GenHack 2025

Phase 2: Visualization & Communication

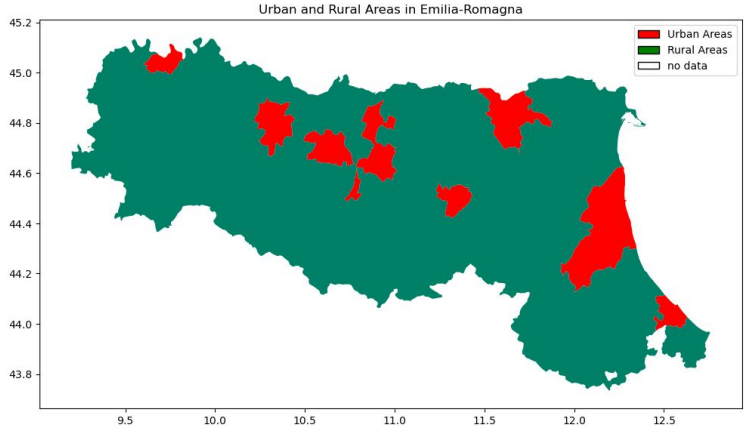
Urban Heat Islands

DEGURBA dataset

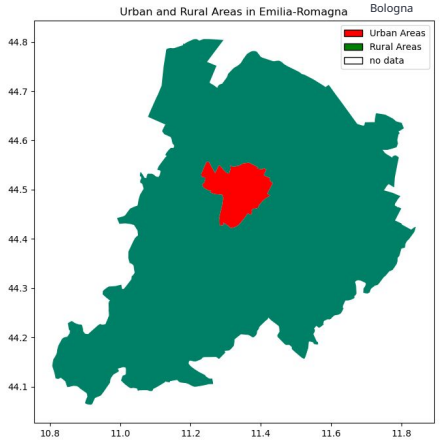
The degree of urbanisation (**DEGURBA**) is a classification that indicates the character of an area. It classifies the territory of a country on an urban-rural continuum,establishing 3 mutually exclusive classes:

- **Cities** (densely populated areas)
- **Towns and suburbs** (intermediate density areas)
- **Rural areas** (thinly populated areas)

In this study, the DEGURBA dataset was employed to achieve a more accurate identification of urban areas, as the NDVI index alone is not sufficiently informative to determine the degree of urbanisation of a given location.



11 urban areas: Bologna, Piacenza, Parma, Reggio nell'Emilia, Carpi, Modena, Sassuolo, Ferrara, Ravenna, Forlì, Rimini

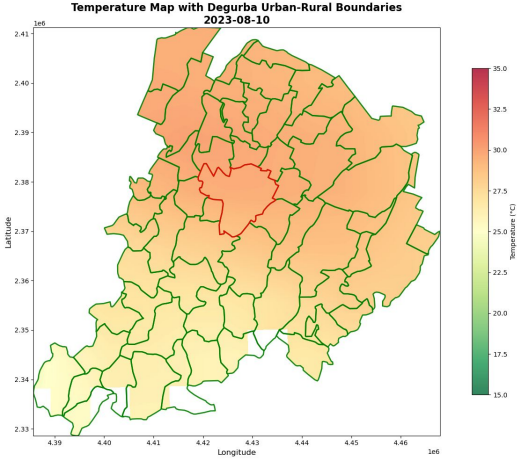


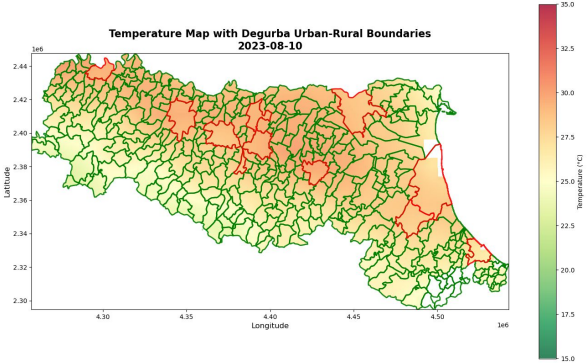
DEGURBA integration and quality assurance

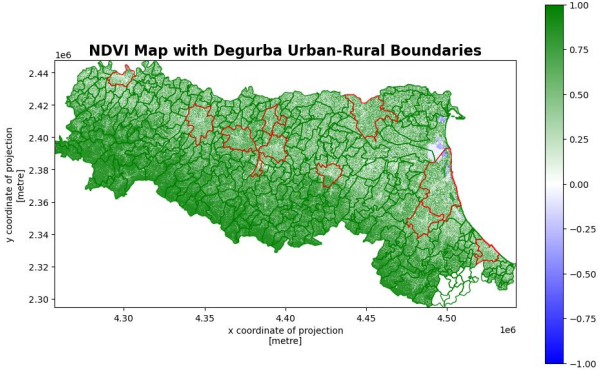
As expected, urban areas classified under DEGURBA exhibit higher temperatures and lower NDVI values.

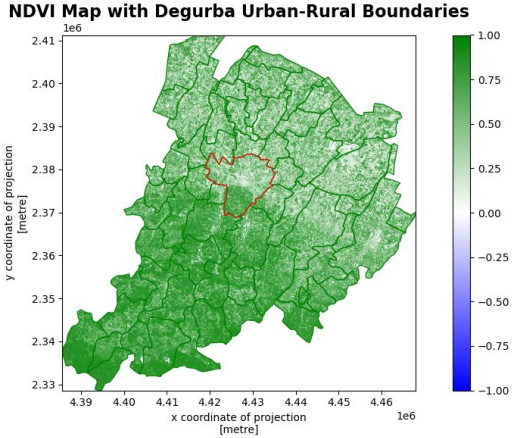
Mismatches between the DEGURBA and GADM datasets were addressed through:

- Case-insensitive standardization of municipality names (including removal of extraneous spaces and chars);
- Rasterized map of DEGURBA areas to match reference grid;
- Manual classification of missing or outdated municipalities.









UHI Differential Index (UHIDI)

Following established approaches in the UHI literature, we define:

$$\mathrm{UHI}(p,d) = T_{\max}(p,d) - T_{\mathrm{rural}}(d)$$

where:

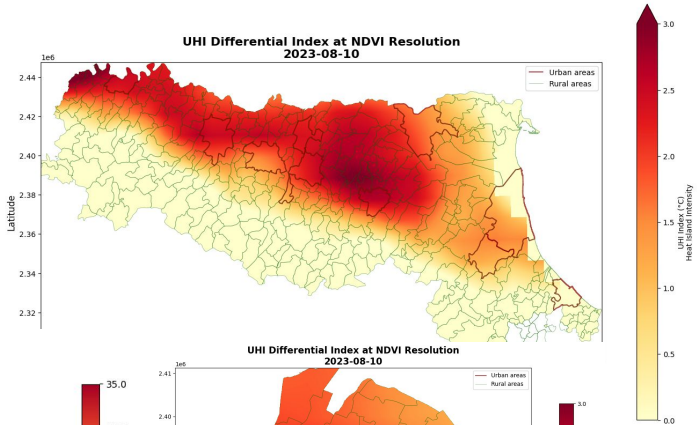
- p = pixel
- d = day
- T_{rural}(d) = mean daily T_{max} of all pixels classified as Rural (DEGURBA Type 3) with NDVI > 0.5

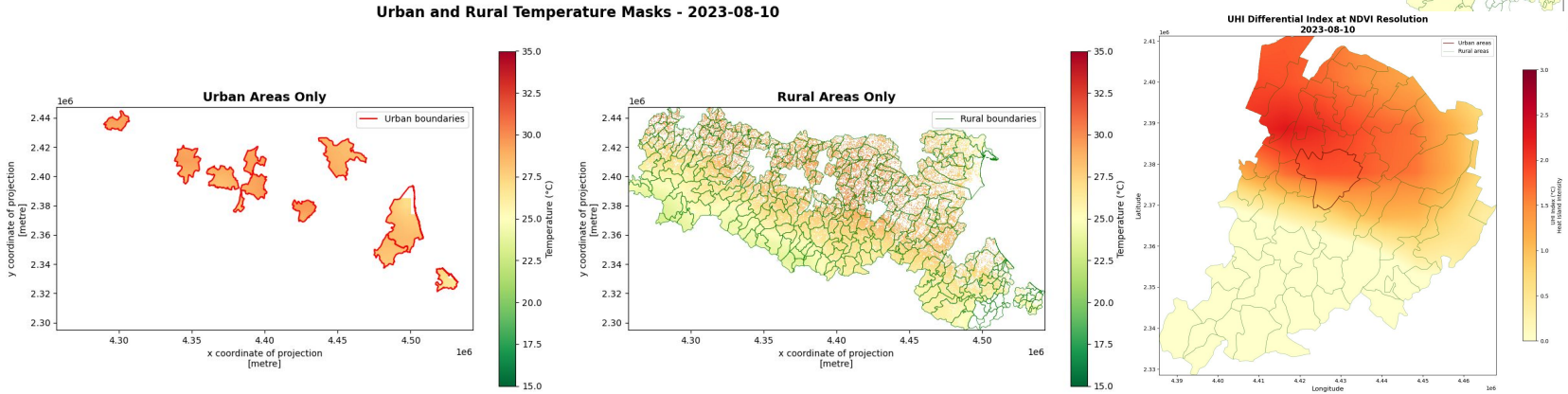
Procedure:

1. Select rural pixels using DEGURBA Type 3 classification;
2. Refine the rural baseline using NDVI > 0.5 to ensure only vegetated areas are included, avoiding bare soil or rock, which can be naturally hotter;
3. Compute the average daily maximum temperature of rural pixels to obtain the daily baseline;
4. Calculate UHIDI for every pixel across the study area.

UHIDI region analysis

Rural reference temperature $T_{rural}(d)$ is derived from a dedicated mask, with a mean rural temperature of 26.92 °C.





- UHIDI is computed at NDVI resolution to capture the highest spatial detail.
- UHIDI values ranged from 0.00 °C—the index never becomes negative—to a **maximum of 4.72 °C**. The average UHI intensity was 0.74 °C, with a **standard deviation of 0.98 °C**, highlighting substantial spatial variability in urban–rural temperature differences.

Urban Heat Island Composite Index (UHICI)

The **Urban Heat Island Composite Index** (**UHICI**) is an integrated metric designed to quantify the intensity of **urban heat island** (**UHI**) effects by combining thermal, vegetative, and urbanisation-related information into a single normalized indicator.

The index incorporates three key environmental and anthropogenic components:

- T_{max}: maximum land surface temperature
- *NDVI*: vegetation cover
- *DEGURBA*: degree of urbanisation

$$\mathrm{UHICI} = N\Big(w_1 \cdot N(T_{\max}) + w_2 \cdot \big(1 - N(\mathrm{NDVI})\big) + w_3 \cdot \big(1 - N(\mathrm{DEGURBA})\big)\Big)$$

Higher **temperature** increases the **UHICI**, reflecting enhanced heat stress.

Higher **NDVI** decreases **UHICI**, capturing the cooling effect of vegetation. Greater **urbanization** increases **UHICI**, representing structural and morphological contributions to heat buildup.

Urban Heat Island Composite Index (UHICI)

The index uses a **min–max normalization** function defined as:

$$N(x) = \frac{x - \min}{\max - \min}$$

Min–max normalization rescales all input variables: **maximum temperature**, **NDVI**, and **DEGURBA** onto a common 0–1 range, allowing the **UHICI** to integrate heterogeneous datasets consistently without any variable dominating due to differing units or ranges.

- The weight w_1 represents the contribution of maximum temperature to the UHICI
- In this study, w_2 was assigned the highest weight to emphasize vegetation cover over temperature, based on literature showing that lower vegetation strongly correlates with higher **urban heat island** intensity.
- The weight w_3 accounts for urban morphology, reflecting the influence of built-up areas on heat retention.

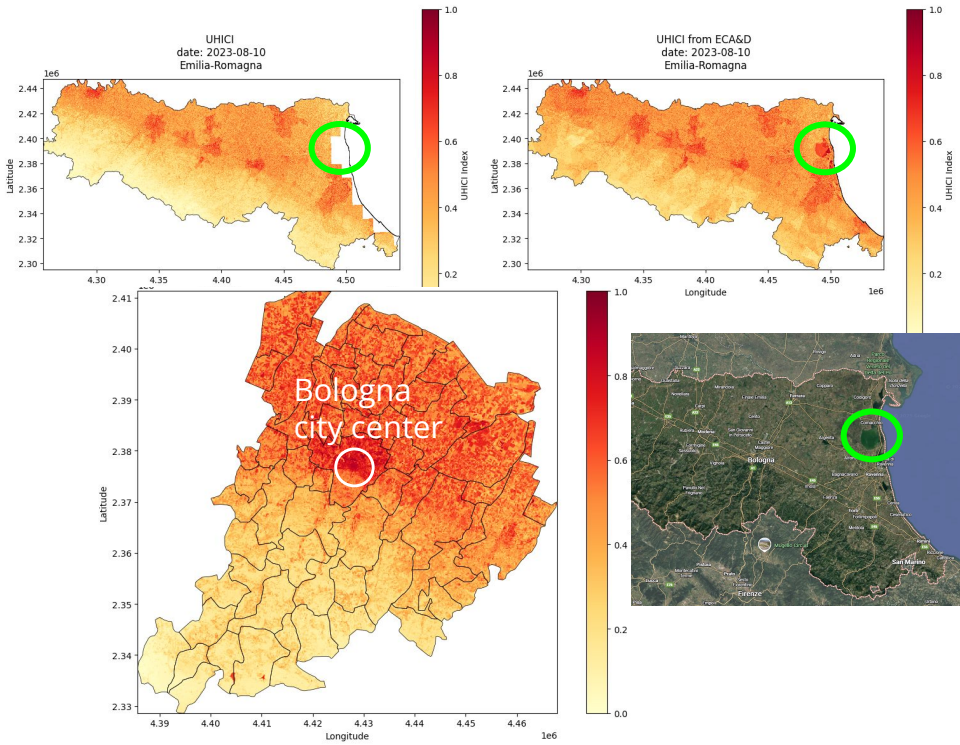
UHICI region analysis

The **Urban Heat Island Composite Index** (**UHICI**) was used to analyze urban heat island effects across Emilia-Romagna and the city of Bologna.

The study was conducted through two parallel analyses:

- one using temperature data from the **ERA5** dataset
- the other using temperatures from **ECA meteorological stations**, which were spatially interpolated to increase resolution and improve accuracy.

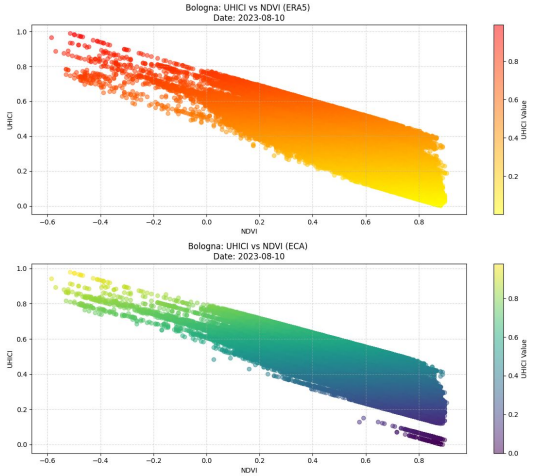
As expected, densely urbanized areas are prominent in the resulting maps.

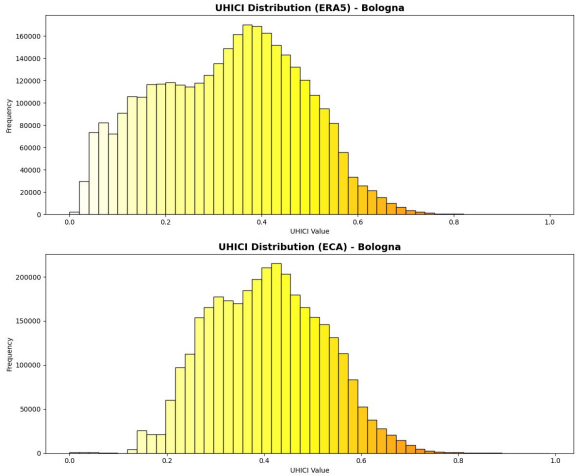


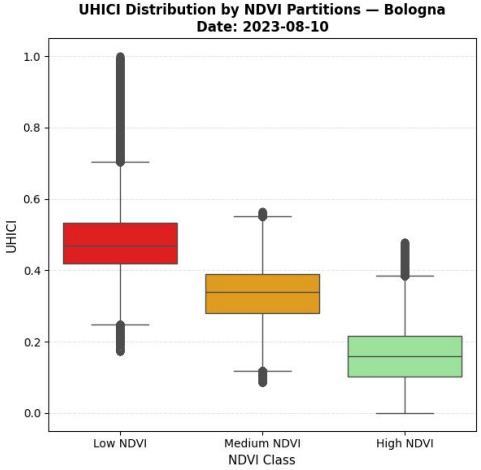
Note: In the eastern part of Emilia-Romagna, the Comacchio Valleys (circled in green) show a data artifact caused by an NDVI error, as the area is a wetland.

Statistical analysis of the UHICI index

A statistical analysis of the Urban Heat Island Composite Index shows that higher **UHICI** values are associated with lower **NDVI** values, as expected, highlighting the **strong influence of vegetation** on urban heat island intensity.





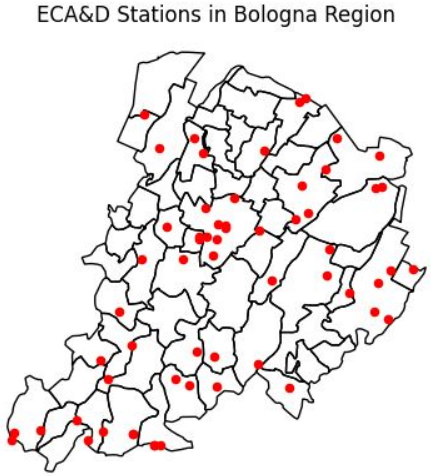


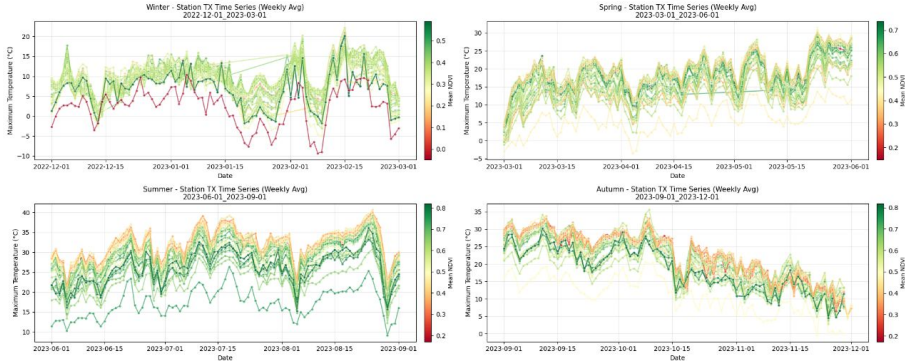
TX - NDVI Correlation Analysis

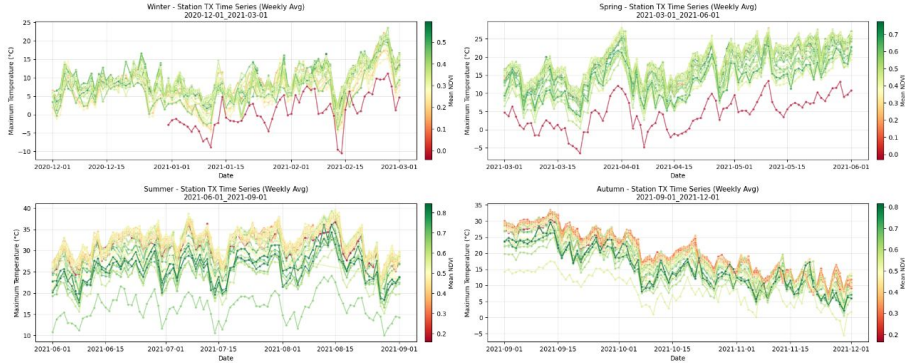
To validate our results on the UHI analysis, we can analyze the **correlation between maximum daily temperature (TX) and NDVI values** across our region of interest.

As we can see the low value NDVI curves have mostly higher temperature in all the seasons.

We will at first analyze the region of Bologna, and then compare it with other big citie in the region of Emilia-Romagna.







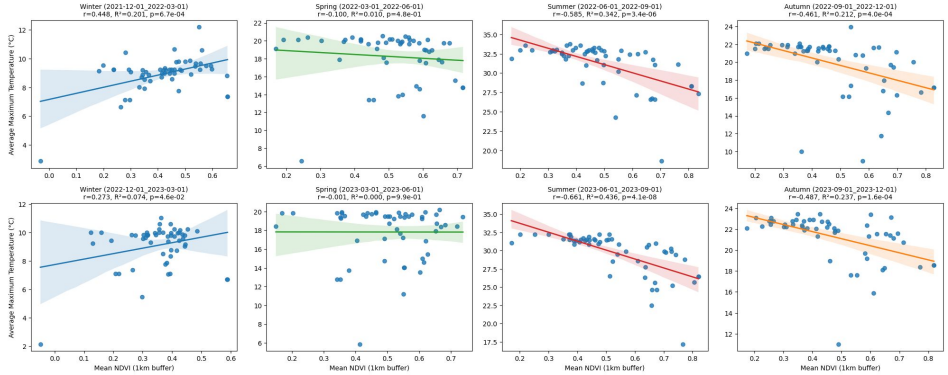
TX - NDVI Correlation Analysis: Bologna and Modena

For the city of **Bologna**, we can see a trend in the TX-NDVI correlation across the same season in each year.

- In **winter**, a lower NDVI (less vegetation) corresponds to lower TX values
- In **summer**, a higher NDVI corresponds to lower TX values, indicating the cooling effect of vegetation during hotter months.

The region of **Modena** shows a similar trend to Bologna, with a clear negative correlation between TX and NDVI during the summer months.

Bologna



Modena