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Evaluating the impact of extreme temperature based indices in the 2003 heatwave excessive mortality in Portugal

Ricardo M. Trigo [a,b,*], *Alexandre M. Ramos* [a,h], *Paulo J. Nogueira* [c], *Filipe D. Santos* [d], *Ricardo Garcia-Herrera* [e], *Célia Gouveia* [a,f], *Fátima E. Santo* [g]

[a] CGUL, IDL, Faculdade de Ciências, Universidade de Lisboa, Portugal
[b] Departamento de Engenharias, Universidade Lusófona, Lisbon, Portugal
[c] Observatório Nacional de Saúde, Instituto Ricardo Jorge, Lisbon, Portugal
[d] SIM, IDL, Faculdade de Ciências, Universidade de Lisboa, Portugal
[e] Escola Superior de Tecnologia, Instituto Politécnico de Setúbal, Setúbal, Portugal
[f] Dto. Física de la Tierra II, Facultad de Físicas, Universidad Complutense, Spain
[g] Instituto de Meteorologia, Lisbon, Portugal
[h] Environmental Physics Laboratory, Facultade de Ciencias, Universidade de Vigo, Ourense, Spain

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ABSTRACT

This paper analyses the impact of the 2003 European heatwave on excessive human mortality in Portugal, a country that presents a relatively high level of exposure to heatwave events. A total of 2399 excessive deaths are estimated in continental Portugal, which implies an increase of 58% over the expected deaths. When these values are split by gender, it is seen that women increase (79%), was considerably higher than that recorded for men (41%). The increment of mortality due to this heatwave was detected for all the 18 districts of the country, but its magnitude was significantly higher in the inner districts close to the Spanish border. When we split by gender all districts reveal significant mortality increments for women, while the impact in men's excess deaths is not significant over 3 districts. Several temperature derived indices were used and evaluated in their capacity to explain, at the regional level, the excessive mortality (ratio between observed and expected deaths) by gender. It is shown that the best relationship is found for the total exceedance of extreme days, an index combining the length of the heatwave and its intensity. Both variables hold a linear relationship with $r = 0.79$ for women and a poorer adjustment ($r = 0.50$) for men. Additionally, availability of mortality data split by age also allowed obtaining detailed information on the structure of the population in risk, namely by showing that statistically significant increments are concentrated in the last three age classes (45–64, 65–74 and 75 or more). The use of air conditioning systems in some Portuguese hospitals had a major impact on the decrease (up to 40%) in excessive mortality values. A finer approach is relevant for prevention strategies, since it allows to identify better the target population of any preventive strategy regional and national authorities may be interested to implement.

* *Corresponding author at*: Centro de Geofísica da Universidade de Lisboa, Departamento de Física, Faculdade de Ciências, Univ. de Lisboa, Campo Grande, Ed C8, Piso 6, 1749-016 Lisboa, Portugal. Tel.: +351 217500855; fax: +351 217500977.
E-mail address: rmtrigo@fc.ul.pt (R.M. Trigo).

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1. Introduction

The summer of 2003 was characterised by extremely high values of temperature at the daily, weekly and monthly scales, particularly during the first fortnight of August. During the first 2 weeks of August several countries have observed new all time records of daily maximum temperature, namely in Great Britain (38.1 °C), in Germany (40.2 °C), Switzerland (41.5 °C) and Portugal (47.5 °C). Monthly temperatures observed for June and August 2003 in central Europe were beyond the historical distribution range (Schär et al., 2004). Even at the seasonal scale, it was considered the warmest summer in Europe since the early-16th century (Luterbacher et al., 2004). However, most health impacts, particularly the step increase in mortality rates, were related with the relatively short-lived heatwave that occurred during the first fortnight of August 2003 (Díaz et al., 2006; INVS, 2003) associated with an extreme anticyclonic pattern (Trigo et al., 2005). The summer 2003 heatwave had two major distinct impacts in continental Portugal, namely on excessive mortality and wildfire activity with an estimated total burnt area of 450,000 ha, including 280,000 ha of forest (Trigo et al., 2006). Other ecological impacts felt throughout Western Europe include extensive loss of livestock (e.g., chickens), wilted crops (e.g., potato, wine and cereals) and loss of forest cover (UNEP, 2004; Fink et al., 2004). The total economic losses associated with the European heatwave of 2003 have been estimated to exceed US$ 10bn (Munich Re, 2004). A review of the impacts of this event at European level can be found in García-Herrera et al. (in press).

It is now accepted that this heatwave triggered a considerable large number of excessive mortality in Europe (approximately 45,000 extra deaths evaluated in Robine et al., 2008), mostly of elderly people. France and Spain have suffered the largest burden with approximately 15,000 (INVS, 2003; Cassadou et al., 2004) and 6000 (Díaz et al., 2006; Martínez et al., 2004) extra deaths, respectively. However, other European countries have suffered considerably, in particular; Germany (Schönwiese et al., 2004), Italy (Bisanti et al., 2004), Holland (Garssen et al., 2005), Portugal (Botelho et al., 2004), Belgium (Sartor, 2004), Switzerland (Grize et al., 2005) and the United Kingdom (Burt, 2004) have contributed decisively to the total figure.

There are several different definitions of what can be regarded as a heatwave episode (Robinson, 2000). In any case, these events can hardly be considered a rare phenomena. Prior to the major 2003 event, Europe has suffered, in recent decades, intense heatwave episodes such as those which occurred in France in 1976, Portugal in 1981 and 1991, Greece in 1987 and the UK in 1995 (INVS, 2003). In the USA, the summers of 1980 in St. Luis and of 1995 in Chicago (Kalkstein, 1995; Semenza et al., 1996) were also affected by "killing" heatwaves. However, we now know that the combined figure of excessive deaths associated with all the heatwaves mentioned above is smaller than those attributed to the single event of 2003.

Portugal presents a relatively high level of exposure to heatwave events, with large impacts in health, including excessive mortality. Fortunately these events are not so common in other mid-latitude regions, namely among most European countries. However, according to the latest climate change scenarios released in 2007 in the IPCC report, the Mediterranean basin (including southern Europe, northern Africa and Middle East) will be drier and more prone to heatwaves in the following decades. In fact, the Mediterranean area is considered a hot spot of climate change (recent and future) because it is one of the few world regions where global (and regional) circulation models agree with the increase of extreme events (generalised dryness with higher probabilities of intense precipitation and heatwave episodes).

Therefore, Portugal's experience dealing with recent heatwave events (and their associated excessive mortality) bears a larger relevance for the many countries in this populated area of the world. In particular, it is important to understand from the climatological and human behaviour perspectives why it has been possible to establish relatively solid relationships between the occurrence of heat waves and mortality in the Iberia Peninsula.

The assessment of the impact, on excessive mortality, generated by intense heatwaves in Portugal has only been possible since the start of consistent archive of mortality data, i.e., since the early-1980s. About 1900 excessive deaths have been estimated (for the entire country mainland) as a consequence of the very intense heatwave that struck Portugal in June 1981 (Garcia et al., 1999). Similarly, about 1000 extra deaths have been estimated for the heatwave that occurred in July 1991 (Paixão and Nogueira, 2003). In recent years several authors have analysed the association between mortality and extreme temperatures in Lisbon based on a simple empirical model for Lisbon (Dessai, 2002, 2003) and more complex time series methodologies (García-Herrera et al., 2005).

This significant number of heatwave studies prompted Portugal to develop one of the first heatwave alert systems developed in Europe, labelled ÍCARO and implemented in 1999 for the capital city of Lisbon. However, to the best of our knowledge no study has investigated the links between excessive mortality rates and the number of days (nights) with maximum (minimum) temperature above a certain threshold in Lisbon.

As a consequence of the outstanding heatwave over Portugal in 2003 a number of measures had to be taken by the National health authorities. It is within this context that a contingency plan was developed to deal with the possibility of occurrence of a heatwave and to minimize the effects of heat in the population (DGS, 2008). The main objectives are to increase the inter-institutional coordination between the National Health Service which led this contingency plan and other institutions such as the national civil defence organization or the national institute of medical emergency. Improving the forecast and alert system for the heatwaves is paramount, requiring a tight connection to the national authority in meteorology. For this purpose the plan requires extensive improvement on the timing and quality of public warnings sent to the media.

The aim of this paper is to evaluate the excessive mortality observed in Portugal during the 2003 heatwave. This evaluation will be presented with a breakdown by age and sex and the excessive mortality will be evaluated on a district by district basis. This is the first time that a detailed evaluation of the mortality impact of the 2003 heatwave is made for Portugal, no previous estimation being available in the refereed scientific literature. Moreover, we will provide an objective comparison on the use of various temperature related indices in order to explain the mortality rates in each district and breakdown by sex.

The following section presents the data used and the methodologies employed, then Section 3 provides information on the observed vs. expected mortality for this heatwave. Section 4 introduces several temperature related indices that are related with the excessive mortality in Section 5. Finally some discussion and conclusions are given in Section 6.

2. Data and methods

2.1. *Observed and expected mortality in Portugal for the summer 2003 heatwave period*

Daily mortality relative to "all causes" was obtained from the official Portuguese mortality data bases (Instituto Nacional de Estatística) for the period that spans between 1995 and 2004 for Portugal mainland (excluding the autonomous regions of Madeira and Azores). The deaths of non resident in Portugal mainland were not included in this work. Observed deaths were also disaggregated by age group (0–14, 15–24, 25–44, 45–64, 65–74 and ≥75 years old), by sex and district. Particular attention was given to the excessive mortality associated with the heatwave period between 30th of July and 15th of August, 2003.

Excessive mortality associated with extreme events must be carefully assessed. Such an evaluation requires the use of appropriate data for comparison. However, this effort can be particularly difficult when the total population is changing and also when the population remains unchanged but the structural age distribution changes, typically with older people. Many epidemiological studies have used relatively short periods, immediately before or after the extreme event, in order to guarantee the stability and similarity of the underlying population structure (Nogueira et al., 2005). Here, we have made a small sensitivity study to evaluate the impact of using different comparison periods within the available period with comparable mortality data for the entire country (1995–2004). For this purpose we have computed the standard period proportional mortality ratio (PPMR) adapted from occupational epidemiology (Colton and Clapp, 2005):

$$\text{PPMR}_i = \frac{M_i}{M_1 + M_2 + \ldots + M_{i-1} + M_{i+1} + \ldots + M_k} \quad (1)$$

with M the total mortality observed in time periods and K refers to the total number of years considered.

However, we found more appropriate to use the averaged period proportional mortality ratio (APPMR) that is derived in the following way:

$$\text{APPMR}_i = \frac{M_i}{(M_1 + M_2 + \ldots + M_{i-1} + M_{i+1} + \ldots + M_k/k - 1)} \quad (2)$$

with M the total mortality observed in time periods and K refers to the total number of years considered. The advantage of using APPMR lies on the direct comparison since the denominator represents the average number of deaths in similar periods (of equal duration in days, during the same time of the year), making it an direct estimate of the expected number in the *i*th period of interest, and where a value higher than 1 means more mortality than expected. Conversely the PPMR only gives the overall relative weight of the number of observed deaths in the *i*th period to the total number of deaths observed in the remaining comparison periods, a statistic that is more difficult to interpret.

Therefore, to estimate the fortnight expected mortality, for each district, in the period comprised between 30 July and 15 August, we have used five distinct periods of mortality (Fig. 1).

Results appear to be relatively stable, despite the highest values of APPMR are obtained with the 2002–2004 comparison period, reflecting the fact that 2004 was relatively close to the average (1961–1990) summer temperature values (IM, 2004). Finally, we decided to use the period that spans between 2000 and 2004, as it corresponds to a good compromise between a relatively long period (to guarantee some stability) and a sufficiently short period (to guarantee the similarity of the underlying population structure).

The methodology presented above (APPMR) was chosen and these values will be referred hereafter simply as the ratio between observed deaths and expected deaths for the period 30 July–15 August. This *O/E* ratio was computed for every group age described above, and discriminated also by sex and district.

2.2. *Meteorological temperature fields for Portugal*

The heatwave over Portugal was also characterised with surface values of daily maximum and minimum temperature data observed at 23 synoptic stations from the National Weather Service (IM), covering the whole territory. This data set includes values for the summer of 2003 and the corresponding climatological values for the normal reference 1961–1990 period. Ideally we would like to use the same climatological period for both datasets (temperatures and mortality), however, due to the problems described above (lack of sufficiently long

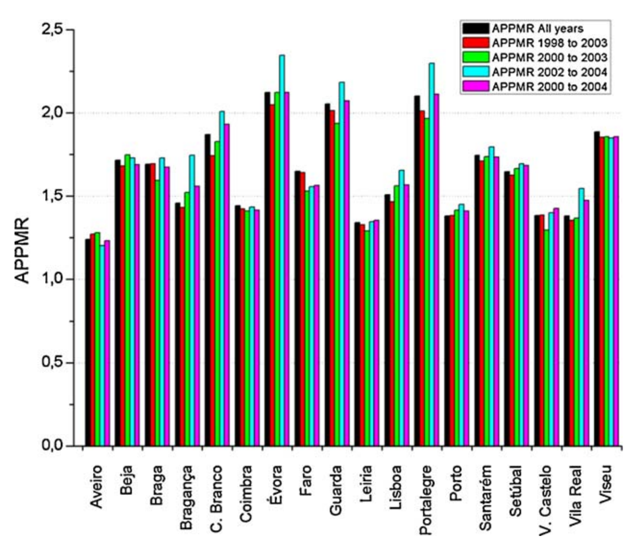


Fig. 1 – Averaged period proportional mortality ratio (APPMR) values obtained with different comparison periods.

mortality data, changes of the underlying population) we decided to use a traditional normal period (1961–1990).

Besides the standard use of maximum and minimum temperatures we have also computed additional variables that can be better related with the heat burden imposed upon the population, namely the number of days with temperatures above an appropriate threshold. We believe that the 23 stations are representative of the distribution of extreme values of the vast majority of the population considered in this study.

2.2.1. Maximum and minimum temperatures

Based on daily maximum (T_{max}) and minimum (T_{min}) temperature anomalies we computed the averaged anomalies for the period that spans between 30 July and 15 August. These anomalies were derived as departures from the respective daily climatological mean values obtained for the correspondent summer period (30 July–15 August) for the 1961–1990 normal. This approach was applied independently for all the 23 synoptic stations used.

2.2.2. Extreme hot days (EHD) and extreme hot nights (EHN)

In a recent work that evaluated the impact of the 2003 heatwave in terms of excessive mortality in Spain it was shown that raw maximum temperature values were not the best prognostic environmental variable (Díaz et al., 2006). In fact, other less well known variables that accounted for the accumulated heat stress over a long period were found to be better suited for that purpose. One of the simplest choices is to use the number of extreme hot days (EHD) and extreme hot nights (EHN) that can be easily computed for each synoptic station. Basically the EHD (EHN) index corresponds to those days (nights) where T_{max} (T_{min}) values are higher than the respective daily 95th percentile computed for the climatological normal period of 1961–1990. This 95th percentile threshold was computed at a daily basis as it varies slightly over the summer.

Following the approach used in Díaz et al. (2006) we have also computed an additional index of the heatwave intensity based on the sum of exceedance degrees (°C) whenever an EHD or an EHN occurs. Therefore, the index that quantifies the total degree days of exceedance EHD (EEHD) is defined as follows:

$$\mathrm{EEHD} = \begin{cases} \sum_{j=30\,\mathrm{July}}^{j=15\,\mathrm{August}} (T_{\max,j} - T_{\max95,j}) & \text{if } T_{\max,j} > T_{\max95,j} \\ 0 & \text{if } T_{\max,j} < T_{\max95,j} \end{cases} \quad (3)$$

with $T_{max,j}$ being the daily T_{max} values for 30 July–15 August and $T_{max95,j}$ the correspondent daily 95th percentile of T_{max} computed for the 1961–1990 daily distribution. The percentiles were computed from samples of 30 y × 17 days = 510 days, which provides a robust estimate of the percentiles.

Similarly, the index that accounts for the total degree nights of exceedance EHN (EEHN) is derived as follows:

$$\mathrm{EEHN} = \begin{cases} \sum_{j=30\,\mathrm{July}}^{j=15\,\mathrm{August}} (T_{\min,j} - T_{\min95,j}) & \text{if } T_{\min,j} > T_{\min95,j} \\ 0 & \text{if } T_{\min,j} < T_{\min95,j} \end{cases} \quad (4)$$

with $T_{mix,j}$ being the daily T_{min} values for 30 July–15 August and $T_{min95,j}$ the correspondent daily 95th percentile of T_{min} computed for the 1961–1990 daily distribution.

Since we have mortality data with district information, we need to use an interpolation technique to transfer the point wise variables (T_{max}, T_{min}, EEHD and EEHN) computed for each individual 23 stations to the entire territory. For this purpose we have used a biharmonic spline interpolation technique (Sandwell, 1987) computed with the MATLAB® software.

3. Observed and expected mortality in the 2003 heatwave

3.1. Evaluating by gender and age group

At the national level, i.e., including all the 18 districts of Portugal mainland, a comprehensive comparison between observed and expected deaths (between 30 July and 15 August 2003) is shown in Table 1. According to the latest figures derived by the Portuguese health institution authorities during this period 6469 people died in Portugal including 2974 (46.0%) men and 3495 (54.0%) women (Calado et al., 2004). For both sexes a statistically significant increment of deaths was found (i.e., mortality significantly above the expected value), with about 864 men and 1535 women above the expected values (2399 excessive deaths in total). The ratio between observed deaths and expected deaths (*O*/*E*) was also larger in women (1.79) than men (1.41). These results present an asymmetrical gender risk which is in accordance to what was noted by Kosatsky (2005) and Nogueira and Paixão (2007). However, this outcome is in disagreement with previous widely accepted results, where identical risks were expected for both genders (e.g., WHO, 2004). It should be remembered that expected values were computed as the mean observed mortality values for 2000 and 2004 for the same period of the year. The statistical significance (*p*-values) was calculated assuming a Poisson distribution or its approximation to the normal distribution.

When we analyse these results split by different age groups it is evident that the largest increases occur for the older groups. In general the *O*/*E* ratio is higher in woman population than in men. In women, the age group 15–24 also reveals a death increment (*O*/*E* = 1.68), although this value falls short of being statistically significant at the 5% level. In relation to men, mortality rates are normal for all age groups until 24 years old. However, there is an increment of mortality for the 25–44 class (*O*/*E* = 1.16) that is significant at the 5% level (while the similar increment for women *O*/*E* = 1.17 is not statistically significant).

From 45 years old every age group (both men and women) present a positive excess of deaths and the *O*/*E* ratios are statistically significant for both sexes. The age group ≥75 years old presents the largest excess of deaths for both sexes, but, as we mention before, with the number of excess deaths greater in women.

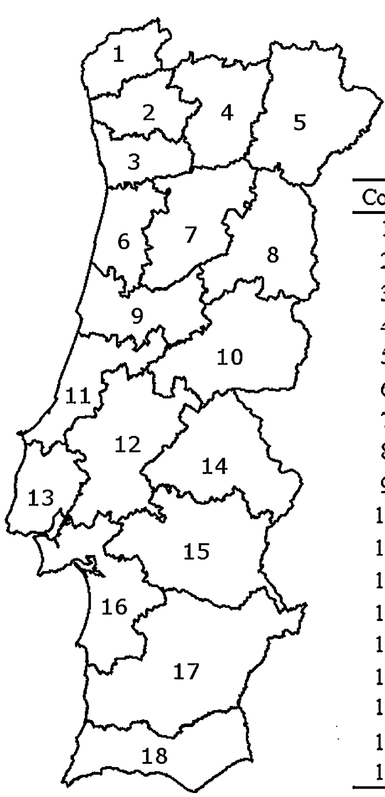
3.2. Evaluating by district and gender

For every Portuguese district (Fig. 2) we have also computed the ratio between observed and expected (*O*/*E*) deaths for males and females separately, but also independently of gender.

Table 1 – Observed (*O*) and expected (*E*) deaths for the period 30 July–15 August of 2003. Also shown are estimates of excess deaths (*O* − *E*) and *O*/*E* ratio. Expected mortality computed using the 2000–2004 period. All results are shown with split by gender and age group. *p* refers to the significance level.

	Observed deaths (*O*)		Expected deaths (*E*)		Excess of deaths (*O* − *E*)		*O*/*E*		*p*	
Men	2974		2110.5		863.5		1.41		<0.001	
Women	3495		1960.3		1534.8		1.79		<0.001	
Total	6469		4070.8		2398.25		1.58		<0.001	
Age groups	M	W	M	W	M	W	M	W	M	W
0–14	21	26	21	18.3	0	7.8	1.00	1.42	1.000	0.102
15–24	38	16	37	9.5	1	6.5	1.03	1.68	0.913	0.067
25–44	191	64	164.5	54.8	26.5	9.3	1.16	1.17	0.039	0.240
45–64	476	229	395.25	197.3	80.8	31.8	1.20	1.16	0.000	0.024
65–74	675	469	496.00	328.0	179	141.0	1.36	1.43	0.000	0.000
≥75	1573	2691	996.75	1352.5	576.3	1338.5	1.58	1.99	0.000	0.000

The results for *O*/*E* ratios are presented spatially disaggregated (per district), for the total population and also separated into male and female population (Fig. 3). Considering the entire population, the total number of observed deaths was larger than expected, with the highest values of *O*/*E* ratios ($2.0 < O/E < 2.2$) occurring in 3 districts located in the interior of Portugal (Fig. 3a). Again, the increment of deaths was statistically significant (at the 5% significance level) for all 18 districts represented; however, the interior districts (Portalegre, Guarda, Évora, Viseu and Castelo Branco) reveal the highest risk of excessive deaths. We have also evaluated the *O*/*E* ratios but taking into account the gender the vast majority of districts present a significant increment (at the 5% significance level). The few districts that do not present a significant increment of mortality are highlighted with the black dot in Fig. 3.



Code	District Name
1	Viana Castelo
2	Braga
3	Porto
4	Vila Real
5	Bragança
6	Aveiro
7	Viseu
8	Guarda
9	Coimbra
10	Castelo Branco
11	Leiria
12	Santarém
13	Lisboa
14	Portalegre
15	Évora
16	Setúbal
17	Beja
18	Faro

Fig. 2 – Location of the 18 administrative regions (districts) for the continental Portugal.

When analysing only the male population (Fig. 3b) it becomes evident that the vast majority of districts present lower values of *O*/*E* than those obtained for the entire population (Fig. 3a). The districts with higher values of *O*/*E* are not spatially contiguous as these include the center districts of Alentejo (14, 15), but also Guarda (8), Braga (2) and Viseu (7). With the exception of three districts; Bragança (5), Coimbra (9), Viana do Castelo (1), all the remaining districts present significant exceedance of deaths.

In respect to the female population, statistically significant excess of *O*/*E* occurred in all districts (Fig. 3c). The highest values of *O*/*E* can be found in central interior districts, namely; Castelo Branco (10), Évora (15), Portalegre (14), and Guarda (8) with these last three districts revealing values of *O*/*E* higher than 2.4 (Fig. 3c).

Comparing results obtained for male and female population we should highlight that the male population had lower values of *O*/*E* than the female population for all districts, with the two exceptions of Aveiro (6) and Braga (2), both located close to the Atlantic coast.

4. The role of heat related variables

4.1. Maximum and minimum temperatures

Referring to T_{max} anomalies, the entire country is characterised by positive anomalies for that period, with anomalies larger than 6 °C occurring throughout most of the territory (Fig. 4a) and a large N–S strip presenting values above 8 °C. The exceptions to this correspond to a small section of Algarve in the south and the coastal area around the 40°N parallel. The maximum values of T_{max} anomalies occurred in the southern Alentejo region and the northern interior sector. Interestingly a quite different pattern emerges in relation to the T_{min} anomalies, although positive anomalies can be also observed over the entire territory for that period (Fig. 4b). T_{min} anomalies are characterised by a maximum region (with anomalies

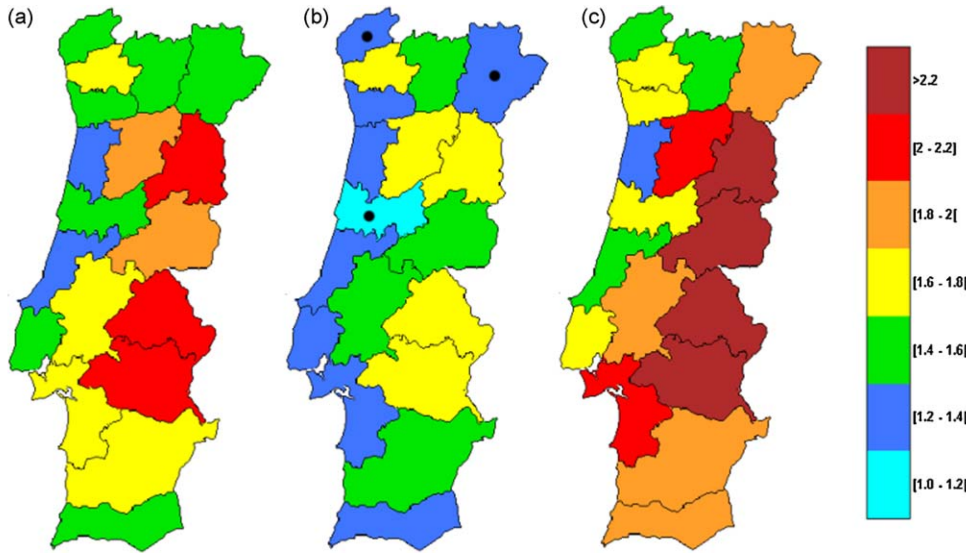


Fig. 3 – Spatial variability of the observed/expected (O/E) ratio per district, considering (a) the total population, (b) male and (c) female population. All the increments are statistically significant (5% significance level) except those identified with the black dots.

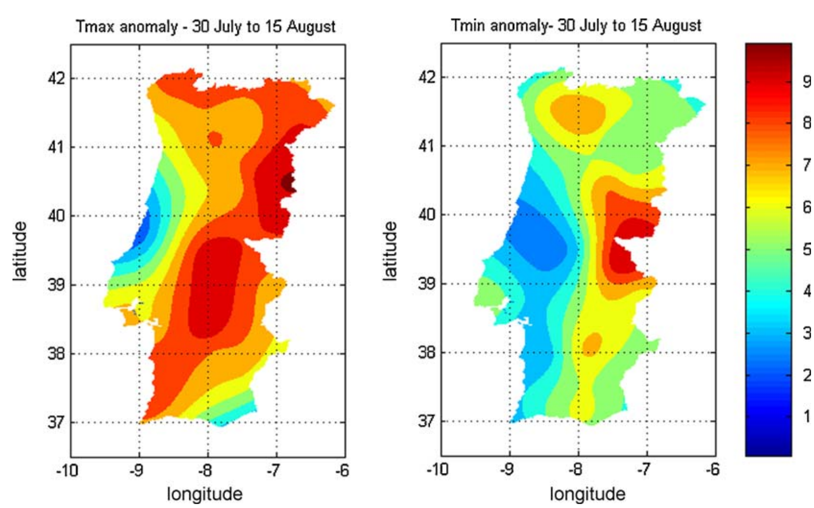


Fig. 4 – Average values of (left) T_{max} and (right) T_{min} anomalies (°C) for the period spanning between 30 July and 15 August of 2003. Anomalies computed against the 1961–1990 average.

above 8 °C) located close to the Spanish border (between the 39°N and 40°N parallels). Lower values of T_{min} anomalies are clearly more widespread than the corresponding T_{max}, with anomalous values lower than 5 °C dominating the costal areas between the north and southern districts.

4.2. Exceedances in extreme hot days (EEHD) and extreme hot nights (EEHN)

The spatial distribution of EEHD index (Fig. 5a) shows some similarities with the corresponding map of T_{max} (Fig. 4a). However, for EEHD, the maximum is clearly centred in the southern region of Alentejo (with values above 55 °C), high values being also recorded in the interior region of Portugal (Fig. 5a). The lowest values of EEHD occur over the relatively narrow coastal strip and also in southern Algarve (with less than 20 °C). Similarly, the spatial distribution of the EEHN index (Fig. 5b) resembles somewhat the T_{min} pattern distribution (Fig. 4b) but with a larger range of values. In this case the lowest values were recorded in all costal area with less than 20 °C, again with the exception of Lisbon region. Values of EEHN present maximum values in the interior centre regions, but also in the northern districts of Braga (2) and Vila Real (4), with values higher than 45 °C.

We have computed similar figures with the EHD and EHN fields (not shown) for the entire territory and their patterns are relatively similar to those depicted here for EEHN and EEHD and thus are not included for the sake of simplicity.

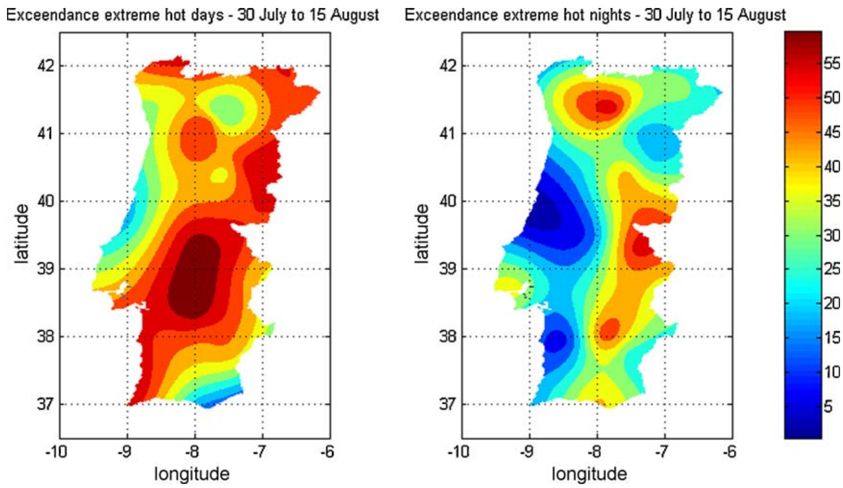


Fig. 5 – Values of (left) *exceedence extremely hot days* (EEHD) and (right) *exceedence extremely hot nights* (EEHN) (°C) for the period spanning between 30 July and 15 August of 2003. Exceedance values computed using the 95th percentile obtained with the 1961–1990 period.

5. Impact of extreme temperature based indices in mortality

In order to assess the role of the extreme temperature indices presented during the 2003 heatwave, we have performed a regression analysis between these indices and the *O/E* mortality ratio (Table 2). In this way, we intend to evaluate the best pair of variables that accounts for the highest value of explained variance. We have computed the district average of each extreme temperature index presented previously (T_{max}, T_{min}, EHD, EHN, EEHD and EEHN) taking into account the spatial extent of the district as it was shown in Fig. 2. The relationship between extreme temperature indices and *O/E* (total, men and women) was evaluated and a linear fit emerged always as the most appropriate regression. Therefore we have also computed the linear correlation coefficient between these extreme temperature indices and the *O/E* ratio. The correlation coefficient (*R*) and the corresponding significance level (*p*) can be observed in Table 2. The analysis of this table shows that all variables associated with maximum temperature present a higher level of relationship with the *O/E* mortality ratio then the corresponding variables associated with minimum temperature. This result is in accordance with several authors that have detected the overwhelming role of maximum temperature in excessive summer mortality in Iberia (Dessai, 2002; Díaz et al., 2002a,b; García-Herrera et al., 2005). Furthermore, it is worth mentioning that among the variables based on maximum temperature (T_{max}, EHD and EEHD) there is generally an increment in the amount of explained variance as we progress from T_{max} to EEHD (results highlighted in bold).

Table 2 – Results for the relationship between T_{max}, T_{min} and additional temperature related variables with the *O/E* ratio. Best results are highlighted in bold.

	O/E—total		O/E—men		O/E—women	
	R	*p*	R	*p*	R	*p*
T_{max} anomaly	0.68	0.00	0.49	0.02	0.69	0.00
T_{min} anomaly	0.45	0.04	0.37	0.07	0.42	0.05
EHD	0.72	0.00	0.44	0.04	0.77	0.00
EHN	0.23	0.19	0.26	0.16	0.16	0.25
EEHD	**0.75**	0.00	**0.50**	0.02	**0.79**	0.00
EEHN	0.27	0.15	0.31	0.11	0.21	0.20

The linear correlation obtained with the best models (between EEHD and *O/E* ratio) present a value of $R = 0.75$, $R = 0.50$ and $R = 0.79$, for the total, men and women population, respectively. It should be emphasised that all these three results are statistically significant at the 2% significance level, nevertheless it is obvious that the women subset (Fig. 6a) presents a better relationship than the equivalent for men (Fig. 6b). This suggests that only about 25% of men's mortality explained variance can be associated with extreme temperatures, i.e., a large percentage of male mortality appears to be related with other factors. According to some authors (e.g., Kenney, 1985; Mehnert et al., 2002), the average woman presents a lower capability to sweat reducing latent heat flux and sub skin fat tissues is thicker compared to men. More precise evaluation of the gender effect reveals that differences in thermoregulation are minimal, and that some of these differences are climate specific, with females performing better (worse) in warm/humid (hot/dry) climates (Shapiro et al., 1980). We must acknowledge that other relevant socio-economic factors may play an important role, namely if women are more likely to live in care homes or in poor housing condition. Unfortunately we have lack of additional data covering some of those relevant socio-economic factors, therefore we must de-emphasise the potential role played by the climatic effects on the differences observed for men and women.

Our approach to link excessive mortality and EEHD over Portugal was based on the good experience that some of us had when employing this new variable (EEHD) in a previous work for Spain (Díaz et al., 2006). Mortality data used in Díaz

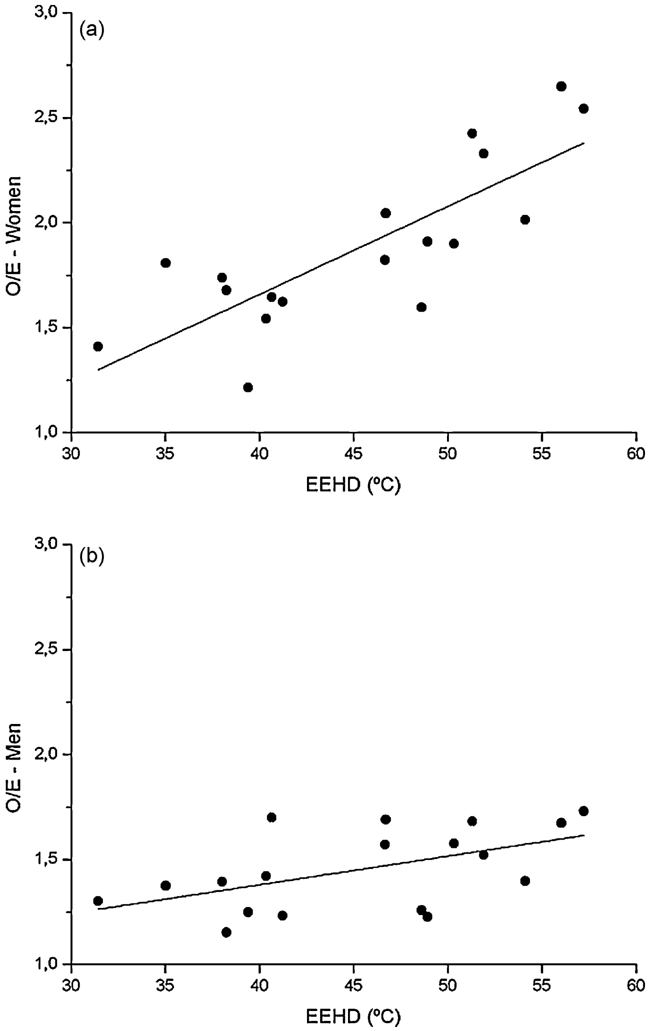


Fig. 6 – Scatter plot relating EEHD with the O/E ratio for (a) women and (b) men population.

et al. (2006) respected only Spanish provinces and no mortality data from Portugal was used. In the paper of Díaz et al. (2006) the mortality analysis was much simpler being based in total mortality only. No insight was given to mortality values split by gender and age, as it is done in this paper (although limited to the available information for Portugal). Thus, this analysis provides much more detail as regards the structure of the population at risk. Moreover several methodological modifications must be taken into account.

a) Besides using the mortality rate index we have also assessed the link between the spatial variability of the *O/E* ratio and all the temperature related variables. It became apparent that the latter one (*O/E* ratio) provided the best results.
b) In order to improve the relationship between EEHD and mortality rates Díaz et al. (2006) restricted their analysis to the Spanish provinces with population higher than 750,000. Here, we have used all districts independently of their total population, otherwise we would only retain 4 or 5 districts, undermining the entire analysis. In fact, the strength of the relationship shown in Table 2 and Fig. 6 does not seem to be dependent on the total population of each district.
c) Besides the use of T_{max} we have also analysed the role of T_{min} that revealed to be minor, despite the promising spatial distribution similarity with the women excessive mortality. This is in agreement with the previous studies made in Iberia (Díaz et al., 2006).

The level of relationship between extreme temperatures indices and mortality as it has been shown in Table 2 raises additional questions namely: (1) they are referred to the general population, thus, the signal is weakened, since the maximum and detectable impact is know to be higher on the group older than 75 (see Table 1), and (2) the population structure varies among the different districts, with the population living in the northern coastal districts being characterised by a higher proportion of younger people while Lisbon and several districts in the interior of Portugal have a higher proportion of older people. Mortality figures were not disaggregated by sex at the district level because for most of them, the number of deaths would have been too low to produce robust results.

6. Conclusions

The August 2003 heat wave had a major impact in terms of excessive mortality in Western Europe. Here we analyse this heatwave impact on the Portuguese population and link it with different thermal variables. The overall impact on Portuguese mortality was estimated to be an increase of 58% of the expected deaths, with an absolute number of excess deaths of about 2398. However, if we split the impact analyses by gender, a clear larger impact on women is evident, with an increment of 79% of the corresponding expected mortality, while for men this increase was of 41%. This difference between gender has generated a considerable amount of discussion (e.g., Kosatsky, 2005, Nogueira and Paixão, 2007), and requires further analysis.

When we analyse the impact of the heat wave with the ratio *O/E* considering the gender and age groups results showed a wide variation with clear statistically significant increments concentrated in the last three age classes (45–64, 65–74 and 75 or more). The differentiated gender impact is especially true for the ages above 75 years old with an estimated increase of 58% in males' mortality and 99% in women's. A closer look at the average age for the open age group of individuals with 75 year or more (that actually died during this heatwave) helps to clarify this conundrum. In fact, the average age for men is 82.4 years while for women it is considerably higher with 85.2 years. This indicates that this age group, where the majority of extra deaths have occurred, presents a highly asymmetrical gender impact due to the particular age structure that characterises this open age class of people with 75 year or more, reflecting the existence of many more women of very advanced age and a lack of men of these ages. Some additional statistically significant increments observed for younger age groups are more puzzling and might be explained by the relatively small number of people involved.

We must acknowledge that other unaccounted socio economic factors play a major role in determining the amount of excessive deaths. Among these factors, housing quality and access to air conditioning are vital. A recent work by the national heath authority shows that during this 2003 heatwave, the use of air conditioning (AC) systems in some Portuguese hospitals had a major impact on the decrease in excessive mortality values (INS, 2008). This was especially the case in the intensive care units, where the use of AC led to a reduction of roughly 40% of dying related with heat stress when compared with others that were not equipped with AC. This study provided useful information to the Portuguese health care system in order to introduce a program that stimulates the widespread installation of AC systems, particularly in the intensive care units.

We have shown that the heat wave affected the entire continental Portugal (excluding Madeira and Azores) and all the districts presenting *O*/*E* ratios above one (for both men and women). Overall, the impact estimation showed larger values in the interior districts than those close to the Atlantic Ocean, however, this spatial gradient was particularly prominent for women.

In the second part of the work we have used six different heat-related variables to evaluate the impact of the 2003 heatwave in Portugal. It should be stressed that the role of humidity is usually negligible over Portugal (Dessai, 2002; Díaz et al., 2004), unlike other regions of the world prone to heatwaves impacts in excessive mortality such as the USA. This lack of a major effect associated with humidity is most probably due to the typical synoptic characteristics of heatwaves episodes over Iberia that are always characterised by an intense advection of hot and very dry air from north Africa and intense subsidence of air (García-Herrera et al., 2005). Thus, in Portugal, the use of humidity indices does not improve the model adjustment obtained from purely thermal indices. Therefore besides the local maximum (T_{max}) and minimum (T_{min}) temperatures we have used the additional heat stress related variables: extremely hot days (EHD), extreme hot nights (EHN), total exceedance EHD (EEHD) and exceedance EHN (EEHN) days. It was found that the best variable to explain the link of excessive mortality (based on the *O*/*E* ratio) was obtained with the EEHD that presents a linear correlation value of $R = 0.75$ for the entire population but reaching $R = 0.79$ for women. We must acknowledge that these results were obtained with relatively short time series corresponding to the 18 districts. Nevertheless all these three correlation coefficients are statistically significant at the 2% significance level, with those attained by women and the total population being significant at the 1% level. On the other hand, although statistically significant it remains unclear the representativeness of this short 2-week period. In this regard it would be desirable to see if the results obtained are also valid for other heatwaves, namely for the 1981 and 1991. However, mortality rates for those episodes are not available with sufficient spatial detail, namely split by gender and age group.

Finally it must be stressed that the availability of mortality data split by gender and age has allowed to obtain a detailed information on the structure of the population at risk. As our results clearly demonstrate, this fine approach is relevant for prevention strategies, since it allows to better identify the target population of any preventive strategy regional and national authorities may be interested to implement.

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Ricardo Trigo is a senior researcher at Lisbon Geophysical Centre (CGUL). His expertise is in climate variability and associated large-scale circulation models; climate change scenarios for the Iberian Peninsula; statistical methods applied to hydrology and meteorology, and also long-term variability of solar activity and the geomagnetic field.

Alexandre M. Ramos is a graduate student at the Environmental Physics Laboratory of the University of Vigo (Spain). His main areas of research interest are related to the development of new classifications of atmospheric circulation weather patterns and the impact of extreme events within the framework of climate change.

Paulo J. Nogueira is a biostatistician at the department of epidemiology of the National Health Institute of health (INSA) since 1994. He is an epidemiology assistant at the Faculty of Medicine of the University of Lisbon. He is the responsible for the Portuguese Heat Health Watch/Warning ICARO Surveillance system thand the Portuguese Daily Mortality Monitoring established in 2003.

Filipe Duarte Santos is professor of physics, geophysics and environment at the University of Lisbon and Director of the Research Center SIM—Systems, Instrumentation and Modeling in Environmental and Space Sciences and Technology. He is vice-president to the UN Commission on the Peaceful Uses of Outer Space, delegate to the Conference of Parties of the United Nations Framework Convention on Climate Change and has been research fellow at the Atomic Energy Authority in Lisbon.

Ricardo Garcia-Herrera is an associate professor at the department of earth sciences II at the Universidad Complutense in Madrid. His research interests include weather and climate extremes impacts, climate reconstruction from documentary sources and middle atmosphere dynamics. He is currently coordinating several national and international research projects related to climate change and extremes impacts in Iberia and the Mediterranean area.

Célia Gouveia received her PhD in 2008 with an assessment for Iberia on the impact of large-scale atmospheric circulation on vegetation health using satellite information. Her main interests are related with the impact of climate variability and extremes on urban pollution, vegetation health and human mortality.

Fátima Espírito Santo obtained an MSc in meteorology science at the University of Lisbon and since early-1990s she has been working as a senior meteorologist and a climate expert at the Portuguese Meteorological Institute. She is a member of Commission for Climatology of WMO.