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Time trend in the impact of heat waves on daily mortality in Spain for a period of over thirty years (1983–2013)

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ABSTRACT

Many of the studies that analyze the future impact of climate change on mortality assume that the temperature that constitutes a heat wave will not change over time. This is unlikely, however, given the process of adapting to heat changes, prevention plans, and improvements in social and health infrastructure.

The objective of this study is to analyze whether, during the 1983–2013 period, there has been a temporal change in the maximum daily temperatures that constitute a heat wave ($T_{threshold}$) in Spain, and to investigate whether there has been variation in the attributable risk (AR) associated with mortality due to high temperatures in this period.

This study uses daily mortality data for natural causes except accidents CIEX: A00-R99 in municipalities of over 10,000 inhabitants in 10 Spanish provinces and maximum temperature data from observatories located in province capitals. The time series is divided into three periods: 1983–1992, 1993–2003 and 2004–2013. For each period and each province, the value of $T_{threshold}$ was calculated using scatter-plot diagram of the daily mortality pre-whitened series. For each period and each province capitals, it has been calculated the number of heat waves and quantifying the impact on mortality through generalized linear model (GLM) methodology with the Poisson regression link. These models permits obtained the relative risks (RR) and attributable risks (AR). Via a meta-analysis, using the Global RR and AR were calculated the heat impact for the total of the 10 provinces.

The results show that in the first two periods RR remained constant RR: 1.14 (CI95%: 1.09 1.19) and RR: 1.14 (CI95%: 1.10 1.18), while the third period shows a sharp decrease with respect to the prior two periods RR: 1.01 (CI95%: 1.00 1.01); the difference is statistically significant.

In Spain there has been a sharp decrease in mortality attributable to heat over the past 10 years. The observed variation in RR puts into question the results of numerous studies that analyze the future impact of heat on mortality in different temporal scenarios and show it to be constant over time.

1. Introduction

Climate models that predict the evolution of temperature over different time horizons and for diverse climatic scenarios coincide in signaling that heat waves are going to become more frequent and intense (IPCC, 2013). However, from the perspectives of the impact on health and predictions about the effects of heat, it is not so clear. One of the principal uncertainties of these studies (Linares et al., 2014) is that it is not known whether the impact of heat will remain constant across time or whether, on the contrary, its effects may tend to increase or decrease.

A large number of studies carried out to date related to heat waves over different time horizons and for different emission scenarios assume that both the temperature that constitutes a heat wave and the increase in mortality associated with each degree increase above this temperature threshold will not change over time (Martinez et al., 2016; Wu et al., 2014; Peng et al., 2011; Roldán et al., 2016). On the other hand, other studies assume that there will be a change in the temperature related to a spike in mortality (Sánchez-Martínez et al., 2018), and their estimates assume that the series percentile that corresponds to the actual temperature of a spike in heat wave-related mortality will remain constant. As temperatures increase, this percentile will correspond to ever increasing high temperatures.

It is evident that the impact of heat in the future cannot remain constant and will vary over time, as demonstrated by different studies carried out to date (Díaz et al., 2015a; Mirón et al., 2015; Roldán et al., 2016). On one hand, the progressive adaptation of the population to

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heat (Bobb et al., 2014) and the implementation of prevention plans that aim to minimize the impacts on health (especially in vulnerable groups) (Díaz et al., 2015a), will result in a decrease in the effects of heat.

Furthermore, improvement in health services - in particular for patients with cardiovascular health problems - (Ha and Kim, 2013), socioeconomic improvements and improvements in the housing infrastructure (Vandentorren et al., 2006), could result in a decrease in the impact of heat waves in the future (Konkel, 2014). This has been shown in studies that analyze the temporal evolution of heat-related mortality (Schifano et al., 2012; Mirón et al., 2015; Ha and Kim, 2013).

Studies carried out in different parts of the world show that far from remaining constant, heat waves' effects are changing over time, with a tendency toward decline (Schifano et al., 2012), and that this decrease is more pronounced in mortality due to cardiovascular causes (Ha and Kim, 2013), while in the case of respiratory issues, the effects remain practically constant (Mirón et al., 2015).

However, other factors such as the increase in and ageing of the population (Montero et al., 2012), or the increase in the frequency, intensity and persistence of heat waves (Guo et al., 2017) could be related to a greater impact in the future.

Clearly there is a need to study the past effects of heat on mortality in order to infer what the effect might be in the future. The objective of this study is to analyze whether there has been a temporal change in the maximum daily temperatures that constitute a heat wave in 10 Spanish provinces and to investigate - in each city - whether there has been variation in the attributable risk (AR) associated with mortality due to high temperatures in this period. The time series 1983–2013 was divided into three periods; for each period $T_{threshold}$ and corresponding AR were calculated. Time trends were analyzed and a meta-analysis was carried out in order to obtain an estimate of global behavior for the total of the analyzed cities.

2. Materials and methods

2.1. Data

From a total of 52 Spanish provinces, ten were selected based on geographical and population criteria that are representative of each of the zones in which heat behaves differently in terms of its effect on mortality. About the features of the study areas and their classification in terms of weather conditions and temperature, these areas are mainly defined by their behavior with heat waves analyzed previously, taken account since provinces with a very low percentile of threshold temperature in relation with daily mortality (p82) to provinces with high percentile such as Asturias (p97) (Tobías et al., 2014; Díaz et al., 2015b).

The dependent variable used was the daily mortality rate for all causes except accidents (CIE X: A00-R99) in province capitals and in cities with over 10,000 inhabitants during the 1983–2013 period. Both the daily mortality data and population data used to calculate the rate were provided by the National Statistics Institute. In these areas there is enough mortality data to be representative.

A recent study realized from 400 communities in 18 countries/regions and defined 12 types of heat waves by combining community-specific, concludes that the daily mean and maximum temperatures had similar ability to define heat waves rather than minimum temperature (Guo et al., 2017). The variable temperature that constitutes a heat wave was maximum daily temperature (T_{max}), because in Spain this is the variable that has the greatest correlation with daily mortality (Díaz et al., 2002; Díaz et al., 2015b). The meteorological data were obtained from observatories located in each province capital and were provided by the State Meteorological Agency (AEMET). Furthermore, these daily maximum temperature values were used to establish the High Temperature Prevention Plan of the Spanish Ministry of Health (MSSSI, 2017). The analysis also controlled for average relative daily humidity.

2.2. Methodology

The series of the dependent variable and the independent variables for the 1983–2013 period were divided into three periods: 1983–1992; 1993–2003; 2004–2013. The last two periods were selected in this way in order to account for the period prior (1993–2003) and after (2004–2013) the implementation of the High Temperature Prevention Plan in Spain, which took place in the summer of 2004 (Ministerio de Sanidad, 2004). The study of the impact of heat was carried out for the summer period (June–September).

We controlled: firstly, for seasonalities of quarterly nature, using the sine and cosine functions with these same periodicities; and secondly, for trend and the possible autoregressive nature of the series. To control the trend a variable called n1 has been introduced. This variable was defined as n1 = 1 for June 1st 1983, n1 = 122 for September 30th 1983, and so on in the rest of the period.

Following the methodology commonly employed for determining the threshold temperatures used to define heat waves (Mirón et al., 2015; Linares et al., 2015; Díaz et al., 2015b; Sánchez-Martínez et al., 2018), we first fitted a univariate autoregressive integrated moving average (ARIMA) model (Box et al., 1994) for daily mortality in each provincial capitals, which allowed us to obtain the residuals of the mortality series. The advantage of working with residuals rather than daily mortality is that, after modelling, residuals display neither trend nor periodicities (both of which are inherent in daily mortality), with the result that any associations found will therefore show a genuine causal mortality-temperature relationship from a statistical standpoint ($p < 0.05$).

We then proceeded to plot the following on a scatterplot diagram: the mean value of the mortality series residuals (vertical axis); the maximum daily temperatures at 2 °C intervals (horizontal axis), and their corresponding 95% confidence intervals (CIs) (upper and lower limits of the CI: UL and LL respectively); and the 95% CIs of the mean of the residuals for the entire study period (shown by parallel broken lines). The temperature from which the mortality residuals increased significantly vis-à-vis the mean would thus be the threshold temperature. The value $T_{threshold}$ in each period was associated with the percentile that corresponds to the temperature in the time series of maximum daily temperatures for the summer months (June–September).

Based on the values of $T_{threshold}$ for each province and for each period, the variable T_{cal} was calculated, defined in the following way (Díaz et al., 2006; Díaz et al., 2015b; Carmona et al., 2016; Sánchez-Martínez et al., 2018):

$$T_{heat} = 0 \qquad \text{if}\, T_{max} < T_{threshold}$$

$$T_{heat} = T_{max} - T_{threshold} \qquad \text{if}\, T_{max} > T_{threshold}$$

Given that the effect of each heat wave on mortality is not immediate, the following lag variables were calculated: T_{heat1} (lag 1), that takes into account the effect of the temperature on day "d" on mortality one day later "d + 1"; T_{heat2} (lag 2), which accounts for the effect of temperature on day "d" on mortality on two days later "d + 2", successively. The number of lags were selected based on existing literature, which establishes that heat has a short term effect (T_{heat}: lags 1–4) (Alberdi et al., 1998; Díaz et al., 2002; Díaz et al., 2015b; Sánchez-Martínez et al., 2018). The variable relative humidity was considered linear, with an effect of up to 14 lags (Alberdi et al., 1998; Díaz et al., 2015b).

In order to determine the corresponding relative risk attributable to heat values for each city and period, generalized linear model (GLM) methodology with the Poisson regression link were used. The attributable risk (RA) associated with this increase was calculated based on RR using the equation (Coste and Spira, 1991):

$$RA = (RR - 1)/RR.$$

This model controls for quarterly and trimestral seasonalities,