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The impact of the summer 2003 heat wave in Iberia: how should we measure it?

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Abstract We present a new approach to improve the reliability of quantifying the impact of a heat wave on mortality rates. We show, for the recent European summer 2003 heat wave, that the use of absolute maximum temperature values, or number of days above a given threshold, can be misleading. Here, we have assessed the impact of the heat wave on Iberian mortality by applying a four step procedure: (1) calculating, for each observatory, the local maximum temperature (T_{max}) distributions, (2) calculating the corresponding 95th percentile values ($T_{threshold}$), (3) locally defining extremely hot days (EHD) as those days on which the local threshold of the 95th percentile of the series is exceeded, and (4) calculating the total degrees-days (DD) of exceedance, by calculating the difference $T_{max}-T_{threshold}$ and summing these values for all days above $T_{threshold}$. We show that the relationship between summer mortality rates and the DD index is non-linear and can be described by a logarithmic function, with a correlation coefficient of 0.78, which explains 60.6% of the mortality variance (F value of 24.64, significant at P<0.0001). Using maximum temperatures, no significant relationship is found with mortality, whereas the EHD frequency shows a significant association with mortality, albeit weaker than that obtained with DD.

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Introduction

Summer 2003 has been perceived as exceptionally hot, especially in most of Western Europe. In fact, during the first 2 weeks of August at least four countries experienced new all-time records of daily maximum temperature (38.1°C in Great Britain, 40.2°C in Germany, 41.5°C in Switzerland and 47.5°C in Portugal). The Spanish (and European) absolute record (50.0°C in Seville in 1881) was not broken but, according to the Spanish National Institute of Meteorology (http://www.inm.es), 19 observatories (weather stations) recorded daily maximum temperatures higher than or equal to 40°C. In eight of these observatories, maximum temperatures higher than or equal to 40°C occurred with unprecedented frequency. Thus, in Spain the heat wave was characterised mostly by the persistence of very high values, but no absolute maximal values seem to have been exceeded. Besides an unusually large number of extensive forest fires, which occurred in Portugal, Spain and France, the other main impact of the heat wave was increased mortality, especially in south-western Europe (Trigo et al. 2005).

Mortality records usually require a considerable amount of time to be published, with a delay of more than 2 years being frequent. This fact undermines the possibility of carrying out unambiguous fine epidemiological studies to assess the real impact on mortality of extreme temperatures. Official (but not definitive) records held by the World Health Organisation (WHO 2004), based on national health authority inquests, indicate that an additional 30,000 deaths can be attributed to the summer 2003 heat wave over Europe. About 50% of this excess mortality occurred in France, with approximately an additional 15,000 deaths, but Germany (~5,000), Italy (~3,000), Holland (~1,500) and the United Kingdom (~2,000) also contributed to the total figure (Grynszpan 2004; WHO 2004; Trigo et al. 2005). Over Iberia, official statistics point to a further 1,950 additional deaths in Portugal (Botelho et al. 2004) and 6,112 in Spain (http://www.ine.es; Martínez et al. 2004). Generally, these values were calculated as the difference between deaths that occurred in July and August 2003 and the corresponding average values for the same months in the previous three summers (2000–2002). Thus, the margin of error associated with these values is considerably larger than if comparisons were performed against a longer period average.

Usually, analysis of the association between heat waves and mortality has been performed through the use of daily maximum temperature (T_{max}) or derived indices, and such studies have often included the effects of air moisture (Nakai et al. 1999; Whitman et al. 1997; Smoyer 1998; Jendritzky et al. 2000). Heat wave duration was also introduced in some of these papers, commonly as an independent variable (Nakai et al. 1999). Other approaches make use of synoptic patterns, derived at the local or regional scale (Kalkstein 1991). However, to the best of our knowledge, none of these studies takes into joint account the intensity, duration and local character of the heat wave. In fact, it is well known that the impact of extreme summer temperatures on mortality rises dramatically when the 95th percentile of the local T_{max} distribution is exceeded (Díaz et al. 2002a,b; García-Herrera et al. 2005; Dessai 2002). This is attributable to a failure of adaptative physiological mechanisms (Havenith 2001). Thus, the potential health impact depends not only on the highest absolute T_{max} value observed, but also on the local maximum temperature distribution, which should be taken into consideration. Consequently, in this paper, we have assessed this impact by calculating, for each observatory, the local T_{max} distribution and the corresponding 95th percentile values ($T_{threshold}$).

The main objective of this paper was to analyse the impact on mortality of the abnormally high temperature values observed during the summer of 2003 in Iberia. Our aim was to provide a new approach to properly quantify the impact of heat waves on mortality rates, since absolute temperature values do not necessarily provide the best tool with which to measure expected effects. Thus, we have defined a new index, DD (degrees-days of exceedance), which jointly accounts for the number of days with daily maximum temperature (T_{max}) above a certain local threshold ($T_{threshold}$) as well as the magnitude of the exceedance.

Methods

Temperature data

The temperature data used in this study are the daily maximum temperatures (T_{max}) for the period 1991–2003 registered at 50 observatories in Spain and 4 in Portugal. However, data for the 1991–2002 period were used for comparison purposes only. Spanish data correspond to those cities that are capitals of Provinces, while those of Portugal correspond to the country's two largest cities near the coast (Lisbon and Porto) and to two smaller inner cities: Beja in the southern plains and Braganza in the northern mountains. As can be seen in Fig. 1, the data thus provide

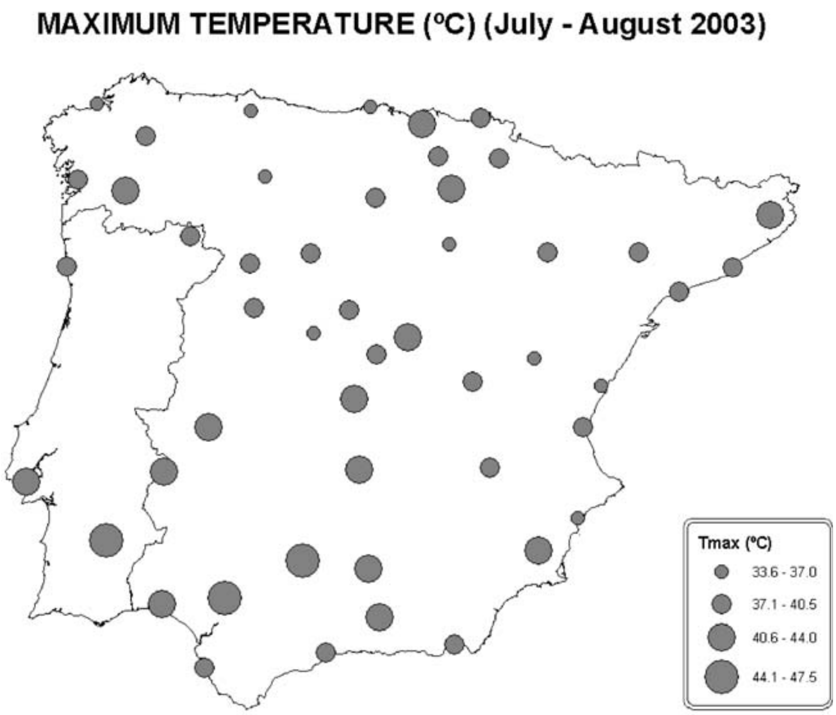

Fig. 1 Maximum temperature (T_{max}) values recorded in Iberia during 2003

Table 1 Values of the main parameters used in the study

Weather station	T_{max} (°C)	EHD (days)	DD (°C)	Mortality rate
A Coruña	34.2	8	24.2	17.56
Álava	38.0	15	46.0	13.02
Albacete	38.8	10	9.1	16.61
Alicante	35.4	17	21.6	15.37
Almería	38.8	12	19.9	12.60
Asturias	35.6	15	46.7	19.03
Ávila	36.2	13	23.9	17.32
Badajoz	43.6	3	6.5	17.41
Baleares	38.5	34	81.9	15.49
Barcelona	37.3	53	115.2	16.38
Burgos	38.8	20	47	18.66
Cáceres	40.6	3	2.5	14.94
Cádiz	37.5	16	17.2	14.04
Cantabria	34.6	11	30.6	17.34
Castellón	37.0	27	39.8	14.67
Ceuta	33.9	7	10.4	10.77
Ciudad Real	41.8	7	9.7	18.14
Córdoba	46.2	10	16.2	15.98
Cuenca	38.1	12	11.1	14.28
Girona	41.2	36	90.3	17.19
Granada	41.2	10	8.2	12.21
Guadalajara	40.9	13	15.9	17.14
Guipúzcoa	37.8	6	65.3	14.68
Huelva	40.8	11	13.3	14.92
Jaén	41.0	7	10.4	14.27
La Rioja	40.6	20	36.6	10.52
Las Palmas	30.8	2	0.9	10.76
León	35.4	16	31.6	18.29
Lleida	39.4	19	26.3	19.08
Lugo	39.1	14	55.2	19.68
Madrid	38.6	8	8.2	12.50
Málaga	40.5	8	11.3	14.79
Melilla	35.8	10	15	11.90
Murcia	41.0	8	9.8	12.40
Navarra	39.8	18	40.1	14.52
Ourense	42.0	12	35.8	16.81
Pontevedra	38.2	7	17.7	14.14
Salamanca	38.0	17	27.6	17.74
Sta. Cruz Tfe.	33.2	7	4.5	11.37
Segovia	38.3	17	31.6	15.51
Sevilla	45.2	7	12.5	14.03
Soria	36.8	14	17.9	22.27
Tarragona	40.0	21	42	13.96
Teruel	36.8	9	3.8	17.74
Toledo	42.4	13	18.9	16.59
Valencia	38.4	18	29	16.42
Valladolid	39.5	15	25.1	16.56
Vizcaya	41.9	9	34.9	15.37
Zamora	39.2	17	23.6	18.99
Zaragoza	39.6	21	22.5	17.69
Beja	44.8	12	27.6	
Braganza	38.2	14	29.6	
Lisbon	41.6	10	35.3	
Porto	37.6	7	15.9	

T_{max} Maximum temperature, *EHD* extremely hot days, *DD* degrees-days homogeneous geographical coverage of the entire Iberian Peninsula. We have considered a short summer definition restricted to July and August, since our main goal is to analyse those months in 2003 exhibiting anomalous behaviour from the point of view of mortality.

To characterise jointly the intensity and duration of the heat wave, the following four-step methodology was applied:

1. T_{max} value distributions were calculated for each observatory during the period studied for the July–August interval.
2. The local 95th percentile of the T_{max} distribution was computed for each observatory ($T_{threshold}$).
3. Next, we defined locally as extremely hot days (EHD) those days on which T_{max} was higher than the local $T_{threshold}$ value, i.e. EHD frequency is the number of days when the local $T_{threshold}$ is exceeded.
4. Finally, we defined an index of intensity of the heat wave by calculating the total degrees-days of exceedance (DD), obtained using the following expressions:

$$DD = \sum_{1July}^{31Aug} (T_{max} - T_{threshold}) \; if \;\; T_{max} > T_{threshold}$$
$$DD = 0 \;\; if \;\; T_{max} < T_{threshold}$$

Mortality data

Official detailed mortality data for Spain are available at http://www.ine.es. These values correspond to total mortality values per Province during the period July–August 2003. To take into account the very different baseline populations residing in each Province, we standardised these values by dividing the mortality values by the 2001 census population according to information from the Spanish National Institute. Mortality rates shown in this paper have been adjusted to per 10,000 habitants.

Several curves were fitted between mortality rates and the different heat wave parameters (T_{max}, EHD and DD) and, for each curve, the values of the correlation coefficient, Snedecor F parameter, and level of statistical significance were calculated.

Results

Table 1 shows the values of the main parameters used in the study (maximum T_{max}, EHD, DD, mortality rate) for all the observatories considered.

Maximum temperature

Figure 1 shows the maximum T_{max} values recorded in Iberia during 2003. It can be seen that only eight observatories recorded values lower than 37°C, while four stations in south-western Iberia recorded values above 43°C. The distribution is rather homogeneous, but with a latitudinal dependence, with most of the highest values essentially concentrated in the south-western sector of Iberia. However, the information provided by this picture is limited when trying to characterise the nature and, above all, the impact of the heat wave. After calculating the 2nd step of the methodology outlined above we also obtained all individual T_{max} thresholds for each observatory. The threshold values ($T_{threshold}$) range between 26.2°C and 41.2°C, and their distribution (data not shown) is very similar to the pattern exhibited in Fig. 1, with the highest values concentrated in the south-western corner of Iberia.

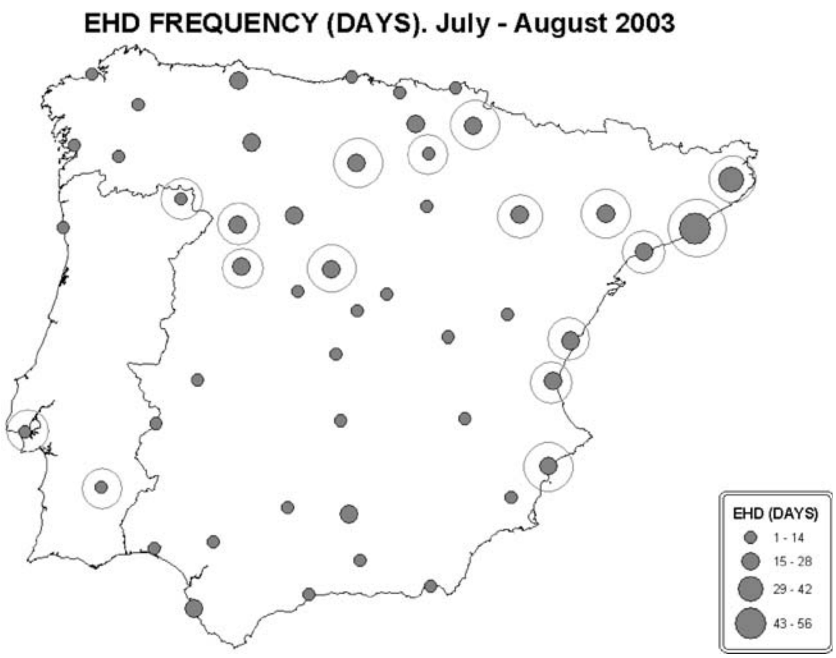

Fig. 2 Distribution of extremely hot days (EHD) frequency recorded in the summer of 2003. Observatories surpassing the average annual frequency plus one standard deviation are circled

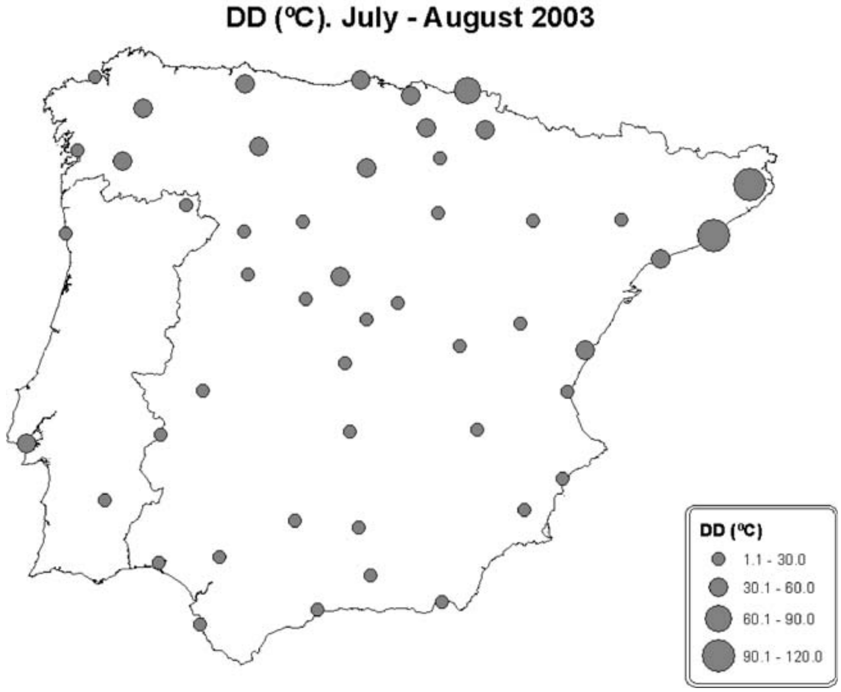

Fig. 3 Magnitude of degree-days of exceedance (DD) values for all the considered Provinces

Extremely hot days

Annual EHD frequencies were calculated for each year and observatory. Figure 2 shows the distribution of the EHD frequency recorded in the summer of 2003. If the average annual frequency plus one standard deviation was surpassed, the corresponding observatory was circled on the figure. Most of the observatories with more than 14 EHDs are concentrated on the Mediterranean coast and in northern central Iberia. This spatial distribution is similar to that of stations presenting larger deviations from the average EHD frequency (circled observatories).

Degree-days of exceedance

Figure 3 shows the magnitude of DD values for all the considered Provinces; the spatial distribution of this field is roughly similar to that of EHD in Fig. 2. However, while the area of maximum temperature anomaly covers the entire northern half of Iberia (not shown), the maximum expected impact of this heat wave is restricted to the Catalonian cities of Barcelona and Gerona, and to the north-eastern Iberian corner, particularly to the city of S. Sebastian (Basque Country).

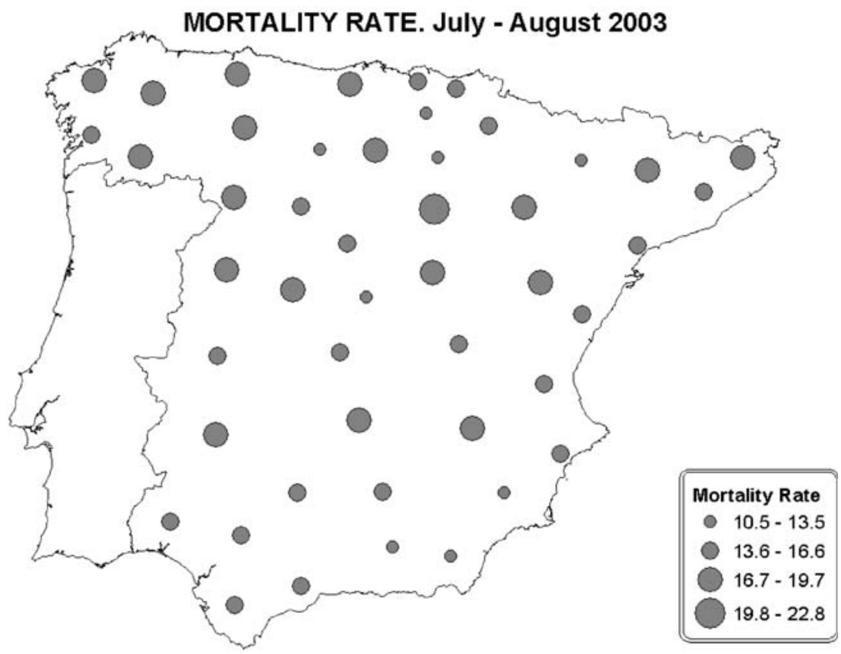

Fig. 4 Mortality rate values for all Provinces considered in Spain

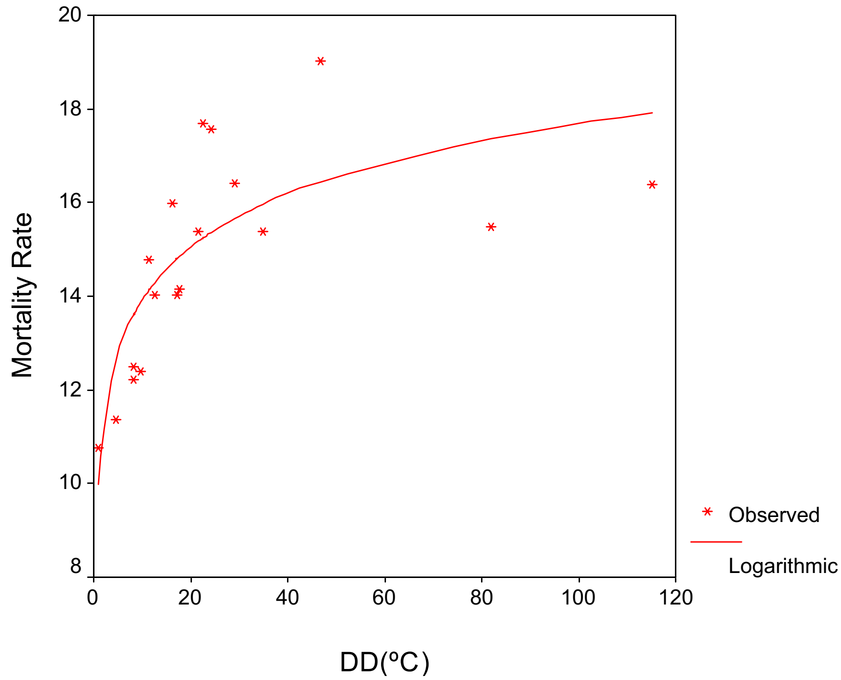

Fig. 5 Relationship between summer mortality rates (total number of deaths during July and August divided by the population and multiplied by 10,000) and the DD index. The logarithmically adjusted curve is indicated

Analysis of mortality data

Figure 4 shows the spatial distribution of the mortality rate in the Spanish Provinces. Use of these data for analysis of the association between extreme temperatures and mortality is hampered by different factors:

1. These mortality rates are not differentiated according to their causes, including accidents and pathologies not related to heat.
2. The mortality rates refer to the general population. The signal is thus weakened, since the maximum and detectable impact is known to be higher on individuals older than 65 years.
3. The population structure also varies considerably among the different Provinces. Some of these provinces have a relatively large percentage of the population living in rural areas or small towns. The proportion of elderly people in these communities is higher than in large cities (e.g. 14.6% of the population is older than 65 years in Madrid vs 26.9% in Soria) (http://www.ine.es)

All these possible sources of bias cannot be completely eliminated until detailed records splitting mortality by age, gender and cause for each Province are available. However, bias can be minimised by choosing the regions with the highest percentage of urban population, which show a more homogeneous demographic pattern. Thus, we restricted our analysis of the association between DD and mortality rate to the sub-set of 18 Spanish Provinces with absolute population numbers greater than 750,000. This allowed us to investigate the relationship between summer mortality rates and DD index. Figure 5 shows that this association is non-linear in nature, and is best described by a logarithmic function, with a correlation coefficient of 0.78 (16 *df*) and an F value of 24.64, significant at $P<0.0001$. The adjusted curve can be expressed as: mortality rate $=1.63$ log DD$+10.1$, and it explains 60.6 % of the mortality variance, the highest among the different curves and heat wave parameters.

Discussion

Standard procedures to evaluate the impact of heat waves on human health have usually looked at the simultaneous evolution of both local maximum temperature and mortality rates (Nakai et al. 1999; Whitman et al. 1997; Díaz et al. 2002a,b; Dessai 2002). Moreover, most of these studies have concentrated their analysis on a single city or restricted region, typically characterised by a single meteorological station. Here, we have studied the 2003 heat wave impact on T_{max} and EHD, looking at the large spatial variability in all 50 Spanish provinces, and at the mortality rate in the 18 most populous provinces.

We compared local values of T_{max} for 2003 with local averages calculated using data from a relatively short time period (1991–2002). While we acknowledge the difficulties in obtaining longer homogeneous T_{max} time series, we nevertheless stress that the use of this recent but relatively small climatological period is, in our view, more appropriate to calculate summer 2003 EHD values, since the use of a longer baseline period definition (e.g. 1960–1990) would implicate slightly larger values of EHD. This fact is in agreement with recent studies that have shown evidence of increases in the frequency of extreme temperatures during the second part of the twentieth century (Klein Tank 2002; Frich et al. 2002; Santos et al. 2002).

Interestingly, the EHD pattern is very different from the T_{max} distribution shown in Fig. 1, with the most relevant anomalies concentrated in north-eastern Iberia. Thus, in this sense, the highest absolute temperature values recorded in southern Iberia can be regarded as less locally anomalous than the rest. Moreover, this spatial distribution of EHD frequency is in good agreement with the corresponding atmospheric circulation anomalies observed for the corresponding summer of 2003. Readers interested in the atmospheric circulation pattern associated with this heat wave are referred to Trigo et al. 2005 for a detailed analysis.

Finally, we would like to stress two important points to note when analysing Fig. 5:

1. We have included both Provinces of the Canary Islands because (1) these Provinces fulfill the population requisite, and (2) they can be used as control case studies against which the remaining Provinces can be properly evaluated, since it is known a priori that these regions did not suffer the heat wave effect.
2. Some of the northern Spanish Provinces present higher mortality rates than those expected from the logarithmic rule. We believe this is due mostly to the extremely hot week observed between the 3rd and the 12th of August in both northern Spain and most of France (http://www.inserm.fr/servcom/servcom.nsf). However, the fact that mortality data split on a week-by-week basis are not available makes it impossible to confirm such a hypothesis for Iberia.

A non-linear relationship between extreme temperatures and mortality in Iberia has also been evidenced in previous studies covering Lisbon (Dessai 2002) and Madrid (Prieto et al. 2003), and seems characteristic of the biological mechanisms controlling the adaptation of living beings to extreme environments. Interestingly, when T_{max} values are used, no significant relationship is found with mortality (F=0.179 with P<0.678 for a linear fit, and F=0.269 with P<0.613 for a logarithmic fit), while EHD frequency shows a significant, but weaker, association with mortality (F=3.7 with P<0.07 for a linear fit, and F=9.2 with P<0.01for a logarithmic fit). Thus, the use of DD (F=24.64 and P<0.0001) is decisive in assessing the real impact of extreme temperatures on mortality, since it takes into account local characteristics.

Final remarks

This work shows that, when assessing the impact of extreme climatic events, it is not enough to measure absolute temperature values. When dealing with human health, or effects on other living organisms, factors such as adaptation to the local environment should be accounted for. This is of outstanding importance in the proper evaluation of diagnostic studies of recent heat waves, but also when assessing future climate and climate impact scenarios. Our results provide an example of how their impact on human health can be adequately measured. We strongly believe that DD is better designed to represent, in a single index, the accumulated impact on mortality of higher than usual T_{max} values during a heat wave (or even an entire summer). However, more efforts are needed to identify, for each case and impact variable, the most appropriate evaluation measure capable of integrating the underlying mechanisms in the climate-impact interaction.

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