Introduction and background

Nowadays, the rise in the global temperatures is a source of concern, particularly in the Mediterranean region, where Spain is already witnessing notable consequences for its aging population. Predictions for the end of the XXI century reveal a persistent increase in air temperatures along with an increment of extreme episodes. Abnormal heat, once considered an 'environmental accident', is now a serious public threat. An extensive body of literature developed over the past decades shows that older populations, individuals with pre-existing health conditions, and those living in regions with limited adaptation strategies are particularly vulnerable to heat exposure.

In this context, Andalusia, a large autonomous community in southern Spain characterized by hot-summer Mediterranean climate, provides an important case study. As the hottest region in Spain, it regularly experiences extreme temperatures, with heat waves becoming more frequent and severe each year. These conditions provide an ideal natural settings to examine how sustained heat exposure along with extreme heat exposures over the life course affect mortality.

Andalusia has a diverse population of around 8.5 million, representing nearly 18% of Spain's total population. It encompasses both highly urbanized areas like Seville and Málaga, as well as vast rural regions, allowing for an analysis of urban-rural disparities in climate vulnerability. The region's varied geography, from coastal areas to mountainous terrain, contributes to significant local variations in climate, which makes it representative of the broader environmental and health challenges faced by Spain as a whole. On the other hand, Andalusia has one of the lowest life expectancy in Spain and lowest socioeconomic levels overall. Additionally, this region is characterized by the highest prevalence of diabetes and obesity in Spain. These factors make it a compelling case to study the broader effects of climate change over the life course on mortality, with insights applicable to similar Mediterranean regions.

This paper investigates the cohort-specific impacts of heat wave exposure on mortality using the Longitudinal Database of the Population of Andalusia. By employing a cohort-based approach, we examine how cumulative exposure to extreme temperatures over the life course relates to mortality differentials across geographic areas, age groups, gender and socio-economic statuses. The aim is to contribute to a deeper understanding of how cumulative environmental exposures, particularly heat waves, interact with demographic and socio-economic factors to influence mortality outcomes.

Data and Methodology

Data sources

The **Longitudinal Database of the Population of Andalusia** (LDBPA) follows all the individuals residing in the community from 1998 onwards, following around 10 million of different individuals with at least one demographic event registered at the LDBPA from 1998 until present. The LDBPA includes information from the Administrative Census (Padrón), all vital events (births, deaths and marriages) which took place in Andalusia or of Andalusian residents from that date onwards, all the changes in legal residence of the Andalusian residents from 1998 onwards, sociodemographic characteristics included in the 2001, 2011 and 2021 Census of Population of Spain and other sociodemographic and administrative data.

Temperature of air at 2m above the surface of land, sea or inland waters. Daily mean, maximum and minimum temperature from the ERA5 reanalysis was used to estimate exposure indicators. ERA5 is the fifth generation ECMWF reanalysis for the global climate and weather from 1940 onwards and provides hourly values of a large number of atmospheric, ocean-wave and land-surface variables globally, with a 0.25◦×0.25◦ horizontal resolution (approximately 25x25km).

Historical settlement data. As a proxy for human distribution in space we leveraged the cadastral data with rich thematic property attribution, such as building usage and construction year. These data come as gridded surfaces, describing the evolution of human settlements in Spain from 1900 to 2020, at 100 m spatial and 5-year temporal resolution. In the present study we included the surfaces representing the measures of building density from 1960 to 2020.

Indicators of environmental exposure

Heat Wave Definition. Among different heat wave definitions in the literature, we followed a modification of the one adopted by the Spanish Weather Service (AEMET), also similar to the warm spell duration index, which are calculated using a percentile-based threshold. AEMET issues a heat wave special alert when there are 3 or more consecutive days with daily maximum temperature above the 95th climatological percentile in July and August for the period 1971-2000 in more than 10% of the stations in the region. In this work, we included two effects which can accentuate the negative impacts of heat stress. First, the effect of night-time heat by considering daily minimum

temperature together with daily maximum counterparts, since residents may not recover from the daytime heat and suffer from sleep loss because populated areas often cannot cool down at night. Secondly, we considered prolonged summer seasons for the percentile calculation, since summers tend to extend beyond July and August in a climate change context. Thus, we consider a heat wave a spell of 3 or more days with daily maximum and minimum temperatures above their 95th climatological percentiles calculated in June-September for the period 1981-2010. Heat waves are estimated for each ERA5 grid box independently but only grid boxes with a minimum of 10% urban land cover are considered (hereafter urban grid boxes). A heat wave occurs in a province when at least 10% of the urban grid boxes are under the effect of a heat wave.

Cumulative Exposure

The conceptual basis of our work is the Life Course Epidemiology[1] approach, originally designed to investigate the relationship between climate extremes and human health, with specific focus on:

- "Acute health effects of climate change-related exposures that occur at all ages, as well as the delayed effects of single or cumulative climate exposures", and
- "Comparative analysis of health effects across birth cohorts to investigate the effect of increasingly frequent and intense climate change-related exposures on human health, as well as the protective effects of possible adaptations made by individuals or societies".

We estimate the cumulative exposure variables by reconstructing individual exposure profiles between late 1990s and present times based on the aforementioned data sources. To address the issue of multicollinearity caused by the age at death being inherently correlated with accumulated heat wave exposure (simply because older individuals have lived through more heat waves), we redefine our indicators so it represents the cumulative exposure in the last X years of the individual´s life. By using the cumulative heat wave intensity scores[2] in the last 40, 30, 20 and 10 years of life we ensure that these indicators accurately capture the impact of heat waves without being directly tied to the age of the individuals. The schematic representation of this approach is presented on the figure below.

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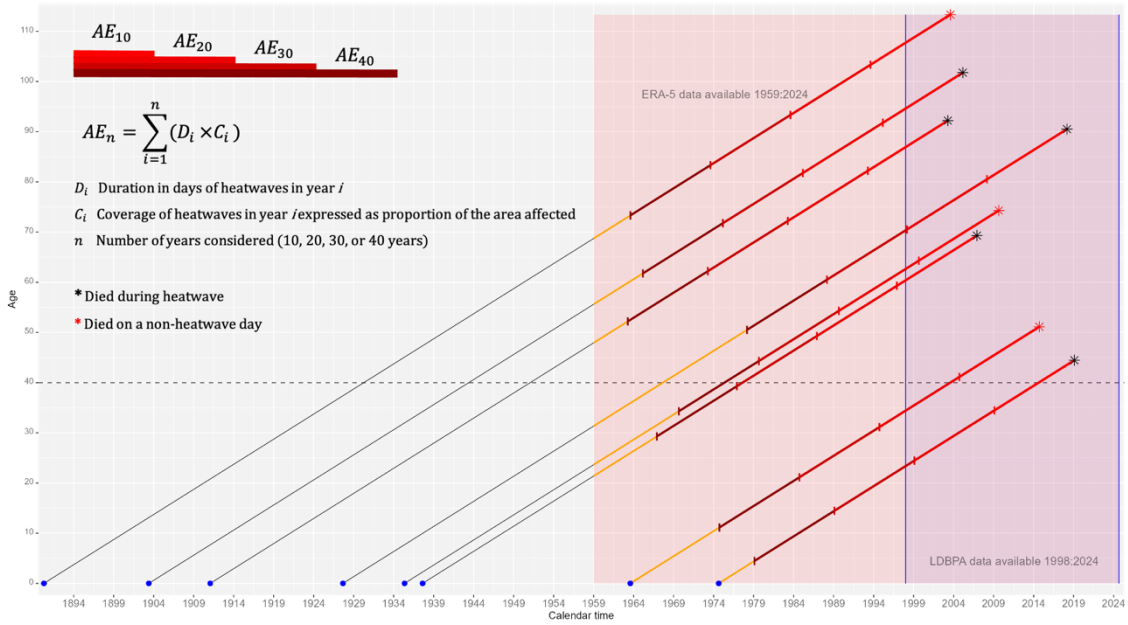
[1] *Burrows K, Fussell E. A life course epidemiology approach to climate extremes and human health. Lancet Planet Health. 2022 Jul;6(7):e549-e550. doi: 10.1016/S2542-5196(22)00146-2. PMID: 35809583; PMCID: PMC9773632.*

[2] Instead of merely counting the number of heat waves, this indicator considers both the duration and extent (coverage) of each heat wave. Longer and more widespread heat waves would have a higher impact on the indicator than shorter or less extensive ones.



There are some additional indices that might be used for analyzing the mortality answers including the ratio of heat waves experienced during a sensitive period (e.g., the last 5 or 10 years of life) to the total number of heat waves during their lifetime and average exposure during specific developmental windows (e.g., childhood, adolescence, elderly).

Expected results

The preliminary results of our analysis include a clear increase in cumulative heat wave exposure across more recent birth cohorts, reflecting the increasingly harsh climate conditions over the past decades. We anticipate that older age groups, particularly those exposed to extreme temperatures later in life, will show higher vulnerability to heat-related mortality. Additionally, the analysis is likely to reveal gender and socio-economic disparities, with women and lower-income individuals disproportionately affected by cumulative heat wave exposure due to factors such as housing conditions and access to resources. These findings will highlight the differential impacts of climate change on mortality across demographic groups and locations.

Next Steps

This study's cohort-based approach offers a novel lens for exploring how cumulative exposure to heat waves across the life course influences mortality. While preliminary results indicate rising risks for more recent cohorts, further analysis is needed to quantify these impacts and identify the most at-risk groups.