REACHOUT

shaping climate resilient cities

Thermal Assessment Tool (TAT) - User guide.

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Thermal Assessment Tool. User guide

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CI	Classified, as referred to in Commission Decision 2001/844/EC	

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Version Log

Version	Date	Released by	Nature of Change
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1 Introduction

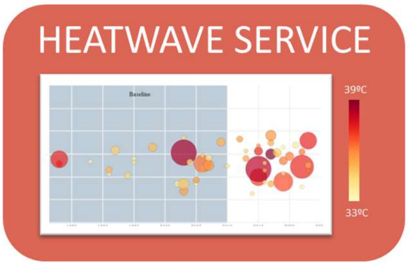
Climate change is leading to an increase in the frequency and intensity of heatwave events. Record temperatures are continually being reached across the globe and concurrent heatwaves hit multiple countries and cities. These events typically generate thermal discomfort, lack of productivity, more energy consumption, health problems or even deaths. However, not all regions, urban areas and, hence, inhabitants will be hit equally hard.

To reduce or at least mitigate these impacts TECNALIA has developed an easy-to-use Thermal Assessment Tool (TAT) within the REACHOUT project. The tool visualizes heat-related data and offers added-value information regarding the impact of heatwave events at both regional and local scale. This information is crucial to improve knowledge and, thus, the adaptative capacity of regions and cities and supports different stakeholders in the design of adaptation plans and regional policies.

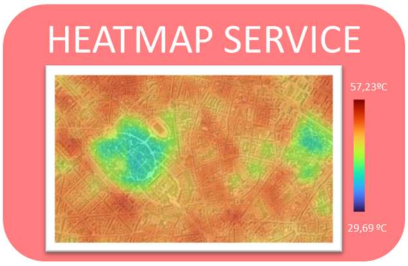
2 What is the TAT for?

The Thermal Assessment Tool is a user-friendly means of visualizing past, present, and future extreme heat events in European regions and cities. It has been applied within REACHOUT project to support planning in 7 EU regions. Additionally, public datasets are available for an easy replication in continental Europe.

The tool provides two type of climate services:



- This service provides a user-friendly visualization of past, present, and future heatwaves in European regions at different regional scales.
- It has been useful to raise awareness and better support heat-stress risk assessment.
- The climate data comes from a public, independent and authoritative Copernicus Climate Change Service (C3S) data, homogeneous across the EU.



- This service provides high-resolution land surface temperature maps (LST) to characterize the heat phenomena at city level.
- LST can provide a useful information about the behaviour of a city's surfaces and materials.
- The input data required contextualization for each city by gathering and processing data from Landsat 8

For each of the above service, customized visualisations have been co-designed within REACHOUT city-hubs to support the assessment of the thermal behaviour of cities/regions. The analysis for the heatwaves is conducted under current and future climate conditions, considering the intermediate (Representative Concentration Pathway RCP4.5) and very high (RCP8.5) emissions scenarios, while the analysis for the heatmap service is conducted considering the the last seven 5-year windows from 2013 to 2023.

3 TAT-Heatwave service

3.1 TAT-Heatwave service overview

The TAT-heatwave service is designed to provide a user-friendly visualization of past, present and future extreme heat episodes (heatwaves) in European regions and cities to raise awareness and better support heat risk assessment.

The tool provides customized visualisations to show the magnitude of extreme heatwave events in Europe and categorized on three different risk levels “warning”, “alert”, “alarm” that are based on the severity of the potential impacts. The analysis is conducted under current and future climate conditions, considering the intermediate (Representative Concentration Pathway RCP4.5) and very high (RCP8.5) emissions scenarios. The information is provided at various regional scales, including municipality, province, and region levels.

This information can be integrated and used in policy and adaptation planning processes (e.g. Sustainable Energy and Climate Action Plans (SECAPs) or Climate Adaptation Plans) or used to assess health impacts or energy consumption patterns.

Heatwave characterization

A heatwave is typically defined as an event that is characterized for reaching high temperatures during a prolonged period of time in a particular region or location. But what is the meaning of *high* or *prolonged* period of time?. As there is not a standard definition, in REACHOUT, a heatwave has been considered as *“a period of two or more days with excessively high temperatures, relative to the usual climate in the area and relative to normal temperatures for the summer season”.*

The percentiles 95 and 90 of maximum and minimum temperature, respectively, were obtained considering the values of maximum and minimum temperature at NUTS2/NUST3 or LAU level during the summer months (June, July, August, and September). The historical timeframe considered for this analysis was from1981 to2010.

Considering this definition a heat wave has been characterized considering the following parameters:

- Peak intensity: The maximum temperature reached during the heatwave.
- Daytime intensity: The total amount of degrees by which daily maximum temperatures exceed the temperature threshold (95th percentile) during a heatwave event.
- Night-time intensity: The total amount of degrees by which daily minimum temperatures exceed the temperature threshold (90th percentile) during a heatwave event.
- Risk Level: assigned according to the duration of the heatwave and thresholds exceeded.

Next Figure 1 provides a graphical representation of these 4 parameters.

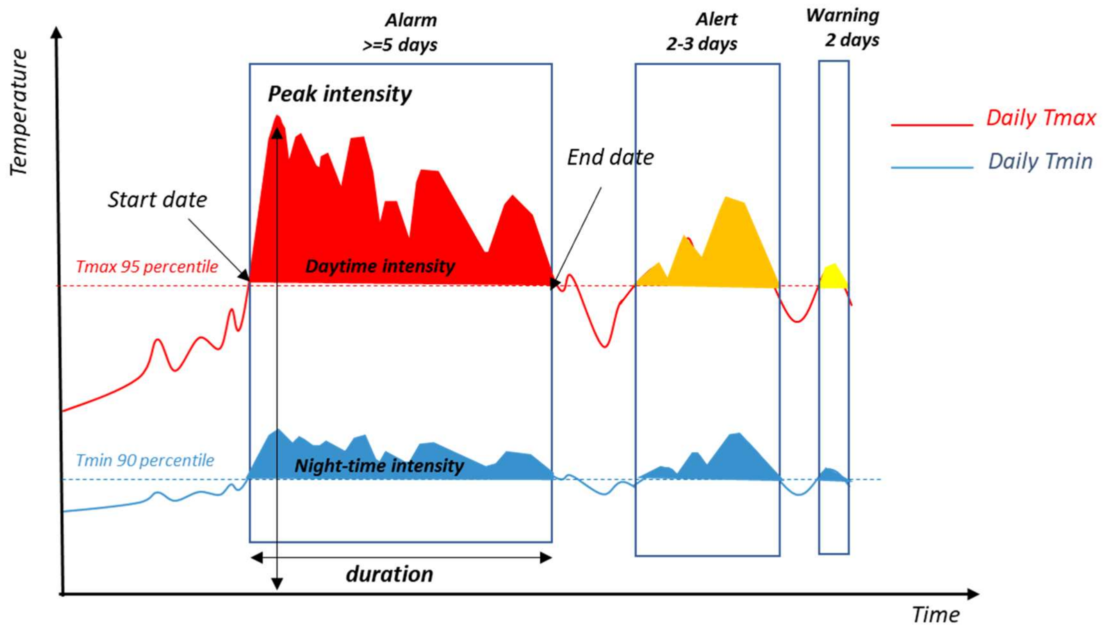


Figure 1. Heatwave characterization considering maximum temperature (tmax) and minimum temperature (tmin) evolution.

Based on the above different risk levels are assigned in REACHOUT according to the number of consecutive days on which the established maximum and minimum temperature thresholds are exceeded.

Table 1. Risk levels assigned in REACHOUT For a heatwave event considering the percentiles 95 and 90 of maximum and minimum temperature, respectively.

Risk Level	Denomination	Trigger and meaning
Level 1	Warning	This level is considered when there are 2 consecutive days where maximum and minimum temperature thresholds are exceeded. There is no risk for the general population, although some specific activities might be affected.
Level 2	Alert	This level is considered when there are 3 or 4 consecutive days where maximum and minimum temperature thresholds are exceeded. The damage, especially in some sectors, is starting to be significant and physical integrity is at risk.
Level 3	Alarm	This level is considered when there are 5 or more consecutive days where maximum and minimum temperature thresholds are exceeded. It involves a clear risk for the population, endangering the physical integrity of some of its sectors.

3.2 How to navigate and use the TAT-Heatwave service?

The landing page (Figure 2) of the Thermal Assessment Tool (TAT) – Heatwaves Service provides an overview of the platform’s purpose and functionality.

The left side features a welcome message explaining that the tool visualizes heatwave intensity, frequency, and trends across European regions based on past and future climate conditions.

Below the welcome text, six images represent the 7 REACHOUT region information, which users can click to access specific city or regional heatwave assessments. The user can zoom in and zoom out to select NUTS2, NUTS3 or local administration units for the European regions of Lombardia, La Rioja, Pomorskie, Oslo og Viken, Southern Irland and Attica.

The right side contains an interactive map where users can select regions to explore heatwave data.

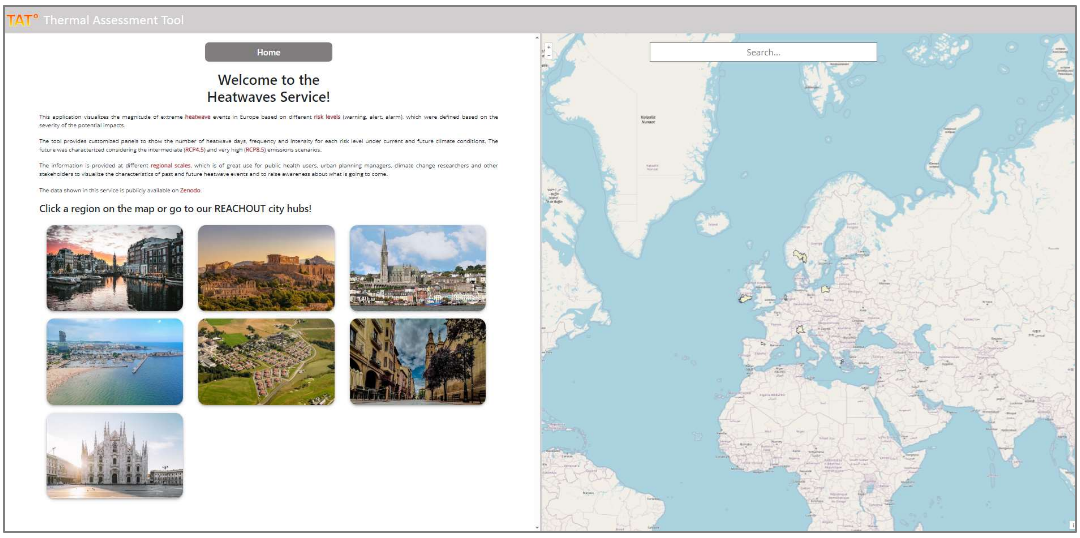


Figure 2. Welcome page of the Heatwave service

In the landing page, user can also access publicly available datasets via Zenodo. These datasets provide frequency and severity of heatwaves under past, current and future climate conditions which allows to integrate these outcomes in other climate services that are dealing with extreme heat impacts.

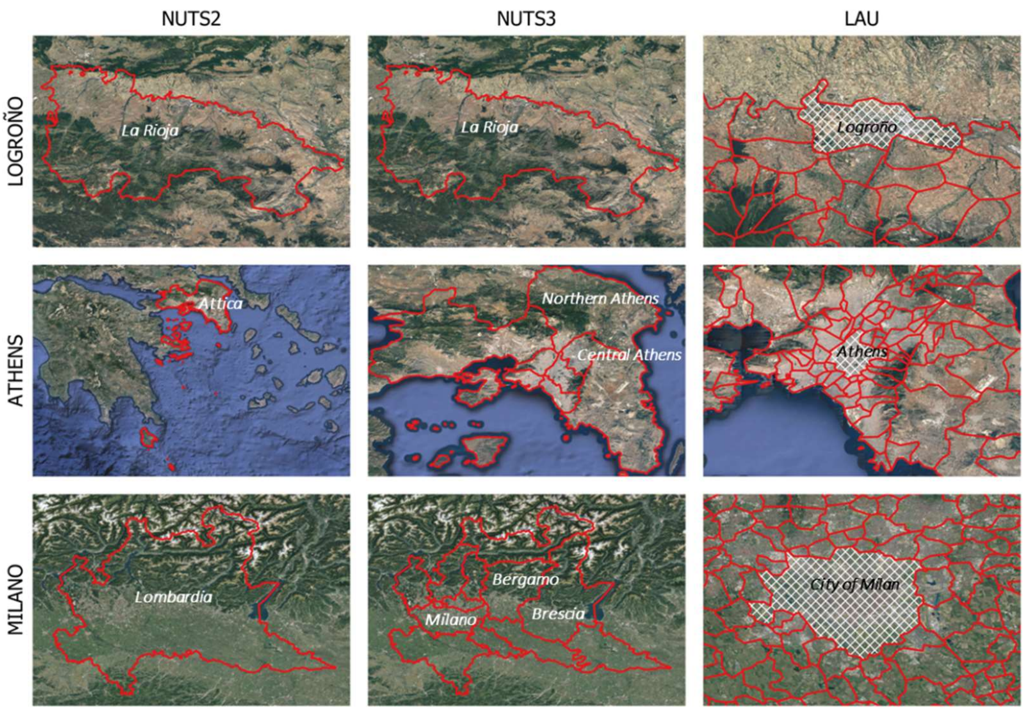


Figure 3. Examples of NUTS2, NUTS3 and LAU for La Rioja, Attica and Lombardia.

Once the user accesses a city or region information, it can further explore its heatwave characteristics and compare current and future conditions to analyze heatwave trends within a city or LAU level. It also allows the user to compare spatially the differences in the heatwave characteristics by clicking the different areas within a region. This information is shown by the following customized and interactive panels.

Historical Heatwave panel

This panel is composed by an interactive plot that shows the historical heatwave events that took place between 1981 to 2022 in a specific region. Each bubble represents a heatwave event. The bubble's color represents the maximum temperature reached during that event and the size represents the duration of the heatwave. Moving the mouse over each bubble allows to get specific information on the starting date, maximum temperature, severity and duration of the heatwave event. The plot also allows to zoom in or zoom out to better visualize different heatwave events happened in the past.

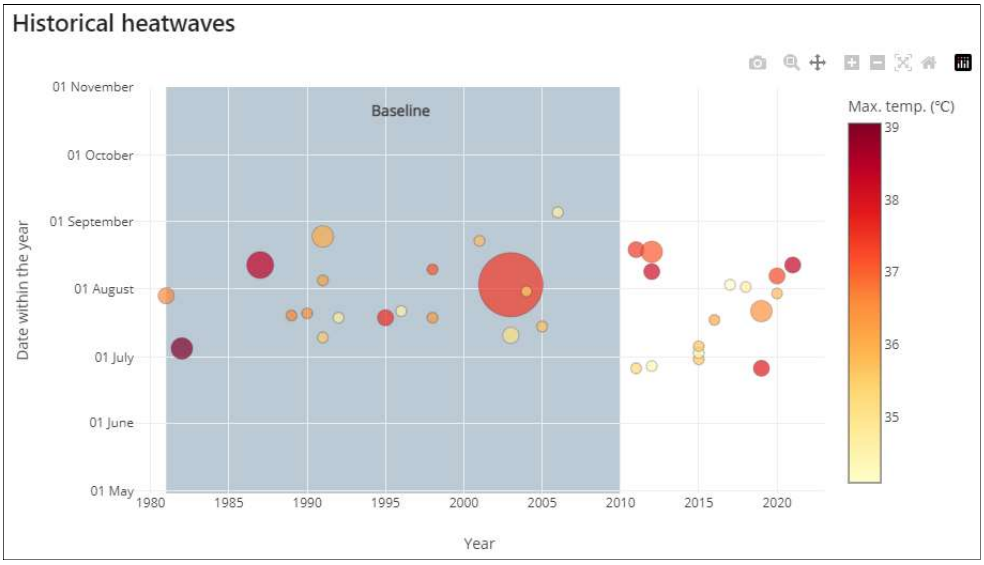


Figure 4. Historical heatwaves

Projected frequency of heatwaves per decade

This plot shows how the frequency of heatwaves is expected to evolve over time for three risk levels:

- Warning (yellow)
- Alert (orange)
- Alarm (red)

The dots in the lines represent the average number of events per decade, while the shaded areas show the uncertainty range. Clicking on any dot reveals details about the minimum, average, and maximum predicted frequencies (best, mean and worst-case scenario respectively)

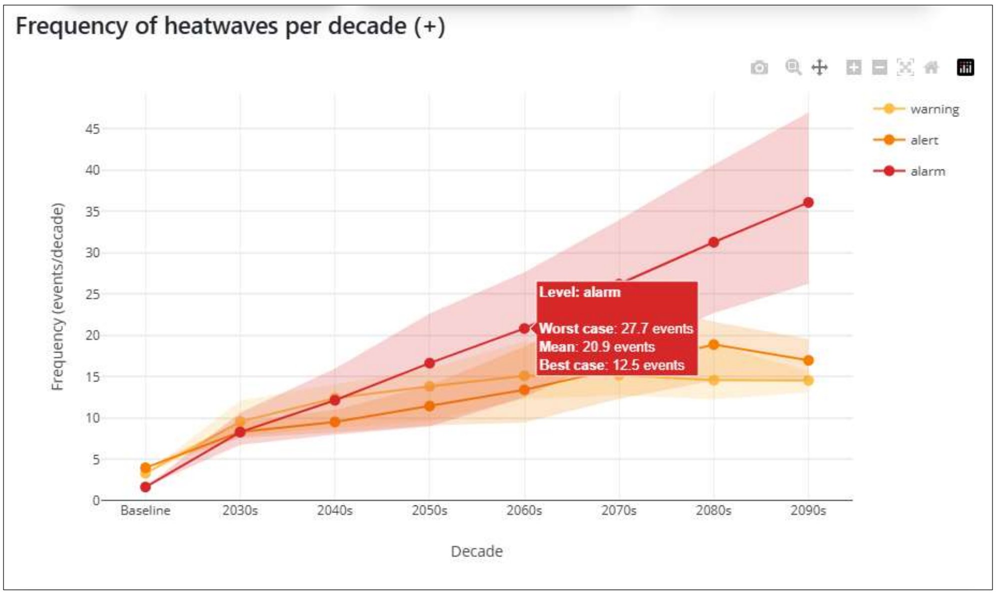


Figure 5. Evolution of the heatwaves' frequency per decade

The projections are based on 30-year periods, with the baseline (1981-2010) serving as a reference.

Projected heatwave days per year

This plot allows to visualize the evolution of the average number of heatwave day type (warning/alerts/alarms) per year in the following decades and the baseline. In this case, each bar provides the average number of days on annual basis, considering the different 30-year periods. Clicking on the bars the user can also visualize the exact number of days per risk typology as well as the proportion over the total number of heatwaves.

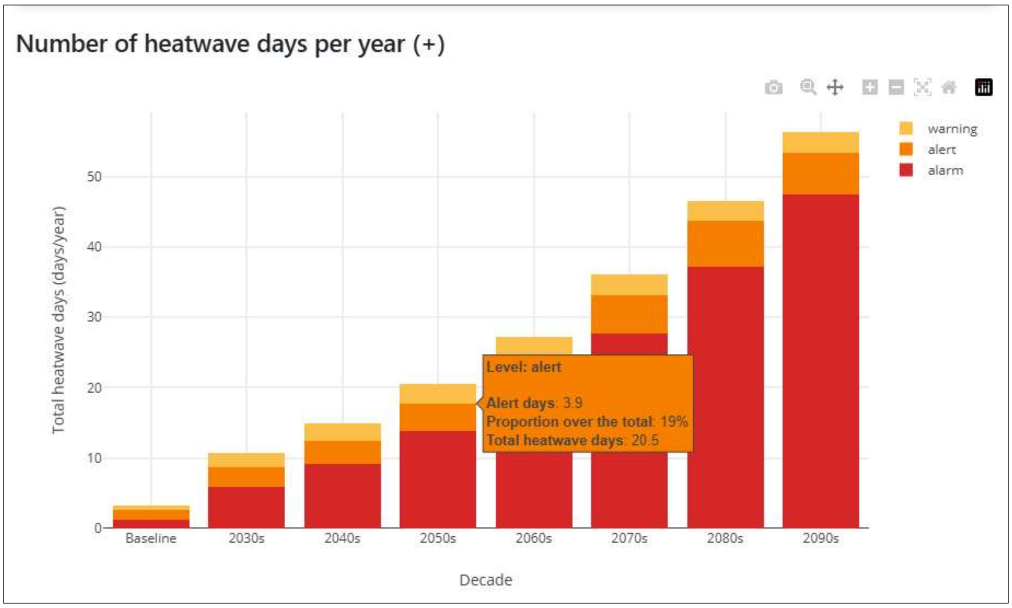


Figure 6. Evolution of the heatwave days per year

This user can select or remove any risk level (warning/alert/alarm) by clicking on the top-right corner legend to better visualize what is the evolution for that specific hazard level.

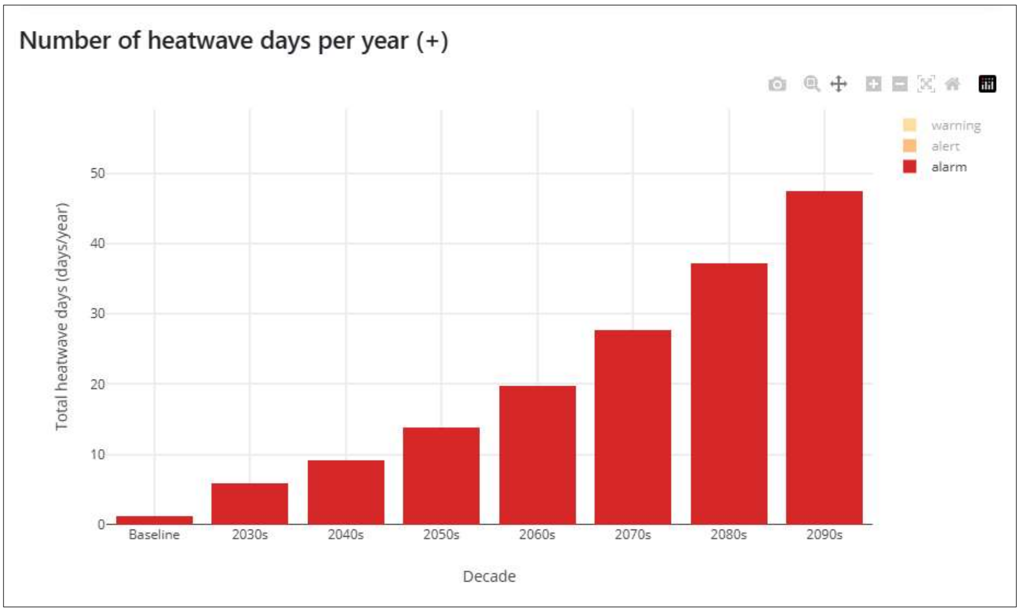


Figure 7. Example of the evolution of alarms days per year

Evolution of heatwaves intensity

This plot shows the future evolution of the heatwaves day-time and night-time intensity per risk level. The intensities are provided on an annual basis. The night-time and day-time intensities are defined as the number of degrees over the minimum and maximum temperature thresholds used to detect the heatwaves, respectively.

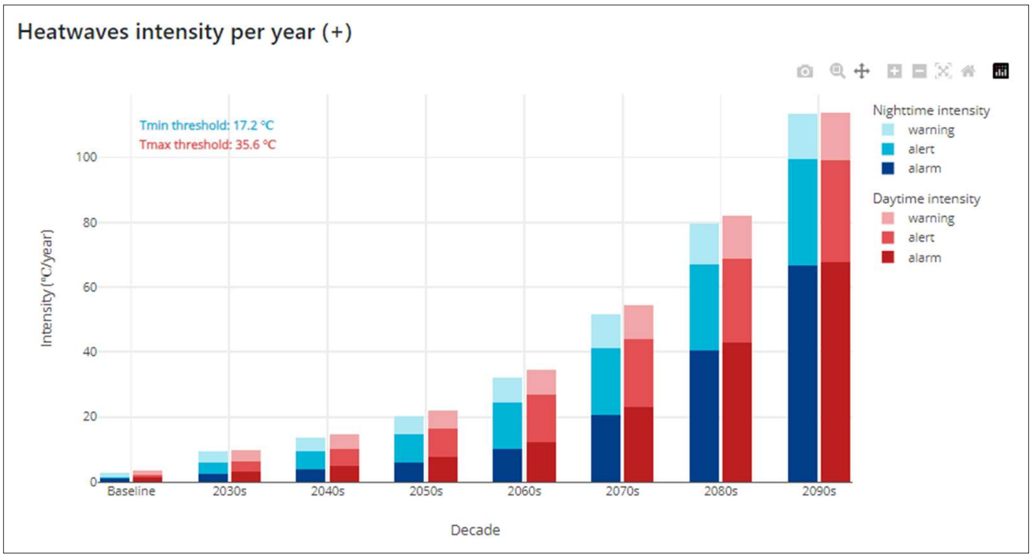


Figure 8. Evolution of daytime and night-time intensity per hazard level

The projections are based on 30-year periods, with the baseline (1981-2010) serving as a reference,

This user can select or remove any hazard level (warning/alert/alarm) by clicking on the top-right corner legend to better visualize what is the overheating evolution for that specific hazard level.

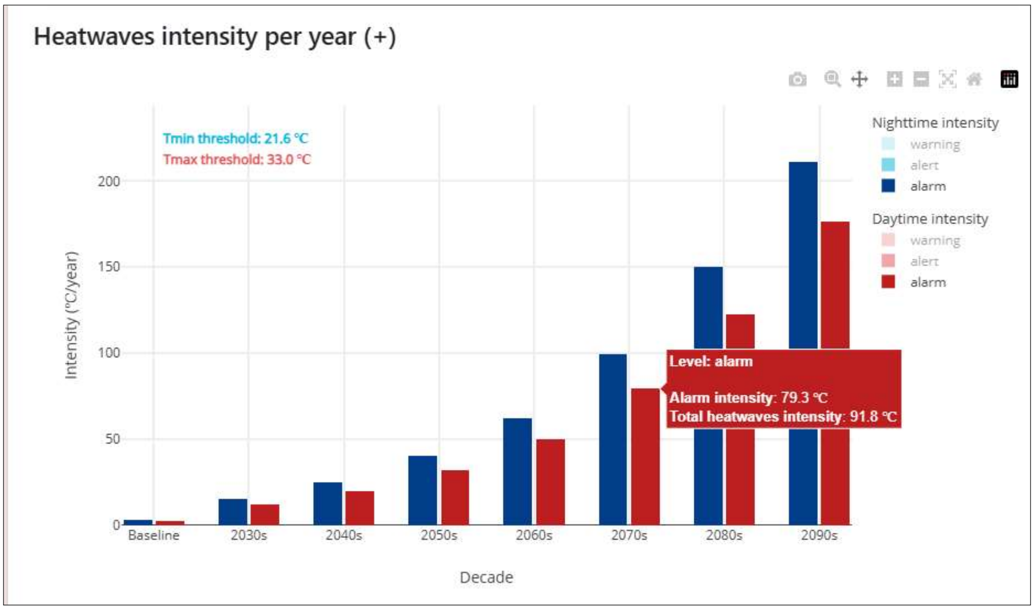


Figure 9. Example of the evolution of daytime and night-time intensity of alarms per year

Possible future scenarios

The analysis for the heatwaves is conducted for both current and future climate conditions, considering two emission scenarios: an intermediate scenario (Representative Concentration Pathway RCP4.5) and a very high (RCP8.5).

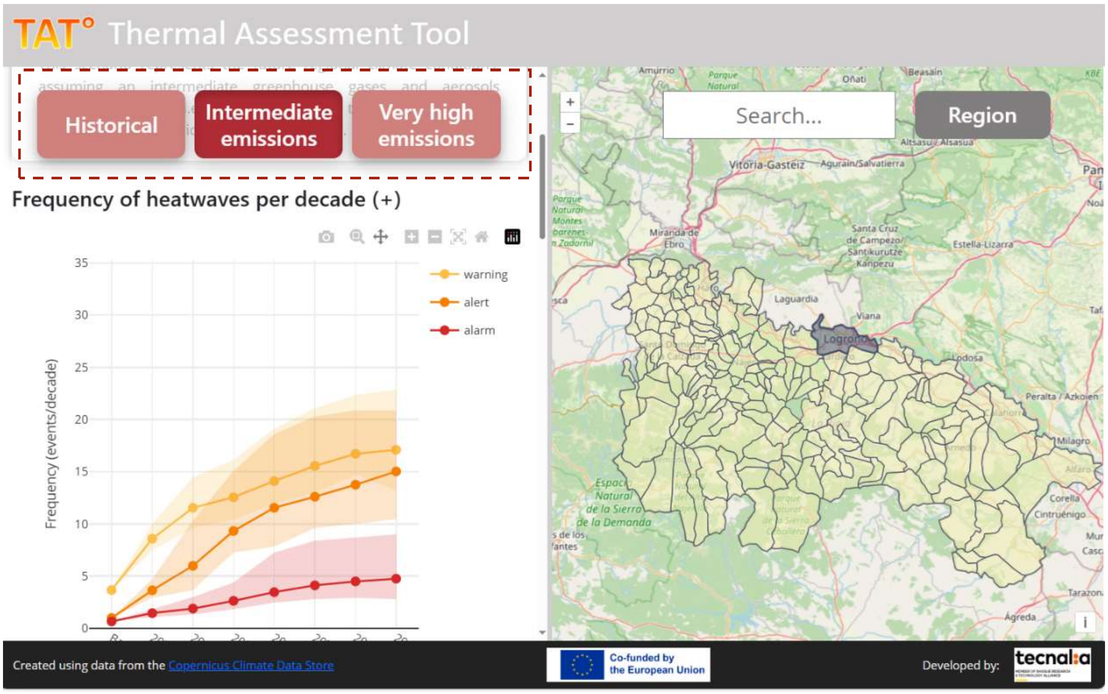


Figure 10. Screenshot where the historical and future scenarios panel has been highlighted.

This allows the user to perform comparative analyses by selecting from three available scenarios in the interface.: the *historical record* (1981-2021), the *intermediate emissions* scenario (2011-2100) – considering future regional climate conditions, assuming an intermediate greenhouse gases and aerosols emissions scenario (RCP 4.5) - or the *very high emissions scenario* (2011-2100) - which represents the future regional climate conditions, assuming a very high greenhouse gases and aerosols emissions scenario (RCP 8.5).

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This presents several benefits for e.g. climate risk assessment, urban planning and policy development as well as awareness raising. Understanding the difference in heatwave severity between intermediate and very high emissions scenarios can motivate the adoption of stronger climate policies aimed at reducing emissions, improving resilience, and meeting adaptation goals or citizen engagement in climate action.

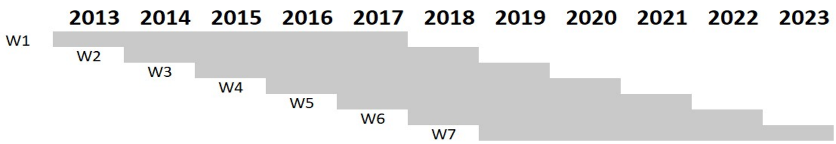
4 TAT-Heatmap service

4.1 TAT-Heatmap service overview

The Heatmap-service provides high-resolution (30m) land surface temperature (LST) map as way to characterize the heat phenomena at city level based on remote sensing observations from Landsat 8.

Although thermal indices are considered more suitable when characterising thermal comfort, still the LST can provide a useful information about the behaviour of a city's surfaces and materials. This has implications for several applications such as urban energy efficiency or urban environmental health.

This service uses as input images acquired since 2013 by Landsat 8 to characterise not only the current (2019-2023) thermal behaviour of the city, but also its evolution considering the last seven 5-year windows.



LST characterization

The concept of Concept of annual cycle parameters (ACP) described in [1] has been considered to deal with anisotropy. All daytime acquisitions of the full period were gathered and assigned to the respective day in the annual cycle (relative to the spring equinox), and a sine function was fitted using a least square optimization resulting in the annual cycle parameters (ACP) mean annual surface temperature (MAST) and yearly amplitude of surface temperature (YAST).

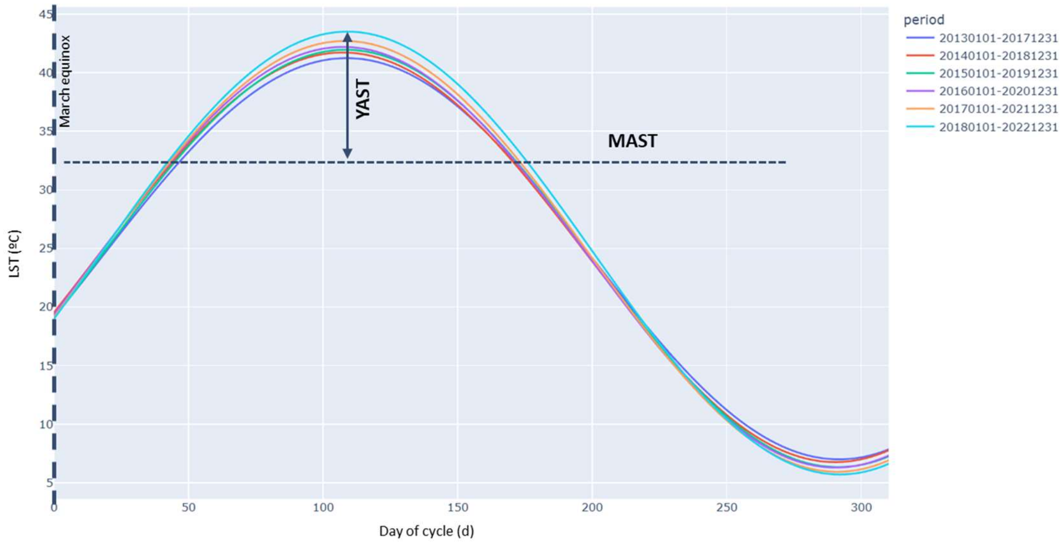


Figure 11. Example of Annual cycle parameters for Milan city. The plot starts on the spring equinox (day 0 = 20 march)

4.2 How to navigate and use the TAT-Heatmap service?

The tool provides an easy-to-use interface and self-explanatory plots allowing non-expert users to understand its outputs. This service allows end-users and decision-makers to easily visualize the thermal behaviour of the city by visualizing 3 main outcomes: the Mean Annual Land Surface Temperature – MAST (ºC), the Yearly Amplitude of Land Surface Temperature – YAST (ºC) and the Peak LST. Thes three indicators are valuable tools in climate monitoring, environmental management and planning.

While YAST can assist in understanding the evolution of temperature amplitudes over time, MAST is better suited for long-term climate trend analysis by for example assessing warming or cooling patterns over time. Peak LST on the other hand helps identify the hottest areas and understand the most extreme temperature conditions experience at city scale.

Regarding the practical application of these indicators, planners may use YAST values to understand energy demand forecasting, as high YAST values indicate significant temperature swings, which may increase the need for heating and/or cooling. On the other hand, another example on the Peak LST use may be associated to heatwave response planning, understanding higher risk areas and setting appropriate adaptation action in these areas.

Mean Annual Land Surface Temperature – MAST

This panel allows to visualize the MAST indicator per the whole city. So, the user can click on any point in the map and visualize the mean annual LST value at that point. The resolution is a 30 meters resolution, so the user can zoom in or zoom out in the map to better visualize the city behaviour.

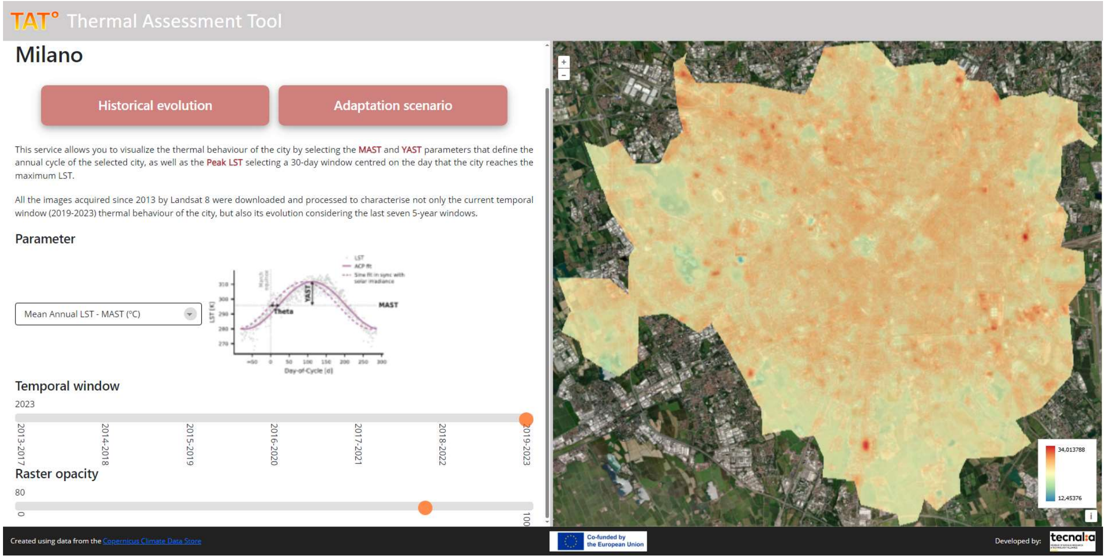


Figure 12. Example of MAST for the city of Milan

The user can always select the raster opacity to better visualize the city's surfaces or materials at different points.

Yearly Amplitude of Land Surface Temperature – YAST

This panel allows to visualize the YAST indicator per the whole city. So, the user can click on any point in the map and visualize the yearly amplitude of LST at any cell (30m) of the city. The user can zoom in or zoom out to better visualize these values and better understand city behaviour.

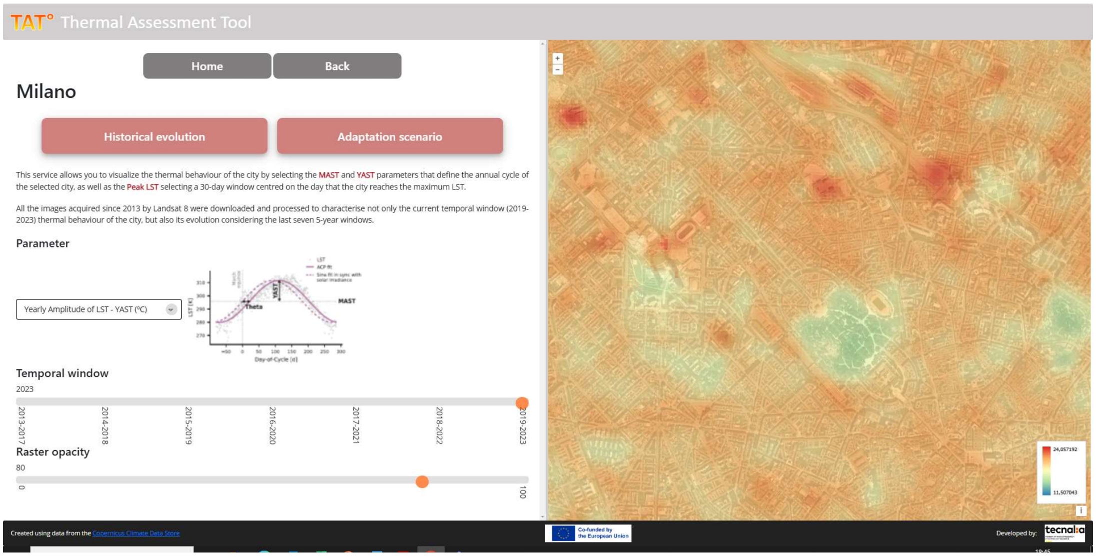


Figure 13. Example of YAST for the city of Milan

Peak Land Surface Temperature (Peak LST)

This panel allows to visualize the Peak LST values in the city area. The Peak LST is obtained after getting the Annual Cycle Parameters of each of the periods and selecting a 30-day window centred on the day that the city reaches the maximum LST. This way, the user can observe the city behaviour during those days where maximum LST values are reached.

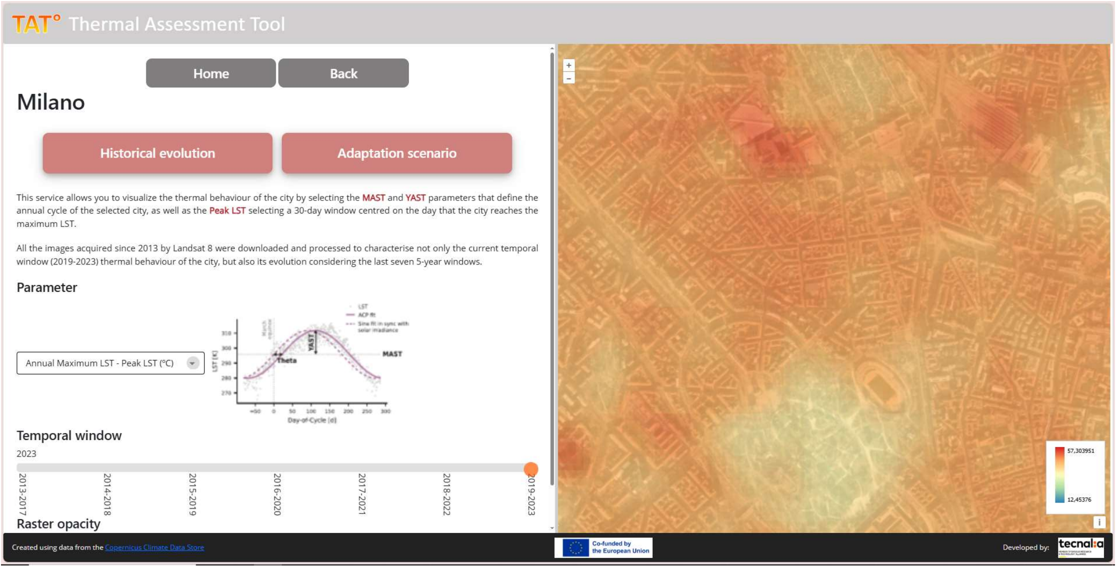


Figure 14.Example of Peak LST for the city of Milan.

5 Connection with other EU-level frameworks

The Urban Adaptation Support Tool (UAST) is designed to guide cities through critical steps to build climate change resilience. The TAT tool can play a key role in supporting tow steps within this broader adaptation process: (1) *Preparing the ground for adaptation* and (2) *Assessing risk and vulnerabilities*.

1. Preparing the Ground for Adaptation

This step focuses on creating a solid foundation for the adaptation process, ensuring that the city or region is ready to take the necessary actions to address climate impacts. The TAT supports this step mainly in building awareness of climate hazards. The TAT can provide cities with valuable information and data on current and projected heatwave events.

2. Assessing Risk and Vulnerabilities

This step involves identifying and understanding the specific climate risks and vulnerabilities that the urban area is exposed to. The TAT supports this phase by providing information to comprehensively assess and analyze heat related risks. Key contributions include:

- **Risk Identification and Mapping**:
  The TAT helps cities identify heat related risks by providing access to climate data, historical trends, and future projections. It can assist in mapping highly exposed areas, understanding the hazard levels along time and assess the land surface temperature during the day which can be an input to the urban heat island effect. The tool enables urban planners to visualize how climate impacts are spatially distributed across the city, helping them identify high-risk areas that may require urgent intervention and well as understand better the potential health impacts related to heat stress.
- **Scenario Planning and Climate Projections**:
  The TAT incorporates future climate scenarios to help cities understand how different levels of climate change (e.g., moderate vs. high emissions) could impact their urban systems. By exploring multiple future scenarios, cities can better assess the range of possible outcomes and prepare for a variety of future risks. This scenario-based

approach allows for flexible planning and ensures that adaptation measures can address both current and potential future conditions.

Furthermore, due to the importance of heat related impacts and its user-friendliness, MIP4Adapt has included this TAT) in the Mission tool database, because it illustrates for users what local risk of heatwaves exist and thereby offers a better understanding of spatial uses for heat episodes in summer.

6 References

[1] *Heatwaves characterization derived from reanalysis and climate projections to assess thermal behavior of 7 European city-hubs: Milano, Athens, Logroño, Cork, Gdynia, Lillestrøm and Amsterdam (1981-2100)*

[2] *Heatwaves characterization derived from observations and climate projections to assess thermal behavior of 7 European city-hubs: Milano, Athens, Logroño, Cork, Gdynia, Lillestrøm and Amsterdam (1981-2100)*

[3] *Heatwaves characterization derived from reanalysis and climate projections to assess thermal behavior of regions in Europe (1981-2100)*

[4] *Heatwaves characterization derived from observations and climate projections to assess thermal behavior of regions in Europe (1981-2100)*

[5] *Sismanidis, P., Bechtel, B., Keramitsoglou, I., Göttsche, F., & Kiranoudis, C. T. (2021). Satellite-derived quantification of the diurnal and annual dynamics of land surface temperature. Remote Sensing of Environment, 265, 112642. https://doi.org/10.1016/j.rse.2021.112642*

[6] *Land surface temperature (heatmaps) derived from earth observation data to assess thermal behaviour of 3 European cities: Milano, Logroño and Athens.*

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