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Abstract Few studies have analysed the impact of heat and cold waves on mortality in a given population over the same time period and still fewer studies have analysed this impact in terms of cause-specific mortality. This study analysed the impact of both heat and cold waves on daily all-cause, circulatory-cause and respiratory-cause mortality in the region of Castile-La Mancha (CLM) 1975–2008. The dependent variable was daily all-, circulatory- and respiratory-cause mortality registered in CLM from 01-01-75 to 31-12-08, and the independent variables were maximum, minimum, mean daily temperature, daily relative humidity and mean daily air pressure and other related variables, such as heat-wave duration, heat-wave number and pressure trend. Time-series analyses were performed using autoregressive integrated moving average models. The impact of heat on daily mortality was greater than that of cold, with a difference which proved statistically significant for all- and circulatory-cause mortality but not for respiratory-cause mortality. While 16.5 % CI 95 % (15.5–17.4) of summer mortality in CLM was attributable to heat, 12.9 % CI 95 % (12.2–13.8) of daily winter mortality was attributable to low temperatures. The variable, heat-wave duration, was of major importance in all-cause and respiratory-cause mortality, with wave persistence being related to a mean 3.5 % increase in daily organic-cause mortality. Although heat waves have a greater impact on daily mortality than do cold waves, the fact that there were more cold-wave than heat-wave days during the period analysed, coupled with the diseases implicated, means that specific prevention plans should be implemented for both extreme thermal events.

Keywords ARIMA models · Cold and heat waves · Impact mortality causes

1 Introduction

Numerous studies have investigated the changes in extreme temperatures using various methodologies agreeing that the extreme thermal events will increase in frequency and intensity (Zhang et al. 2009; Tao et al. 2014; Siliverstovs et al. 2010; Alonso et al. 2014; Degefie et al. 2014). However its effect on human health still presents significant gaps. Traditionally, the impact of thermal extremes on mortality has been analysed from two different standpoints. While some studies have targeted the effects had by heat on morbidity and mortality (Leone et al. 2013; Baccini et al. 2013; Montero et al. 2012; D’Ippoliti et al. 2010; Basu 2009; Linares and Díaz 2008; Kovats and Ebi 2006; Díaz et al. 2002), others -albeit less numerous- have targeted the effects had by cold waves on health (Montero et al. 2010a; Díaz et al. 2005; Donaldson and Rintamäki 2001; The Eurowinter Group 1997). However, few studies have compared the differentiated behaviour patterns of the respective
extremes on mortality in a given population in the same region over the same period of time (Zanobetti et al. 2013; Hajat et al. 2007; Medina-Ramón et al. 2006; Braga et al. 2002; Huynen et al. 2001). These types of studies are even more important, if possible interactions between the health effects of cold and heat are taken into account (Rocklov et al. 2009; Stafoggia et al. 2009; Ha et al. 2011). Indeed, studies which, in addition to the above conditions, analyse specific-cause mortality (Carson et al. 2006) are practically non-existent. Moreover, while the great majority of the studies published to date analyse the relationship between thermal extremes and all-cause mortality, those which focus on temperature-related cause-specific mortality are even fewer in number (Basu and Samet, 2002; Rey et al. 2007; Zanobetti et al. 2013). Lastly, the time series analysed tend to be of short duration, generally no more than a decade, so that analyses of thermal extremes usually cover the 3 or 4 years in which there is a heat or cold wave during the period surveyed and very seldom cover longer periods of time (Davis et al. 2003; Carson et al. 2006; Rey et al. 2007; Mirón et al. 2010).

In an attempt to remedy the above shortcomings, this study now reports an analysis of the impact of thermal extremes on mortality. A comparative analysis was made of daily circulatory- and respiratory-cause mortality during heat and cold waves, with the study addressing a time series that spanned over three decades (1975–2008) and covered the five Spanish provinces situated in the region of Castile-La Mancha. Since analysis of the impact extended, not only to temperature, but also to other variables, both meteorological (pressure trend, relative humidity) and specific to the extreme thermal event itself (intensity, duration, month of appearance), that has been demonstrated to impact associated mortality (Tamerius et al. 2007). The results obtained by this study amount to a significant advance in terms of the impact of temperature extremes on mortality, in the case of heat and cold waves alike.

2 Materials and methods

The Autonomous Region of Castile-La Mancha (CLM) is situated in the centre of the Iberian Peninsula and comprises the provinces of Cuenca, Toledo, Guadalajara, Ciudad Real and Albacete, with the greater part of its territory extending across the so-called Submeseta Meridional (Southern Subplateau) (latitude, 38°01’ N and 41°20’ N; longitude, 0°55’ W and 5°24’ W). Approximately 70% of CLM lies at an altitude of 600–1,000 m above sea level, and has a land surface area of 79,463 km², which is equivalent to 15.7% of Spanish territory and so makes it the third largest region in the country. It has a Mediterranean-type climate (Instituto Geográfico Nacional 2000) of a pronounced continental nature, with wide-ranging temperatures, both daily and seasonal, i.e. summers generally tend to be dry and hot, with temperatures frequently rising to over 30 °C, and winters are marked by frequent ground frost and an irregular rainfall distribution. The latest official census (2011) shows the population to be 2,099,057, which translates as a population density of only 26.42 inhabitants per km².

The daily regional mortality data for the period 1975–2008 were sourced from the National Statistics Institute (Instituto Nacional de Estadística), were coded as per the International Classification of Diseases (ICD 8: 1975–1979, ICD 9: 1980–1998 and ICD 10: 1999–2008), and covered daily mortality due to organic causes (all except external) (ICD 10, A00-R99), circulatory causes (ICD 10, I00-I99) and respiratory causes (ICD 10, J00-J99).

Daily temperature, relative humidity and air pressure records for the period 1975–2008 were supplied by the State Meteorological Agency (Agencia Estatal de Meteorología, AEMET). We chose those corresponding to the Toledo observatory (formerly known as Lorenzana and currently as Buenavista), which can be regarded as representative of the regional thermometric cluster (Mirón et al. 2006).

In relation to the question of which daily temperature measure (maximum, minimum or mean temperature) is most suitable for defining a heat or cold wave, the approach used was based on previous research in CLM (Mirón et al. 2010; Montero et al. 2012). Some heat-wave research has, however, indicated that the summer minimum may be more important than the maximum, as the human body is not afforded the opportunity of recovering from the day’s heat (Havenith 2001).

We first calculated the trigger temperature of organic-cause mortality in CLM for both low (period November to March) and high temperatures (June–September). To this end, the daily mortality data series was filtered using an autoregressive integrated moving average (ARIMA) model obtained for the purpose (pre-whitened). The residuals obtained by this procedure were used to calculate the threshold temperature. This enabled us to control for variability due to autoregressive characteristics, seasonal cyclical characteristics, periodicities and the series own intrinsic trend, and obtain a series of residuals at lag 0, which was compared, at 2 °C intervals, against the series of maximum daily temperatures (Tmax) in the case of heat and minimum daily temperatures (Tmin) in the case of cold, to calculate threshold temperatures for heat (threshold TH) and cold (threshold TC) from which mortality rose significantly (Mirón et al. 2010; Montero et al. 2012). This threshold temperature would be the midpoint of the interval of maximum/minimum daily temperatures from which - and for intervals of increasing temperatures (or decreasing temperatures in the case of cold)- all the mortality residuals
would be significantly higher ($p < 0.05$) than the mean value of the mortality residuals obtained using the whole series. These heat and cold threshold temperatures would respectively serve to define heat-wave and cold-wave days, as well as the variables, heat-wave temperature ($T_{hw}$) and cold-wave temperature ($T_{cw}$), as follows:

**Heat wave:**

$$Thw = T_{max} - \text{Threshold } TH \quad \text{if } T_{max} > \text{Threshold } TH$$

$$Thw = 0 \quad \text{if } T_{max} < \text{Threshold } TH$$

**Cold wave:**

$$Tcw = 0 \quad \text{if } T_{min} > \text{Threshold } TC$$

$$Tcw = \text{Threshold } TC - T_{min} \quad \text{if } T_{min} < \text{Threshold } TC$$

We then constructed multivariate ARIMA models (Makridakis et al. 1983) for summer and for winter months across the period 1975–2008, for all three daily mortality series i.e. organic, circulatory and respiratory.

The independent external variables included in the analysis were:

- Maximum temperatures ($T_{max}$) higher than the threshold, lagged 0–7 days: $Thw0$, $Thw1$, $Thw2$, ..., $Thw7$, in the case of heat (Montero et al. 2012).
- Minimum temperatures ($T_{min}$) lower than the threshold, lagged 0–14 days: $Tcw0$, $Tcw1$, $Tcw2$, ..., $Tcw14$, in the case of cold (Montero et al. 2010a).
- Relative humidity at 13 h ($Hr_{13}$), lagged 0–14 days: $Hr_{130}$, ..., $Hr_{1314}$.
- Pressure trend ($PT$), obtained as: $PT = P_{t+1} - P_t$ (difference between the following and current day’s respective air pressures), lagged 0–14 days: $PT0$, $PT1$, $PT2$, ..., $PT14$. A positive $PT$ would indicate a rise in air pressure or anticyclonic trend, and a negative $PT$ would indicate a fall in pressure or cyclonic trend.
- Heat-wave duration ($D_{hw}$)/cold-wave duration ($D_{cw}$), whereby a heat or cold wave was coded with a number corresponding to the number of consecutive days on which the threshold was exceeded, e.g. where the threshold temperature was surpassed on only one day, this received a value of 1, where the threshold temperature was surpassed on two consecutive days, a value of 2, and so on.
- Heat-wave number ($N_{hw}$)/cold-wave number ($N_{cw}$). This described the chronological number of a heat/cold wave in any given summer/winter, such that when the threshold was exceeded the first time, it was coded as 1, the second time as 2, and so on.
- Number of daily deaths due to influenza, in the case of cold.

These last two qualitative variables, heat-/cold-wave duration and number, would show the increase in mortality brought about by a variation in their respective ordinal scales, i.e. in a case where wave duration increased by 1 day or, alternatively, where the wave was not the first of the year.

The autocorrelation of the series was controlled by introducing the autoregressive and moving-average operators of the ARIMA model. Trends and seasonalties were controlled using circular functions -sine and cosine- with annual and six-monthly periodicities. The model’s goodness-of-fit was obtained by analysis of residuals (AIC, BIC, ACF, PACF, Box-Ljung). Multi-variable ARIMA models has been performed.

The value of the estimator of the variables that are significant at $p < 0.05$ ($p$ value proportionated by SPSS v15) indicating increased mortality to an increment by one unit of the each independent variable. When for the same variable has several significant lags, the value of the estimator is obtained by summing the values of the all significant estimators. The increment percentage in mortality has been obtained considering average mortality from each cause and period (winter/summer) in relation to the entire period (1975–2008).

Statistically significant differences in the percentage increases in mortality by heat waves and cold of each explanatory variable were evaluated by the non-overlapping confidence intervals.

All analyses were performed using the SPSS v15 software program.

### 3 Results

Table 1 shows the descriptive statistics for the dependent and independent variables. Figure 1 depicts the month-by-month temporal evolution of mortality for organic, circulatory and respiratory causes. The ARIMA model corresponding to organic causes was $(4,1,1)$ for the “non-seasonal component”; moreover, there was no “seasonal component” and there were sin 365 and cosine 365 functions. Mortality-trigger temperatures are depicted in Fig. 2 for heat and Fig. 3 for cold. It should be noted that, in the case of heat, it is the maximum (and not the minimum or the mean) daily temperature which displayed a greater association with mortality. The maximum daily temperature of 37 °C measured at the Toledo Observatory was deemed to be the threshold temperature for the definition of a heat wave. This temperature was the 96th percentile of the maximum daily temperatures for the period 1975–2008. In the case of cold, the definition of a cold wave was established for days on which the minimum daily temperature fell below –2 °C, which was the 4th percentile of the minimum temperature series.
Tables 2 and 3 show the number of days and mean duration of heat and cold waves, for the entire period analysed and for each of the months that constituted the hot and cold periods. It was noteworthy that, though cold waves outnumbered heat waves in terms of frequency and duration, when it came to monthly frequencies, there were more heat-wave days in the month of July than there were cold-wave days in any winter month.

Quantification of the impact of the study variables on organic-cause and circulatory and respiratory cause-specific mortality are shown in Table 4.

Organic causes: With respect to organic-cause mortality, the first finding of note was that the effect of heat was greater in percentage terms than that of cold, accounting for 10.3% of the increase in mortality for each degree that the maximum daily temperature exceeded the threshold of 37 °C versus 8.1%, in the case of cold, for each degree centigrade that the minimum daily temperature fell below the threshold of −2 °C. This difference was statistically significant at \( p < 0.05 \).

Furthermore, the effect of heat on mortality was felt in the short-to-medium term, i.e. until lag 6, whereas the effect of cold extended as far as lag 10. For both heat and cold, the variable, pressure trend, had a positive value (cyclonic trend) and was greater in the case of heat waves, bordering on statistical significance at \( p < 0.05 \).

While the variable, Hr13, registered an impact on heat-related mortality, this was not so in the case of cold. The negative sign indicates that a decrease in humidity was associated with an increase in heat-related mortality.

Lastly, the variable, wave duration, was linked to heat-related mortality but not to cold-related mortality, with a positive sign: in other words, the longer the duration of a heat wave, the greater its impact on mortality. The variable, mortality due to cases of influenza, which was introduced as a control variable, also proved to be significant.

Circulatory causes: The impact of temperature on circulatory-cause mortality was not only much higher in the case of heat than in that of cold -representing a 14.0 versus 9.6% increases in daily mortality- but was also statistically
The effect of heat was also more immediate than that of cold, with an association being observable on the very same day that the heat wave occurred, whereas in the case of cold this effect extended up to eleven days after the thermal extreme. The variable, pressure trend, showed itself to be significant and positive for both heat and cold, with its effect being far greater in the case of heat.

Lastly, as occurred with both organic- and circulatory-cause mortality, the effect on respiratory-cause mortality was greater in the case of heat (16.4 %) than in that of cold (14.7 %) but in this particular instance the difference was not statistically significant. It should be noted that, though the variable, wave duration, had a very important effect on heat-related mortality (a 1.53 % increase in daily mortality due to these causes for each day that the heat wave lasted), it was not significant in the case of cold. The variable, influenza-related mortality, showed itself to be a significant control variable.

The variables, heat-wave number and cold-wave number, failed to prove significant in any of the models.

4 Discussion

As can be seen in Fig. 1, the temporal evolution of mortality due to all the causes considered (organic, circulatory and respiratory) displayed no discontinuity or anomalous behaviour as a result of changes in coding (with ICD 8 in use from 1975 to 1979, ICD 9 from 1980 to 1998 and ICD 10 from 1999 to 2008).

The ARIMA model obtained for daily organic-cause mortality has an autoregressive component \( (AR) = 4 \), meaning that mortality on any given day is influenced by that which occurred four days previously. The integrated component is \( (I) = 1 \), which means that there is a trend, as can be observed in Fig. 1. The moving average component \( (MA) = 1 \) is the random component of the series, while the sine and cosine functions represent annual seasonality in daily mortality.

For analysis purposes, only the maximum, mean and minimum daily temperatures were used, to the exclusion of all other temperature measures that included other meteorological variables (Díaz 2014). Although it is evident that there is a high correlation between minimum, mean and maximum daily temperatures (Mirón et al. 2006; Rocklöv et al. 2011), the fact that it is the maximum daily temperature which is associated with heat-related mortality and minimum daily temperature which is associated with cold-

Table 2  Number of heat-wave days and mean heat-wave duration from 1975 to 2008, divided by months

<table>
<thead>
<tr>
<th></th>
<th>All season</th>
<th>May</th>
<th>June</th>
<th>July</th>
<th>August</th>
<th>September</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of days</td>
<td>475</td>
<td>0</td>
<td>59</td>
<td>344</td>
<td>157</td>
<td>15</td>
</tr>
<tr>
<td>Mean duration</td>
<td>3.9</td>
<td>0</td>
<td>3</td>
<td>3.8</td>
<td>3.8</td>
<td>2.1</td>
</tr>
</tbody>
</table>

The variable, Hr13, appeared with a negative sign in the case of both heat and cold, and was of greater magnitude in the latter.
related mortality is something already reported by other studies conducted in this region (Montero et al. 2012; 2010a; Mirón et al. 2012). Nevertheless, in places near CLM it was the maximum, rather than the minimum daily temperature that displayed a greater association with mortality in cold waves (Díaz et al. 2005).

The production of scatterplot diagrams in Figs. 1 and 2 for detection of threshold temperatures is something rarely done by studies that analyse mortality due to thermal extremes. A great number of such studies use temperatures based on percentiles of maximum or minimum temperatures obtained for other places which, while geographically close, have different socio-economic and demographic characteristics. Indeed, places only a few kilometres apart in the same region have different trigger-temperature percentiles (Montero et al. 2012). This is only logical, bearing in mind that the relationship being studied is determined by different factors, such as the population pyramid, socio-economic structure, cultural values, and social and health services, etc., (Naughton et al., 2002; Nakai et al. 1999; Ledrans et al. 2004; Vandentorren et al. 2006; Schuman 1972; Kovats et al. 2008) and varies with time (Davis et al. 2003; Mirón et al. 2008). It should therefore be stressed that this way of defining the heat-related mortality trigger temperature has the dual advantage of taking local characteristics and their trend into account, something that will doubtlessly contribute to a more efficient management of resources and can act as a basis for future assessments of prevention plans. What is true, however, is that the criterion chosen to select the temperature which defines a heat wave will substantially determine the ensuing number of alerts raised (Montero et al. 2010b). The same may be assumed in the case of cold (Montero et al. 2010a).

A heat-wave threshold temperature based on a daily maximum of 37 °C is in line with the results obtained by previous studies undertaken in CLM (Montero et al. 2012) for the period 1975–2003. In that case, temperatures ranged from 38 °C in Toledo to 32 °C in Cuenca and, since the largest population is to be found in Toledo, it is only logical that the threshold temperature of 37 °C would be closest to that of Toledo. The slight shift in the maximum daily temperature to the 96th percentile is probably due to

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**Table 3** Number of cold-wave days and mean cold-wave duration from 1975 to 2008, divided by months

<table>
<thead>
<tr>
<th></th>
<th>All season</th>
<th>November</th>
<th>December</th>
<th>January</th>
<th>February</th>
<th>March</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of days</td>
<td>516</td>
<td>32</td>
<td>141</td>
<td>222</td>
<td>97</td>
<td>24</td>
</tr>
<tr>
<td>Mean duration (days)</td>
<td>4.3</td>
<td>2.8</td>
<td>4.0</td>
<td>5.2</td>
<td>3.8</td>
<td>2.5</td>
</tr>
</tbody>
</table>

**Table 4** Impact on heat-related mortality, by heat/cold and specific cause of death for significant independent variables ($p < 0.05$)

<table>
<thead>
<tr>
<th>Causes</th>
<th>Heat waves</th>
<th>Cold waves</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Percentage (95 % CI) (significant lags)</td>
<td>Percentage (95 % CI) (significant lags)</td>
</tr>
<tr>
<td>Organic</td>
<td>THW$^1$: 10.3 (9.7, 10.9) (1,2,3,4,6)</td>
<td>TCW$^2$: 8.1 (7.6, 8.6) (1,3,5,7,8,10)</td>
</tr>
<tr>
<td></td>
<td>TP$^1$: -0.41 (−0.52, −0.30) (0)</td>
<td>TP$^1$: -0.27 (−0.32, −0.22) (0,10)</td>
</tr>
<tr>
<td></td>
<td>HR13$^3$: -0.19 (−0.23, −0.14) (1,2)</td>
<td>HR13$^3$: -0.27 (−0.32, −0.22) (0,10)</td>
</tr>
<tr>
<td></td>
<td>DURHW$^5$: 0.80 (0.59, 1.01)</td>
<td>DURHW$^5$: 0.80 (0.59, 1.01)</td>
</tr>
<tr>
<td>Circulatory</td>
<td>THW$^1$: 14.0 (14.9, 15.8) (0,1,2,3,4,6)</td>
<td>TCW$^2$: 9.6 (9.2, 10.3) (2,4,8,10,11)</td>
</tr>
<tr>
<td></td>
<td>TP$^1$: -0.85 (−1.02, −0.68) (0,1)</td>
<td>TP$^1$: -0.20 (−0.28, −0.12) (0)</td>
</tr>
<tr>
<td></td>
<td>HR13$^3$: -0.21 (−0.29, −0.13) (1)</td>
<td>HR13$^3$: -0.87 (−0.90, −0.84) (5)</td>
</tr>
<tr>
<td>Respiratory</td>
<td>THW$^1$: 16.4 (14.8, 18.0) (2,4,6)</td>
<td>TCW$^2$: 14.7 (13.5, 15.9) (2,6,8,12)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TP$^1$: -0.32 (−0.46, −0.18) (7)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>HR13$^3$: -0.13 (−0.17, −0.09) (5)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DURHW$^5$: 1.53 (0.97, 2.09) (1)</td>
</tr>
</tbody>
</table>
the increase in maximum summer-month temperatures detected in recent years. Hence, at the Toledo Observatory, the mean maximum summer temperature of 30.7 °C registered for the decade 1975–1985 rose to 32.3 °C in the decade 1997–2008, and the number of heat-wave days increased from 70 in the first decade to 208 in the second. It is the existence of these greater temperature extremes that has brought about a shift in the percentile. The higher number of heat-induced thermal extremes coincides with IPCC forecasts for Spain (IPCC 2007), which predict an increase in heat-wave intensity and frequency.

With respect to the minimum daily temperature of −2 °C used to define a cold wave, this is appreciably higher than that registered in the same region for the period 1995–2003, which ranged from −5.6 °C in Guadalajara to −3.3 °C in Toledo (Montero et al. 2010a). Although, no substantial changes were observed in the minimum mean winter temperature in the case of cold (3.1 °C in the decade 1975–1985 and 3.2 °C in the decade 1997–2008), a slight decrease was observed in thermal extremes due to cold, declining from 187 cold-wave days in the first decade to 171 in the last. This slight increase in temperature mentioned above coincides with the upward trend in the minimum mortality temperature observed in CLM as a consequence of population ageing (Mirón et al. 2008).

Once again, these results underscore the need for heat-wave definition temperatures to be updated. Some of plans implemented following the 2003 heat wave were based on temperature-mortality analyses that used data which have not been updated. Failure to update the temperatures above or below which thermal-extreme prevention plans are implemented could lead to such plans becoming non-operational (Bittner et al. 2014).

The results in Tables 2 and 3 clearly show that, during the study period, the number of cold waves in CLM (516) exceeded that of heat waves (475). Although, as mentioned below, the impact of heat is greater than that of cold and, moreover, IPCC forecasts (IPCC 2007) indicate a trend towards minimum temperatures that are not so low (but not the disappearance of cold-induced thermal extremes), these results nevertheless show that, from a strictly public-health prevention standpoint, there is no sense in not implementing cold-wave prevention plans, as occurs in a good part of European cities, which, paradoxically, have heat-wave prevention plans in place (The Eurowinter Group 1997; Donaldson and Rintamäki 2001).

The methodology based on traditional time-series analysis, which was used in this study to quantify the impact of extreme temperatures on daily mortality, has recently been compared to more novel methodologies, such as case-crossover (Tong et al. 2012). The conclusion was that both methodologies are comparable.

The results in Table 4 indicate that the effect of heat is statistically significantly greater than that of cold. Bearing in mind that, in the case of heat, the mean number of degrees whereby the threshold temperature is exceeded when there is a heat wave in summer is 1.6 °C, then the impact of extremely high temperatures on mortality would, on average, be 16.5 % (15.5, 17.4). In other words, 16.5 % of all mortality occurring in CLM in summer would be heat-related. In the case of cold, in which the mean number of degrees below the threshold is also 1.6 °C, this means that 12.9 % (12.2, 13.8) of all winter mortality would be cold-related.

The magnitude of the association obtained here is similar to that reported in Spain by other papers, i.e. the increase in organic-cause mortality for each degree above the threshold temperature was stated to be 15 % among 65-year-olds in the city of Madrid, (Díaz et al. 2002), while another paper reported a 12 % increase in organic-cause mortality in the city of Barcelona (Tobías et al. 2010). Recent research on this topic established that in Spain as a whole the risk of mortality on a heat-wave day is 24 % greater than on a day without a heat wave. In the context of CLM, this figure rises to 35 % (Tobías et al. 2012). This pattern is similar to some foreign studies which show acclimatization of people living in southern warmer climates and less negative effects of warm temperatures (Khanjani and Bahrampour 2013).

The fact that heat waves have a greater impact on mortality than do cold waves is fundamentally due to circulatory-cause mortality, as can be seen in Table 2 and 3. Possibly, the most plausible explanation for these results resides in the characteristics peculiar to the relationship existing between cold and adverse health effects, a relationship that is different to the one underlying heat-related mortality. Firstly, part of the aetiology of the excess mortality observed after exceptionally cold days is known to be of an infectious nature, whereas the increase seen during heat waves is caused by the direct effects of heat on the metabolism of the individual, provoking generalised decompensation. In the Czech Republic, the greatest increases in mortality have been reported where low temperatures coincided with the presence of the infectious agent (Kyselý et al. 2009), and in Holland, no significant associations were observed for respiratory causes in the absence of influenza epidemics, in the period 1979–1997 (Huyten et al. 2001). It would therefore seem that the effects of a cold wave are partly influenced by the presence or absence of a pathogenic agent, whose ability to spread is, in turn, favoured by this selfsame drop in temperatures (Hajat and Haines 2002). There can be no doubt that this in itself may account for the size of the confidence interval of the results obtained, something that prevents significant differences from being found during a cold event. This
means that finding a day, a lag, which “captures” the effects of a cold wave in a manner that is representative, is not quite so easy. Yet perhaps one of the most novel findings is to be found in the results described in a recent study (Zanobetti et al. 2013), which linked mortality due to thermal extremes to previously existing diseases. Persons who presented with an added risk of heat-related mortality were those who had previously been hospitalised due to atrial fibrillation (6 %), those with Alzheimer’s disease (8 %), and those with dementia (6 %). In the case of cold, only previous hospitalisations due to disorders of the peripheral nervous system were linked to added risk.

The longer lagged effect seen for cold-related, all-cause and circulatory- and respiratory- cause mortality is in line with: underlying physiological mechanisms; what has been described in the scientific literature (Armstrong et al. 2000; Carder et al. 2005; Kysely et al. 2009); and the most widely accepted aetiological hypotheses, which link mortality occurring soonest after a cold wave to diseases of a cardiovascular aetiology, and mortality occurring at the longest lags to respiratory diseases (Ballester et al. 1997; Díaz et al. 2005). A description of specific-cause mortality related with thermal extremes can be found in a study undertaken by Medina-Ramón et al. (2006).

The significant lags between temperature and daily mortality during heat waves range from 0 to 6. In the case of cold waves, this impact is extended to lag 12 for respiratory causes. These results are in accordance with the physiological mechanisms previously described. It is however surprising that the heat effect is prolonged to lag 6. These results are consistent because they were obtained for both circulatory and respiratory mortality. Although the effect of heat is generally seen in the short term (lags 0–3), it is also possible for such effects to appear in the medium term (lags 7–10) (Basu and Samet 2002).

Another variable linked to heat-related mortality is heat-wave duration. The results yielded by our study show that the persistence of a heat wave goes to further augment the mortality risk due to increases in temperature per se. In the case of all-cause mortality, this increase in daily mortality is 0.8 % for each day that the wave lasts, e.g., given that the mean duration of a heat wave in CLM during the period analysed was 4.3 days, the added risk attributable to the persistence of heat-induced situations was 3.5 %. These findings are in agreement with those of other studies undertaken in CLM (Montero et al. 2012) and with research that has focused exclusively on this effect (Gasparini and Armstrong 2011; Rocklöv et al. 2011). The effect of persistence in the case of cold was not observed in our study, with its effect being more diffuse as suggested by other authors (Rocklöv et al. 2011).

In the models constructed for both cold and heat, the variable, pressure trend, was related to cyclonic trend and to lagged effects, up to lag 7, in the case of respiratory-cause mortality due to cold waves.

Although in a general context the onset of high pressure in summer is associated with increasing temperature, clearing skies and reduced winds, in winter it is associated with lower temperatures (along, again, with clearing skies and little wind). On the Iberian Peninsula the studies performed showed that a cyclonic trend is coherent with the synoptic-scale of meteorological situations that most frequently cause thermal extremes in Spain and, by extension, in CLM. In the case of heat, these situations take the form of depressions situated in the south-east of the Iberian Peninsula, which bring very hot, dry air from the Sahara (García et al. 2002). In the case of cold, one of the most frequent situations is the formation of a depression over the Gulf of Lion, which brings an inflow of cold dry air from Siberia (Prieto et al. 2004), so the trend towards low pressures seen here is consistent with the meteorological situation on the synoptic-scale.

Lastly, attention should be drawn to the variable, relative humidity, which is present in the models with a negative sign in all cases, or put another way, high relative humidity reduces the effect of heat and cold on mortality. The plausibility of these results is closely related to the above-described meteorological situations. In both cases, these involve masses of air having very low humidity content, as indicated by the negative sign of the association. This result, already reported by other studies conducted in Spain (Díaz et al. 2002; Montero et al. 2010a, b; Tobías et al. 2010). Apparent temperature (and similar measures) are based upon a known human physiological response to high heat and humidity, i.e., namely, the evaporative cooling rate of bare skin, which is based on the vapour pressure gradient between the skin and the air surrounding it, justifying its use in some but not all studies (D’Ippoliti et al. 2010; Leone et al. 2013). The results obtained in this paper indicate that in some cases it is preferable to address temperature and relative humidity separately. This aspect is fundamental when it comes to defining heat and cold waves (Montero et al. 2013) and, by extension, estimating their respective effects (Tong et al. 2010a, b).

The results yielded by this combined study of cold- and heat-related mortality in CLM serve to underscore the true importance of thermal extremes on daily mortality due to organic as well as circulatory and respiratory causes. Although the effect of heat is greater in absolute terms than that of cold, the latter is by no means negligible, not only because of its impact on mortality but also because extreme cold situations are more frequent than those of extreme heat, and highlights the need for specific low-temperature prevention plans to be implemented. The slight shifts in heat- and cold-wave definition thresholds and the local
nature of the variables involved in the estimation of the impact of such waves go to stress the need for up-to-date, ad hoc studies to ensure the proper implementation of prevention plans that would serve to mitigate the effects of thermal extremes on health.

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