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Study of the heat wave of the summer 2003 at the Mediterranean coast of the Iberian Peninsula

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Abstract

The heat wave that affected much of Europe during the summer of 2003 also had a strong impact on the Mediterranean coast of the Iberian Peninsula (IP). The aim of this study is to place the instrumental context and determine the exceptional or unexceptional nature of the heat episode which occurred between June and August 2003 by analyzing a series of maximum and minimum temperatures adjusted to the daily scale, corresponding to 5 stations distributed along the Mediterranean coast of the IP, located from north to south in: Barcelona, València, Alacant, Murcia and Málaga. The heat wave has been placed in the instrumental context (1900-2007) and both the extreme and average values of the temperature of the summer of 2003 have been analyzed at a regional level and by individual weather stations. The results indicate that the episode of 2003 can be considered extreme and unusual, with a real average temperature for June-July-August that is above the 1900-2007 average by 3.3°C, which exceeds the previous record, from 2001, by 1.6°C. It should be noted, however, that the episode was more pronounced in the north than in the south of the Mediterranean coast of the IP.

Key words: heat wave 2003, instrumental period, thermal distribution, Mediterranean coast of the Iberian Peninsula

1 Introduction

Due to the significant impact on human health and mortality, as well as the increased risk of forest fires, there is great interest in the study of episodes of sustained heat of high temperature for several consecutive days. There is evidence that the global warming observed over the last 150 years (Trenberth et al., 2007) is affecting the frequency and intensity of heat waves, which makes their study at smaller scales than the global, hemispheric or continental highly recommended.

The annual occurrence of heat waves has significantly increased over the central and eastern part of the United States, Canada and parts of Europe and Russia (Alexander et al., 2006). According to Della-Marta et al. (2007a, 2007b) in Western Europe there has been a significant increase in the persistence of summer heat waves from 1880 to 2005 and the duration of this one has doubled. Studies made on climate change suggest that European heat waves will become more frequent and longer during the 21st Century (Meehl and Tebaldi, 2004). In terms of impact on health (Fischer and Schär, 2010), the projections indicate that the negative effects will be much more severe for low-altitude river basins in southern Europe and the Mediterranean coast, where the frequency of dangerous heat waves, which is already quite high, will grow faster.

In Europe, Schär et al. (2004) analyzed the heat wave of summer 2003 in Switzerland from 4 representative series of north-western foothills of the Alps and obtained that the summer (June to August) average value and those June and August for the mean value of the daily mean temperature in the 4 observatories analyzed was far from the statistical distribution. The summer thermal anomaly was 5.1°C regarding the average for the period 1864-2000, corresponding to 5.4 standard deviations.

However, Beniston (2004) and Beniston and Díaz (2004) analyzed the mean and extremes of temperature in the summer of 2003 (average of June, July and August) in the city of Basel, located in the northwest of Switzerland, to evaluate the extent to which the heat wave of 2003 represented a significant change from the early 20th Century. They found that although the maximum temperature anomaly of the summer is the highest of the whole period, the 2003 event does not break any records (1901-2003) in the city of Basel, as the maximum temperatures exceed the threshold of 30°C in less days than in 1947. The number of consecutive days with maximum temperatures above the threshold is the same for 2003 and 1911, and these years have less days than 1947 and 1976.

For the whole Iberian Peninsula (IP), warm spells have increased throughout the 20th Century. There has been a significant seasonal and annual warming of the maximum temperature (T_x), minimum temperature (T_n) and mean temperature (T_m) variables and a significant increase in the moderately extreme warm days and warm nights detected (T_x and $T_n >$ 90thP) (Brunet et al., 2007a and 2007b).

Pejenaute (2004) analyzed the atmospheric dynamics of the first fortnight of August 2003 in Navarra, when the heat was something exceptional due to its intensity and especially due to its duration. This study was carried out using temperature data provided by the manual and automatic station network of Navarra, which recorded an unprecedented period due to the presence of several consecutive days with high temperature settings, with very little cooling at night.

From the study by Díaz et al. (2006), with maximum daily temperature data for the period 1991-2003 recorded at 50 observatories in Spain and 4 in Portugal, the results show that the annual frequency of extreme heat days in the summer of 2003 is higher on the Mediterranean coast and in northern central of the IP. As for the level of days of T_x excedence over the threshold, the maxima are located in the northern peninsula.

Furthermore, it should be noted that the heat wave in Spain caused around 6500 deaths, as the study published in the report of the Spanish Society of Public Health and Health Administration by Martínez et al. (2004) concludes.

The European heat wave of summer 2003 has been the subject of works published in international scientific papers as referenced above. The importance of this study is that it is the only one that analyzes its impact particularly on the Mediterranean coast of the IP, and puts it into the instrumental context of the past 107 years in order to evaluate whether its character was unusual or not. We made an approximation toward the statistical "detection" of the exceptionality of this summer by the statistical analysis of temperature series adjusted to the daily scale of 5 stations distributed along the Mediterranean coast of the peninsula.

The article is organized as follows: a description of the data and methodology used is provided in Section 2. The results and discussion are presented in Section 3, which consists of two subsections, the first one with an introduction to a heat wave on the Mediterranean coast of the IP and the second one with its time context. Finally, Section 4 summarizes the conclusions.

Figure 1. Location map of the 5 SDATS stations in the Mediterranean coast of the Iberian Peninsula.

2 Data and methodology

As it is widely recognized, performing a climate study, especially an analysis of variability and climate change, is based on the previous requirement of having reliable, high quality and uniform time series (Brunet et al., 2008). Therefore, the data used in this study are adjusted to the daily scale and are part of the database called Spanish Daily Adjusted Temperature Series (SDATS) developed by Brunet et al. (2006, 2007a, 2008). The SDATS are composed by the 22 longest, most continuous and most reliable series of daily temperatures recorded in Spain since the mid-nineteenth century until the early 21st Century. This database was created under the European project named European and North Atlantic daily to MULtidecadal climATE variability (EMULATE: http://www.cru.uea.ac.uk/projects/emulate/) in order to relate variations and trends in atmospheric circulation patterns and in anomalies in the sea surface temperature with the European temperature and precipitation for the period 1850-2003.

These series have been carefully processed under a strict quality control, correction of deviations by the effect of the type of protective screen of thermometers in the past and adjusted to the daily scale to minimize the homogeneity breaks caused by a diverse set of factors (Brunet et al., 2006 and 2008).

The 5 stations used to create this study are located along the Spanish Mediterranean coast (Barcelona, València, Alacant, Murcia and Málaga) and are represented in Figure 1. Table 1 gives information on its geographical location and the period of analysis (1900-2007). The period has been limited to 1900-2007 because this is the interval with the most complete data in the five stations. As the SDATS series are extended over the period 1850-2005, they had to be updated to 2007 using data obtained from the Spanish Meteorological Agency (AEMET).

Table 1. Geographical location, height and time series of the 5 stations used.

Location	Longitude	Latitude	Height (m)	Period
Barcelona	02°10'36"W	41°25'05"N	420.1	1900-2007
València	00°22'52"E	39°28'48"N	11.4	1900-2007
Alacant	00°29'40"W	38°22'00"N	81.5	1900-2007
Murcia	01°07'14"W	37°58'59"N	57.0	1900-2007
Málaga	04°28'57"W	36°39'57"N	6.5	1900-2007

The time series of the variables of the daily T_x, T_n and T_m have been used for each weather station, and the uniqueness of the summer of 2003 was analyzed both locally and regionally. The regional representative series of the whole Mediterranean coast of the IP has been calculated from the simple average of the records of the 5 stations.

In order to identify the successive spells of warm days and nights that took place in the summer of 2003 and make an intraseasonal valuation, as well as between observatories, the 90th, 95th and 98th percentiles of June, July and August of T_x and T_n for each station were calculated and compared with the daily evolution of T_x and T_n of the summer of 2003. The 92 daily mean values of the summer for these variables were also calculated using the summer data set of the analyzed period (1900-2007), to initially identify the extreme or not extreme character of the summer of 2003.

Both for the individual and regional series, the absolute anomalies series have been calculated regarding the reference period 1961-1990, using the approach developed by Jones and Hulme (1996) that descomposes the values in their two basic climatic components: climatology (average value) and anomaly (difference respect to a reference period).

To contextualize the heat episode, the statistical distributions of frequency T_m, T_x and T_n have been represented and analyzed as a tool to find out the position of the summer of 2003 within all summer seasons during the period 1900-2007, both in terms of individual stations as well as on the whole of the Spanish Mediterranean coast. However, the monthly and seasonal statistical distribution of T_m of the regional and seasonal series of T_m, T_x and T_n has been estimated for each of the points considered, and the standardized anomalies of the corresponding regional and individual series were estimated using 1900-2007 as the base period.

To evaluate the persistence of warm summer days during the period 1900-2007, the number of days when the T_x and the T_n exceeded the 90th percentile in each of the summer months during the period from 1900 to 2007 has been calculated. The duration index of warm spells (Warm Spell Duration Index, WSDI) defined by the expert group Expert Team on Climate Change Detection and Indices (ETCCDI, http://www.clivar.org/organization/etccdi/etccdi.php) was also calculated. However, this index has been adapted to analyze the summer months and represents 6 or more consecutive days with maximum temperatures above the 90th percentile. Similarly, the daily T_n has been analyzed to study the duration of spells of warm nights, understanding them as at least 6 consecutive nights that record a T_n higher than the 90th percentile.

3 Results and discussion

This section is divided into three subsections in order to better understand the summer of 2003. In the first section the episode has been introduced, focusing it on the summer being studied, and the evolution of the daily T_x and T_n during the three months (June, July and August) has been analyzed. In the second section the summer is contextualized within the period 1900-2007 and has been compared to previous years. And finally, in the third part, the length of warm days and nights has been analyzed from climate indicators based on percentiles (TX90p, TN90p, WSDI).

3.1 Characterization of the heat wave of 2003 on the Mediterranean coast of the Iberian Peninsula

To characterize the heat wave of 2003 and to determine whether it is exceptional or not, the values for each observatory of the daily T_x and T_n in the summer of 2003 have been represented with the corresponding summer daily averages calculated for the whole period 1900-2007, together with the 90th, 95th and 98th percentiles (P) thresholds. These thresholds identify the warm events (T_x and T_n above 90thP), very warm events (above 95thP) and extremely warm events (over 98thP). Figure 2 shows the representations for Barcelona, València and Málaga.

The two strongest episodes of the heat wave happened in June and August and mainly affected Barcelona, València and Alacant. A decrease in affectation towards locations further south could be seen. The first episode begins in early June and lasts until the end of the month, while the second most intense and persistent episode occurs in the first fortnight of August. In Alacant these spells of warm days are less marked.

In contrast, high T_x are observed in Málaga and Murcia mainly in June and late July, with very warm and extremely hot days. However, unlike in the north, there is no persistence of the heat in the south of the coast, as warm days alternate with others that are less warm.

For T_x, it should be noted, as indicated by Serra et al. (2010), that on 13 August 2003 in the Fabra Observatory,

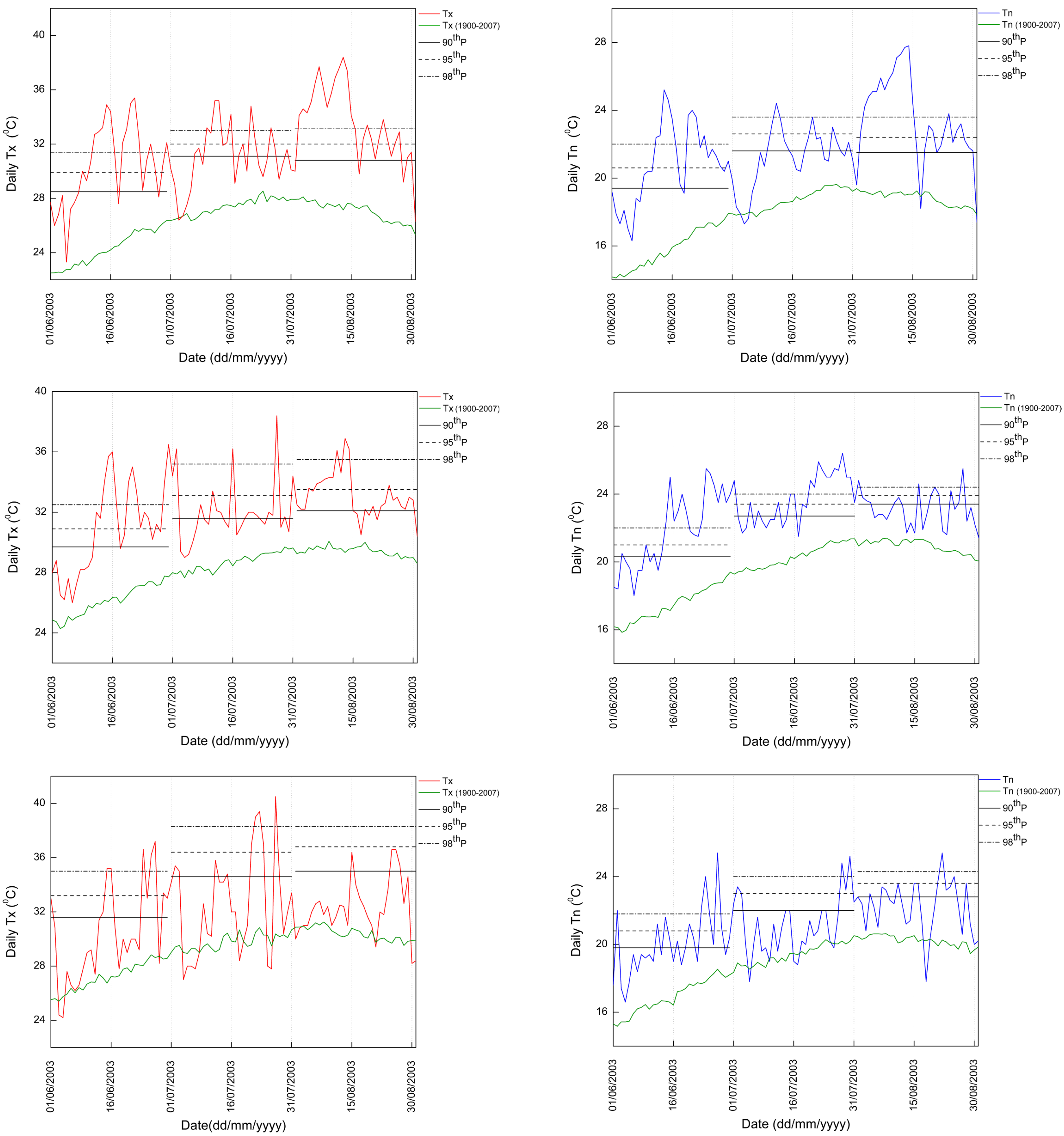

Figure 2. Daily evolution in summer of 2003 with the 90th, 95th and 98th percentiles and evolution of the average value for the period 1900-2007 of T_x (left) and T_n (right) in Barcelona (top), València (middle) and Málaga (bottom).

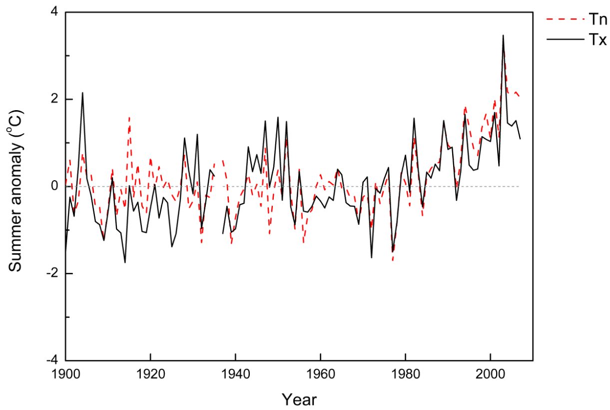

Figure 3. Temporal evolution of the summer average anomalies of the T_x and T_n regarding the reference period 1961-90 in the Mediterranean coast of the Iberian Peninsula during the period 1900-2007.

near Barcelona, the temperature reached a record of 38.4°C, in agreement with our results.

Regarding the T_n in Barcelona, an intense episode is observed in June with spells of warm and extremely warm nights with T_n above the 98thP, and in the first half of August there was a new episode with a long and intense spell. In the other cities the first spell of warm nights also started in the second half of June with very warm nights until the end of the month, but unlike Barcelona, the second intense and persistent episode occured in late July. In Málaga the spells are shorter and there is a high T_n daily variability.

The temporal evolution of daily T_x this summer compared with the average daily value of the period indicates that the T_x of the summer of 2003 was exceptional within the range studied. In València the maximum is well above the daily average of the period, followed by Barcelona and Alacant. However, as we go down to the south temperatures are closer to the average, especially in Murcia and Málaga, where they are closer than the rest, and there are even some days when the T_x and T_n are lower than the average period.

The difference between the temporal evolution of the T_n in the summer of 2003 and the average 1900-2007 indicates that these are considerably higher in the whole coast than the average T_n, particularly high compared to the T_x of 2003 in Alacant and Murcia, although the difference is less in Málaga.

3.2 Time context of the heat wave of 2003

Series of summer anomalies of T_x and T_n that are indicative of the global climate signal have been calculated for the whole of the Mediterranean coast of the IP. And in order to analyze local differences, a series of anomalies from each locality have been calculated.

Figure 3 shows the temporal evolution (1900-2007) of the regional summer anomalies of the T_x and T_n calculated with respect to the reference period 1961-1990. Both the T_x and the T_n of the summer of 2003 exceed approximately in 3.5°C the climate normal, indicating that the summer of 2003 was exceptional in having no precedent in the period analyzed.

In the last decades (1980 onwards), the anomalies of T_x and T_n have nearly always oscillated above the climate normal for all points considered. The summer of 2003 recorded the highest anomalies in both variables in all localities, except for Murcia. The average summer anomalies of T_x and T_n for each individual observatory are provided in Figure 4 arranged from north to south.

The T_x anomalies were 5.5°C in Barcelona, 4.2°C in València, 2.6°C in Alacant and Murcia and 2.8°C in Málaga, with all cases the highest during the period. The summer averages of the T_n were also outstanding: 4.4°C above the normal in Barcelona, 3.2°C in València, 3.4°C in Alacant, 3.6°C in Murcia and 2.3°C in Málaga. The minimum in Murcia were also notable, however they were not the highest, since in 2006 and 2007 they exceeded by 4.0°C and 4.5°C the climate normal, respectively.

To evaluate the exceptional nature of the heat wave on the Spanish Mediterranean coast as a whole, an analysis of the monthly and seasonal statistical distribution of daily T_m of the corresponding regional series was carried out.

Figure 5 shows the Gaussian probability density function fitted to the T_m data of the months of June, July and August and of the summer (JJA) for the averaged whole of the Mediterranean side of the IP, together with the values of the monthly and seasonal averages of the T_m for the period 1900-2007, ranked from smallest to largest, therefore allowing the placement of the summer of 2003 in its instrumental context.

In agreement with the results obtained by Schär et al. (2004) in Switzerland, where the summer of 2003 was the warmest in both June and August as during the whole summer average for the area of Switzerland, for the Mediterranean coast the summer of 2003 is also far from the average in the distribution of temperatures, being placed in the upper end of the distribution in the three cases as well as in July, matching the temperature of July 2006. The temperature in June 2003 shows a deviation of 4.1°C on the average of 1900-2007, 2.8°C in July, 3.0°C in August and in summer the deviation is 3.3°C.

Table 2 contains the standard deviation (σ), the anomaly regarding the 1900-2007 average and the standardized anomaly of the summer months and the whole summer (JJA) of 2003 of the regional series. Of the three months studied, June 2003 was the warmest, placed at 3.7σ of the average. July was the most modest, but also stands, together with 2006, at the upper end of the distribution with 2.9σ. Table 3 shows the standardized anomaly of the T_m, the T_x and the T_n of the summer in each town.

Except for the T_m and T_n in Murcia, the summer of 2003 was the warmest in the 1900-2007 period, with record daily average summer temperatures of the 1900-2007 series.

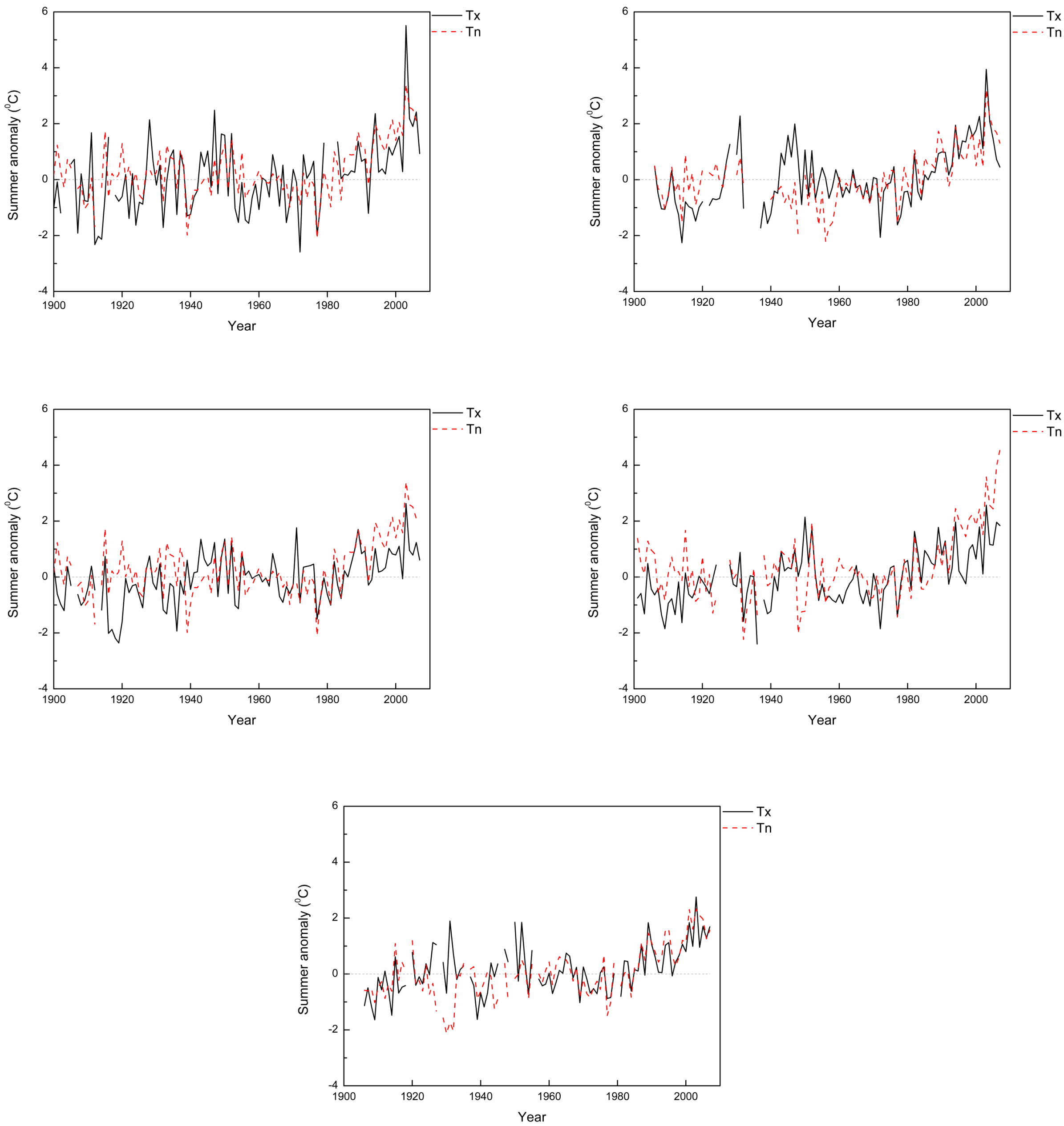

Figure 4. Anomaly of the T_x and T_n of the summer compared to the average 1961-90 in Barcelona (left, top), València (right, top), Alacant (left, middle), Murcia (right, middle), Málaga (bottom).

At the five locations the temperatures of the summer of 2003 are located at the upper tail of their respective distributions, particularly in Barcelona for the three variables, which is indicative of a greater impact of the heat wave on the north coast.

To quantify whether the summer of 2003 is unique or not on the Spanish Mediterranean coast, the differences were estimated applying the t-test between the mean values of the regional series of T_m, T_x and T_n for the whole summer and for the months of June, July and August 2003, with the summers and months with above average values that are first place in the classification after the summer in study. The results indicate that for the three variables, the summer and the months of June and August 2003 are significantly higher, with a significance level of 0.05. This is not the case of July, when the difference between the two months compared do not reach the significance level adopted by any of the variables.

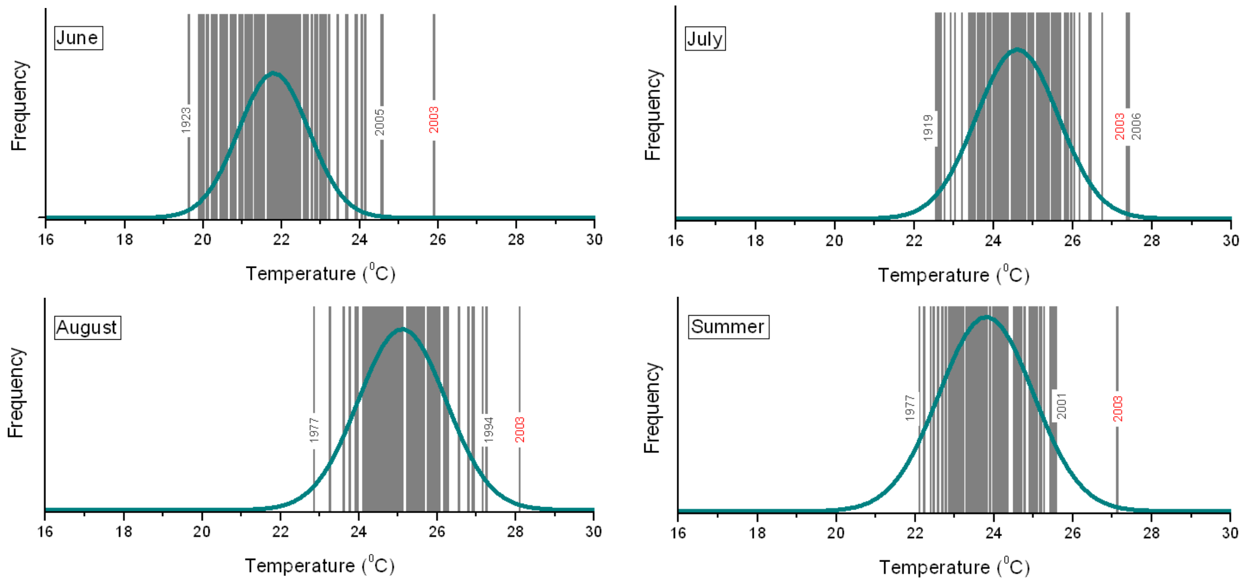

Figure 5. Monthly and seasonal distribution of the daily T_m on the Mediterranean coast of the Iberian Peninsula in the period 1900-2007. The Gaussian function fitted to the data is shown in green. Tagged with the corresponding year, the two highest (right side of the Gaussian) and lowest (left) values are highlighted, appearing in red for 2003.

Table 2. Standard deviation, anomaly of the T_m of 2003 regarding the 1900-2007 average and standardized anomalies for the months of June, July and August and the summer of 2003 on the Mediterranean coast of the T_m.

	σ (°C)	T'_m (°C)	$\frac{T'_m}{\sigma}$
June	1.12	4.1	3.7
July	0.97	2.8	2.9
August	0.90	3.0	3.3
JJA	0.84	3.3	3.9

3.3 Analysis of the evolution of warm extremes from extreme climate indicators

In order to consider whether the warm summer of 2003 was also exceptional in the occurrence of extreme temperature events, the number of days with T_x and T_n higher than the 90th percentile (warm days and warm nights) and the duration of heat spells for each of the observatories examined have been estimated for the summer period from 1900 to 2007. To identify warm spells, the indicator WSDI of the ETCCDI has been adopted, as indicated in the methods section. This indicator is defined as 6 or more consecutive days with T_x and T_n above the 90th percentile, adapting it to T_n (warm nights) and calculating it only for summer. The consideration of relative thresholds, such as the 90th percentile, rather than absolute thresholds for all observatories, allows avoiding possible local climatic differences between the five stations.

In Figures 6a, 6c and 6e the number of summer days per year when the T_x exceeds the 90th percentile (warm days) and the WSDI index for 3 of the 5 studied points (Barcelona, València and Málaga) is represented in the same graph. In Figures 6b, 6d and 6f, the same information is provided, but for T_n.

The analysis of the summer occurrence of warm days and warm spells during the reported period confirms that the impact of the heat wave of 2003 is degraded latitudinally, being more important on the northern locations of the peninsular Mediterranean coast.

In Barcelona, summers with a high frequency of warm days and daytime heat waves are common during the period, although in the last decade there have been more consecutive waves (see Figure 6a). The wave of the summer of 2003 was a record both in number of days with T_x exceeding the 90th percentile (doubling the number of days regarding the second summer, 2006, rising in rank), as well as the persistence of warm spells (tripling over the following summer with more observed spells, 1928). This fact is also confirmed when considering the frequency of warm nights and spells of warm nights both in the last decade, which accumulates an abundant number of these events, as particularly during the summer of 2003, when nearly 60 warm nights and 51 nights with spells of at least 6 consecutive nights with a T_n exceeding the 90th percentile were recorded (Figure 6b).

Further south, there is a similar situation in València (Figures 6c and 6d), the summer of 2003 stands out from the rest of summers during the period from 1900 to 2007. That summer, both warm days and nights, as well as the spells of warm days and nights, are unprecedented, remarkable in the last decade for the number of spells of warm nights.

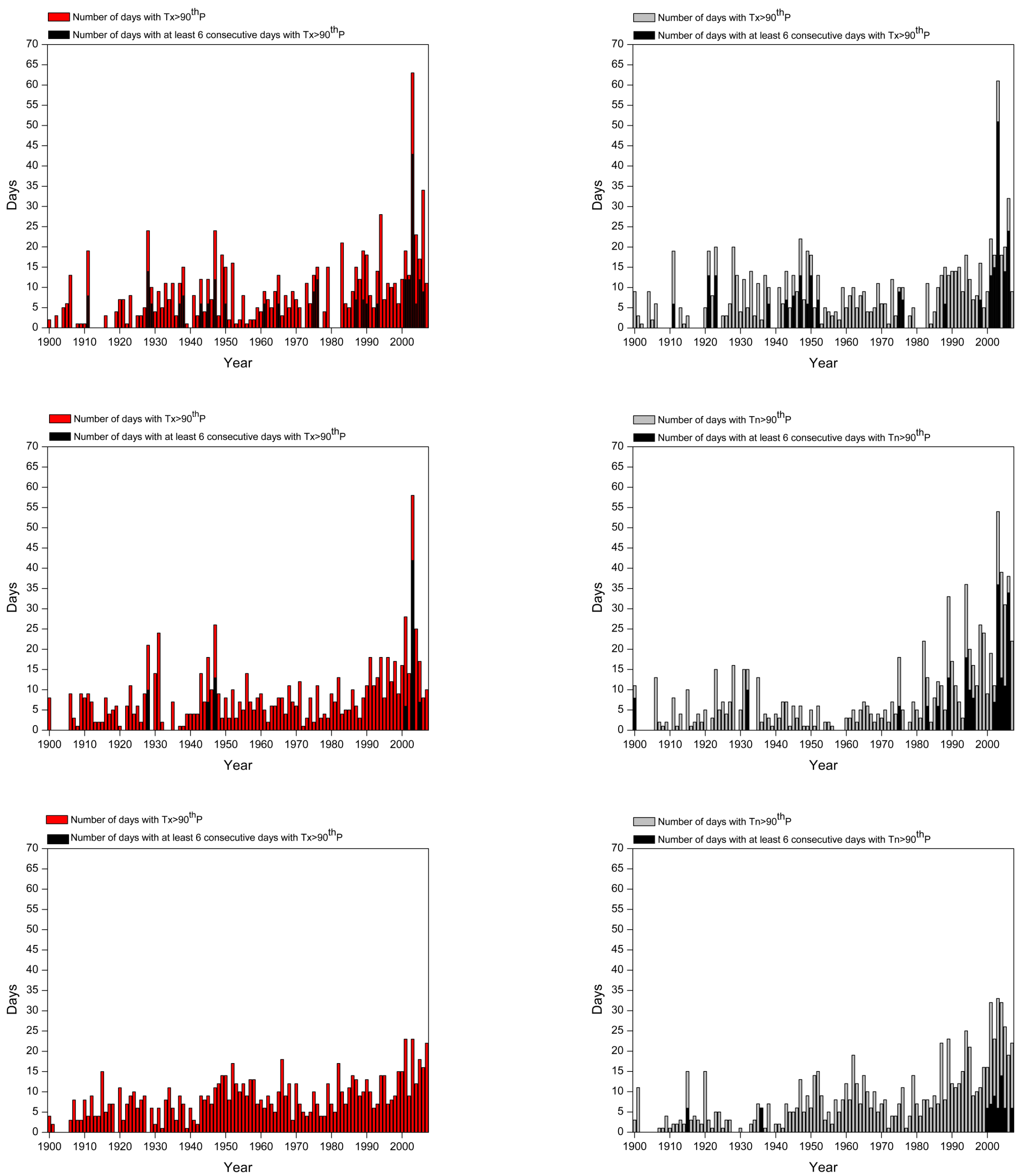

Figure 6. Number of warm days (a, top left, c, middle left, e, bottom left) and nights (b, top right, d, right in the middle, and f, bottom right) and duration of spells of warm days (a, c, e) and warm nights (b, d, f) in Barcelona (a, b), València (c, d) and Málaga (d, f).

Table 3. Summer standard deviation (JJA) and standardized anomaly of summer 2003 regarding the period from 1900 to 2007 for T_m, T_x and T_n at the 5 stations analyzed and the whole coast.

	σ JJA T_m (°C)	$\frac{T'_m}{\sigma}$	σ JJA T_x (°C)	$\frac{T'_x}{\sigma}$	σ JJA T_n (°C)	$\frac{T'_n}{\sigma}$
Barcelona	1.06	4.4	1.26	4.3	0.98	4.1
València	0.92	3.2	1.15	3.4	0.94	3.4
Alacant	0.82	3.5	0.90	3.0	0.97	3.2
Murcia	0.95	3.0	0.95	2.7	1.17	2.7
Málaga	0.79	3.1	0.85	3.1	0.91	2.5
Regional	0.84	3.9	0.89	3.8	0.87	3.7

Table 4. Normal climate (average 1961-1990) of the number of days in summer with $T_x > 90$thP, number of warm days and total and partial duration of spells of warm days in summer 2003 at the five locations analyzed.

Stations	Nr. of days $T_x > 90$thP (average 61-90)	Nr. of days $T_x > 90$thP JJA 2003	Partial and total Nr. of days of warm spells JJA 2003	
Barcelona	8	65	9, 9, 15, 10	43
València	6	58	6, 12, 15, 9	42
Alacant	8	34	7, 11	18
Murcia	9	25	0	0
Málaga	9	23	0	0

In Alacant, both the number of warm days and warm spells are reduced in comparison to the previous two locations, and although the highest frequency in the two indicators of extremes is recorded in 2003, there are other years that have similar occurrences, particularly in the 1940s. However, both the number of warm nights and spells of warm night exceeded the number of warm days and warm spells. The number of warm nights are notable, and especially the number of warm spells from 2000 onwards, with a total of 31 consecutive days of spells of warm nights in 2003. This differential daily warming, with a higher frequency of night extremes than day extremes, will become the most remarkable fact of the evolution of these temperature extremes in the other southern locations.

In the evolution of warm days in Murcia, a lower frequency is observed compared to the three points above; and although the highest frequency is reached in 2003, the difference regarding the following years in the upward classification is small. In addition, heat waves are isolated phenomena, observed in only five years of the period, with the last one during the summer of 2001. However, the frequency of warm nights and spells of warm nights increased since the beginning of the 90s and particularly in 2000, without any previous precedent. Although the summer of 2003 recorded 55 (33) warm nights (warm nights spells), it does not exceed the frequencies recorded in 2006 and 2007, the latter showing the records of the period.

Finally, in Málaga there is a similar situation to the one in Murcia. Figure 6e shows that although there have been very warm days during the period, especially in the last ten years, there are no warm days spell recorded. However, the summer of 2003, along with 2001, reaches the highest occurrences of warm days. Regarding warm nights, the highest frequencies are observed in the early decade of 2000, although also individual years of the decades of the 80s and 90s are recorded, with 2003 reaching the highest frequency with little difference from 2001 and 2004. With regard to the spells of warm nights, although there have been some sporadic ones throughout the period (1900-2007), these were more common from 2000, with spells of warm nights almost every summer (Figure 6f). However, the summer of 2003 did not exceed 2005, ranking second in the instrumental record of this season.

Table 4 provides the climate normal (average 1961-1990) of the number of days in the summer with $T_x > 90$thP, the number of warm days and partial and total duration of spells of warm days in summer 2003. Table 5 provides the same information for nights and spells of warm nights in order to quantify the excesses of the summer of 2003 in number of warm days (nights) and spells of warm days (nights) compared to the climate normal.

The climate normal of warm days ($T_x > 90$thP) calculated for the standard reference period (1961-1990) indicates that these events in the summer occur almost in the same number of days in all observatories, with a slightly higher frequency in more southerly locations. Upon comparing the occurrence of warm days observed in summer 2003 with their climate normal, the high occurrence of warm days in all the observatories during the heat wave of 2003 becomes apparent; it is much more intense in the northern observato-

Table 5. Climate normal (average 1961-1990) of the number of days in summer with $T_n > 90$thP, number of warm nights and partial and total duration of spells of warm nights in summer 2003 at the five locations analyzed.

Stations	Nr. of days $T_x > 90$thP (average 61-90)	Nr. of days $T_x > 90$thP JJA 2003	Partial and total Nr. of days of warm spells JJA 2003	
Barcelona	7	61	10, 11, 6, 15, 9	51
València	7	54	18.18	36
Alacant	6	47	7, 8, 16	31
Murcia	4	54	18, 15	33
Málaga	9	33	6	6

ries than in the southern ones, which shows the latitudinal gradation of the impact of this extreme event. As for warm nights ($T_n > 90$thP) the climate normal is of the order of a week along the coast with a number slightly lower in Murcia and higher in Málaga. If compared with the summer of 2003, as with the warm days, the number of warm nights was much higher than the average climate with a greater number of occurrences in the north end and less in the south end.

Therefore, the heat wave was especially pronounced in Barcelona, and less in Málaga and Murcia. The results of this study are in agreement with those obtained by Díaz et al. (2006) in his study on the impact of the heat wave of 2003 in Spain, although that study only analyzed a series of 13-year length.

The analysis of the spells of warm days also indicates the southerly grading of the effects of the heat wave of 2003 (Table 4), and at the same time points to the first fortnight of August as an exceptional period for the intensity and duration of these, especially in the north coast. The originality of the wave is in conjunction with the persistence of consecutive days with high temperatures, that is consistent with the results obtained by Pejenaute (2004) in Navarra. It was found that on the north coast the persistence is the highest of the series, a result that contrasts with that found by Beniston and Díaz (2004), because they got that the heat wave of 2003 in Switzerland is identical to that of 1911 and less persistent than the waves of 1947 and 1976.

4 Conclusions

The episode of heat experienced during the summer of 2003 affected the Mediterranean coast of the IP and it was unusual along the whole coast, although it had a greater impact in the north. There were long and intense heat waves in Barcelona, València and Alacant mainly in June and August. In the south, temperatures were high, but their persistence was lower, alternating very warm days with others less warmer, and there were no spells of warm days in Murcia or Málaga.

It is notable that this episode was characterized not only by a high T_x but also very high and persistent T_n in all observatories, including those in the south, with long spells of warm nights, which made the episode extremely hot and had a clear impact on mortality in Spain.

In all series the anomaly of the summer average of T_x and T_n broke records, as well as the summer and monthly average of 2003. In June, July and August all the daily variables of temperatures (T_x, T_n and T_m) are in the upper end of the irrespective statistical distribution of frequencies, which characterizes the extreme and unprecedented event with respect to monthly and seasonal averages during all the summers in the 1900-2007 period.

The summer analyzed was the warmest of the whole series at all observatories and the heat waves in Barcelona, València and Alacant were the most persistent since 1900, especially in Barcelona, where they were very intense as well.

Although the summer averages of T_x and T_n were a record for almost all observatories, in terms of daily values they were only very important in Barcelona on 13 August 2003, with a T_x of 38.4°C, which equaled the previous record of 15 August 1987; value in accordance with the study done by Serra et al. (2010), and the days 12, 13 and 14 August 2003 with T_n of 27.3°C, 27.7°C and 27.8°C respectively, surpassing the record for three consecutive days.

The episode was characterized by the persistence of heat, especially in the northern half, and although there was no breaking of daily records, the records of monthly and seasonal average were surpassed and broken. This fact made the summer of 2003 exceptional and unprecedented in the instrumental record. The two daily temperatures extremes (T_x and T_n) largely reflected the heat wave, but we know that an isolated and divisive analysis of the daily time series of these extreme temperatures breaks the supportive physical reality of heat waves, as it loses the continuous temporal sequence in which they occur. We will devote our future studies to the definition and analysis of all these extreme events and to the detection and attribution of causes to them.

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