AIR4health: Leveraging Earth Observation for Compound Climate and Air Quality Extremes Early Warning

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ABSTRACT

Climate resiliency is a key challenge of the 21st century, as the impacts of climate change and weather extremes come forth as pressing challenges. Nonetheless, public health stakeholders still struggle to take advantage of the state-of-the-art scientific knowledge on geospatial data science considering that many dose-response uncertainties remain regarding (i) the best practices in mapping the exposure to environmental and climate-induced hazards, (ii) the attribution and measurement of correlated impacts and (iii) our ability to produce meaningful future impact assessment scenarios. That is the case of Compound Climate and Air Quality Extremes. As extreme temperatures are already becoming significantly more frequent and severe in Portugal in the last decades (and overall, in Europe), their occurrence has translated into significant cases of excess human mortality and morbidity, also in tandem with the simultaneous air quality loss, with corresponding human and societal impacts. However, such impacts have only been documented in a case-specific manner, i.e., describing the consequences of Cold and Heat Waves (CW and HW, respectively) and low Air Quality (AQ) events separately, or by focusing on very specific events and locations, limiting the ability of the public health sector in deriving meaningful and generalisable policy guidelines for early warning and response actions.

OBJECTIVES

OBJ-1: To Deliver a Downscaled Atlas of Compound Climate and Air Quality Extremes, a geospatial time series of extreme temperatures and poor air quality events

OBJ-2: To Develop Two Novel Compound Climate and Air Quality Extremes Risk Indices (AIR4health Risk Algorithms) for predicting excess mortality and morbidity, while controlling for human sensitivity and geographical features

OBJ-3: To Deploy the Compound Climate and Air Quality Extremes Early Warning Prototype Digital Twin Component, as a precursor for an operational early-warning system for public health risk assessment

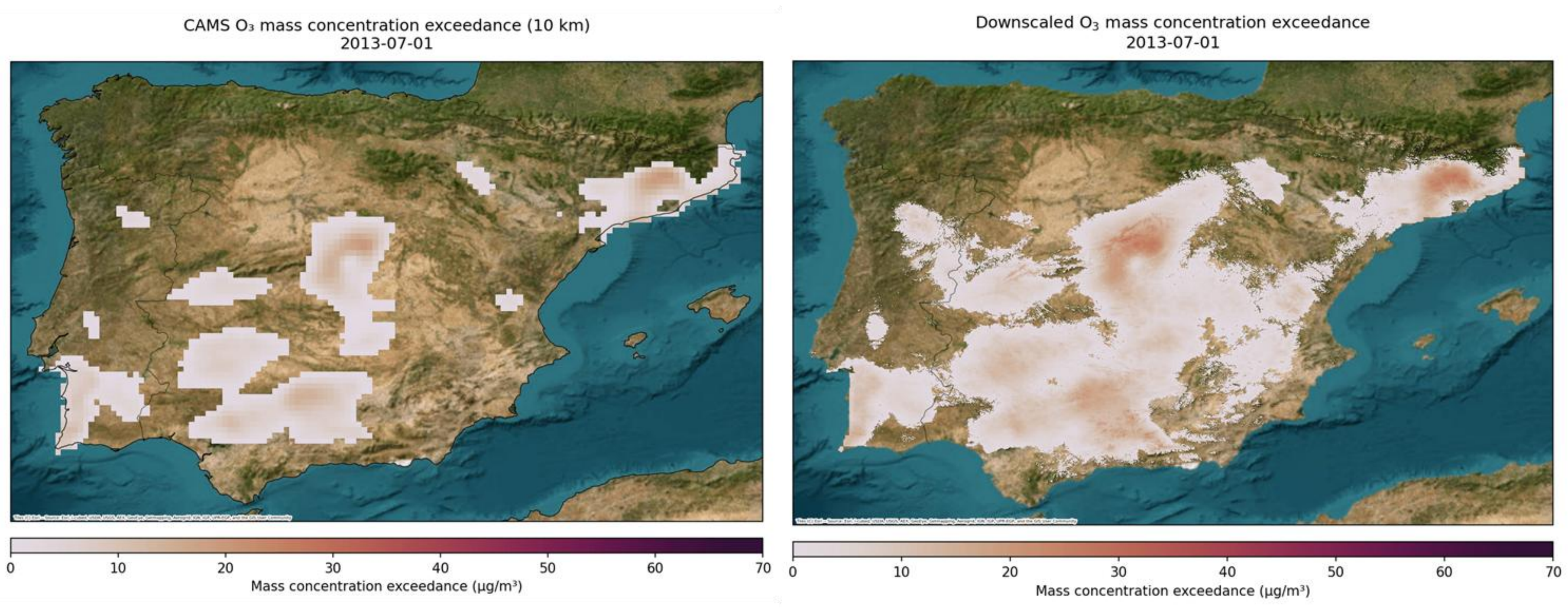
DATA & METHODS

The AIR4health overarching goal is to develop two spatiotemporal Compound Climate and Air Quality Extremes Risk Algorithms (AIR4health Risk Algorithms) for predicting excess mortality and morbidity by major diagnostic groups, using the available data pertaining to mainland Portugal as an opportunity for operationally servicing a European Heat Waves and Cold Waves (HW/CW) and Air Quality (AQ) surveillance system. AIR4heath Risk Algorithms will consider the following facts:

Use Case 1

Heat and Ozone

During a heatwave, high temperatures speed up photochemical reactions between pollutants (like NOx and VOCs) and sunlight, leading to increased formation of ground-level ozone (O_3), a key smog component. This effect is intensified by elevated emissions and heat. The resulting high O_3 levels, combined with heat stress, contribute to serious health problems, including respiratory (asthma, bronchitis), cardiovascular (strokes, oxidative stress), and heat-related illnesses.(Hertig et al., 2020; Carvalho et al., 2010).

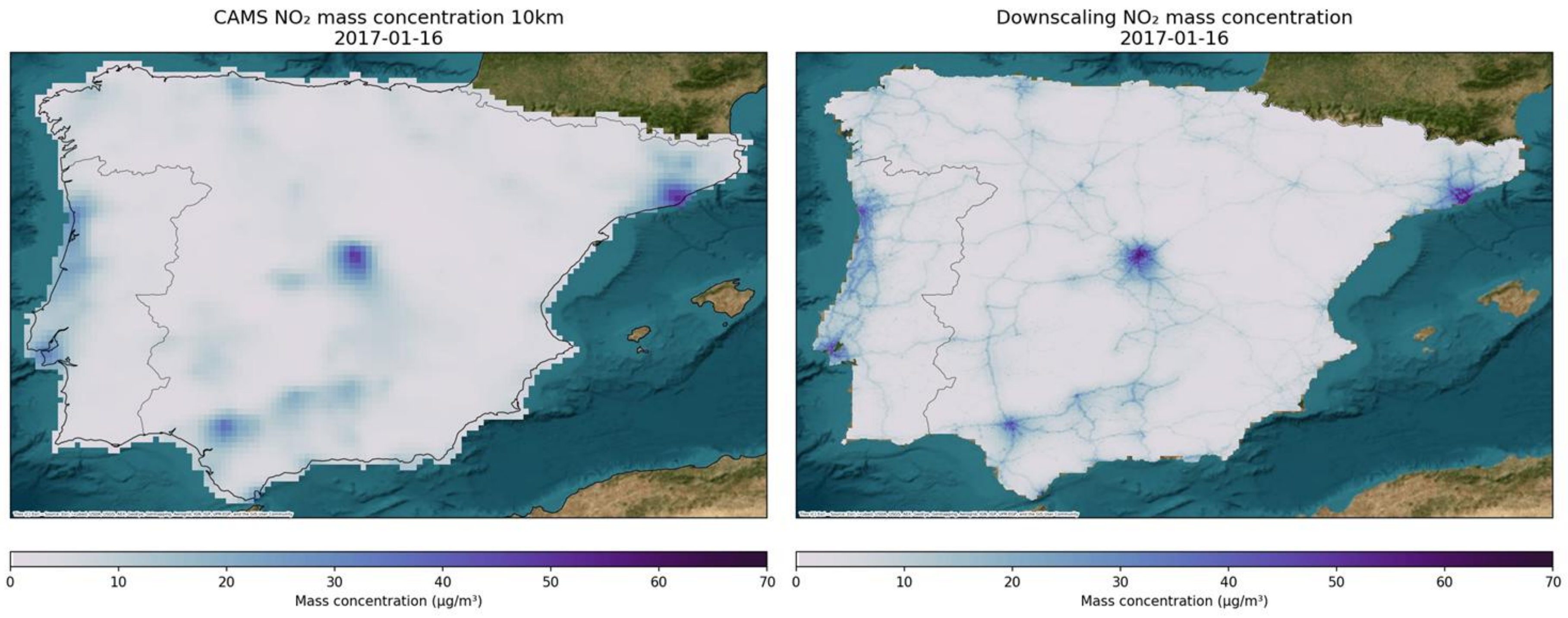


Ozone concentrations at the near-surface level: CAMS reanalysis versus ML Downscaled results, masked per the threshold suggested by WHO concerning health impacts, showcasing the added value of the higher resolution in depicting the areas exposed to harmful concentration levels.

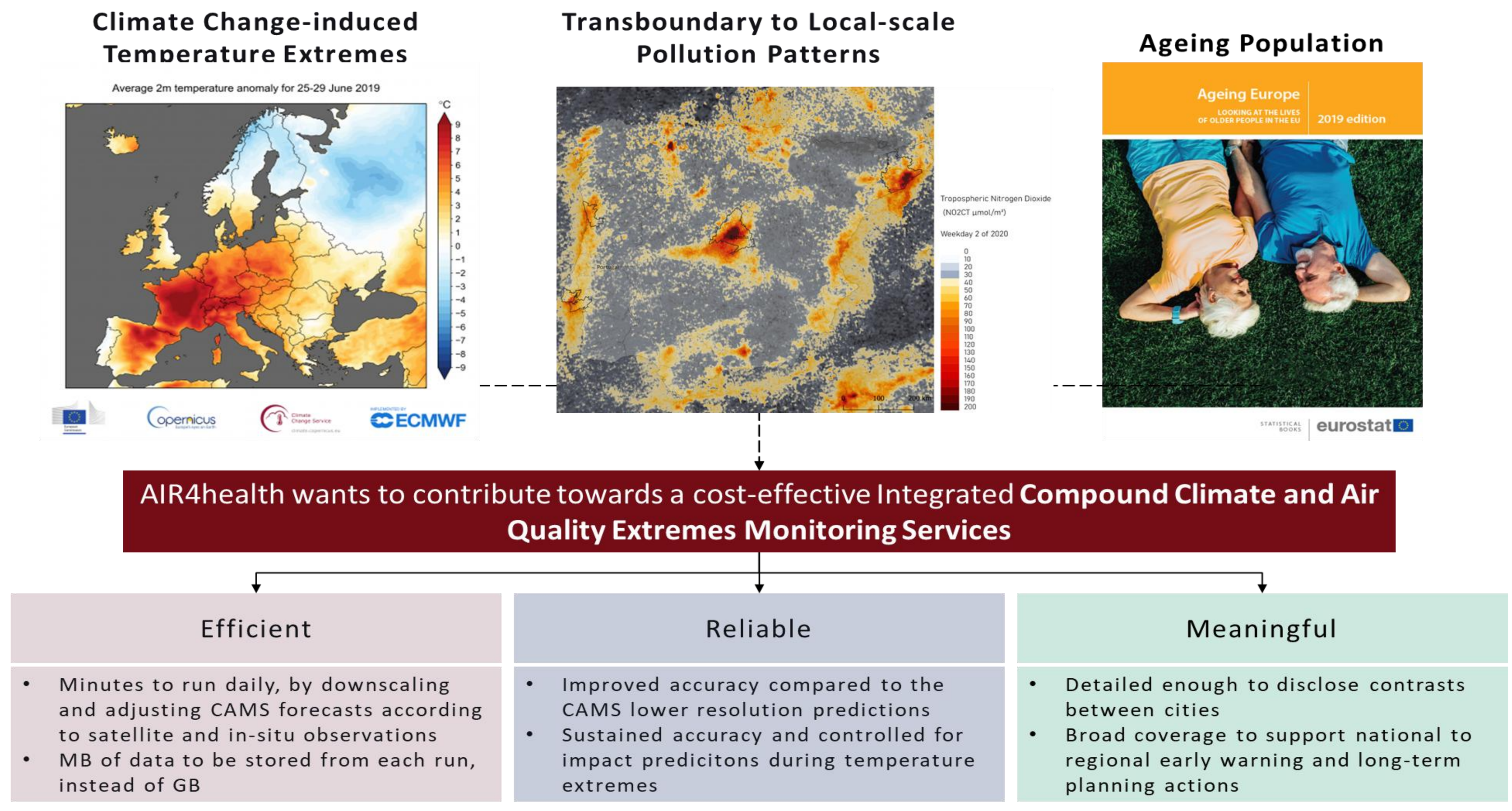
Use Case 2

Cold and Nitrogen Dioxide

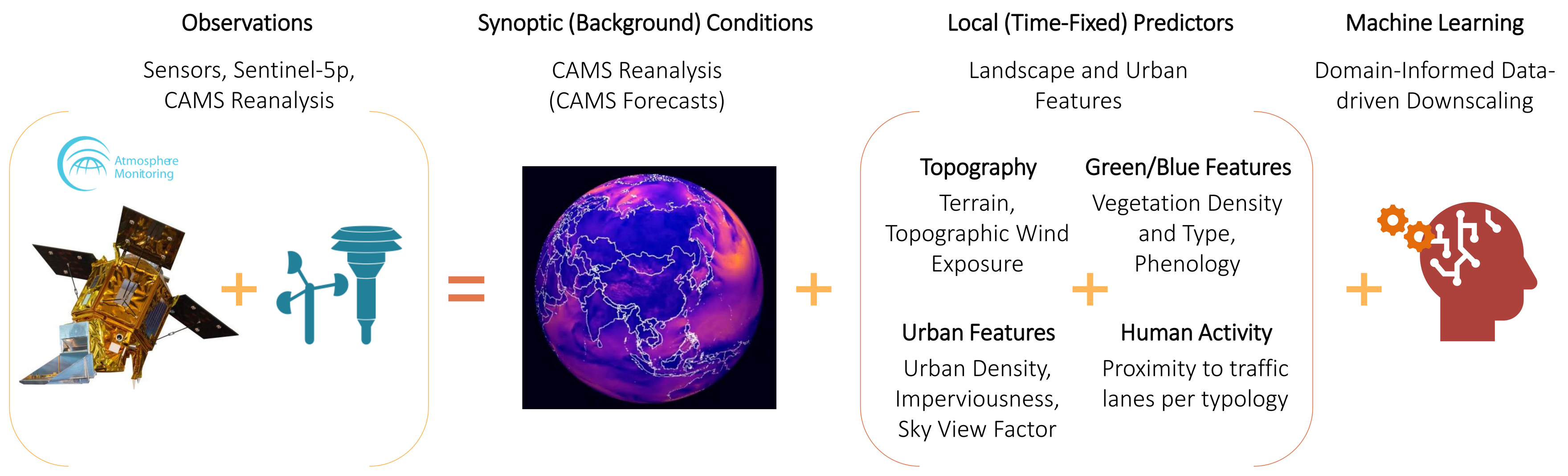
During a coldwave, increased use of combustion for heating and transport raises nitrogen dioxide (NO_2) emissions. Cold, stable atmospheric conditions and low wind speeds trap these pollutants near the ground, worsening air quality. The combined effects can lead to respiratory (e.g., asthma, infections), cardiovascular (e.g., heart attacks), and cold-related illnesses like hypothermia.(Laurinavičienė D. and Dėdelė A., 2013; Chen W., Yan L. and Zhao H., 2015) .



Nitrogen Dioxide concentrations at the near-surface level: CAMS reanalysis versus ML Downscaled results, absolute values showcasing the added level of detail near the largest metropolitan regions and main roadways.

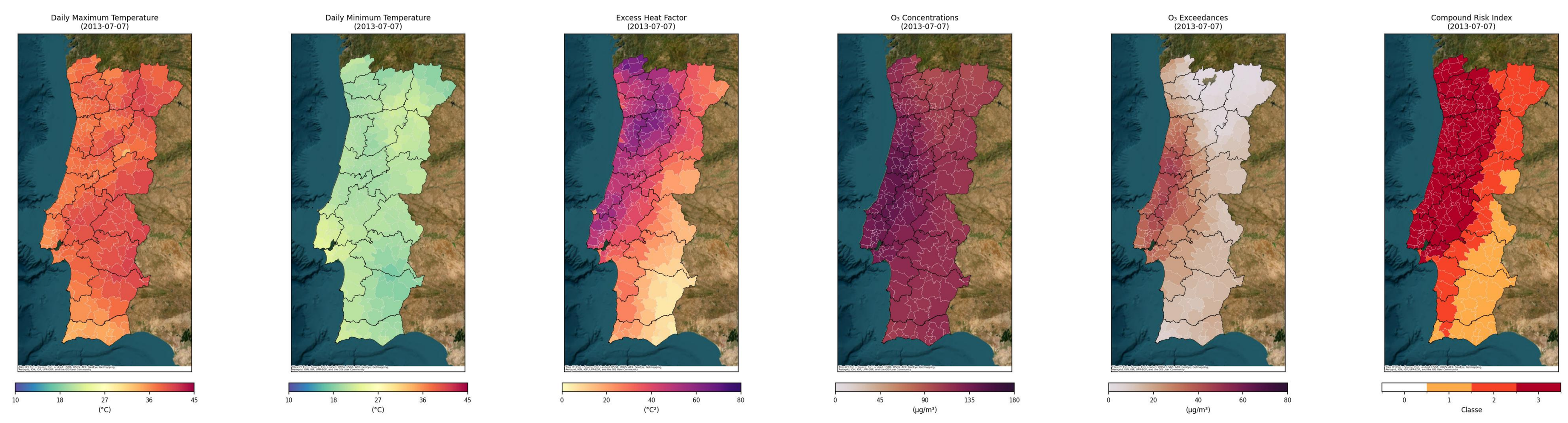


To develop the AIR4health Risk Algorithms, a set of environmental, meteorological, and emission data sources is integrated using a harmonised and quality-controlled framework. The approach combines in-situ air quality observations, numerical weather prediction outputs, satellite-based observations, landscape characteristics and emission-related indicators (e.g., land cover, built-up density). AIR4health Risk Algorithms, will also utilise a highly detailed, two-decades-long healthcare database for Portugal mainland.

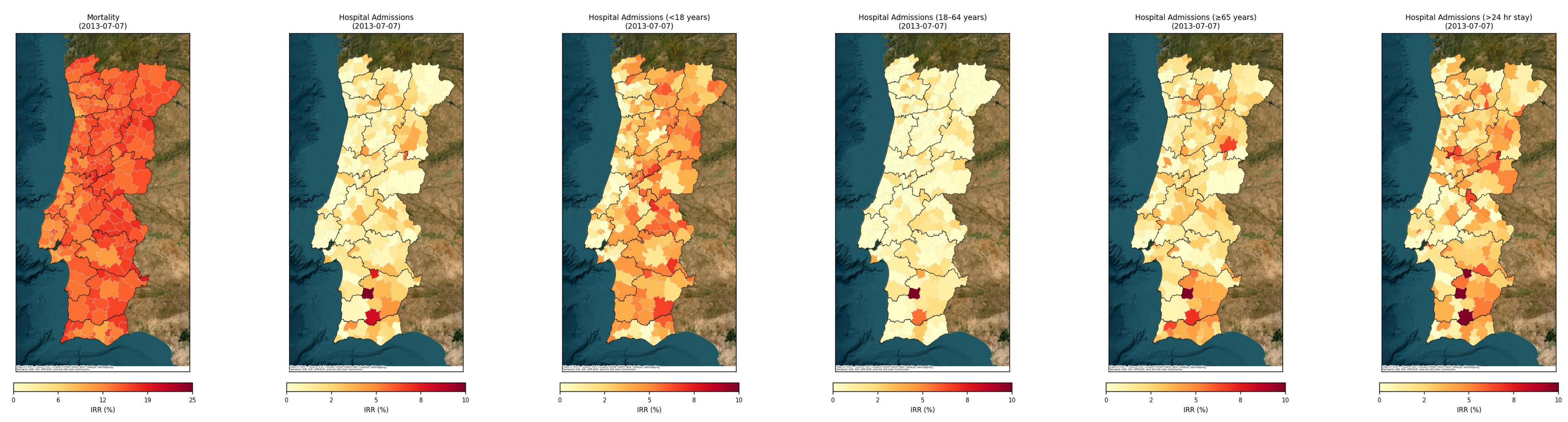


Methodological Framework: using observations as the response variable for bias-adjusting and downscaling background kilometric modelled data, using Machine Learning.

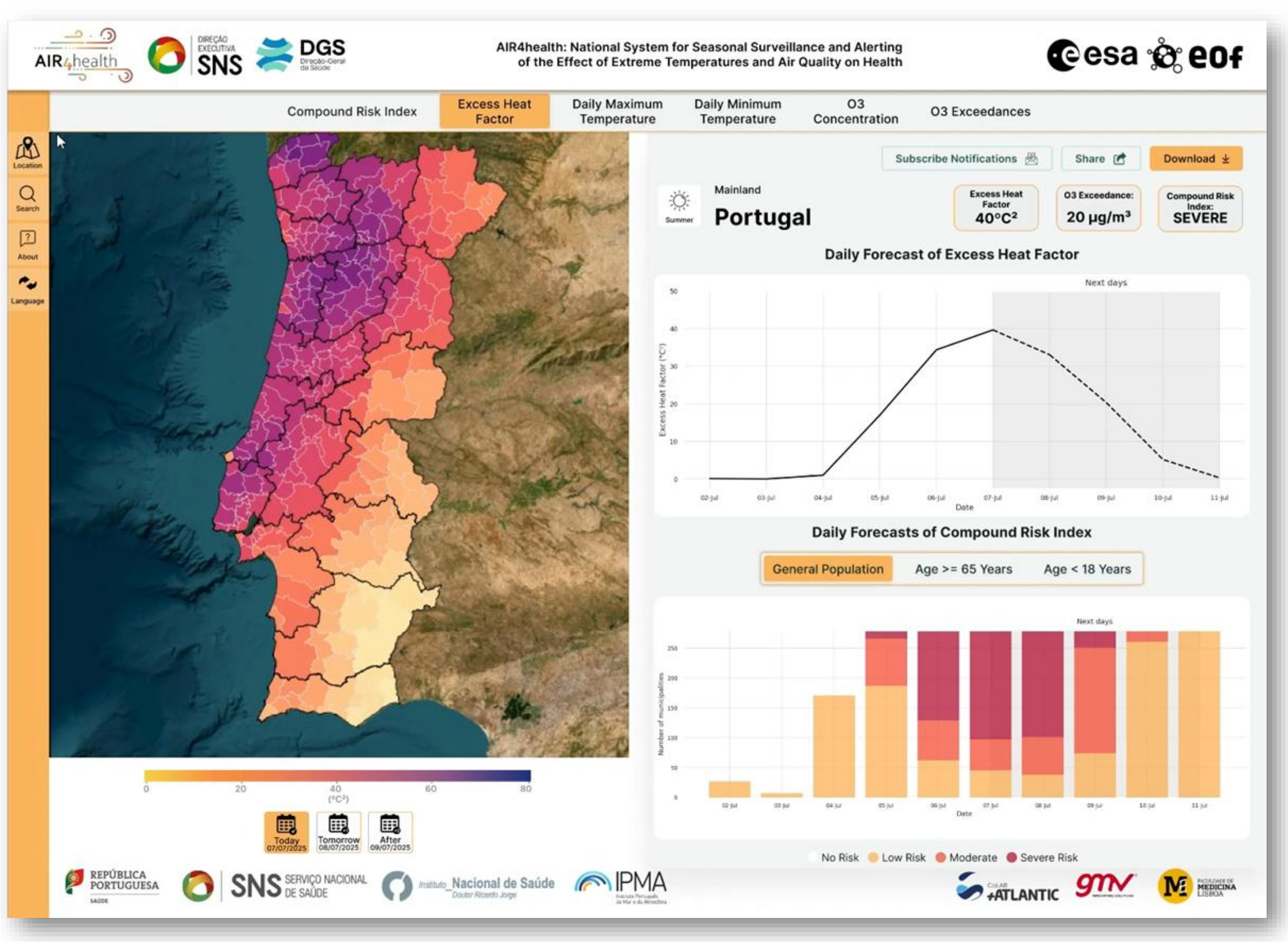
Building on the robust foundation of the operational country-level Ícaro warning system (Nogueira, 2005), this project aims to generate a high-resolution daily time series of Compound Climate and Air Quality Extremes at the municipal level. These series will be downscaled from reanalysis dataset using advanced Machine Learning (ML) techniques, informed by ancillary in-situ observations and satellite and satellite-based data. This approach follows methodologies successfully applied to downscale air temperature for operational use in Lisbon (Oliveira et al., 2021; 2022)



Maps of Portugal on July 7 2013, highlighting the combined effects of extreme heat and air pollution. It includes maximum and minimum temperatures (TX, TN), heatwave intensity (EHF), Ozone concentration (O_3), Ozone levels exceeding WHO health thresholds (O_3 Excess), and compound events where heatwaves and ozone excess occurred together (HW O_3 Event). The maps reveal how heat and pollution overlap spatially, helping identify regions at potential greater health risk.



Human health impacts during the heatwave 2013 July period, per municipality: Incidence Risk Ratio, calculated as the relative per cent change compared to expected baseline mortality and morbidity rates per location, age group and length of stay.



AIR4health Dashboard Mockup: example from the summer season.

CONCLUSION

AIR4health will deploy two new algorithms in Portugal's health and weather sectors to improve predictions of heatwaves, cold waves, and poor air quality impacts using Earth Observation (EO) data. By shifting from simple time-series to detailed spatiotemporal models at the municipal level, it will enhance the local health risk forecasting. The project will benchmark its results with European data, aiming to serve as a model for international climate and health preparedness. Its outcomes will also support broader EU initiatives like "Destination Earth" and the European Green Deal by contributing to a federated, locally-informed European Digital Twin system.

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