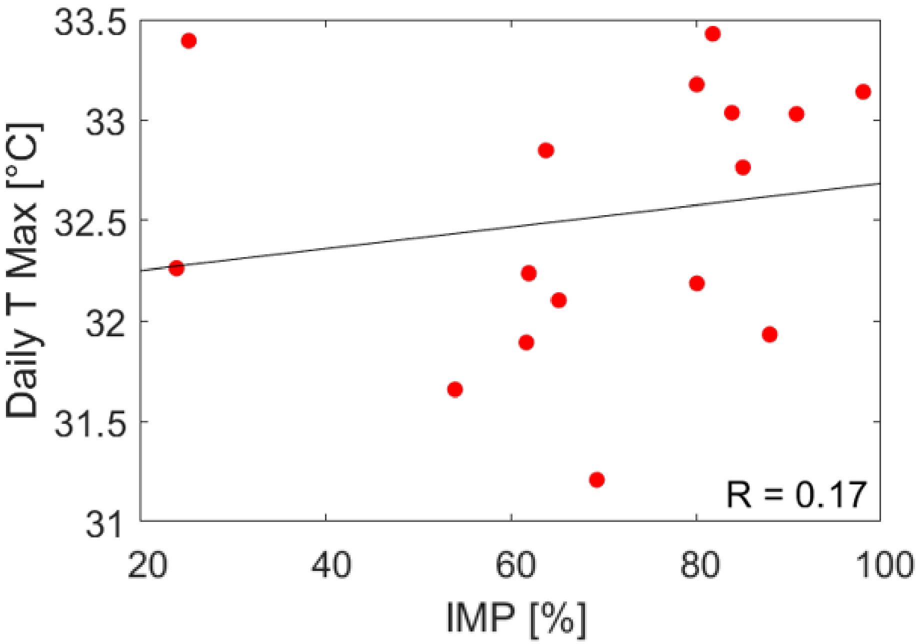
Associating an IMP value to each station

- The IMP associated with each station was calculated as the **average of the IMP within a circumference** with a radius r = 1400 m centered at the measurement point.
- The radius was chosen as to **maximize the correlation** between temperature and IMP, quantified by the coefficient R and calculated as the average over the whole study period.
- This analysis was conducted **varying the radius** in the interval $r \in [400,3000]$ m with a step of 100 m.



Daily maximum temperature



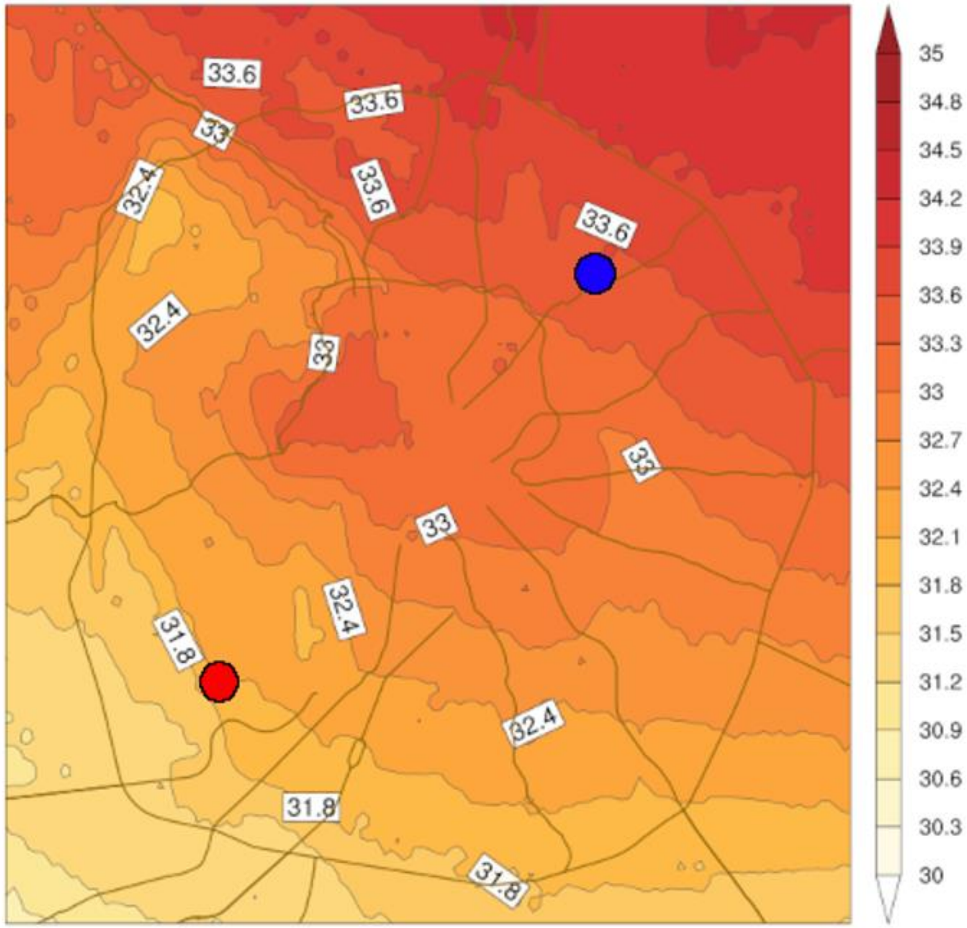


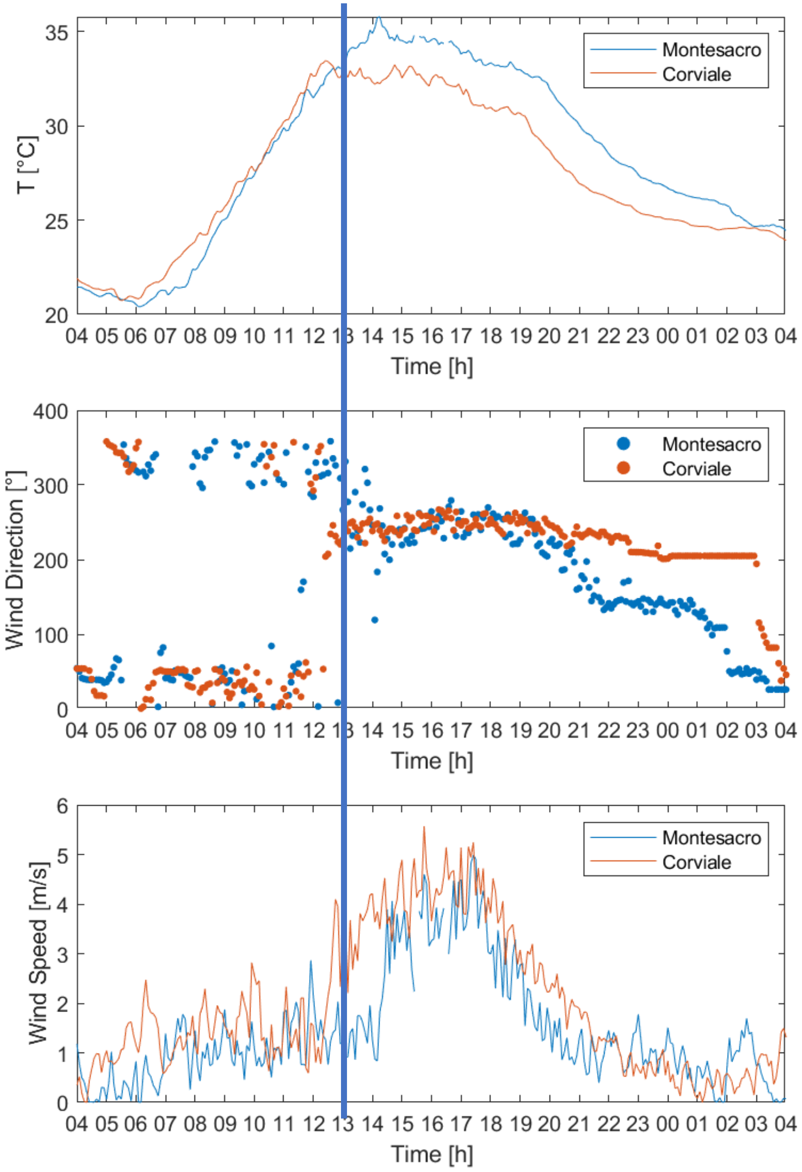
During day:

- **No UHI**, according to theory.
- Sea breeze, blowing from WSW, is the principal shaping factor of the temperature spatial pattern.

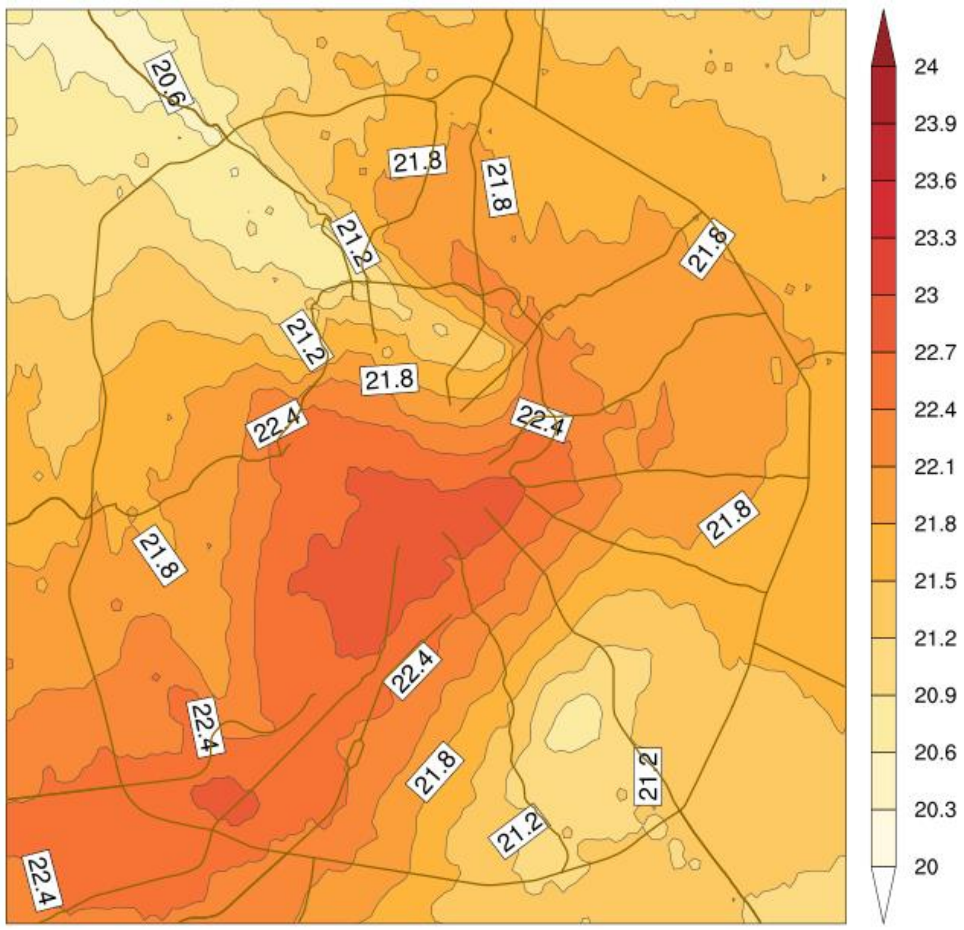
Cecilia, A., G. Casasanta, Petenko I., A. Conidi, and S. Argentini. **Measuring the urban heat island of rome through a dense weather station network and remote sensing imperviousness data**. *Urban Climate*, 47, 01 2022. https://doi.org/10.1016/j.uclim.2022.101355

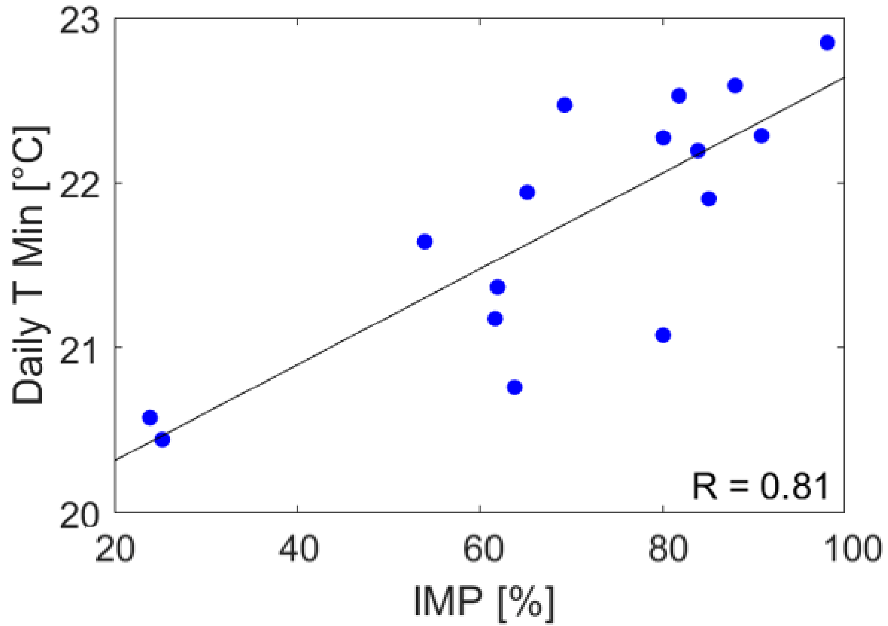
Sea breeze effect





Daily minimum temperature

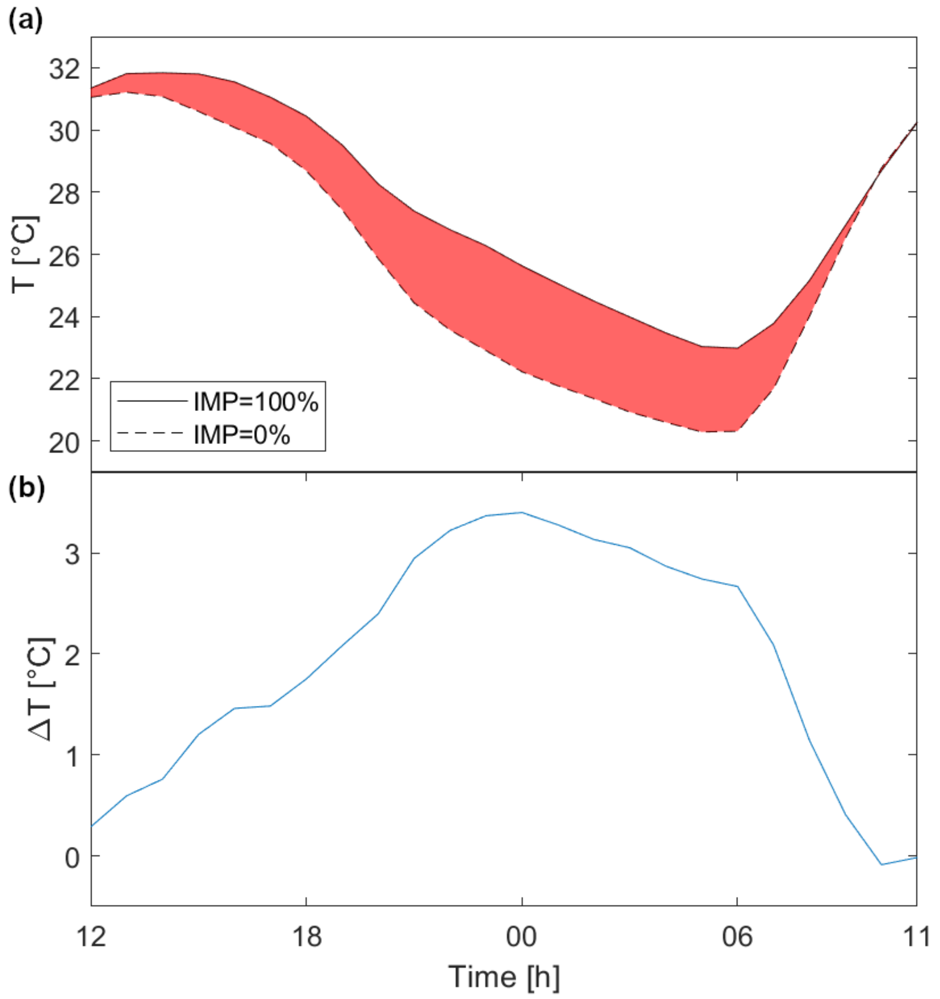




During night:

- Good correlation between T_{min} and IMP, the UHI phenomenon is evident.
- The few anomalous points are correlated with night cool breezes from parks.

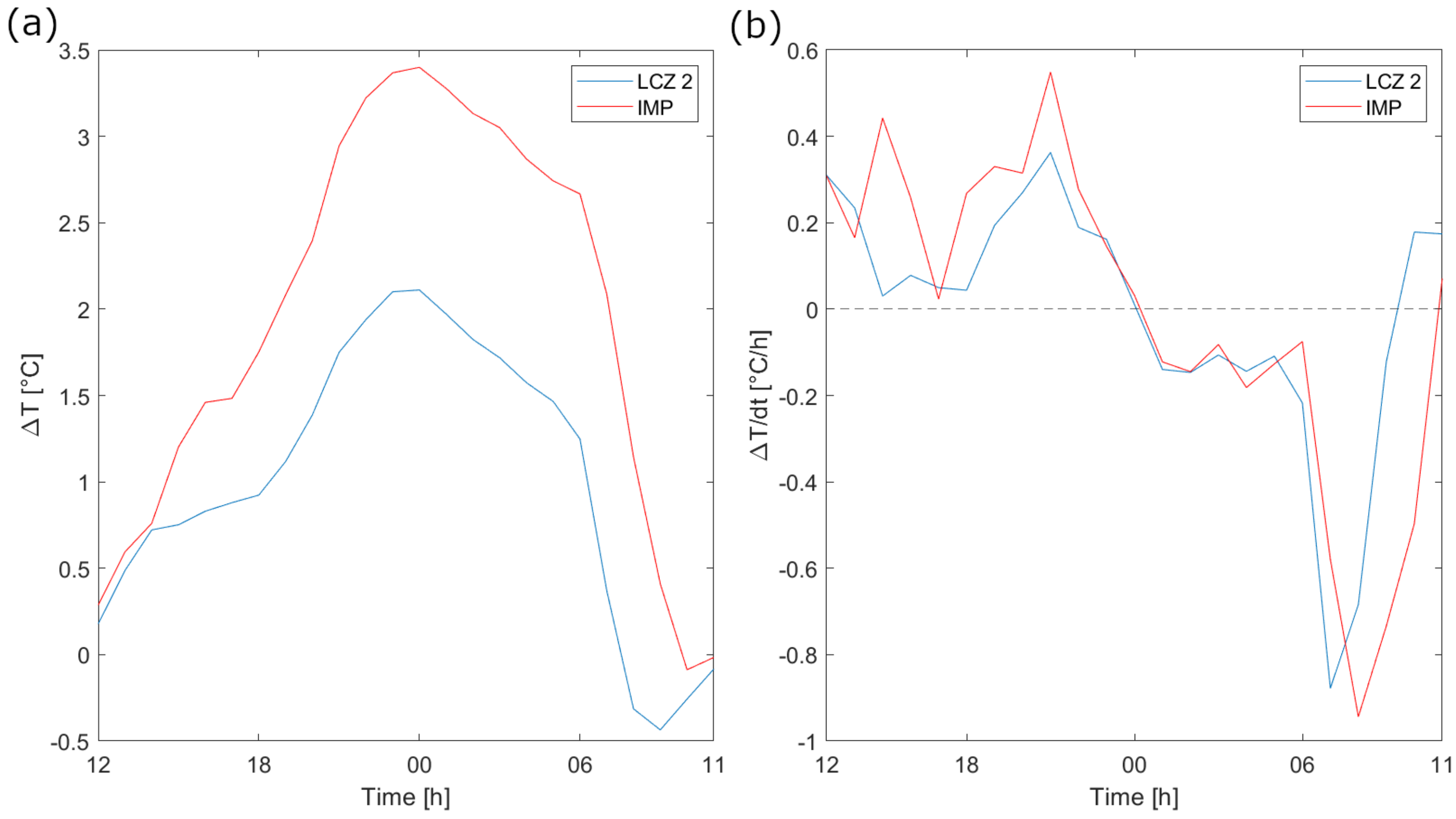
Temporal dynamics: UHI diurnal cycle



- ΔT_{MAX}= $3.4°C$ at 00:00 (CET)
- ΔT_{min}= $-0,1°C$ at 10:00 (CET)
- Extrema: $6.2°C$, $-1,8°C$

Comparison with LCZ-based approach

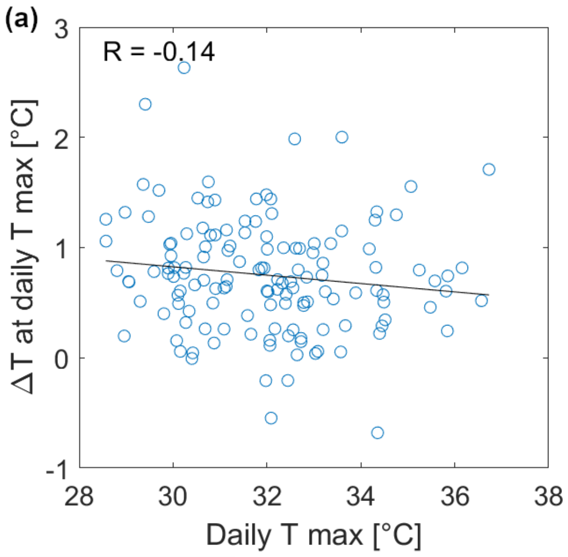
- The trends are similar with an **offset** of about 1.3°C, with the highest values found by the IMP-based method.
- The IMP-based method extraploates the UHI intensity by a linear fit, which gives the extremal temperature values at IMP=0% and IMP=100%, while with the LCZ-based method it is calculated as the temperature difference between two stations that not always are located at 100% and 0% IMP sites (in the specific case, they are 88% and 22% respectively).
- The IMP-based method **is reliable**.

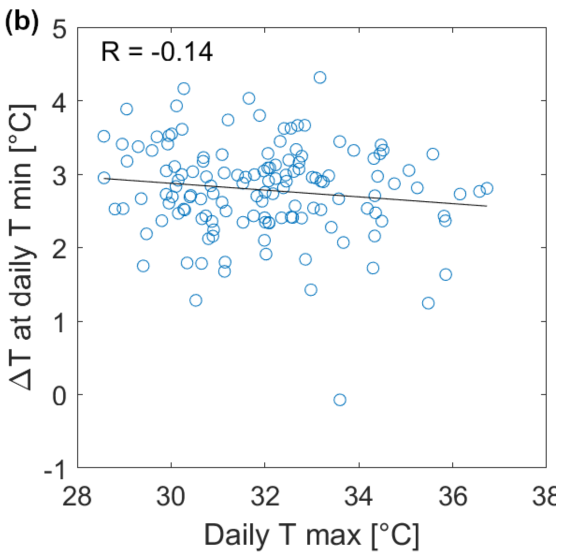


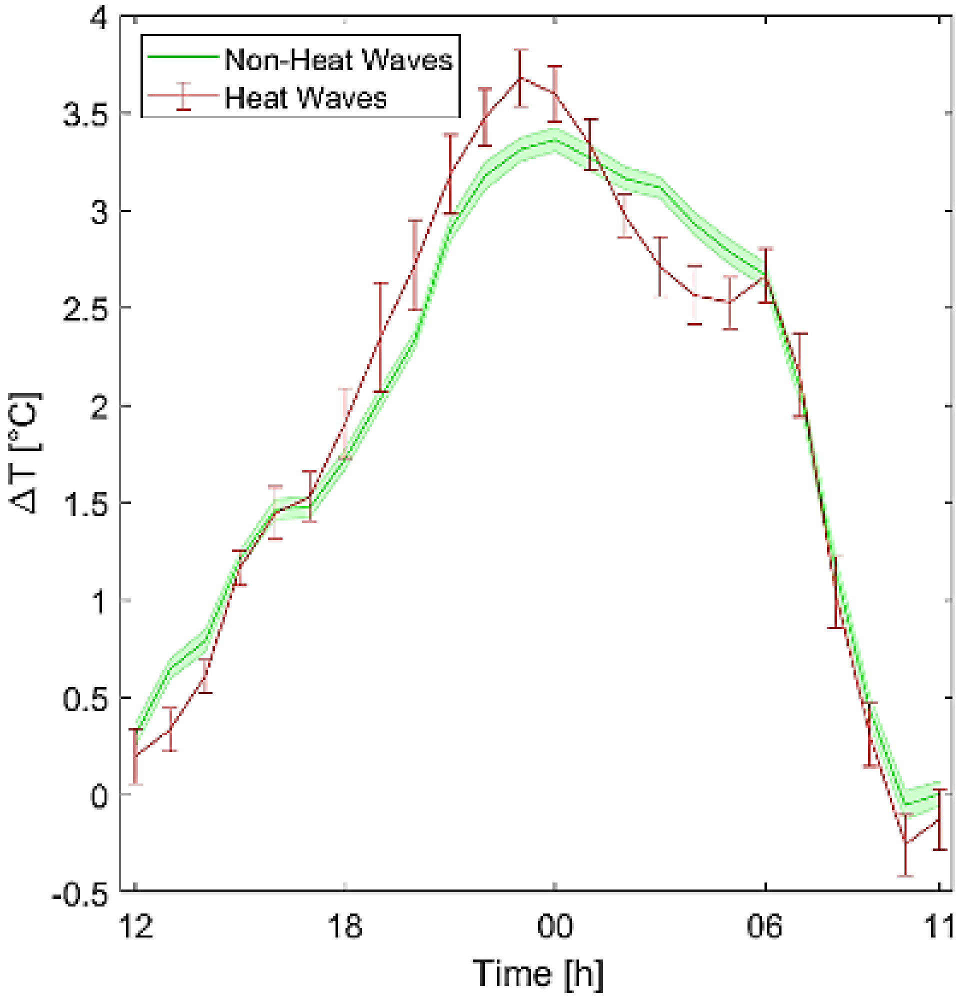
Heat waves and UHI

- **Definition:** a heat wave (HW) day is when the daily maximum temperature exceeds the 90° percentile of the distribution for the climatic 30 years of reference
- Threshold for Rome Ciampino: **34.0°C**
- Observed HW days during the study period: 22/138

No correlation is observed



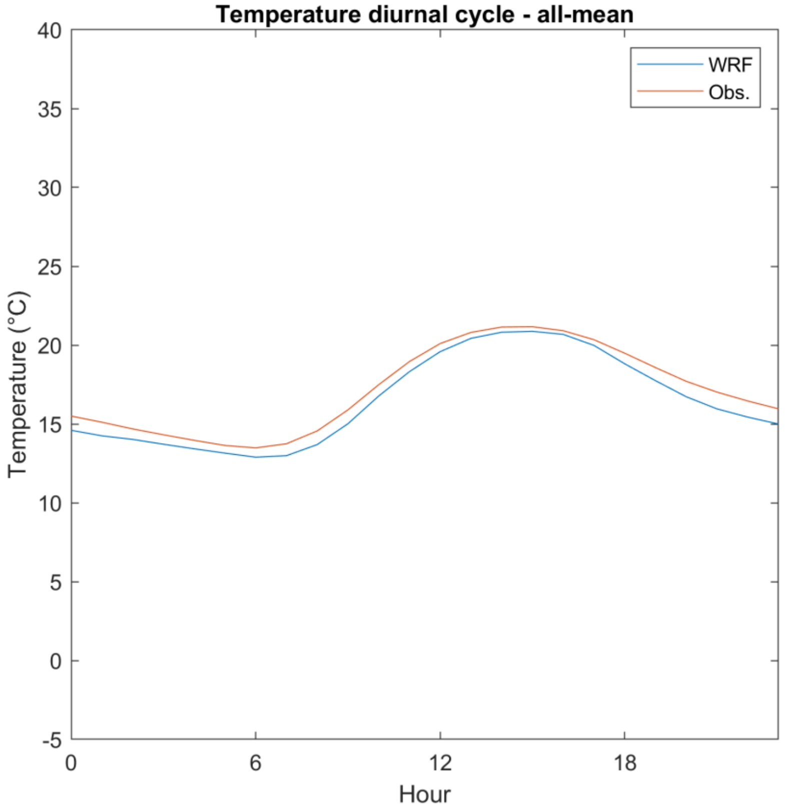


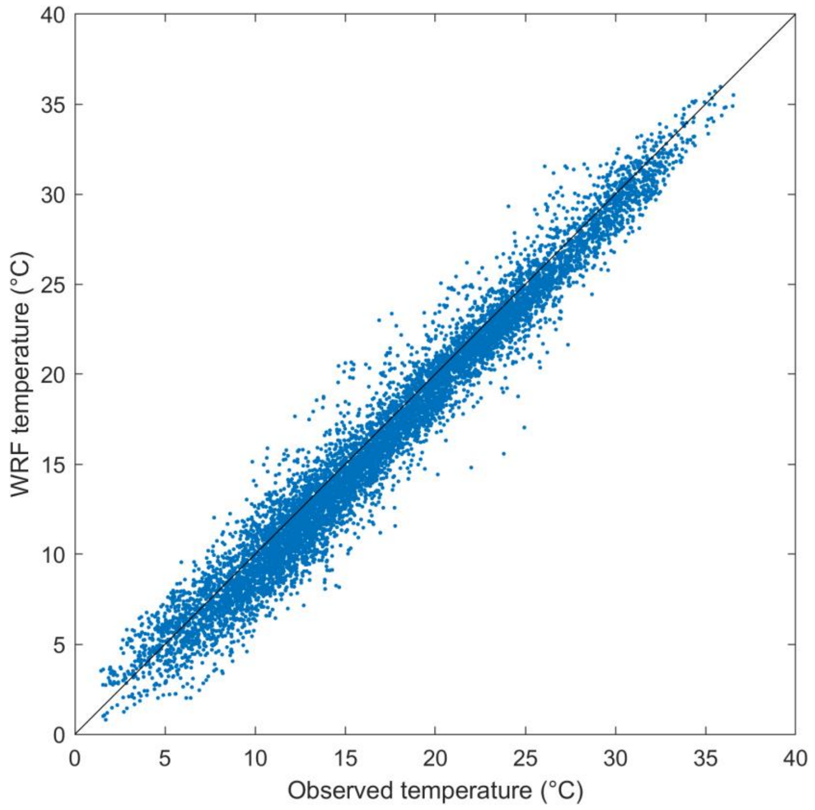


Validation of the LIFE-ASTI WRF Model

	R	IoA	Rmse	fb
T	0,982	0,989	1,526	-0,040
RH	0,841	0,896	10,874	-0,048

Validation of the LIFE-ASTI WRF model over the year 2020, statistically comparing the observations *in situ* with the model elaborations, for the parameters temperature and relative humidity.

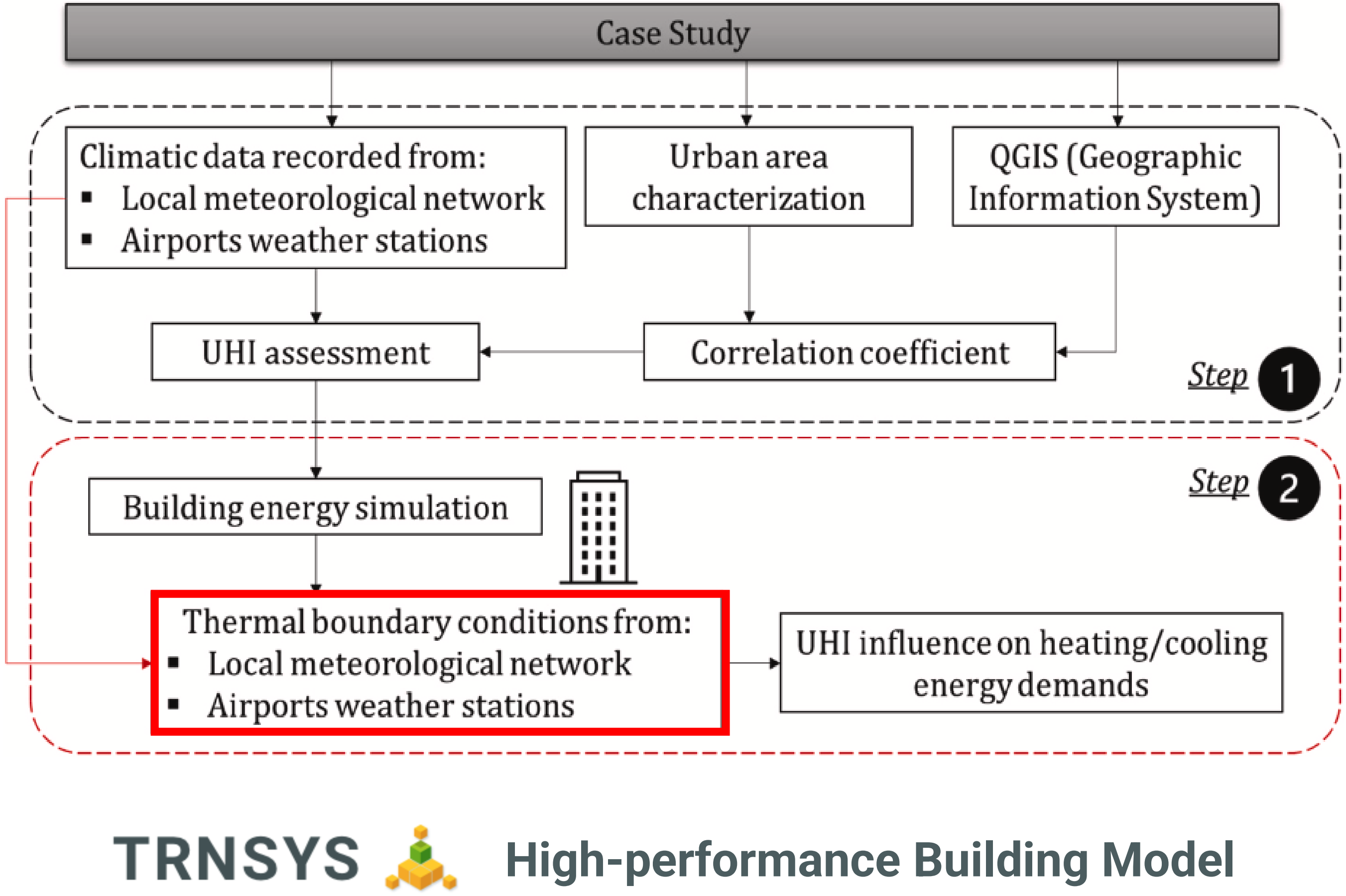




UHI effects on energy performance of buildings

In this study it was found that it is **not recommended** to use meteorological data derived from **airports measurements**, as was classically done, for estimating the energy performance.

The UHI can significantly affect the energy performance of buildings. It leads to an appreciable **variation of energy demand for heating and cooling**.



Battista, G., Evangelisti, L., Guattari, C., Roncone, M., Balaras, C.A. (2023). **Space-time estimation of the urban heat island in Rome (Italy): Overall assessment and effects on the energy performance of buildings**. *Building and Environment*, 228, 109878 10.1016/j.buildenv.2022.109878

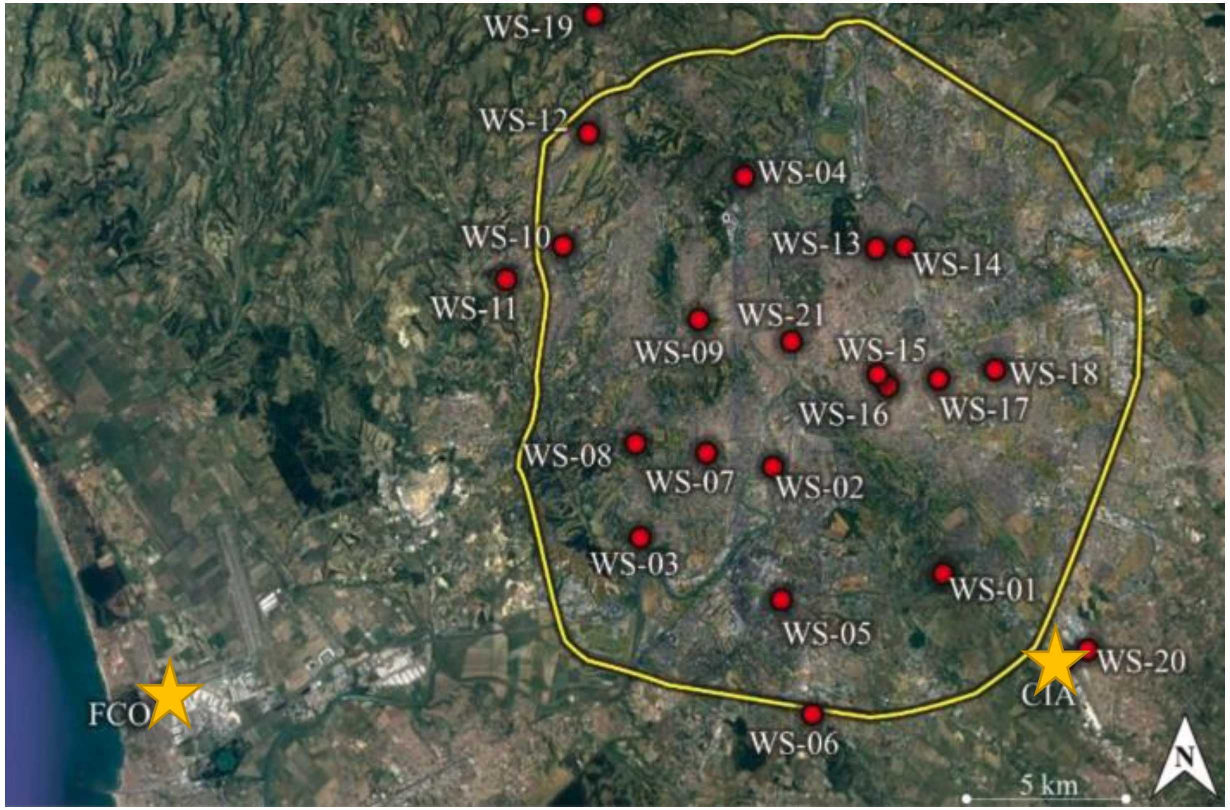
Results

UHI index: **+2.91°C** in summer, **+1.78°C** in winter, with respect to the airport weather stations.

Old building
- FCO: -18% heating, +58% cooling
- CIA: -18% heating, +31% cooling

Recent building
- FCO: -18% heating, +40% cooling
- CIA: -20% heating, +22% cooling

ASTI-Network weather data (23 stations), year 2020



Future perspectives

Use of Land Surface Temperature (LST) satellite data to characterize the UHI in a continuous way in space.

Development of ad hoc spatial interpolation algorithms for the main meteorological parameters.

Inclusion of the results in the context of global climate change and mitigation and adaptation strategies.

Machine learning random forests

Main activities (2)

New Article

Estimating the urban heat island of Rome with random forests algorithm using satellite and in situ temperature measurements

Andrea Cecilia[1,2], Giampietro Casasanta[1], Igor Petenko[1], Alessandro Conidi[1], Stefania Argentini[1]

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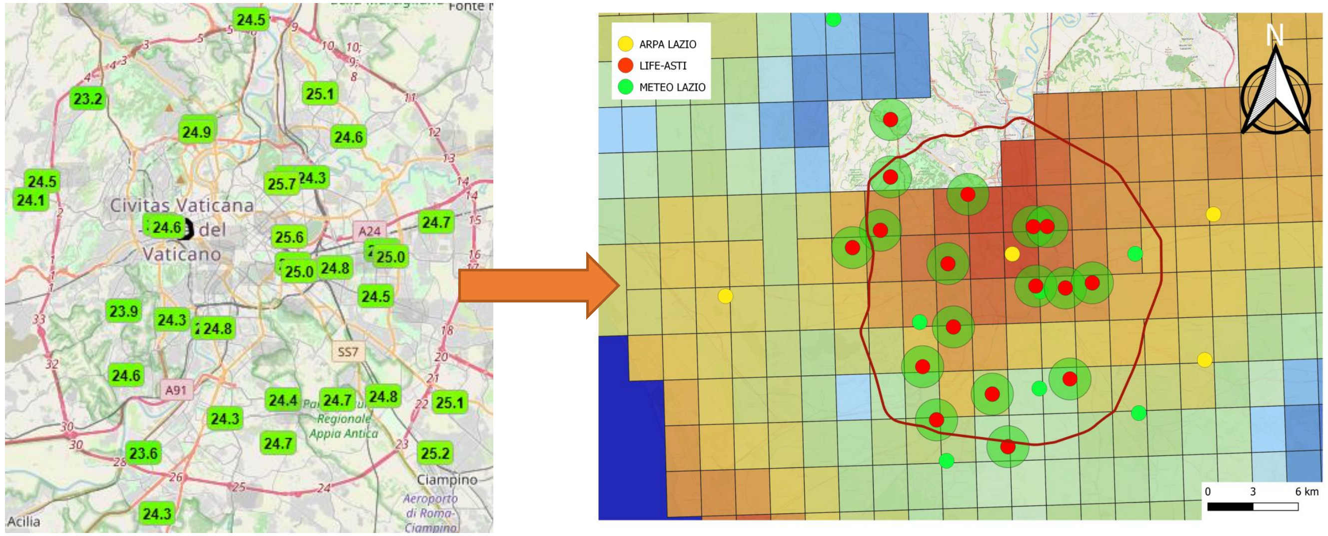
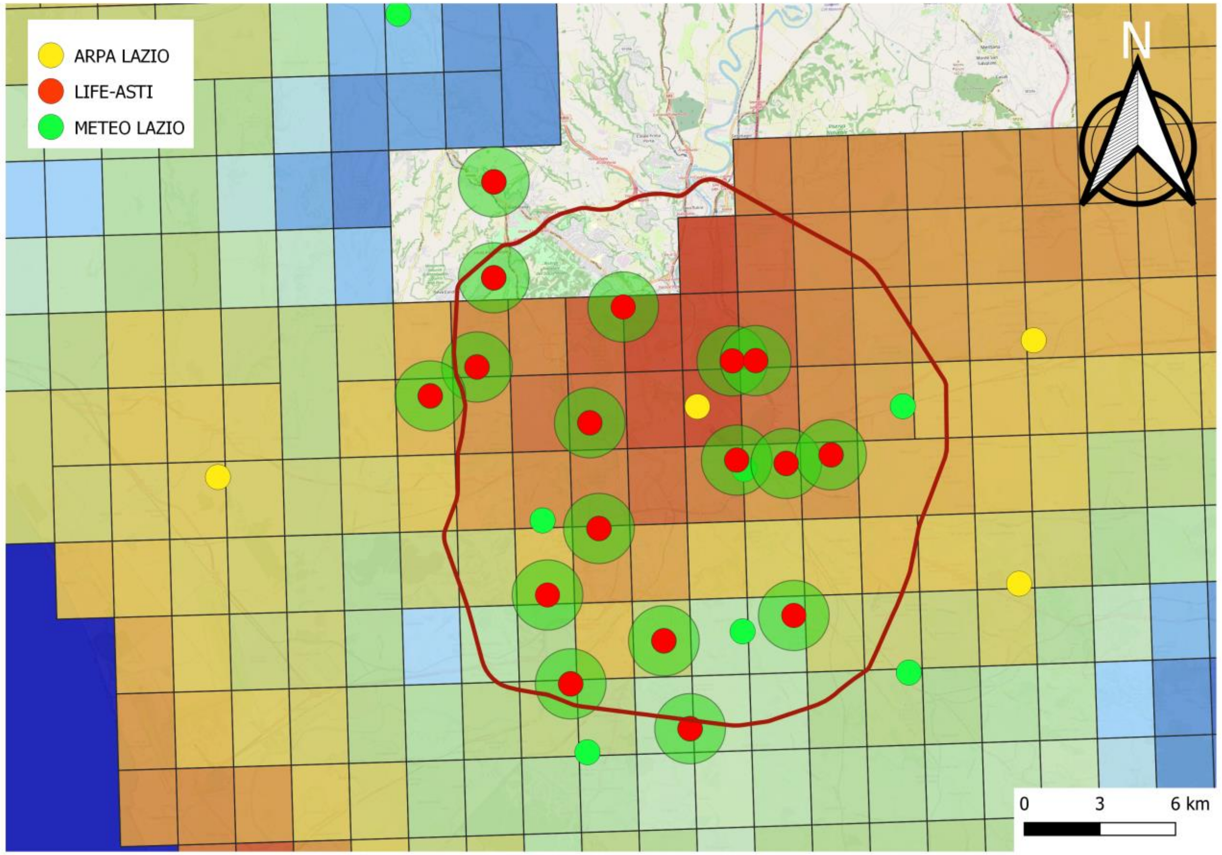


Expected result

Air temperature (Ta) will not be available for all coordinates, as there are no stations everywhere, and **the goal is to predict the value corresponding to the coordinates where it is missing** by doing model training based on the rows where LST and Ta are simultaneously present. This yields a complete grid of Ta, with the same resolution as that of LST.



Global warming and UHI mitigation strategies

UHI ≠ Global Warming (GW)

Urban Climate = UHI+GW

GW leads to more intense and long-lasting heat waves

Increasing interest in UHI mitigation strategies

Urban Greening

- Green roofs
- Trees
- Park areas

Using LIFE-ASTI model for simulating their impact, replacing some urban areas with green areas or varying the surface properties.