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Spring and summer time extreme temperatures in Iberia in relation to circulation types frequency

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Abstract — In the Iberian Peninsula (IP) the rise of temperatures during last decades has been noticeable, especially in spring and summer seasons. The aim of this study is to identify characteristic circulation types (CTs) conducive to the occurrence of warm extremes and to describe long-term changes both in circulation and in the percentage of associated extremes. A sample of 29 long station series of daily maximum (Tmax) and minimum (Tmin) temperature across the IP are considered for the study. Daily mean Sea Level Pressure reconstructions from the EMULATE project for the period 1850-2003 were classified into daily CTs using a simulated annealing clustering technique, separately for spring (MAM) and summer (JJA). The distinct CTs are examined for their tendency to give rise to daily temperature extremes at each specific location. Moreover, the existence of significant trends in the temporal frequency of the CTs is discussed, as well as their within type temporal variations in association to local extremes.

In both seasons, spring and summer, a warming signal has been detected in specific circulation types: especially in spring, an increasing incidence of high pressure conditions in the north of Iberia together with a warming of CTs indicating westerly and south-westerly flows explain the increase in warm days. In summer there is significant long-term positive trend in strong North Atlantic Anticyclone and Iberian thermal low-type patterns, but most of the warming has to be explained by within-type changes: the same CTs give rise to high temperatures more frequently, especially from around the 1970´s.

Keywords — Iberian extreme temperatures, daily circulation types, within-type changes, spring and summer warming, long-term changes

1 INTRODUCTION

Greenhouse warming has had an indisputable effect on temperature extremes in Europe (see, e.g, [1]), but it is crucial to analyse whether the atmospheric circulation has also suffered changes (forced both by natural and human factors) and how they influence changes in regional climate. In this context it is necessary to distinguish to what extent fluctuations in temperature extremes can be explained by circulation variability (e.g, in terms of circulation types frequency or circulation indices, like in [2]) and how the link between circulation and regional climate has been affected (e.g, atmospheric circulation types are warmer than in former times, shown by [3], [4], [5]).

Analysing fluctuations in climate extremes and their causes is especially important for regions of high natural variability such as the Mediterranean area, since extremes have large environmental and human impacts and risks (e.g, fire hazards, see [6]). The reader is directed to [7] for an extended description of the main factors influencing Mediterranean area temperature variability. The Iberian Peninsula (hereafter IP) climate variability, highly affected by atmospheric circulation and by both Mediterranean and Atlantic influences, has been subject of many works in recent times. Focusing on long-term temperature changes in Spain, [8] found increases of warm extremes and decreases of cold extremes during the last century; moreover, they found that, for the recent period 1973-2005, both maximum and minimum temperatures have risen quickly and at similar rates (0.51 vs. 0.47 °C/decade), above all due to warming in spring and summer. For Portugal, an increase of temperature extreme indices in 1976-2006 is also notable and more important in spring and summer than in winter and autumn [9]

Many publications have related Iberian rainfall to atmospheric circulation types, e.g, [10], [11], and [12]. By contrast, synoptic climatology studies regarding long-term temperature extremes in Iberia are quite rare. Links between circulation types and Iberian temperature anomalies are only partially described by [4], who analyse European series and examples of seasonal changes. Focussed on changes in 100 weather types for second half of 20th Century, [5] found increases of temperatures (Spain) within most of the types, more so in the minimum than in maximum temperature. Another recent work about changes over 1950-2006 in annual indices of

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warm days and cold nights in the IP, [13], shows that warm days have increased in the IP and may be linked to high pressure over the Mediterranean and decrease of the Scandinavian index [14]. However, the above works do not account for extremes values of maximum and minimum temperatures in a long-term and in relation to characteristic atmospheric types. Moreover, some studies have focussed on synoptic patterns related to, for example, extreme hot events in Lisbon and Madrid in 1958- 1997 [15] or the more comprehensive work [16] analysing large-scale and sea surface temperature forcing in Western Europe summer heat-waves during 1880-2003.

Philipp et al (2007) [17] developed a classification based on daily sea level pressure (SLP) grids for each 3-month season in 1850-2003, from which long-term variability of central European mean temperature was reproduced in a large degree, specifically for winter and spring. This novel cluster method ([17], [14]) is used in this study for classifying daily SLP also for the period 1850-2003. Here the classification is made for a smaller domain centred in the IP, thus, it is more appropriate for linking circulation to Iberian station series.

For the period 1960-2001, [18] classified daily circulation types for Western Europe on an annual scale and analysed trends in the frequency of the patterns, obtaining significant trends mainly in patterns of high frequency in summer and spring months, such as a negative trend in two patterns with northerly flow in Western Europe, east in south Iberia.

The objective of this study, focused in the IP and spring and summer seasons, is to contribute to the knowledge of observed long-term fluctuations in the atmospheric circulation as well as identify the patterns more related to local extreme temperatures in these seasons. A further main aim is to determine whether the changes in the extreme temperatures are well explained by frequency changes of the circulation types or there are large within-type variations. Section 2) describes the temperature and pressure data, as well as the methods for deriving the circulation types and relate them to extremes; in section 3) results are presented for spring and summer seasons, and in section 4) the most important conclusions from the work are highlighted.

2 DATA AND METHODS

2.1 Station temperature series

The database consists of long-term series of daily minimum and maximum temperature (Tmin & Tmax, 29 Stations across the Iberian Peninsula (see Table 1). This database presents a reasonable good spatial coverage across Iberia. Table 1 shows the length of the series considered for the present work, after applying completeness criteria described below.

Most of the data come from the databases of Spanish Daily Adjusted Temperature and Precipitation series (SDATS and SDAPS), provided by the University of Rovira I Virgili-GCC, whose sources and homogeneity procedures are described in [19] and [8]. These data have been quality controlled (QC) and homogenized on the daily scale by following procedures such as those described by the World Meteorological Organization/ World Climate Data Monitoring Programme Guidance on the development of daily adjusted temperature data sets [20]. Homogenization procedures and QC of ECAD -European Climate Assessment and Dataset series (PE, BR, L, and PO) are described in [21], [22].

Table1: Description of station series of daily maximum and minimum temperatures, latitude (LAT, in decimal degrees), longitude (LON, decimal degrees), altitude (ALT, in meters above mean sea level), and length of the period for the complete series.

STATION (ALIAS)	LAT	LON	ALT	LENGHT
CADIZ (CA)	36,45	-6,2	30	1850-2008
MADRID (M)	40,4	-3,67	679	1853-2008
MURCIA (MU)	38	-1,12	57	1863-2008
BADAJOZ (BA)	38,88	-6,82	185	1875-2008
HUESCA (H)	42,08	-0,32	541	1891-2008
BURGOS (BU)	42,35	-3,6	881	1892-2008
VALLADOLID (VA)	41,63	-4,77	691	1894-2005
SORIA (SO)	41,77	-2,48	1083	1895-2008
ALBACETE (AB)	38,95	-1,85	699	1895-2008
CORUNA (LC)	43,37	-8,42	67	1900-2008
LISBOA (L)	38,72	-9,15	77	1900-2008
ALICANTE (A)	38,37	-0,48	81,5	1901-2008
GRANADA (GR)	37,13	-3,62	685	1901-2008
PERPIGNAN (PE)	42,73	2,87	430	1901-2008
HUELVA (HV)	37,27	-6,9	19	1903-2008
CIUDAD REAL (CR)	38,98	-3,92	627	1904-2008
VALENCIA (V)	39,47	-0,37	11,4	1905-2008
TORTOSA (TO)	40,82	0,48	50	1905-2008
SALAMANCA (SA)	40,93	-5,48	790	1906-2008
MALAGA (MA)	36,67	-4,48	6,54	1906-2008
BARCELONA (B)	41,42	2,12	420	1918-2008
SEVILLA (SE)	37,42	-5,88	31	1922-2005
PAMPLONA (PA)	42,82	-1,63	452	1922-2005
ZARAGOZA (Z)	41,65	-1	245	1922-2008
SAN SEBASTIAN (SS)	43,3	-2,03	252	1928-2008
LEON (LE)	42,58	-5,63	911	1938-2007
OPORTO (PO)	41,13	-8,6	93	1941-2007
BRAGANCA (BR)	41,8	-6,73	690	1945-2007
BILBAO (BI)	43,28	-2,9	35	1947-2007

The completeness has been tested for all the series in a seasonal scale, in order to fix a period for each station complete enough for the purpose of the present work. The criteria applied by [1] has been taken: each 3-month season (spring and summer for this work) is considered complete if there is less than

4 missing values (maximum 3 missing days per season). Then each 20-years block -since the beginning of each series- was checked to have at least 10 complete years according with the rule above. The last blocks end in 2003 and differ in length (<20 years). As we will not asses trends in temperature indices we did not apply stricter criteria for the first and last blocks like in [1]. Even though most of the stations are nearly complete with less than 5 "missing years" per block. Considering overall missing data, the series with more missing values in spring (summer) are Albacete with around 9.2% (8.5%) of missing values in its whole period, Pamplona with 8.2%(9%), Huesca with 7.4% (6.4%), Valencia with 7%(6.3%) and Barcelona with 4.9 (5.4%). The rest of stations have less than 5%. For the more recent and common period 1950-2003, only Barcelona has more than 5% (6.2%) of missing values.

A simple additional QC were realized to the whole database by means of Rclimdex software (http://cccma.seos.uvic.ca/ETCCDMI/RClimDex/rclimdex.r") to detect possible digitalizing or instrumental errors such as a) Daily Tmax below Tmin (no errors in these sense) and b) extreme values ("outliers") in Tmax and Tmin. The "outliers" are daily values that fall out of a region defined by the user, in our case, 4 times the Standard Deviation (stdv) of the sample. In the most extreme cases we investigated (searching in newspapers, historical SLP maps) to check whether they likely refer to real registered extreme-values. Therefore we finally did not remove any of these "potential outliers" as we found documentary evidence of them.

Extreme indices were calculated from daily Tmax, Tmin series separately for each station. Thus moderately daily temperature extremes are defined as warm days (warm nights) taking into account those days on which Tmax (Tmin) exceeds the station specific monthly 90th percentile value of the reference period 1971-2000. Taking these percentiles is a compromise between studying Tmean 90th percentile -smoother than Tmax and Tmin 90th percentiles- and higher thresholds –that make the statistical method less robust since very few extremes could be retained-.

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2.2 Mean Sea Level Pressure

In order to do a daily classification of atmospheric circulation extended as far as possible in the past, we have used daily reconstructions of mean sea level pressure (SLP) from the Emulate project (European and North Atlantic daily to MULtidecadal climATE variability). The development and quality features of Emulate reconstructions are described [23] They are built from 82 land stations and ship observations. The spatial resolution of the grids is $5^{\circ}x5^{\circ}$, and we make use of the complete available period 1850-2003. Reconstructions for the first period 1850-1881 has, as describe in Ansell et al, (2006) less confidence -in comparison with more recent data-, I.e, exists a higher mean squared error associated to such interpolations. Despite of this, for the second half of 20th century, SLP Emulate data explain in a 90% the variability of SLP from ERA-40 Reanalysis pressure data (ECMWF).

2.3 Relating Circulation types to extreme temperatures

. The Application of Circulation types classifications [24] allows the deriving of distinct circulation types or patterns which are subsequently analysed regarding their frequency variations and their meaning for the occurrence of warm days and/or nights. The representative circulation types for the period 1850-2003 are defined in terms of Mean Sea Level Pressure (SLP) for a domain centred in the Iberian Peninsula (between 30°N-50°N and 30°W-20°E). Seasonal circulation classifications were obtained using non-hierarchical Simulated Annealing and Diversified Randomization Clustering (SANDRA), described in detail [17]: The algorithm is based on conventional k-means Clustering but differs in the ability to approximate the final solution (Classification) to the global optimum.

Non-hierarchical cluster analyses require an a priori determining of the number of clusters. This decision is reached here by the "Dominance Criteria" ([25],[17]): the same SLP data-Set is initially decomposed in independent weather types (Principal Components, PCs) using t-mode Varimax-Rotated Principal component Analysis (PCA, [26]). To ensure that the extracted PCs are real manifestation of circulation variability and not artificial results of linear combinations, the "Dominance criteria" demands: each of the extracted PC has to represent best the variability of at least one input variable (daily SLP-patterns 1850-2003) resulting in the highest amount of the corresponding PC-loading (correlation coefficient between PC-Score and the given input variable). Further restrictions are applied: all the PCs must explain more than 1% of the variability and contain at least one case with loading factor above 0.5. These criteria pointed out to 9 classes for the spring (March to May, MAM) and 8 classes for summer (June to August, JJA).

An advantage of SANDRA classification algorithm regards to the achievement of more optimized and stable clusters, hence increasing credibility of the trends in the temporal frequency of these clusters [17]. We make use of the same tests and procedures than in the cited paper for investigating temporal evolution in the frequency of the circulation types (hereafter CTs or clusters) in the IP.

A Mann-Kendall (M-K) non-parametric test [27] is used to detect the existence of significant (p-value<0.05) trends in the annual frequency of each CT, considering the whole period 1850-2003. This test assesses the relative order of the points and says whether more increases than decreases occur (or the contrary). In case of significant trends for M-K test, a lineal regression by least squares is done to quantify them, assessing trend-to-noise ratio tests to estimate the significance of such linear trend.

Additionally, normalized series of cumulative anomalies of the temporal frequency were used. They are assessed for each year as the difference between the frequency of the cluster in that year minus its mean long-term frequency (in 1850-2003); after that, cumulative series are obtained adding to target anomaly all the previous anomalies. To normalize, the series are divided by the standard deviation (STD) of the cumulative anomalies of the frequency. They allow identifying periods with predominant positive anomalies (curve is increasing) or predominant negative anomalies (curve is decreasing).

We compute an index (called index EF) for each CT and station to measure the mean efficacy of the CT to give rise to extremes in such station, for the common period 1950-2003: it is the quotient among percentage of extreme days (from total extreme days) that occur under CT among percentage of non-extreme days (from total non-extreme days) that occur under such CT.

Then, if the index is significantly above 1, such CT is considered as conducive to extreme in the station, because the attributable percentage of extreme days is significantly larger than the attributable percentage of non-extreme days. The value of the index is assessed at 0.01 of significance level (99% of confidence level) by Monte-Carlo resampling of 1000 series.

The index EF is similar to that in [28] in their characterization of extremes in Central Europe. The difference is that, in the cited paper, series of mean Temperature/Precipitation are used from averaging 16/33 central-European series. Owing to the great spatial variability of the climate in the IP, we would rather consider individual series to search for CTs - local extremes relationship. This is even more important when referring to the occurrence of extreme temperatures, as orographic and local factors may usually play an important role.

Relationships between CTs and surface temperatures are not always stable in time, regarding to daily temperatures [5] as well as extreme values [28]. Then, the next step is analysing the temporal variations in the relationships between CTs and local extreme temperatures. As justified in [29] and [30], the use of 31-years moving averages results appropriate for studying these within-type variations. By this moving-window we study, for the most important types (related to extremes) and some representative stations:

-The percentage of extreme days within-type (respect to the overall occurrence of the CT).

-The percentage of extreme days owing to such CT (respect to total observed extremes).

3 RESULTS

Daily SLP grids for spring (MAM) and summer seasons (JJA) in 1850-2003 were classified, i..e, a total of 14168 days for each 3-month season. Fig. 1a (Fig. 4a) show the derived 9 (8) SLP centroids for spring (summer): in the SLP scale, in hPa, the highest values are in red (orange) and the lower are in blue. On the right hand side of each centroid (Fig. 1b,4b), is shown the temporal frequency (days) of the CT in each year (black bar-charts, left axis) in 1850-2003. The normalized series of seasonal cumulative anomalies of the frequency are shown in red (right axis). In the following, we will analyse results separately for spring (warm days) and summer (warm days and warm nights)

3.1 Spring

Centroids patterns of SLP clusters for spring are shown in Fig1a. They show the average SLP field and are sorted according to the number of days belonging to the clusters (first accounts for 2278 days, i.e., 16% of the days, second 13,8%, etc..). In CT 1 and CT 8 (Fig.1a), extensions of Azores High appear, with cores over Western France and Northern Iberian Peninsula respectively, thus prevailing easterlies winds exit in Iberia. Meridional circulation types are CT 3 (more extended Anticyclone in North-Atlantic and West Europe) and CT 5 (Northern Circulation). Zonal circulations are presented in CT 9 (W-SW winds), CT 6 (SW) and CT7 (NW, low pressure over Western France). Another variant of Anticyclone type is CT 2. Finally CT 4 represents a weak Azores High and NW stream over North-western Africa that could explain cyclogenesis in the lee of Atlas mountain (Sahara low), quite frequent in spring [31].

The presence of trends in the annual frequency for the whole period is tested by means of Mann-Kendall and trend-to-noise tests, results are shown in table 2. Mann-Kendall test has detected significant (p-value<0.05) negative trends for clusters 4, 7, and 9, and positive trend for cluster 3. These results indicate that, for the last century and a half, there have been significant increases in the frequency of North Atlantic Anticyclone (CT3) and decreases in the frequency of zonal circulation (CT 7, CT9 and CT4)

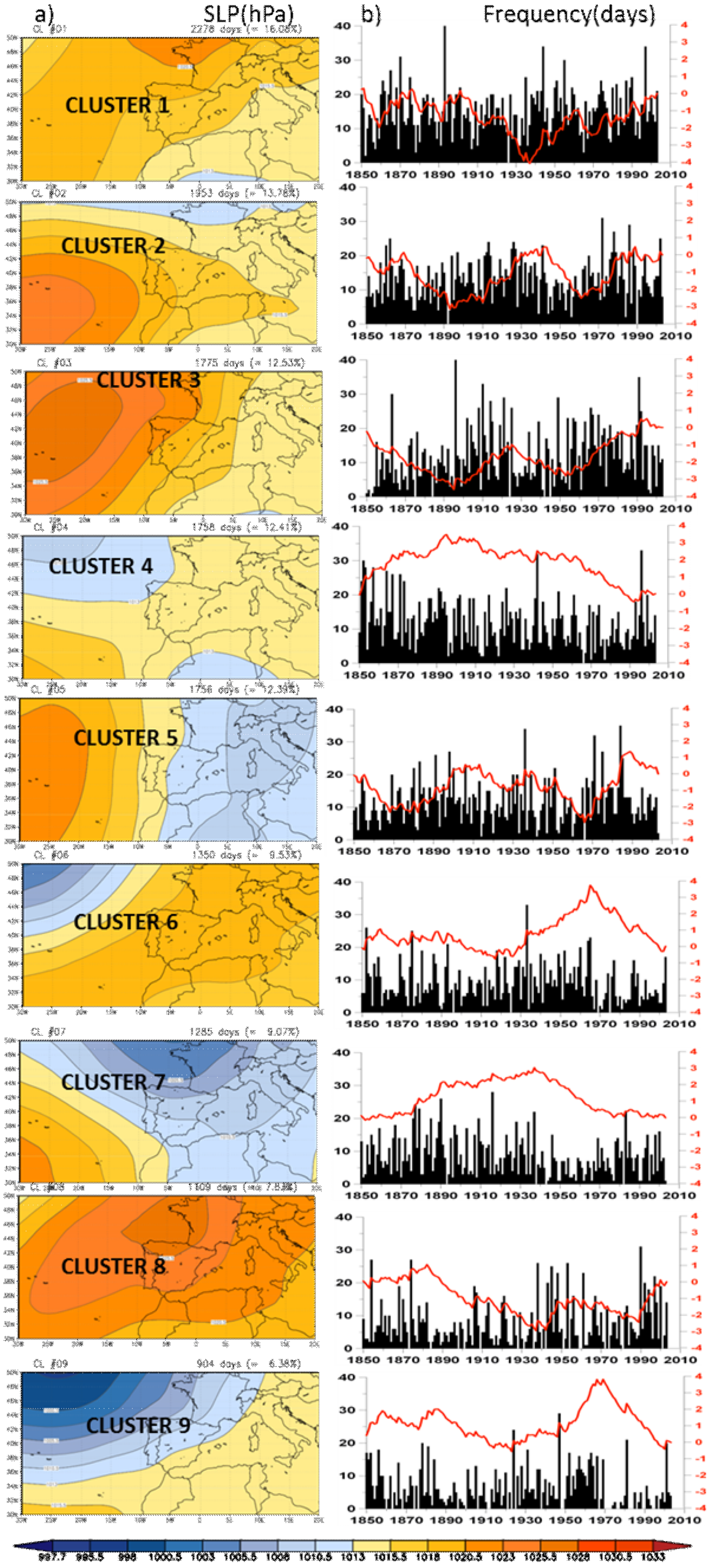

Fig.1. Centroids patterns of the SLP clusters (hPa, scale in the bottom) for spring (MAM) season; in the right hand side annual frequencies (days) of the clusters are shown (bar charts, left axis) as well as normalized cumulative anomalies of the frequency (red, right axis)

Table 2. Trends in the frequency of spring (MAM) SLP-Clusters in 1850-2003. Mann-Kendall statistic (Z) is shown in bold when trends are significant (p-value<0.05). Linear trend (Trend in days /154 years) refers to the magnitude in the whole period and T/noise is the quotient between linear trend and standard deviation. No significant linear trends are detected (T/noise above 1.96)

Cluster	Z(M-K)	p-value(M-K)	Trend	T/noise
1	1,46	0,1436	2,319	0,345
2	1,24	0,2149	2,176	0,364
3	**3,18**	**0,0015**	6,081	0,756
4	**-2,95**	**0,0032**	-6,079	-0,886
5	0,48	0,6305	1,410	0,215
6	-1,06	0,2908	-1,744	-0,295
7	**-2,30**	**0,0213**	-4,223	-0,700
8	0,59	0,5542	2,403	0,353
9	**-2,04**	**0,0409**	-2,344	-0,395

In Fig. 2, box-plots of daily Tmax, Tmin (25 series in 1929-2003), composites for each of the CT, are shown. In the box-plots, are shown the median, the 25th and 75th quantiles (that demarcate the limits of the boxes), as well as 10th and 90th percentiles of distributions (top and lower extremes of the plots). Below a short qualitative analysis of changes in spring temperatures in Iberia linking to the CTs frequencies (Fig.1b) is done.

The highest maximum temperatures for the set of 25 stations in the IP are presented for the CT 1, 2, 6, and 8, and the lowest for the CTs 7, 9, and 5 (Fig.2). A rise in spring temperatures in the last century, especially in 1970's onwards ([8], [9]), could be explained by enhanced occurrences of cluster 1 (in 1930-1960, and 1970-2003) and cluster 2 (1960-1980), and 8 (1990´s) as well as a decrease in the frequency of the clusters 9 (1970's onwards), 5 (1980 's onwards), and 7 (in 1940-1970). The CT linked to highest minimum temperatures is CT4 (follow by 1, 2 and 9) and the lowest Tmin are linked to CT 3, 5, and 8. So, the rise observed in the minimum temperatures in spring can be dynamically related to a higher frequency of CT 1 and 2, and increase of CT4 in the last decade of study, meanwhile between the "cold types" both CT3 and CT 5 seem to diminish their frequencies from 1980`s onwards. This feature agrees with the negative trends in northern circulation in 1960-2001 found by [18].
In the Fig. 3a is shown the incidence of the CTs (clusters) to the occurrence of warm days (Tmax>Tmax90th). We found 5 out of 9 CT to be significantly (p-value<0.01) conducive to moderately warm days in part or whole IP.

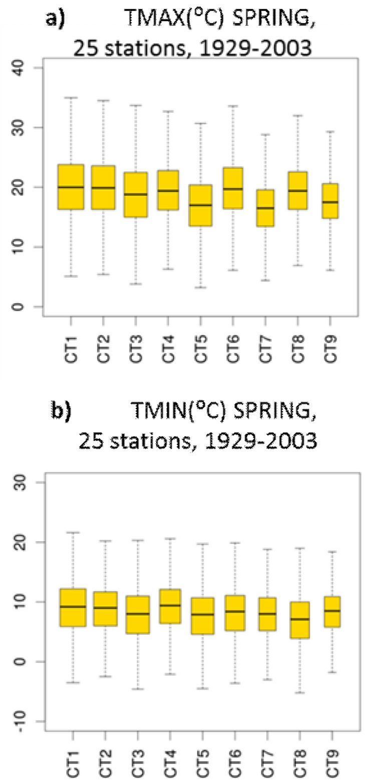

Fig.2. Box-plots of daily Tmax, Tmin (25 series in 1929-2003), composites for each of the CTs in spring. In such box-plots are shown the median, the 25th and 75th quantiles (that demarcate the limits of the boxes), as well as 10th and 90th percentiles of distributions (top and lower extremes of the plots)

The index EF (maps in Fig 3a) is plotted in red when above 1, i.e, the percentage of warm days is higher than the percentage of non-extreme days attributable to the corresponding CT. Therefore, analysing these maps:

-CT 1 and CT 8 are conducive to moderately warm days in the IP because predominant High Pressure blocks West and North flows. The exception is in Mediterranean E/SE, because the associated east flow brings fresh sea breeze in these coastal regions.
-CT6: The link of this type (SW flow over Northern Iberia) to warm days is significant for a large number of stations, mostly inland and more significant in Northern coast because of larger Föhen effect.
-CT2: Regarding the occurrence of warm days in Mediterranean and Ebro Valley, one of the most important clusters is CT2 (Fig 3a), showing Azores High quite extended over Iberia which involves west-inland flow over the Mediterranean coast.
-CT9: This westerly type gives rise to moderately

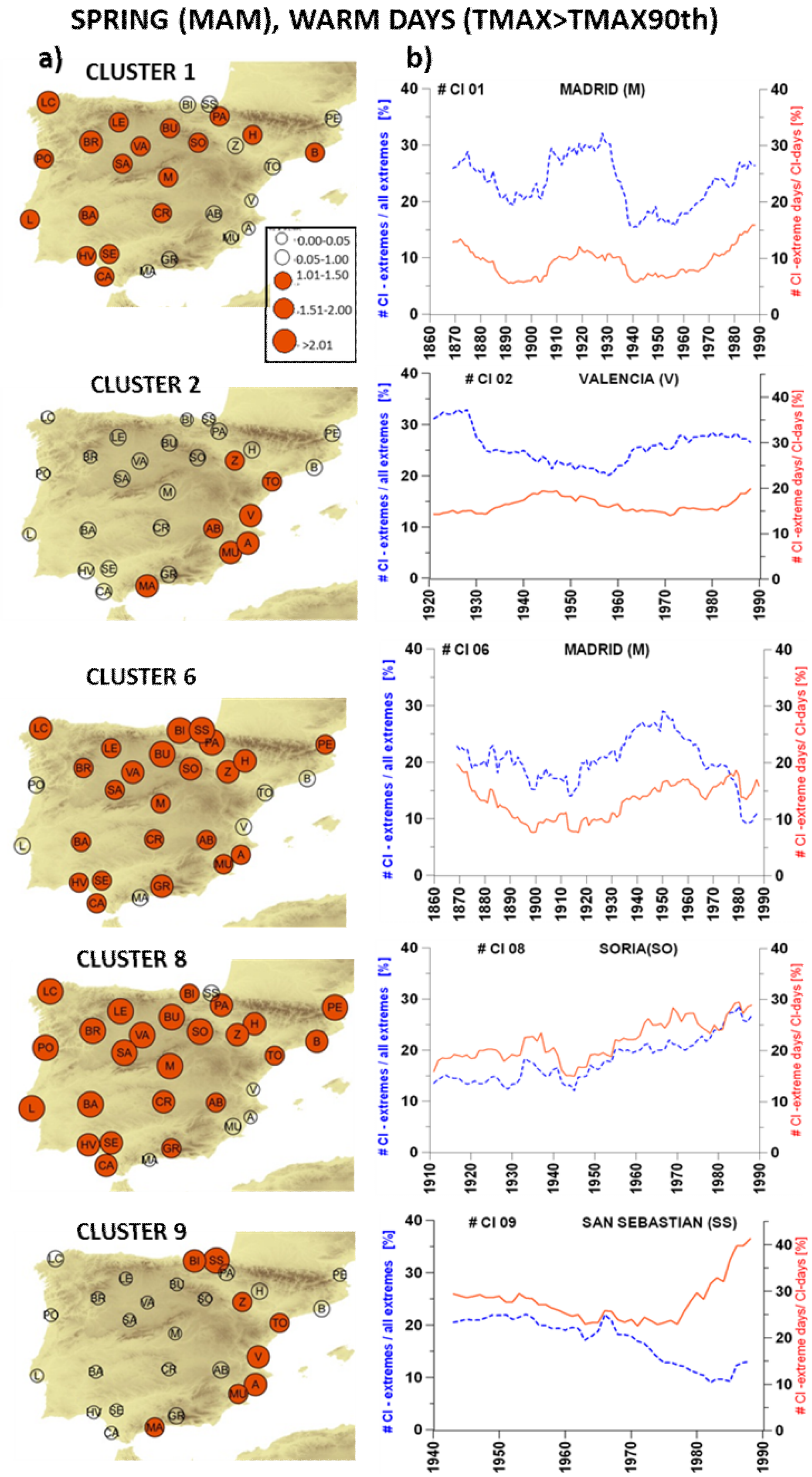

Fig.3. Index EF (see legend in first map and definition in method section) for spring clusters (CTs) significantly conducive to the occurrence of warm days. On the right hand side: The percentage of extreme days within-type respect to the overall occurrence of the CT is plotted in solid red line (right axis), while the percentage of extreme days owing to such CT respect to total observed extremes is plotted in discontinue blue (left axis).

extreme warm days in Mediterranean Fringe and East Cantabrian Coast due to warm westerly (W/SW) winds over Mediterranean and SW flow over Northern Iberia.

The above mentioned relationships between local temperature extremes and synoptic scale circulation variability (in terms of CT-specific extreme indices) were obtained taking the whole period 1950–2003 into account. As discussed in previous sections it is likely that these relationships vary on inter-annual and/or inter-decadal time-scales. Hence it is necessary to analyse the so-called within-type changes [29] and to characterise periods of stronger and weaker coupling between the focused CT's and spring "extreme" temperature conditions.

Here only a few examples are shown (Fig.3b) thought within-types changes for a large number of stations in every CT have been analysed. In solid line (right axis), the within -type extreme character (warm days in the CT/ all days in the CT) is shown; this is related only to how efficient the CT in relation to extremes is. In discontinuous line (left axis) is shown the contribution of the CT to the total number of warm days (extremes in the CT/all extremes). This percentage, besides efficiency, is related to the frequency of the CT.

-Both for CT 1 and CT8, it is observed an increase in the within -type percentage of extremes (solid line) since around 1960 's onwards (see Fig. 3b, Madrid and Soria examples). At the same time, owing to this increase in the extreme character and to an increasing frequency of both types (Fig.1b), the percentage of the total warm days due to these clusters (discontinue lines) has increased.

-With respect to CT6, it can be observed that the relative importance of this CT for warm days is diminishing (Madrid, discontinue line, Fig.3b), which is related to a lesser frequency from 1960's (Fig. 1b). Nevertheless, the within-type extreme character does not diminish but only suffers small fluctuations since the 1950's (continue line, around 15%). The same stationary character is found also for Soria and San Sebastian (not shown). In contrast, we found an increase in warm days linked to this type for La Coruña (LC) in the last two decades (not shown).

-For CT2, within-type variations are weak, after analysing its behaviour for Valencia (Fig 3b) and Barcelona (not shown).

-Finally, probably the most worth mentioning is the sharp rise in moderately extreme warm days in Mediterranean Fringe (Valencia, not shown) and East Cantabrian Coast (San Sebastian, Fig.3b) due to CT9, even if its frequency has decreased in 1970's onwards (Fig 1b)

3.2 Summer

For summer season (Fig 4a), Azores High is present in all the SLP centroids, thought with different intensity and extension: the anticyclone is more intense in the CT 2, 5 and 7, and it is quite more extended for CT 4, 5 and 6. The Azores High is weaker in CT 8, 4 and 1. Heat low is observed in Northern Africa in all the CTs, as well the relative low pressure in South Spain in the CTs 4, 5, and 7 is very likely linked to heat troughs development.

Table 3. As in Table 2, but for summer (JJA) season

Cluster	**Z(M-K)**	**p-value(M-K)**	**Trend**	**T/noise**
1	**-3,25**	**0,0012**	-6,194	-0,979
2	0,90	0,3699	1,088	0,177
3	-1,07	0,2858	-1,995	-0,322
4	1,85	0,0644	3,466	0,511
5	**5,20**	**0,0000**	10,430	1,334
6	**-2,29**	**0,0220**	-4,114	-0,698
7	**2,97**	**0,0030**	4,403	0,784
8	**-4,34**	**0,0000**	-7,084	-1,118

Mann-Kendall test (table 3) detected significant (p-value<0.05) negative trends in summer 1850-2003 for CTs 1, 6, and 8, and positive trends for CT 5 and 7. The most pronounced positive trend is detected for CT 5 (deep Azores anticyclone with ridge extended to North Atlantic-West France) and negative trend in cluster 8 (relative low pressure in North Atlantic).

From box-plot represented in Fig.5a, the CT linked to highest values of Tmax are CT 1 and 6. Both follow decreasing frequencies in the last decades (Fig.4b), so recent warming cannot be explained by a higher frequency of these types. CT 4 also has associated high Tmax, and the highest values of Tmin (Fig 5b) distributions. The sharp increase in Tmin in summer months (Brunet et al., 2007) partially could be related to a higher frequency of CT4 since 1990 (Fig 4b). During the last year of our study-period, i.e, the anomalous warm summer of 2003, the CT more frequent were CT1 (25 days), CT2 (19 days) and 4 (11 days). It is worthy to highlight increasing frequencies of the CTs that are heat trough-alike, these are CT 4 (last 2 decades), CT 5 and CT7 (both in 1910's onwards). A further warming in Iberia, in fact, would lead to higher frequency of thermal lows, as projected by [32].

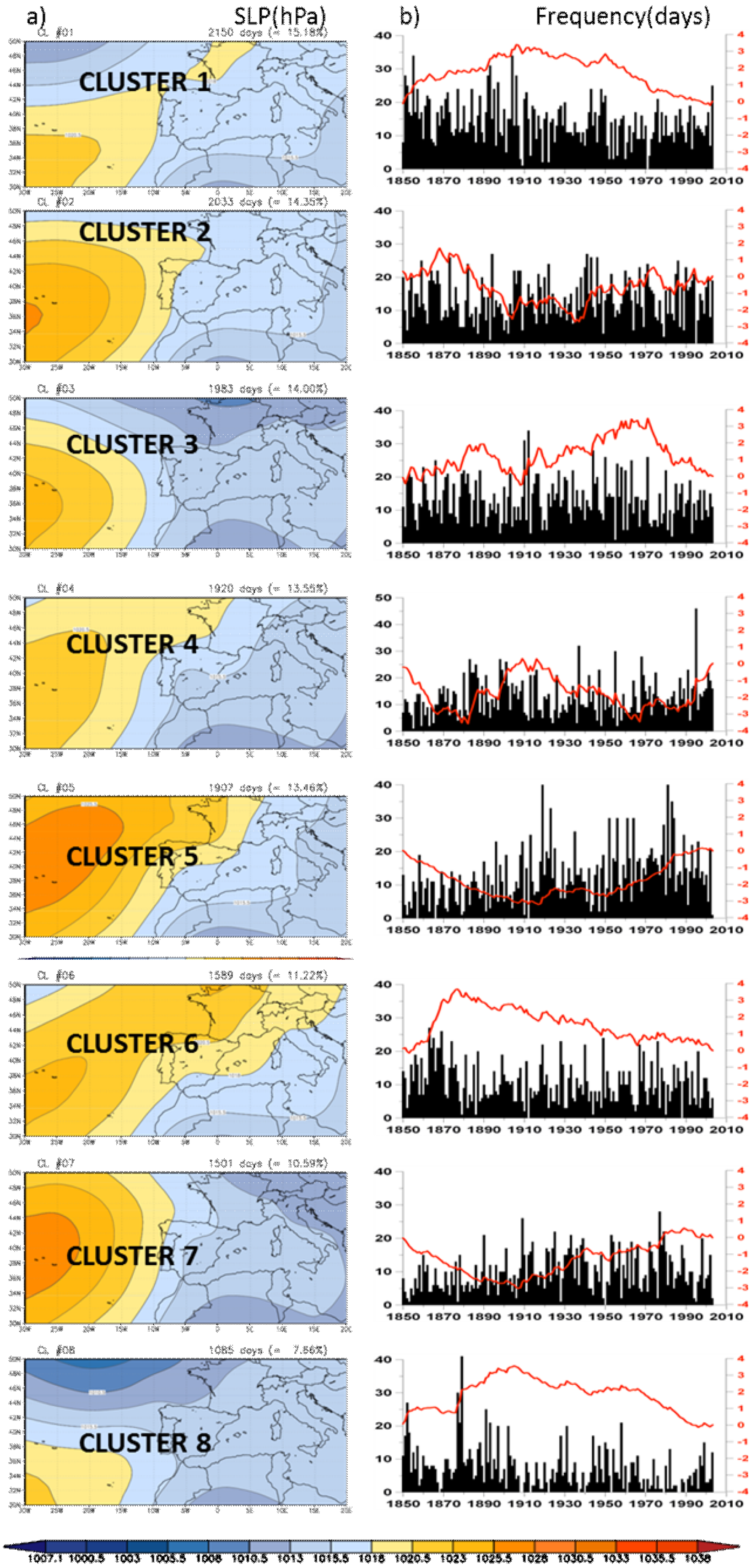

Fig.4. As in Fig.1, but for summer season (JJA)

Focusing in the index EF that links summer CT to the occurrence of warm days (Fig 6a):

-CT 1 and CT6 are conducive to relative warm days in most of the IP. Both types reflect blocking conditions, i.e., high pressure extended over North IP that blocks the displacement of air from the North Atlantic into Iberia. In the first type we observe an anticyclone bridge joining Azores High with central Europe High. In CT6, appears a wide anticyclone (though not strong) with ridge extended to Central Europe, i.e, a more typical blocking situation. These situations tend to provoke high temperatures in most of the IP except in Southern Mediterranean Fringe, where cooler conditions are expected because of east wind (sea breeze wind).

-CT 3 favours the entrance of masses of air from North Atlantic to the North and West of Iberia, hence permitting cool or temperate summer temperatures. Again the exception is SE region (V, MA, MU, A) where masses of air arrive warmer after travelling over the Iberian Peninsula (katabatic effect). Additionally, the thermal low pressure in Africa makes possible the intrusion of air from this continent.

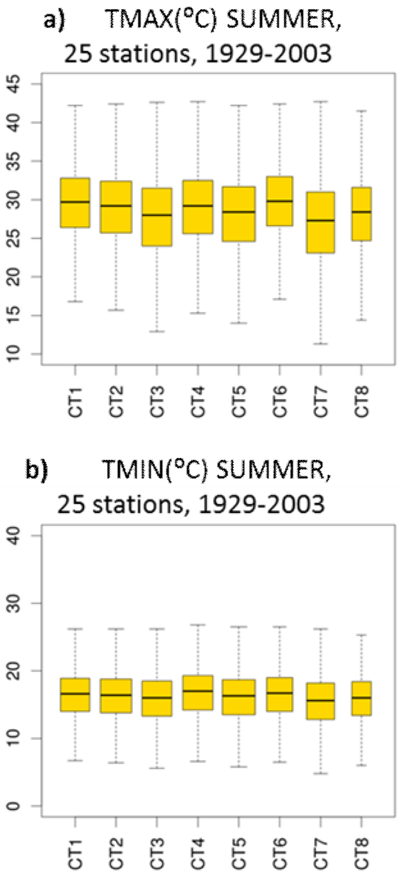

Fig.5. As in Fig.3, but for summer (JJA).

-CT 8 produces a similar temperature pattern than CT 3 in Southern Mediterranean coast, but in this case also Cantabrian Coast is affected because of a SW flow component (i.e, warming because of a Föhn or katabatic effect, depending on the humidity of the air).

In Fig 6b) we represent variations in warm days within the types for some localities.

-In Burgos is observed, both for types 1 and 6, an increase in the occurrence of moderately warm days, specifically in the last 3 decades of the study (solid lines). As well, due both to this increase in the extreme character and high annual frequencies, the contribution of these types to the total number of warm days is higher in the last decades than in former periods.

-Regarding CT3 and 8 (Fig 6b for Malaga) within-type changes towards warming are also observed (solid lines) with jumps in the 1940-1970 and middle 1970's onwards, respectively. CT3 has slightly become less important in recent decades (discontinue line) with respect to overall occurrence of warm days in Malaga. At the same time, CT7 - that reflects conditions of extended and intense Azores high pressure- also is significantly conducive to warm days in the locality (not shown).

Due to the stepped increase observed in warm nights in 1970´s onwards ([8],[9]) and the impacts of high nigh time temperatures in human health stress, we show as well the relationships found between CTs and warm nights in summer (Fig.7a):

-CT1: The Anticyclone bridge avoids the entrance of masses W and N, and at the same time, the fact of this High is a relatively weak may favour the development of cloudiness, leading to high minimum temperatures in many localities in half North Spain.

-CT 4: The heat low extended from North Africa to Iberia and weaker Azores anticyclone (weak subsidence of air) make possible the convection and the formation of clouds that allow high nigh time temperatures. This is backed by the fact that this CT has associated the higher percentiles of precipitation for the set of all stations (not shown).

-CT6; In this type the presence of extended Azores anticyclone in North Atlantic leads to prevailing easterlies that give rise to high minimum temperatures in half North and West Iberia.

-CT 5. In this circulation, as in CT6, flow from E/NE arrives to Iberia, but in this type Azores High is more extended and strong, hence, providing stronger easterlies. This circulation is connected to warm nights in SW, Lisbon and Badajoz, likely linked to a katabatic effect in the air masses.

-CT 8. This type presents the weakest Azores High and the presence of Icelandic low pressure in North-Atlantic, so westerlies provide humidity to North-Western Iberia, again with the probability of clouds formation. The occurrence of warm nights statistically appears more important in Coruna, Burgos, and Pamplona.

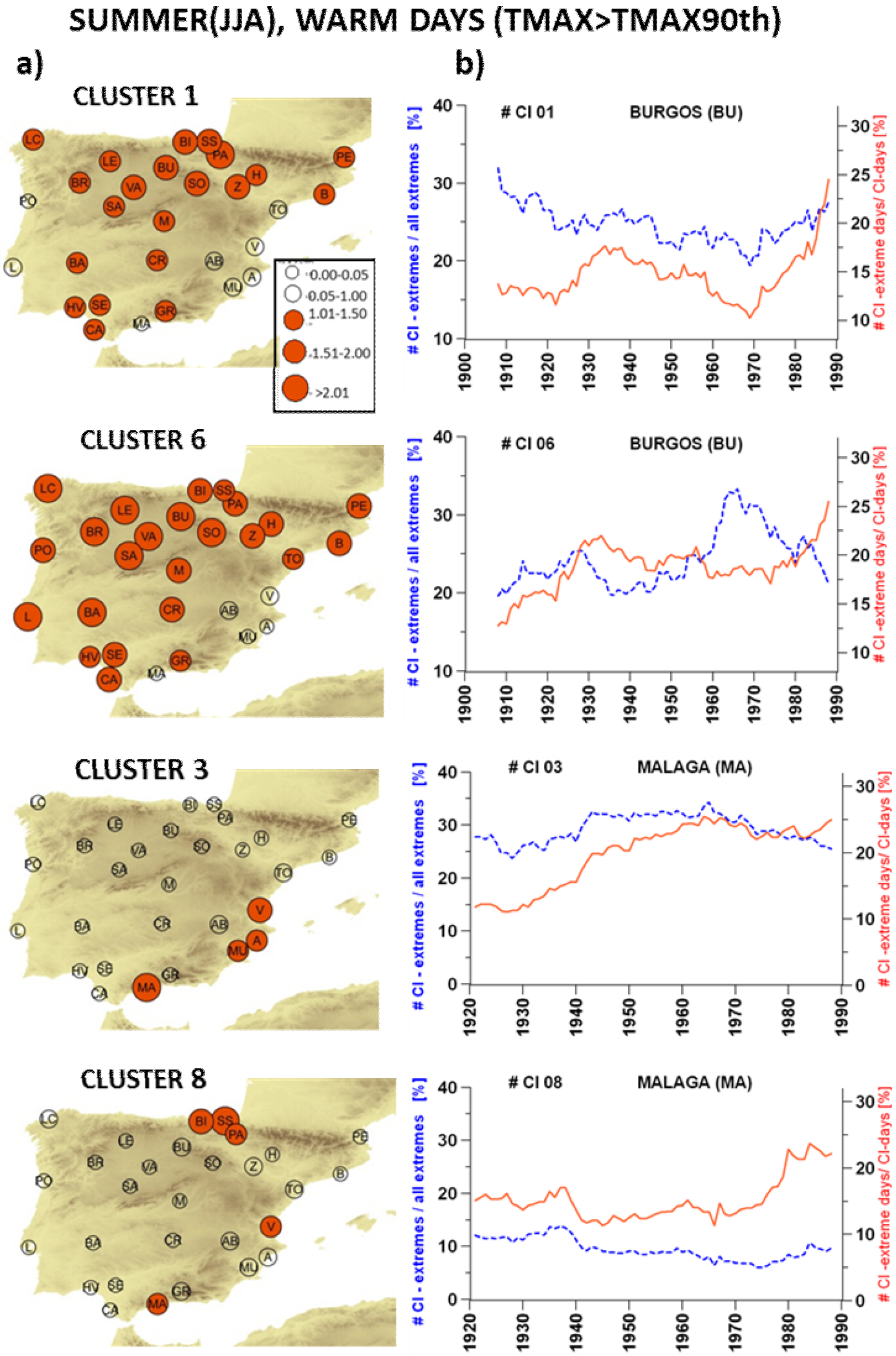

Fig.6. As in Fig. 3, but for summer occurrence of warm days.

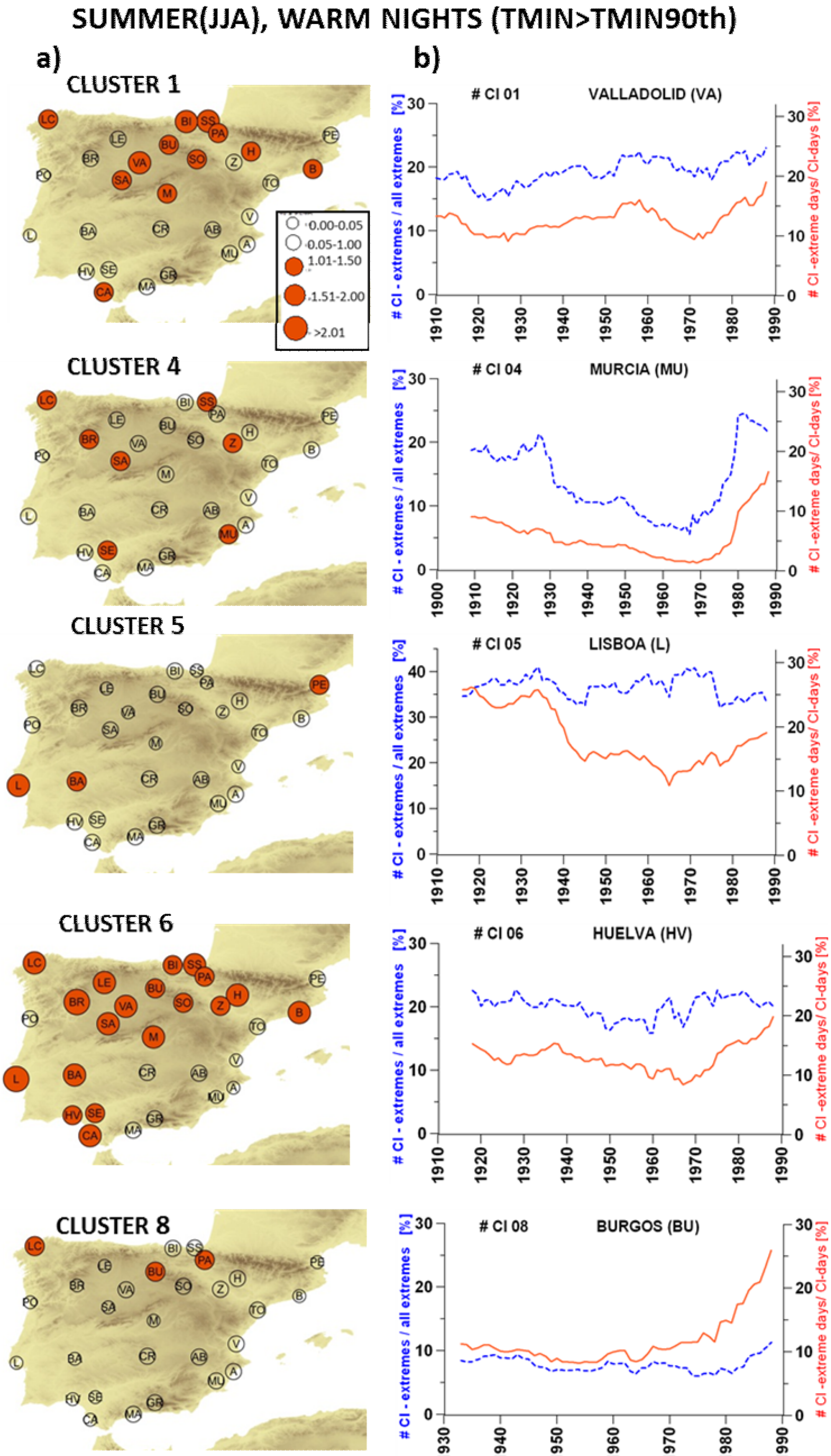

Fig.7. As in Fig. 3 and Fig.6, but for summer occurrence of warm nights.

In Fig 7b, analysing within-types changes, a common feature stands out: there is an increasing in the percentage of warm nights within the clusters since 1970´s onwards. In the case of CT 1 and 6 we show Valladolid and Huelva examples (Fig 7b), but it was as well proved in localities like Cádiz, Barcelona, Murcia (not shown). For CT4, higher frequencies around the 1990´s (Fig 4b) would explain, at least partially, the stepped increase in last decades in the occurrence of warm nights, as in Murcia (Fig.7) and Sevilla (not shown). In contrast a larger impact in Lisbon warm nights occurrence would be expected within CT 5 since it follows a positive trend in frequency, but it does not occurred for Lisbon (Fig 7b), neither for Perpignan or Badajoz (not shown). Finally, the clearest and sharpest increase in warm nights seems to take place within CT 8 (and CT3, not shown) associated to warm nights in SE and Northern stations. In Fig 7b, it is plotted for Burgos the percentage of warm nights within CT 8 (continue line) and one can see the sharp increase since the 1970´s. The same sharp increase is found for this CT in Alicante, Malaga and Murcia (not shown). As in CT 6, the step in warm nights linked to CT 8 is due mainly to a "within type warming", since its frequency do not show clear trends in recent decades.

4 CONCLUSIONS

In summary, an increase of warm extremes in Iberia ([8], [9]) in the last 3 decades (1973-2003) in summer and spring seasons cannot be explained only by changes in the frequency of the distinct circulation types, but an important within-type warming took place. The most important warming seems to have occurred within the zonal circulation types, even if it frequency has generally decreased during the last decades. In both spring and summer seasons an effect from the topography (and other local effects) is clear, e.g, Föhn and katabatic effect for reaching high temperatures.

For spring, our results point to an increase in the occurrence of warm days linked to a recent increase in the frequency of high pressure conditions in the North of the IP (CTs 1 and 8). At the same time, a rise in the maximum temperatures of these types is observed, which means a warming of the surface flow from the east, i.e., from the Mediterranean Sea. Additionally, a significant rise in the maximum temperatures is associated to zonal flow (westerlies, SW) represented by CT 6 and CT9. From the 1970's onwards zonal circulation types have become less frequent but warmer.

For summer, maximum extreme temperatures in mainland Iberia are linked to Atlantic blocking (Anticyclone Bridge and Anticyclone in NW Iberia with ridge to Central Europe). In both configurations –more strongly in the later-, an increase in the occurrence of moderately warm days took place within these clusters from around the 1970´s. For the Mediterranean-SE region, in contrast, moderately extreme warm days are linked to a zonal component (W) in circulation (from inland), usually accompanied by heat low in Northern Africa, hence probably providing South flow.

Extreme minimum temperatures, besides being influenced by the direction of flow, appear related to convection processes associated to weak Azores High and heat troughs development. We found positive trends in the frequency of heat troughs (linked to summer CT4, 5 and 7) in the course of the last 150 years. Increase in warm nights within most of the types are found, except CT5 (meridian pattern with NE flow), even if such type has a significant long-term positive trend in 1850-2003.

Rodriguez-Puebla et al, (2010) [13] inferred that the increase in the annual number of warm days in Iberia in 1950-2006 could be related to higher SLP in the Mediterranean, i.e., linked to air masses coming from North Africa. Focus in spring and summer, this study adds some different nuances: our results point instead to an increasing incidence of high SLP in North-mainland Iberia, i.e., linked to prevailing easterlies. They are found more frequent and warmer in the last decades than in former times. A second main reason for increasing warm days is the warming of the zonal flow. This warming, especially important for the surface air masses coming from the Atlantic Ocean, may be linked to the increase in the Atlantic Sea Surface temperature (SST), that has been notable specifically south of 45°N and deeper than the other oceans (Solomon et al, 2007). As highlighted in many studies, besides large-scale atmospheric circulation, SST is a key factor for temperature variability in the Mediterranean area (eg. [7],[16]). The results obtained here prove once more the importance of the interactions sea-air for describing extreme temperatures variability in the Iberian Peninsula.

Autumn and winter seasons will be subject of future analysis, as well as the importance of circulation types in the occurrence of daily extreme precipitation in Iberia.

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REFERENCES

[1] Moberg A, Jones P, Lister D, Walther A, Brunet M, Jacobeit J, Alexander L, Della-Marta P, Luterbacher J, Yiou P, Chen D, Klein Tank A, Saladié O, Sigró J, Aguilar E, Alexandersson H, Almarza C, Auer I, Barriendos M, Begert M, Bergström H, Böhm R, Butler CJ, Caesar J, Drebs A, Founda D, Gerstengarbe F, Micela G, Maugeri M, Österle H, Pandzic K, Petrakis M, Srnec L, Tolasz R, Tuomenvirta H, Werner P, Linderholm H, Philipp A,Wanner H, Xoplaki E, 2006: Indices for daily temperature and precipitation extremes in Europe analyzed for the period 1901–2000. J Geophys Res 111:D22,106

[2] Scaife, Adam A., Chris K. Folland, Lisa V. Alexander, Anders Moberg, Jeff R. Knight, 2008: European Climate Extremes and the North Atlantic Oscillation. J. Climate, 21, 72–83.

[3] Küttel M, Luterbacher J, Wanner H (2010) Multidecadal changes in winter circulation-climate relationship in Europe: frequency variations, within-type modifications, and long-term trends. Clim Dynam. doi:10.1007/s00382-009-0737-y

[4] Jones, P. D. and Lister, D. H.: The influence of the circulation on surface temperature and precipitation patterns over Europe, Clim. Past Discuss., 5, 535-555, doi:10.5194/cpd-5-535-2009, 2009

[5] Bermejo, M y Ancell, R., 2009. Observed changes in extreme temperatures over Spain during 1957-2002 using Weather Types. Revista de Climatología Vol. 9 (2009): 45-61 ISSN 1578-8768

[6] Trigo R.M., Pereira J.M.C., Pereira M.G., Mota B., Calado T.J., Dacamara C.C., Santo F.E., 2006: Atmospheric conditions associated with the exceptional fire season of 2003 in Portugal. International Journal of Climatology, 26 (13), pp. 1741-1757.

[7] Xoplaki, E., J. F. González-Rouco, J. Luterbacher, and H. Wanner, 2003: Mediterranean summer air temperature variability and its connection to the large scale atmospheric circulation and SSTs. Clim.Dyn. 20, 723-739.

[8] Brunet, M., Jones, P.D., Sigró, J., Saladié, O., Aguilar, E., Moberg, A., Della-Marta, P.M., Lister, D., Walther, A., López, D., 2007: Temporal and spatial temperature variability and change over Spain during 1850-2005. Journal of Geophysical Research, 112, D12117, doi:10.1029/2006JD008249

[9] Ramos, A. M., R.M. Trigo and F.E. Santo (2010) "Evolution of extreme temperatures over Portugal: recent changes and future scenarios" Submitted to Climate Research (Accepted) http://www.int-res.com/prepress/c00934.html

[10] Goodess, C., and P. Jones, 2002: Links between circulation and changes in the characteristics of Iberian rainfall. Int. J. Climatol.,22, 1593–1615

[11] Trigo, R. M. and C. C. DaCamara (2000), Circulation weather types and their impact on the precipitation regime in Portugal, Int. J. Climatol, 20, 1559–1581

[12] Romero, R., Summer, G., Ramis, C., Genovés, A., 1999. A classification of the atmospheric circulation patterns producing significant daily rainfall in the Spanish Mediterranean area. Int. J. Climatol. 19, 765–785

[13] Rodriguez-Puebla C, Encinas A.H, García-Cansado, L.A, and Nieto, S, 2009: Trends in warm days and cold nights over the Iberian Peninsula: relationships to large-scale variables. Climatic Change. DOI: 10.1007/s10584-009-9721 0..

[14] Barnston AG, Livezey RE (1987) Classification, seasonality and persistence of low frequency atmospheric circulation patterns.Mon Weather Rev 115:1083–1126

[15] García-Herrera, R., Díaz, J., Trigo, R.M., Hernández, E., 2005: Extreme summer temperatures in Iberia: health impacts and associated synoptic conditions. Ann. Geophys. 23, 239–251.

[16] Della-Marta P.M., Luterbacher J., von Weissenfluh H., Xoplaki E., Brunet M., Wanner H. Summer heat waves over western Europe 1880-2003, their relationship to large-scale forcings and predictability (2007) Climate Dynamics, 29 (2-3), pp. 251-275.

[17] Philipp, A., Della-Marta, P.M., Jacobeit, J., Fereday, D., Jones, P., Moberg, A., Wanner, H., 2007. Long-term variability of daily North Atlantic–European pressure patterns since 1850 classified by simulated annealing clustering. J. Clim. 20, 4065–4095

[18] Esteban P, Martin-Vide J and Mases M (2006): Daily atmospheric circulation catalogue for western europe using multivariate techniques. Int. J. Climatol., 26:1501–1515.

[19] Brunet M, Saladié O, Jones P, Sigró J, Aguilar E, Moberg A, Lister D, Walther A, Lopez D, Almarza C, 2006: The development of a new dataset of Spanish daily adjusted temperature series (SDATS) (1850–2003). Int J Clim 26:1777–1802

[20] Brunet, M., O. Saladié, P. D. Jones, J. Sigró, E. Aguilar, A. Moberg, D. Lister, A. Walther, and C. Almarza (2008), A case-study/guidance on the development of long-term daily adjusted temperature datasets, WCDMP-66/WMO-TD-1425, 43 pp., WMO, Geneva, Switzerland.

[21] Klein Tank AMG, et al., 2002: Daily dataset of 20th-century surface air temperature and precipitation series for the European Climate Assessment. International Journal of Climatology 22: 1441-1453.

[22] Klok, E.J., Klein Tank, A.M.G., 2009. Updated and extended European dataset of daily climate observations. International Journal of Climatology. Volume 29, Issue 8, 30 June (2009), Pages 1182-119

[23] Ansell, T., Jones, P.D., Allan, R.J., Lister, D., Parker D.E., Brunet-India, M., Moberg, A., Jacobeit, J., Brohan, P., Rayner, N., Aguilar, E., Alexandersson, H., Barriendos, M., Brazdil, R., Brandsma, T., Cox, N., Drebs, A., Founda, D., Gerstengarbe, F., Hickey, K., Jonsson, T., Luterbacher, J., Nordli, O., Oesterle, H., Rodwell, M., Saladie, O., Sigro, J., Slonosky, V., Srnec, L., Suarez, A., Tuomenvirta, H., Wang, X., Wanner, H., Werner, P., Wheeler, D., Xoplaki, E., 2006: Daily mean sea level pressure reconstructions for the European - North Atlantic region for the period 1850-2003. J. Climate.

[24] Huth, R., Beck, C., Philipp, A., Demuzere, M., Ustrnul, Z., Cahynová, M., Kysely´, J., Tveito, O.E., 2008. Classifications of atmospheric circulation patterns: recent advances and applications. Ann. New York Acad. Sci. 1146, 105–152.

[25] Jacobeit, J., 1993: Regionale Unterschiede im atmosphärischen Zirkulationsgeschehen bei globalen Klimaveränderungen (Regional differences of the atmospheric circulation under conditions of global climate change). Die Erde, 124, 63–77.

[26] Preisendorfer, R. 1988. Principal Component Analysis in Meteorology and Oceanography, Developments in Atmospheric Science, Vol. 17. Elsevier, Amsterdam.

[27] Kendall, M.G., 1938: A new measure of rank correlation, Biometrika 30 (1938), pp. 81–93

[28] Jacobeit, J., Rathmann, J., Philipp, A., Jones, P.D., 2009. Central European precipitation and temperature extremes in relation to large-scale atmospheric circulation types. Met. Zeitschrift 18, 397–410.

[29] Beck, C, J. Jacobeit and P.D. Jones, Frequency and within-type variations of large scale circulation types and their effects on low-frequency climate variability in Central Europe since 1780, Int. J. Climatol. 27 (2007), pp. 473–491

[30] Jacobeit J, Wanner H, Luterbacher J, Beck C, Philipp A, Sturm K. 2003. Atmospheric circulation variability in the North Atlantic- European area since the mid-seventeenth century. Climate Dynamics 20: 341–352..

[31] Trigo IF, Davies TD, Bigg GR.1999. Objective climatology of cyclones in the Mediterranean region. Journal of Climate 12: 1685–1696.

[32] Hoinka K.P., Gaertner M., de Castro M. Iberian thermal lows in a changed climate (2007) Quarterly Journal of the Royal Meteorological Society, 133 (626 A), pp. 1113-1126

[33] Solomon, S., D. Qin, M. Manning, R.B. Alley, T. Berntsen, N.L. Bindoff, Z. Chen, A. Chidthaisong, J.M. Gregory, G.C. Hegerl, M. Heimann, B. Hewitson, B.J. Hoskins, F. Joos, J. Jouzel, V. Kattsov, U. Lohmann, T. Matsuno, M. Molina, N. Nicholls, J. Overpeck, G. Raga, V. Ramaswamy, J. Ren, M. Rusticucci, R. Somerville, T.F. Stocker, P. Whetton, R.A. Wood and D. Wratt, 2007: Technical Summary. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.