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# Trends in frequency indices of daily precipitation over the Iberian Peninsula during the last century

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[1] This study provides the first long-term assessment of changes in precipitation associated with different rainfall categories over the Iberian Peninsula (IP). Using recently digitized data from 27 stations in Portugal and Spain, we have examined trends of precipitation indices for the complete period 1903–2003 and the two subperiods 1903–1953 and 1954–2003. These indices were evaluated seasonally according to five rainfall categories: total rainfall (≥0.2 mm), light rainfall (≥0.2 and <2.5 mm), moderate rainfall (≥2.5 and <7.5 mm), intense rainfall (≥7.5 mm), and very intense rainfall (≥15 mm). For the complete period 1903–2003, we have found that the total number of rainy days and that of light rainfall are increasing at many observatories over the IP for all seasons (except in the western zone of Portugal and the Cádiz gulf, where they are decreasing). Both subperiods show opposite behaviors in fall and spring. During the first (second) subperiod spanning 1903–1953 (1954–2003), we can find a generalized decrease (increase) in the number of rainy days in fall in all rainfall categories. In spring, an increase in the number of rainy days is found mainly for total, moderate, and intense categories for the first subperiod, and a slight decrease during the second. In winter, we have verified a decrease in the number of rainy days mainly for total, moderate, and intense rainfall categories in the second subperiod. Finally in relation to the maximum length of dry spells for both subperiods, most observatories show significant trends opposite those of the total number of rainy days. It is worth noticing that the contrasting evolution of trends found between the first and second halves of the twentieth century could only be characterized in this work following a recent comprehensive digitization of historical Iberian precipitation data from the first decades of the twentieth century.

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## 1. Introduction

[2] It is now widely accepted that changes in total precipitation can be associated with changes in the frequency of precipitation events, the amount of precipitation per event, or a combination of both [*Intergovernmental Panel on Climate Change* (*IPCC*), 2007]. Understanding precipitation changes in both climate variability and climate extremes during recent decades or under future climate change scenarios can be harder to disentangle due to possible interactions between the changes in the mean and the variability [*Meehl et al.*, 2000]. To achieve this understanding, the analysis of daily precipitation series is mandatory, namely evaluation of whether changes in precipitation frequency are due to a change in the number of days with heavy precipitation or with light precipitation [e.g., *Brunetti et al.*, 2001; *Groisman et al.*, 1999; *Karl and Knight*, 1998; *Trenberth et al.*, 2003]. Extreme events represent a key aspect of climatic change, and increments or decreases in the frequency of several extremes often correspond to the most sensitive aspects of climate change for ecosystem and societal responses [*Katz*, 1999; *IPCC*, 2007].

[3] A suite of climatic extreme indices based on daily data, including precipitation, were formulated by the joint Expert Team on Climate Change Detection and Indices (ETCCDI; www.clivar.org/organization/etccdi/etccdi.php) and used globally [*Alexander et al.*, 2006; *Trenberth et al.*, 2007] or

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regionally as indicators of climate variability and change. (The expert team is jointly supported by the World Meteorological Organization (WMO) Commission for Climatology (CCl), the World Climate Research Programme (WCRP) project on Climate Variability and Predictability (CLIVAR), and, since 2006, the Joint WMO-Intergovernmental Oceanographic Commission (IOC) of the United Nations Educational, Scientific and Cultural Organization (UNESCO) Technical Commission for Oceanography and Marine Meteorology (JCOMM).) For an overview on the regional analysis carried out by the ETCCDI and their results in the past decade, see *Peterson and Manton* [2008] and *Alexander et al.* [2009].

[4] In order to analyze changes of extreme precipitation, two different approaches have been proposed in recent years. Some authors have looked at changes in the daily precipitation distribution tail, namely the magnitude of the 95th percentile (P95) or the percentage of seasonal precipitation falling on days with rainfall above P95 [*Karl*, 1999]. Other researchers have opted to evaluate changes in the number of days above previously defined thresholds associated with different rainfall categories [*Alexander et al.*, 2006; *Moberg et al.*, 2006]. Both methods have been applied to Iberia by some of us in previous works, but always using relatively short length time series. *Rodrigo and Trigo* [2007] have applied the daily distribution and P95 approach to 22 time series spanning between 1951 and 2002, while *Gallego et al.* [2006] and *García et al.* [2007] have used the predefined threshold method with 35 series between 1958 and 1997. In addition, *Brunet et al.* [2007] have used some of the ETCCDI indices (daily rainfall exceeding the 95th and 99th percentiles, simple daily intensity index, and greatest 1 and 5 day total precipitation) and documented their changes over the period 1901–2005 using 22 daily precipitation series over mainland Spain.

[5] The amount and distribution of precipitation in the Iberian Peninsula (IP) is highly irregular in both the spatial and temporal dimensions [*Esteban-Parra et al.*, 1998; *Serrano et al.*, 1999; *Trigo and DaCamara*, 2000; *Rodríguez-Puebla and Brunet*, 2007]. Moreover, most of the precipitation during the wet winter season can be explained in terms of a relatively small number of large-scale atmospheric modes, such as the NAO (North Atlantic Oscillation) and the EA (Eastern Atlantic) at the monthly scale. However, monthly and annual values may conceal highly different precipitation regimes at the daily scale, and the importance of daily precipitation has not been matched by sufficient scientific attention.

[6] A large fraction of published works dealing with daily precipitation over the IP is limited to the second half of the twentieth century [*Goodess and Jones*, 2002; *Gallego et al.*, 2005, 2006; *Rodrigo and Trigo*, 2007; *García et al.*, 2007; *Rodrigo*, 2009]. However, none of these studies has evaluated the first half of the twentieth century, because the majority of the required precipitation time series was simply not available at the time. Other more detailed analyses have been performed but were restricted to certain sectors of Iberia, such as the region of Valencia [*González-Hidalgo et al.*, 2003], Catalonia [*Lana et al.*, 2004; *Serra et al.*, 2006; *López-Moreno et al.*, 2009], the Spanish Mediterranean sectors [*Romero et al.*, 1998], the Ebro valley and northeastern IP [*Vicente-Serrano and López-Moreno*, 2006], and the south of Portugal [*Costa and Soares*, 2009; *Durão et al.*, 2009]. Other works have looked in more detail at particularly long-term series, such as the Fabra Observatory in Barcelona [*Lana et al.*, 2003] or Cádiz [*Barriendos et al.*, 2002] and Gibraltar [*Rodrigo et al.*, 1999], both in southern Spain. In fact, there have been a limited number of works with long-term changes of daily precipitation characteristics (extreme events, number of rainy days, etc.) with, at least, 100 years of data and with a relatively good density of stations. Exceptions correspond to the early mentioned study of *Brunet et al.* [2007] over mainland Spain and others over different world regions, such as the United States [*Karl et al.*, 1995; *Karl and Knight*, 1998], the United Kingdom [*Maraun et al.*, 2008], parts of Australia [*Suppiah and Hennessy*, 1998], and northern Italy [*Brunetti et al.*, 2000, 2004], among others.

[7] The output of two recently finalized independent projects, aiming at recovering station data for Europe, the Atlantic basin, and Africa, has levered the access to newly digitized data. The completed European Community (EC) funded project EMULATE (European and North Atlantic daily to MULtidecadal climATE variability) has developed new daily data sets of observations since 1850 over Europe, having fostered a number of studies with sea level pressure [*Ansell et al.*, 2006], precipitation, and temperature [*Moberg et al.*, 2006; *Della-Marta et al.*, 2007]. From a different perspective the ongoing Portuguese funded project SIGN (SIGNatures of environmental change in the observations of the Geophysical Institutes) is engaged in a similar task to digitize and make publicly available large amounts of data from the Portuguese mainland, Atlantic islands, and former colonies including astronomical [e.g., *Vaquero et al.*, 2005], geophysical [e.g., *Vaquero and Trigo*, 2005a, 2006], and meteorological [e.g., *Vaquero and Trigo*, 2005b; *Trigo et al.*, 2009; *Fragoso et al.*, 2010] data. In any case, both projects have made available a considerably larger number of long-term daily precipitation time series, since the late nineteenth or early twentieth century. Therefore, there is clearly scope for a comprehensive reassessment of changes of precipitation extremes for the entire IP since the beginning of the twentieth century, considerably expanding the time length analyzed in the previous works of *Gallego et al.* [2006] and *Rodrigo and Trigo* [2007].

[8] Here we will adopt the approach of *Gallego et al.* [2006], but using twice as much data covering the period 1903–2003. We have used daily rainfall data series over Iberia to construct series of rainfall indices based on the frequency of the rainfall events by defining categories of rainfall exceeding certain thresholds. As frequency indices we took the number of rainy days in each category, medians and maxima of dry spells, and the proportion of the number of rainy days in each rainfall category compared with the corresponding total.

[9] Thus the main aims of the present work were (1) to analyze possible changes in precipitation over Iberia by means of the study of trends in daily rainfall frequency indices in a network of observatories in this area and (2) to identify spatially coherent regions with common trend behavior during the entire period (1903–2003) (hereafter, PT) but also for the first (1903–1953) and second (1954–2003) half centuries (hereafter, P1 and P2 respectively).

[10] The structure of the paper is as follows: section 2 describes the data used in this study for the construction

**Table 1.** Selected Observatories: Geographical Coordinates, Height, and Indicative

| Location | Longitude (deg) | Latitude (deg) | Height (m) | Indicative |
|---|---|---|---|---|
| Albacete | −1.86 | 38.95 | 698.5 | Alb |
| Alicante | −0.49 | 38.37 | 81.5 | Ali |
| Badajoz | −6.83 | 38.88 | 185.0 | Bad |
| Barcelona | 2.18 | 41.42 | 420.1 | Bar |
| Beja | −7.88 | 38.02 | 246.0 | Bej |
| Burgos | −3.62 | 42.36 | 881.0 | Bur |
| Cádiz | −6.21 | 36.47 | 30.0 | Cad |
| Ciudad Real | −3.92 | 38.99 | 627.0 | Cdr |
| La Coruña | −8.42 | 43.37 | 67.0 | Cor |
| Granada | −3.63 | 37.14 | 685.0 | Gra |
| Guarda | −7.23 | 40.53 | 1019.0 | Gua |
| Huelva | −6.91 | 37.28 | 19.0 | Hlv |
| Huesca | −0.33 | 42.08 | 541.0 | Hsc |
| Lisboa | −9.15 | 38.72 | 77.0 | Lis |
| Madrid | −3.68 | 40.41 | 678.9 | Mad |
| Málaga | −4.48 | 36.67 | 6.5 | Mal |
| Murcia | −1.12 | 37.98 | 57.0 | Mur |
| Oporto | −8.60 | 41.14 | 93.0 | Opo |
| Pamplona | −1.64 | 42.77 | 452.0 | Pam |
| Salamanca | −5.49 | 40.95 | 789.8 | Sal |
| San Sebastián | −2.04 | 43.31 | 251.6 | Seb |
| Sevilla | −5.90 | 37.42 | 31.0 | Sev |
| Soria | −2.48 | 41.77 | 1083.0 | Sor |
| Tortosa | 0.48 | 40.82 | 50.0 | Tor |
| Valencia | −0.38 | 39.48 | 11.4 | Val |
| Valladolid | −4.74 | 41.64 | 691.4 | Vdl |
| Zaragoza | −1.01 | 41.66 | 245.0 | Zar |

of the rainfall index series. The methods used for trend detection and slope estimation are presented in section 3. The trends found for each rainfall index series are discussed in section 4. Some conclusions are presented in section 5.

## 2. Data

[11] The data used in this analysis were obtained through two unconnected projects relative to each Iberian country, EMULATE (Spain) and SIGN (Portugal):

[12] 1. Spanish stations constitute a temporal fraction (1901–2005) of the records that compose the Spanish Daily Adjusted Precipitation Series (SDAPS) data set, developed in the framework of the European Community (EC) funded project EMULATE (European and North Atlantic daily to MULtidecadal climATE variability (http://www.cru.uea.ac.uk/cru/projects/emulate/)). Under this project, the 23 longest and most reliable time series of raw daily precipitation data over Spain (see Table 1) were collected, and part of them were digitized from different organizations and sources (see *Brunet et al.* [2006] for a list of the Spanish records sources). Most of the data came from the Spanish National Data Bank and Climate Historical archive held at the AEMET (Agencia Española de Meteorología).

[13] 2. Portuguese stations were obtained through the Portuguese funded project SIGN (SIGNatures of environmental change in the observations of the Geophysical Institutes). One of the project's main goals was to convert into a digital database the historical meteorological data recorded from 1856 to 1940 in several annals published by the three Portuguese Geophysical Institutes (of Lisboa, Oporto, and Coimbra) and to join them with the post-1940 digital database of the Portuguese Meteorology Institute (IM). Here we have restricted the analysis to four long-term series (Table 1) that help to cover the western sector of Iberia (Figure 1).

[14] The raw data were quality controlled and homogenized at the daily scale by following procedures similar to those described by the World Meteorological Organization/World Climate Data Monitoring Programme Guidance on the development of daily adjusted temperature data sets [*Brunet et al.*, 2008]. Quality controls (QC) applied to the raw daily rainfall data consisted of the following checks: comparisons between the original source monthly values and the data set of monthly accumulated rainfall, consistency in the number of days per year/month, duplicates, negative precipitation, values exceeding the six standard deviation threshold, two or more consecutive identical values, and exceedences of six standard deviations of the difference between the candidate and the reference series. Moreover, homogeneity tests have been evaluated from the quality-controlled data over Iberia, in order to detect and correct breaks in time series homogeneity. For Spanish data, the standard normal homogeneity test (SNHT) developed by *Alexandersson and Moberg*

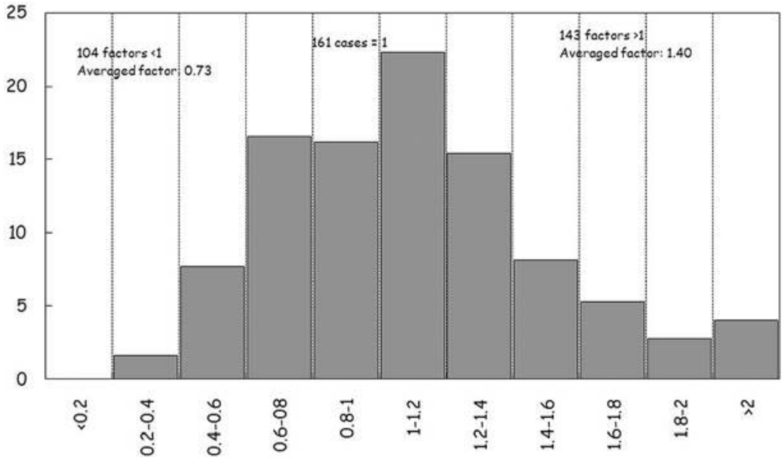

**Figure 1.** Frequency distribution of change point magnitudes referred to the 33 validated and adjusted breakpoints at the monthly scale for the entire Spanish precipitation network.

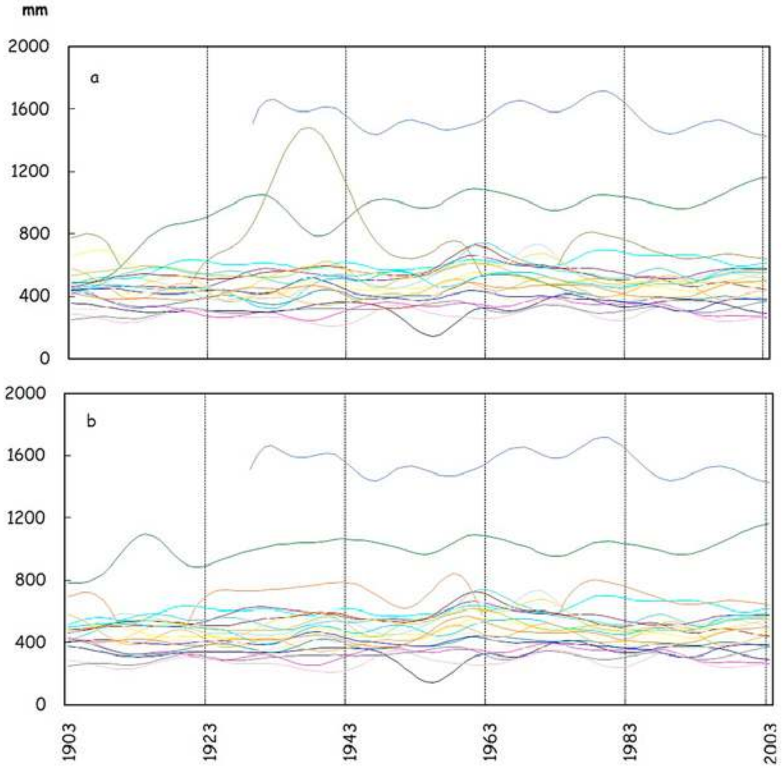

**Figure 2.** (a) Original versus (b) adjusted annual precipitation series for mainland Spain, smoothed by a Gaussian filter of 13 terms.

[1997] was applied, following the procedures described by *Aguilar et al.* [2002]. In order to increase the density of the precipitation network and therefore to enhance the robustness of the QC and homogenization exercises and their results, an extra data set of monthly homogenized precipitation records was employed, which is composed of 91 Iberian records covering the entire twentieth century (see *González-Rouco et al.* [2001] for details on this auxiliary monthly precipitation network).

[15] The detection phase of the SNHT applied to Spanish stations indicated 43 potential breaks in homogeneity in annual and seasonal series. Of these 43, only 33 breakpoints were validated, according to the available metadata and SNHT metrics, and corrected in 16 out of the 23 precipitation series. Only Cádiz, Murcia, Madrid, Sevilla, Tortosa, Zaragoza, and Valencia were considered by the SNHT as homogeneous time series, and therefore no corrections were applied to these quality-controlled records. We have found that the main cause for breaking homogeneity in the Spanish records is related to the stations' relocation (including changes in exposure: e.g., rain gauge moved from courtyard to station's roof), followed by changes in the type of rain gauges employed and for changes in the data source used (e.g., data from the Spanish Met Service to data digitized from other documentary sources). Only we validated and adjusted for six breakpoints undocumented in our metadata, but the SNHT statistics suggested proceeding with their validation, as they consistently appear in four out of five of the annually and seasonally tested scales.

[16] The mean monthly correction factors estimated for the 16 inhomogeneous records varies lightly, e.g., between the values of 0.95 and 1.10 when averaged for the entire set of inhomogeneous records (not shown). However, some individual records and months required higher factors. Figure 1 shows the frequency distribution of change point magnitudes referred to the 33 validated and adjusted breakpoints at the monthly scale for the entire Spanish precipitation network. Some factors are larger than 1.5 and a few of them are lower than 0.5, with most of the required monthly adjustments falling within the 0.6–1.4 range, which also indicates that the homogenization process had little impact in the adjusted records as a whole.

[17] The monthly correction factors estimated by the SNHT were, then, interpolated into the daily values to adjust them by using a not-weighted procedure. As a comparison exercise, we show in Figure 2a (Figure 2b) the original (adjusted) annual precipitation for the Spanish series, smoothed with a 13-term Gaussian filter, in order to better visually explore the impact of the adjustments applied to the original data. The adjusted records show a more coherent temporal behavior than the original smoothed annual series, which also gives us confidence in the satisfactory performance of the homogenization approach adopted.

[18] For Portuguese data, the method used for the study of the series homogeneity is based on *t* and *F* tests and implemented in the *R* program RHTestV2 (http://cccma.seos.uvic.ca/ETCCDMI/RHTest/) [*Wang*, 2003]. No significant change points have been found (at the 5% significance

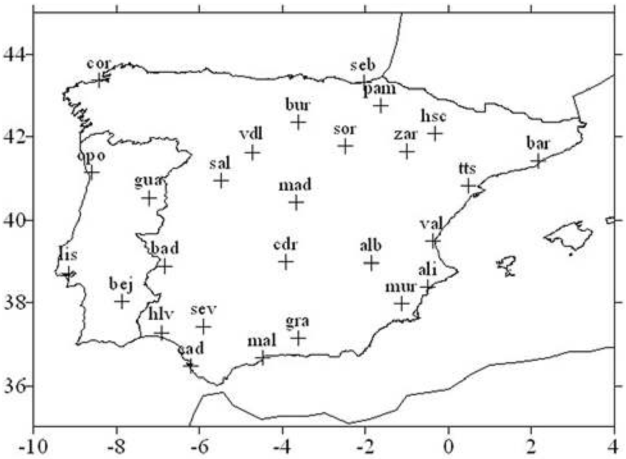

**Figure 3.** Geographical locations of the selected observatories.

level), for neither monthly nor daily series. Therefore, Beja, Guarda, Lisboa, and Oporto were considered as homogeneous time series, and no corrections were applied to the quality-controlled records.

[19] The geographical locations of the 27 daily records employed in this analysis are depicted in Figure 3. The selected network, although moderately coarse, shows a relatively well-spaced distribution of stations, covering the main physiographic units of the IP: coastal lowland sectors (two stations over the northern Spanish Atlantic coast, two over the Portuguese Atlantic coast, two over the southwestern Atlantic coast, and six over the Spanish Mediterranean coast), the Iberian inland plateau (five stations over the northern plateau and five over the southern plateau), the Ebro Valley lowlands (three stations), and the Guadalquivir Valley lowlands (two stations). Although some parts of the IP are not completely well represented, such as the central Cantabrian coast or the western and northwestern parts of Iberia (Figure 3), the long length and the high temporal resolution of the existing records make them very useful to monitor long-term changes in precipitation extremes and to analyze with them long-term climate variability and change, as was done in an exploratory study by *Brunet et al.* [2007] for Spanish series.

## 3. Method

[20] The methodology used in this research is based on the search of trends in time series of rainfall indices obtained from long-term daily rainfall series over the IP. In the following subsections we provide information regarding the choice of indices and their definition, ande we present the statistical procedure used to evaluate the existence of trends and to characterize their spatial patterns.

### 3.1. Indices

[21] We established four categories of daily rainfall in the IP following the same criteria used by *Gallego et al.* [2006]: light (between 0.2 and 2.5 mm), moderate (between 2.5 and 7.5 mm), intense (greater than 7.5 mm), and very intense (greater than 15 mm). These, together with the total rainfall (greater than 0.2 mm), constitute the set of categories by which the rainfall indices will be evaluated. A detailed discussion of the choice of thresholds and the definition of these categories is given by *Gallego et al.* [2005].

[22] A large number of seasonal series of rainfall indices were constructed from the daily rainfall series available for each of the 27 observatories in order to describe the frequency of rainfall. This comprehensive set of frequency indices consisted of the number of rainy days in the categories of total, light, moderate, intense, and very intense rainfall, for each season of the year. Taking into account the high seasonality of rainfall in the IP, each index was evaluated separately for each season defined as follows: spring (March–April–May), summer (June–July–August), fall (September–October–November), and winter (December–January–February). Results obtained for summer must be interpreted with more caution, because the IP is characterized by scarce precipitation events in this season. Nevertheless, for coherence purposes, the summer is included for all the indices.

[23] Also related to the frequency, and complementary to the previous set, were the series of medians and maxima of dry spells, counting the number of dry days between two total rain events. Finally, the corresponding proportion indices are defined through the number of rainy days obtained in each category relative to the corresponding total. The description of this set of indices is summarized in Table 2. Further information about the spatial distribution of the mean values of the frequency indices over Iberia is given by *Gallego et al.* [2004].

### 3.2. Detection of Trends

[24] The evaluation of trends in the rainfall index series has been performed using the nonparametric Mann-Kendall (M-K) test [*Kendall*, 1976]. The null hypothesis $H_0$ is that

**Table 2.** Description of the Set of Rainfall Frequency Indices[a]

| Rainfall Category | Description |
|---|---|
| | *Number of Rainy Days* |
| Total | Seasonal count of days when PRCP $\geq$ 0.2 mm |
| Light | Seasonal count of days when 0.2 mm $\leq$ PRCP $<$ 2.5 mm |
| Moderate | Seasonal count of days when 2.5 mm $\leq$ PRCP $<$ 7.5 mm |
| Intense | Seasonal count of days when PRCP $\geq$ 7.5 mm |
| Very intense | Seasonal count of days when PRCP $\geq$ 15 mm |
| | *Length of Dry Spells* |
| Medians | Seasonal median of number of consecutive days with PRCP $<$ 0.2 mm |
| Maxima | Seasonal maximum of number of consecutive days with PRCP $<$ 0.2 mm |
| | *Proportion* |
| Light | Proportion of rainy days when 0.2 mm $\leq$ PRCP $<$ 2.5 mm with respect to the total |
| Moderate | Proportion of rainy days when 2.5 mm $\leq$ PRCP $<$ 7.5 mm with respect to the total |
| Intense | Proportion of rainy days when PRCP $\geq$ 7.5 mm with respect to the total |
| Very intense | Proportion of rainy days when PRCP $\geq$ 15 mm with respect to the total |

[a] PCRP is precipitation per day.

the data ($X_1$, $X_2$, …, $X_n$) are identical and independently distributed random variables. The alternative hypothesis $H_1$ is that the data are distributed according to an increasing or decreasing trend. The expression of the statistic of the test, $\tau$ (Kendall), is

$$\tau = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \operatorname{sgn}(X_j - X_i),$$

where sgn($X$) is the sign function, with values equal to 1, 0, or 1 depending on whether the argument is negative, zero, or positive, respectively. The variance of $\tau$ under the null hypothesis is obtained through the following expression:

$$\operatorname{var}(\tau) = \frac{n(n-1)(2n+5)}{18}.$$

[25] The exact distribution of $\tau$ can be evaluated and, for $n > 10$, it approaches a normal distribution, especially if the correction $\tau' = \tau - \operatorname{sgn}(\tau)$ is applied. If one considers the normalized variable

$$Z = \frac{\tau'}{\sqrt{\operatorname{var}(\tau)}},$$

then $Z$ is normally distributed with mean 0 and variance 1. The importance of these nonparametric tests is well-known due to their independence from the form of the statistical distribution of the data [*Press et al.*, 1990]. Nevertheless, these methods can be inappropriate when data show substantial serial correlation [*von Storch*, 1995], but for autocorrelations $\leq 0.1$ the tests are adequate. In our case, the lag-1 autocorrelation coefficients are smaller than 0.1 for all the considered series.

[26] In order to estimate the magnitude of the trends, we use the algorithm proposed by *Hirsch and Smith* [1982] that corresponds to an extension of the original test put forward by *Theil* [1950a, 1950b, 1950c] and *Sen* [1968]. The statistic of this Theil-Sen test is related to the slope of the trend found by the M-K test. It is defined as follows:

$$B_k = \operatorname{med}(D_{ijk}),$$

where $D_{ijk} = (x_{ik} - x_{jk})/(i - j)$ for all pairs of $(x_{ik} - x_{jk})$, with $k$ being each one of the seasons and $1 \leq i < j \leq n_k$, $n_k$ being the number of observations in season $k$ during the period considered. The slope estimator $B$ is related to the Kendall statistic $\tau'$ as follows: If $\tau' > 0$, then $B \geq 0$. Moreover, $B$ is a measure of the slope that is insensitive to the effect of the existence of extreme values in the data, since it is evaluated with the median [*Lettenmaier et al.*, 1994].

[27] The M-K test will be evaluated two sidedly for two significance levels: at 5% and at 10%. $B$ will be normalized with respect to the standard deviation of each series so that it is possible to compare the results among observatories as homogeneously as possible. Moreover, a spatial interpolation of $B$ will be performed by kriging [*Nychka et al.*, 1998] using the FIELDS *R* software package (Fields Development Team, tools for spatial data, http://www.image.ucar.edu/GSP/Software/Fields) to explore the spatial coherence of the trends calculated for each IP index series.

[28] The results will be mapped in figures that contain twofold information relative to the trend of every index at each observatory independently and to the spatial distribution of the slopes obtained in the procedure. In order to obtain regional conclusions that take into account the behavior of all the observatories as a whole, we will apply the binomial distribution to our problem, $B(n, p)$ with $n = 27$ and $p = 0.05$. From this binomial distribution, in order that a regional result is significant at the 5% level in the IP from the evaluation of M-K test at 27 observatories distributed over its geography, it is necessary to find at least four trends of the same sign within the whole IP. Thus, any smaller number of significant trends (up to three) might be obtained randomly. A more detailed description of this methodology is given by *Gallego et al.* [2006].

## 4. Trend Analysis

[29] In this section, we will analyze the trends found when one applies the M-K test to the series of rainfall indices for each category in every season and observatory for three periods: the complete period PT and the two subperiods P1 and P2. Results are presented in maps that show the spatial distribution of the Theil-Sen statistic $B$ over the whole of Iberia and, additionally, symbols that represent the character of the trend found in each observatory (if there is a significant trend). Upward-pointing triangles represent increasing trends, and downward-pointing triangles represent decreasing trends. The size of each triangle is proportional to the magnitude of the normalized trend (normalized by the standard deviation of each seasonal index series at each observatory) (see Figure 4). Black triangles represent trends significant at the 5% level, and gray triangles indicate trends significant at the 10% level. The trends with absolute value of <0.125 are represented by circles. Isolines correspond to interpolated values of the normalized trend (in percentages). In order to provide a high enough resolution for the figures, the legends are scaled with respect to each individual figure and this must be considered when comparing results. Nevertheless, the color palette is always the same: blue implies decrease and red implies increase. We will only comment on the statistically significant trends.

### 4.1. Number of Rainy Days

[30] The spatial distribution of the trends in the number of rainy days for the PT is shown in Figure 4. The categories of total and light rainfall present similar patterns: an almost generalized increase in the number of rainy days over the IP (see Table 3 in order to appreciate the high number of significant positive trends especially for the light rainfall category: 15 in spring, 14 in summer, 11 in the fall, and 15 in winter). Only in the Atlantic facade (Portuguese coast and Cádiz gulf) is there a decrease mainly in spring and fall, and also in winter for light rainfall. This increase, in the number of rainy days during the twentieth century, could be related to the linear increasing trend in global precipitation fields during the period 1900–88 found by *Dai et al.* [1997] in midlatitude to high-latitude Eurasia from monthly precipitation data. For the remaining precipitation categories, the behavior is not so generalized. Nevertheless, the positive trend that characterizes most classes for winter, the rainiest season, is worth noticing. The moderate rainfall trends present significant values over

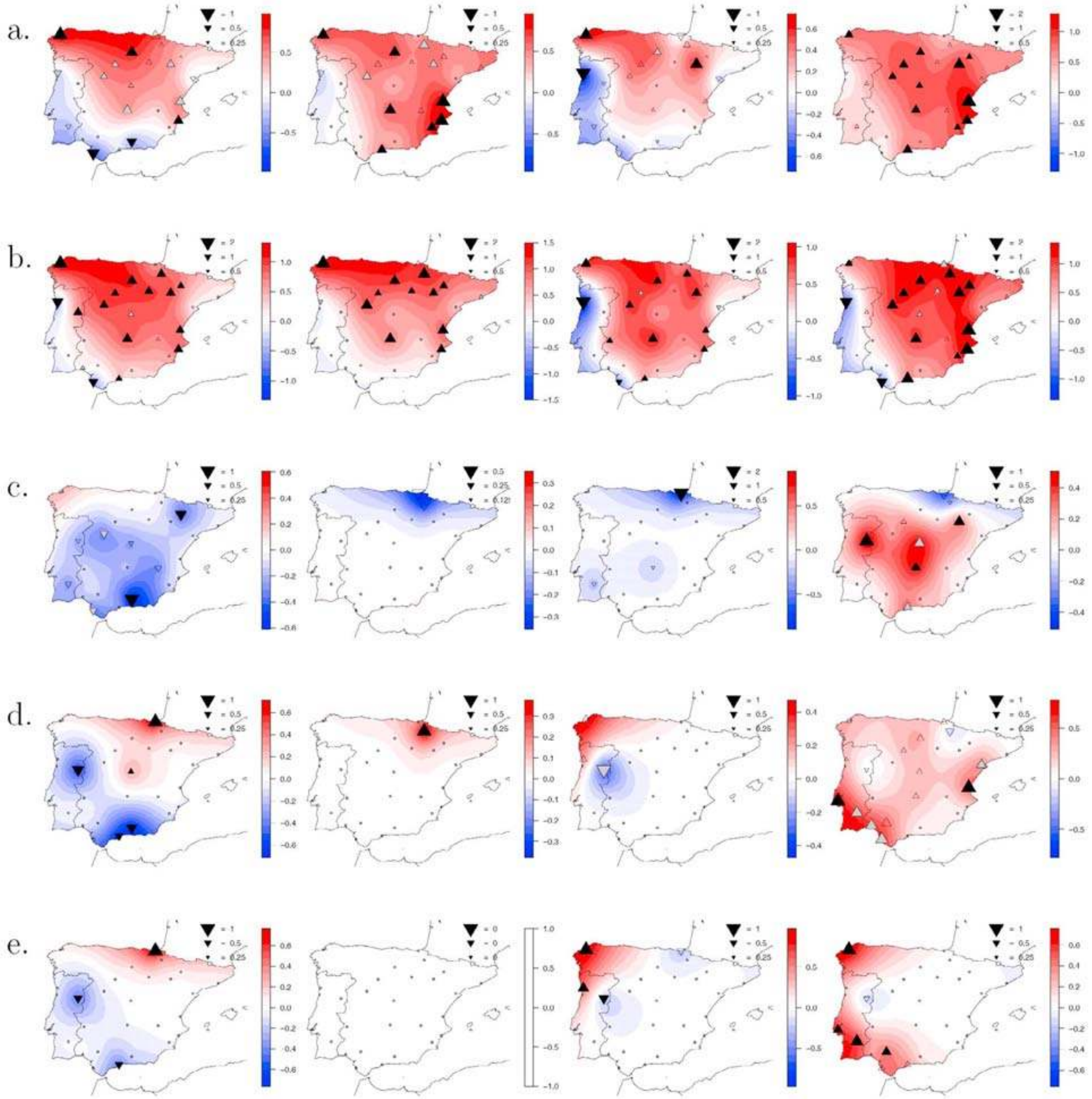

**Figure 4.** Mann-Kendall test for number of rainy days in (from left to right) spring, summer, fall, and winter: (a) total, (b) light, (c) moderate, (d) intense, and (e) very intense. Upward-pointing triangles represent increasing trends, and downward-pointing triangles represent decreasing trends. The size of each triangle is proportional to the magnitude of the normalized trend (normalized by the standard deviation). Solid black triangles represent trends significant at the 5% level, and solid gray triangles indicate trends significant at the 10% level. Isolines correspond to interpolated values of the normalized trend (in percentage). Circles show trends with absolute value of <0.125. Period is 1903–2003.

the interior of the IP, while the intense and very intense rainfall classes concentrate the most significant values in the west and southwest coasts. In spring some decreases appear, mainly in moderate rainfall. Some of the isolated patterns found are a negative trend in northern San Sebastián (Basque Country) for moderate rain in the fall and winter and a positive trend for intense and very intense rain in spring.

[31] The distribution of the same index for P1 is displayed in Figure 5. Maps show a positive trend in the northern half of the IP, mainly in spring, as depicted by the seven significant trends (Table 3), but also in summer and winter for the total rainfall category. A similar behavior is presented by light rainfall, although, for this category, negative trends are depicted in the southern half of IP. For the case of moderate

**Table 3.** Number of Significant Trends Found in Series of Seasonal Number of Rainy Days for Each Rainfall Category[a]

| | 1903–2003 (PT) | | | 1903–1953 (P1) | | | 1954–2003 (P2) | | |
|---|---|---|---|---|---|---|---|---|---|
| | Negative | Positive | WT | Negative | Positive | WT | Negative | Positive | WT |
| *Spring* | | | | | | | | | |
| Total | 3 | 8 | 16 | 0 | 7 | 20 | 2 | 1 | 24 |
| Light | 2 | 15 | 10 | 4 | 5 | 18 | 1 | 5 | 21 |
| Moderate | 4 | 0 | 23 | 0 | 4 | 23 | 3 | 1 | 23 |
| Intense | 3 | 2 | 22 | 0 | 5 | 22 | 5 | 0 | 22 |
| Very intense | 3 | 2 | 22 | 0 | 5 | 22 | 5 | 0 | 22 |
| *Summer* | | | | | | | | | |
| Total | 0 | 10 | 17 | 2 | 4 | 21 | 1 | 0 | 26 |
| Light | 1 | 14 | 12 | 3 | 4 | 20 | 1 | 2 | 24 |
| Moderate | 0 | 1 | 26 | 1 | 2 | 24 | 3 | 1 | 23 |
| Intense | 0 | 2 | 25 | 0 | 2 | 25 | 5 | 0 | 22 |
| Very intense | 0 | 1 | 26 | 0 | 4 | 23 | 4 | 0 | 23 |
| *Fall* | | | | | | | | | |
| Total | 2 | 3 | 22 | 10 | 2 | 15 | 0 | 4 | 23 |
| Light | 3 | 11 | 13 | 5 | 3 | 19 | 2 | 10 | 15 |
| Moderate | 1 | 0 | 26 | 4 | 0 | 23 | 0 | 4 | 23 |
| Intense | 1 | 0 | 26 | 7 | 1 | 19 | 0 | 0 | 27 |
| Very intense | 2 | 2 | 23 | 6 | 2 | 19 | 0 | 2 | 25 |
| *Winter* | | | | | | | | | |
| Total | 0 | 12 | 15 | 0 | 3 | 24 | 3 | 1 | 23 |
| Light | 2 | 15 | 10 | 2 | 7 | 18 | 2 | 2 | 23 |
| Moderate | 0 | 6 | 21 | 1 | 2 | 24 | 4 | 0 | 23 |
| Intense | 0 | 6 | 21 | 0 | 3 | 24 | 5 | 0 | 22 |
| Very intense | 0 | 6 | 21 | 0 | 3 | 24 | 3 | 0 | 24 |

[a] WT, without significant trend.

rainfall, positive trends are shown in the northern half of IP in spring, San Sebastián in summer, and the eastern half of the peninsula in winter. The intense and very intense categories present similar patterns: positive trends appear in the western half of IP in spring and in the northern Cantabrian and Pyrenees regions in summer and winter. In the fall, a similar behavior appears for all the rainfall categories: negative trends in almost all of the IP except in the La Coruña zone, especially for the total rainfall category for which 10 significant negative trends are found, as shown in Table 3.

[32] The spatial distribution for the number of rainy days in the P2 period is depicted in Figure 6. A completely different picture from the previous 50 years emerges, with the total rainfall category presenting generalized negative trends in the western and southern coasts in spring and winter. In fact, in winter the negative trend is almost generalized to the entire IP and for all categories. For the region of Catalonia, this result is in agreement with that obtained by *Martínez et al.* [2007], who detected significant negative trends in the number of rainy days for percentiles up to the 75th in this zone for the 1950–2000 period. In the fall, practically only positive trends are found. For the light rainfall category, almost the whole of the peninsular geography, except the Portuguese coast and the Cádiz gulf, shows an increase in the number of events in this category in spring and especially in the fall when 10 significant positive trends appear (Table 3); this behavior is opposite the one found for P1 for light rainfall in the fall. Negative trends of light rainfall are more intense in winter, when only a positive zone appears in the Pyrenees. In summer, there are isolated cases in this category: a negative trend in Guarda and a positive one in Málaga. For moderate rainfall, the generalized positive trend pattern in the fall, except in the west coast, and the negative trend behavior in winter in almost the whole peninsular geography are noticeable. Intense and very intense categories present similar patterns: negative trends in the west and southwest of the IP in spring, which are also extended to the interior in winter, when a great part of the IP shows this behavior. In the fall, we notice the positive trends in the west coast of the IP.

[33] The overall configuration of these extreme (intense and very intense) precipitation indices trend patterns for P2 are relatively similar to those obtained by *Gallego et al.* [2006] for the period 1958–1997.

[34] A note of caution should be thrown here to draw attention to the fact that, by analyzing Table 3 and Figures 4–6, it is possible to conclude that in several cases the number of stations with significant trends is higher for PT than in the two subperiods P1 and P2. For example, in the light rainfall category, for PT 11 stations show significant positive trends in the fall, whereas for P1 only five stations have significant negative trends although for P2 10 stations have significant positive trends.

[35] This apparent contradiction derives from the Mann-Kendall test significant assessment that is particularly sensitive to the ratio of variance/length of the time series analyzed. In this regard, a time series with a monotonic trend (upward or downward) and constant variability may not fulfill the test hypothesis relative to the first and second halves, but still pass the test for the entire period.

### 4.2. Length of Dry Spells

[36] For the case of the length of dry spells, we have analyzed two indices, medians and maxima, for the three

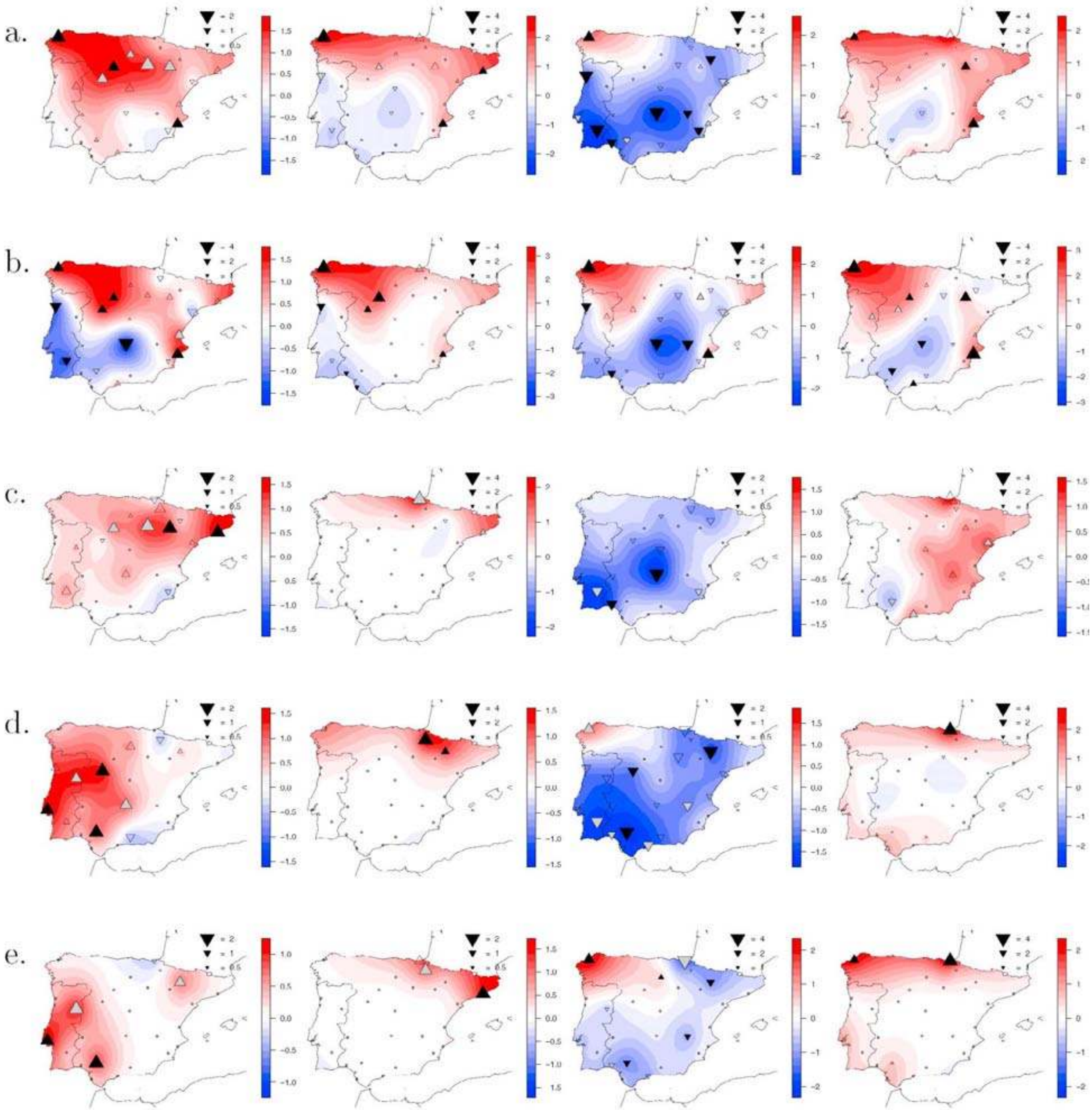

**Figure 5.** Mann-Kendall test for number of rainy days as in Figure 4. Period is 1903–1953.

periods of study. The spatial distribution of these two indices for the PT is shown in Figure 7. There is a widespread tendency for negative trends throughout the year and for both indices. Nevertheless, the behavior of the maxima of dry spells in winter must be pointed out, with generalized negative trends over the IP (with 12 significant negative trends, as Table 4 shows). A similar behavior can be detected for summer (with nine trends; see Table 4), but with light positive trends in Portugal. Spring and fall exhibit similar patterns with a negative zone in a band from the northwest to the southeast of the IP and positive zones in the southwest coast and Catalonia. These patterns for maxima of dry spells in the period of study 1903–2003 are complementary to those displayed in Figure 4 for the total number of rainy days.

[37] When we split the entire period into the two consecutive periods, a number of distinct patterns emerge for each half. The spatial distribution of trends for medians and maxima of dry spells for P1 is depicted in Figure 8. Medians show a negative trend in the north interior of the IP in spring, persisting in the northwest of the IP during summer and fall, but also in Catalonia and the east coast in summer and in some isolated cases in the west interior and the east of the IP in winter. In contrast, positive trends are considerably

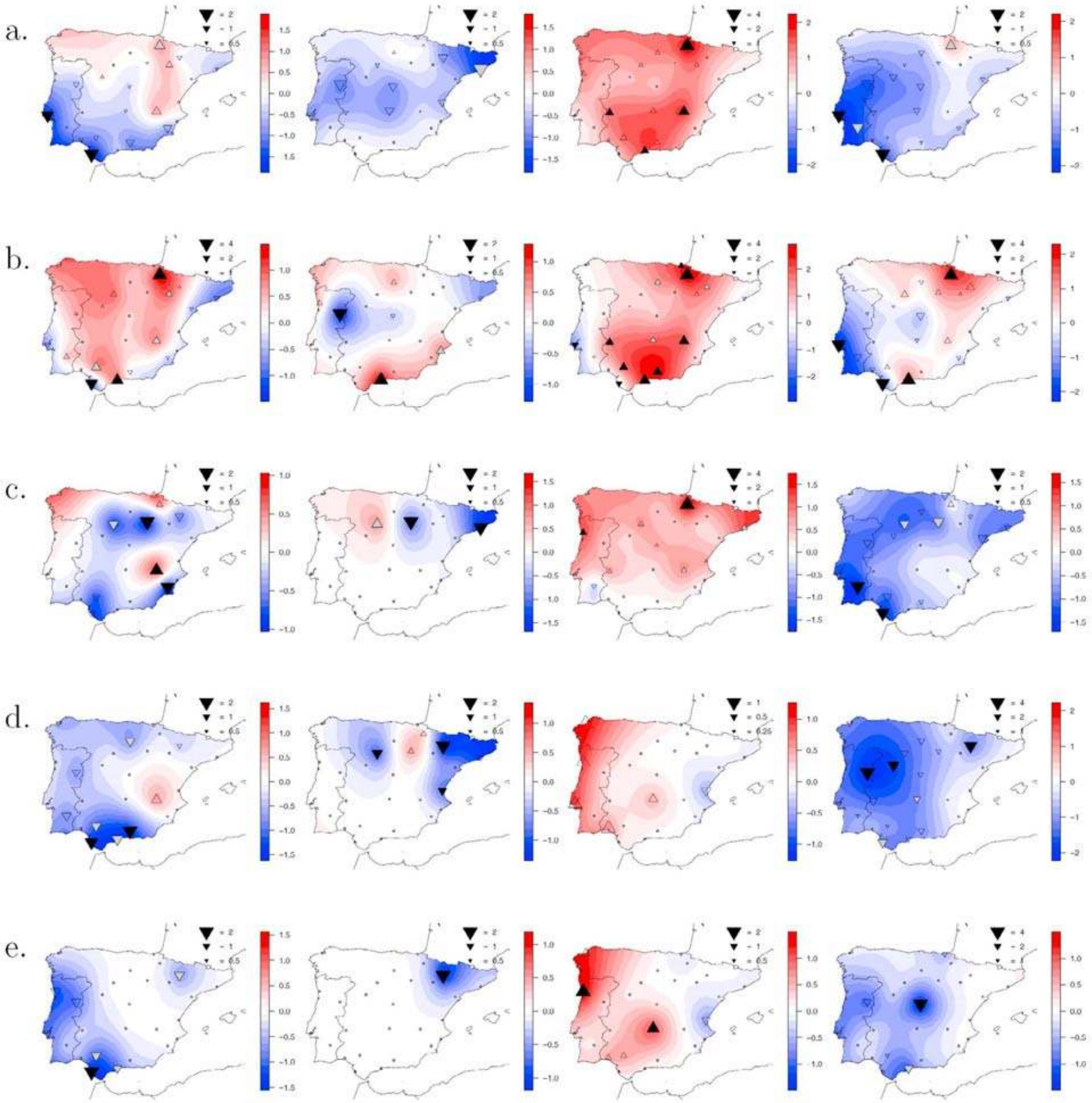

**Figure 6.** Mann-Kendall test for number of rainy days as in Figure 4. Period is 1954–2003.

more limited to the south coast of the IP and Catalonia in the fall. Maxima of dry spells present very similar patterns to those described for the median. It is worth noticing the negative trends in spring in the whole of the IP, except in the Portuguese coast, with positive trends in Oporto and Lisboa. This positive region grows a bit toward the interior in summer, adding Beja and Ciudad Real, with significant positive trends. In the fall, we have positive trends in almost all of the IP, except in the Cantabrian and Portuguese coasts that show negative trends. In winter, two zones with negative trends appear: the northwest sector and the eastern coast of the IP.

[38] The spatial distribution of trends for medians and maxima of dry spells for P2 is displayed in Figure 9. During this second period there is a more generalized tendency for positive trends, contrasting with what was described for the first period. Medians present widespread negative trends only in the fall, with the exception of the northern coast. For the remaining seasons, we have positive trends: in the Mediterranean coast and Cádiz gulf in spring; west, southwest, interior of the IP, and Pyrenees zone in summer; Catalonia, Ebro valley, and Cádiz in winter. A more complex picture emerges for the maxima values, although these still exhibit light positive trends in almost all of the IP in spring, except in the Mediterranean region. In summer, there are isolated zones with opposite behavior. In the fall, a more generalized negative trend appears in all of the IP, with the exception of Murcia, which shows a light increasing trend. The winter season is better described by a bipolar behavior, with an

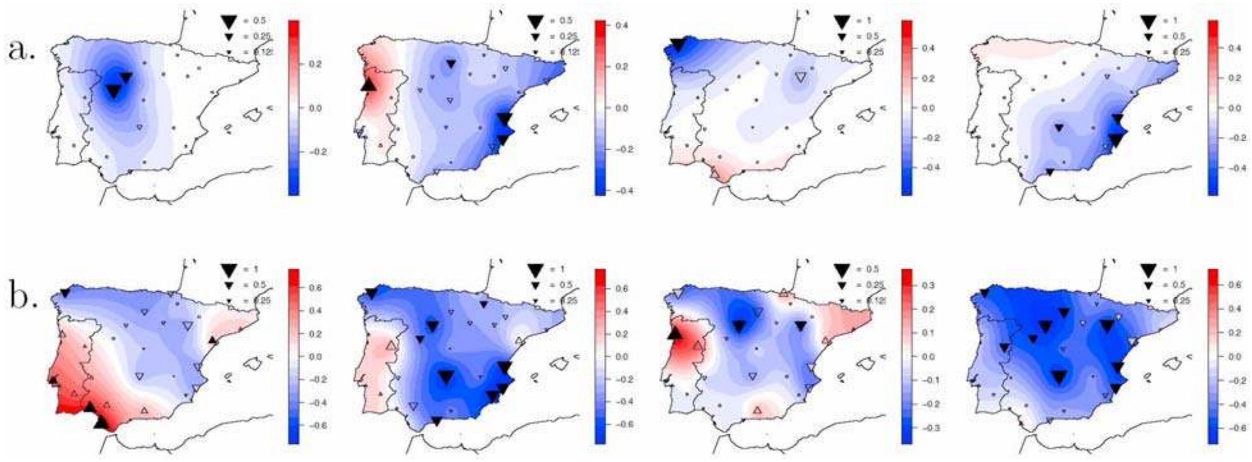

**Figure 7.** Mann-Kendall test for dry spells in (from left to right) spring, summer, fall, and winter: (a) medians and (b) maxima. Upward-pointing triangles represent increasing trends, and downward-pointing triangles represent decreasing trends. The size of each triangle is proportional to the magnitude of the normalized trend (normalized by the standard deviation). Solid black triangles represent trends significant at the 5% level, and solid gray triangles indicate trends significant at the 10% level. Isolines correspond to interpolated values of the normalized trend (in percentage). Circles show trends with absolute value of <0.125. Period is 1903–2003.

increasing trend in Portugal and both Mediterranean and southern coasts and a decreasing trend in the Cantabrian and Pyrenees regions. These decreasing trends are also found by *Serra et al.* [2006] in Catalonia during the second half of twentieth century. *Lana et al.* [2008] also find a variety of local behaviors in observatories around all of the IP for the length of dry spells during the period 1951–2000, but pointing toward a shortening of dry spell lengths. However, other authors also describe an increase of the dry spells in the south of Portugal during 1955–1999, with a tendency toward drier climatic conditions in this area [*Costa and Soares*, 2009], in agreement with our findings.

### 4.3. Proportion of Rainy Days in Each Rainfall Category With Respect to the Total

[39] Trends found through the application of the M-K test to the series of proportion of rainfall in each category are shown in Figures 10–12. This index can be interpreted as a normalization of the number of rainy days in each rainfall category with respect to the total.

[40] Results for PT are displayed in Figure 10, and it can be seen that they vary considerably among different precipitation categories. Patterns shown for the proportion of light rainfall are similar to those seen for the case of number of light rainy days (Figure 4b). A generalized increase in the number of light rainy days relative to the total is found for all seasons over the whole of the IP (17 significant positive trends in spring, 13 in summer, 14 in the fall, and 10 in winter (Table 5)). Only the Portuguese coast and the Cádiz gulf show decreasing trends, with these being more marked in winter. In contrast, moderate rainfall events are decreasing practically in the entire peninsula (12 significant negative trends in spring, seven in summer, seven in the fall, and nine in winter (Table 5)), except for the west Portuguese coast in

**Table 4.** Number of Significant Trends Found in Series of Seasonal Length of Dry Spells for Each Rainfall Category[a]

| | 1903–2003 (PT) | | | 1903–1953 (P1) | | | 1954–2003 (P2) | | |
|---|---|---|---|---|---|---|---|---|---|
| | Negative | Positive | WT | Negative | Positive | WT | Negative | Positive | WT |
| | | | | *Spring* | | | | | |
| Medians | 3 | 1 | 23 | 3 | 1 | 23 | 1 | 4 | 22 |
| Maxima | 2 | 5 | 20 | 4 | 0 | 23 | 1 | 1 | 25 |
| | | | | *Summer* | | | | | |
| Medians | 4 | 1 | 22 | 4 | 1 | 22 | 0 | 7 | 20 |
| Maxima | 9 | 0 | 18 | 7 | 2 | 18 | 3 | 2 | 22 |
| | | | | *Fall* | | | | | |
| Medians | 4 | 2 | 21 | 1 | 3 | 23 | 6 | 0 | 21 |
| Maxima | 4 | 1 | 22 | 2 | 4 | 21 | 3 | 0 | 24 |
| | | | | *Winter* | | | | | |
| Medians | 8 | 1 | 18 | 4 | 0 | 23 | 1 | 5 | 21 |
| Maxima | 12 | 0 | 15 | 6 | 1 | 20 | 1 | 1 | 25 |

[a] WT, without significant trend.

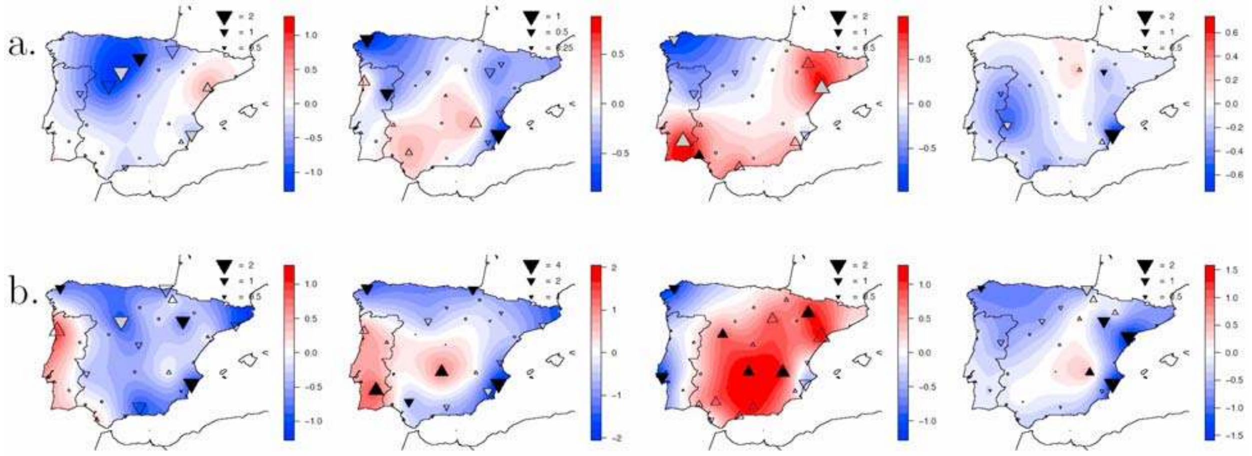

**Figure 8.** Mann-Kendall test for dry spells as in Figure 7. Period is 1903–1953.

the fall. In the case of intense rainfall, the number of events in this category is decreasing in spring, also in an almost widespread way, except in Oporto and Lisboa where they are increasing. A similar evolution is taking place in the fall and winter, although in winter the positive trend zone spreads down to the Cádiz gulf. For the very intense rainfall category we can find a less clear picture, with more isolated patterns and, additionally, with trends of smaller magnitude. Nevertheless, it is worth noting the increasing trends in all the west coast of the IP in the fall, and in the west coast plus the Cádiz gulf in winter. In summary, we can say that during the centennial period that spans 1903–2003 rainfall episodes are becoming less and less intense in the whole IP, with the main exceptions being observed over Portugal and the contiguous Cádiz gulf region, where they are intensifying.

[41] Once again we have repeated the analysis to the split 50 year periods, and the results obtained with P1 can be seen in Figure 11. The patterns found are a bit more complex than those previously described for the entire century (Figure 10). For the proportion of light rain the northwest sector of Iberia presents consistent positive trends all year. In the fall this region is extended to almost the whole western half of the IP, the Pyrenees zone, and the Valencian coast. The Valencian coast also shows a positive trend in spring and winter. Regions dominated by negative trends are concentrated in the southwest and interior parts of the IP, particularly in spring and winter, and the south and interior of the IP in the fall. For the moderate rain category we can detect, in general, patterns opposite those we have mentioned for the light rain category. For the intense rain, we can emphasize the increase of episodes in this category in the west, southwest, and interior of the IP in spring, whereas a decrease takes place in the rest of the peninsula. In contrast, during the fall there appears to be a widespread negative tendency throughout the IP, especially in the peninsular west. Finally, for the very intense rain category, we have a behavior similar to that of the intense rain in spring. The increase of these episodes in summer in the Ebro valley sector and in Catalonia must also be emphasized, while in the fall this positive trend is confined to the northwest and in winter dominates the northern and southern coasts. In contrast, in the fall we have a decrease of episodes of very intense rain in the southern and eastern zones.

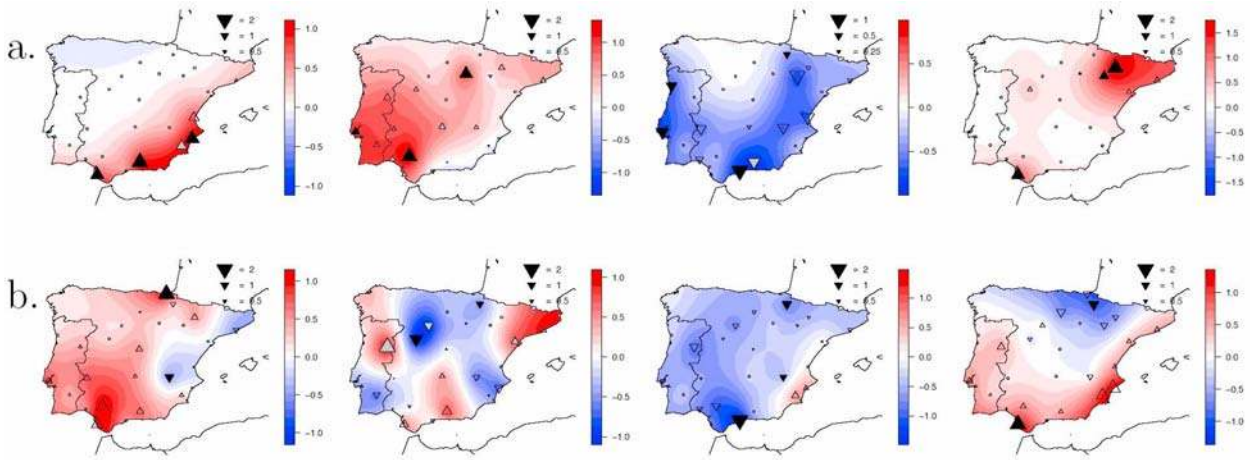

**Figure 9.** Mann-Kendall test for dry spells as in Figure 7. Period is 1954–2003.

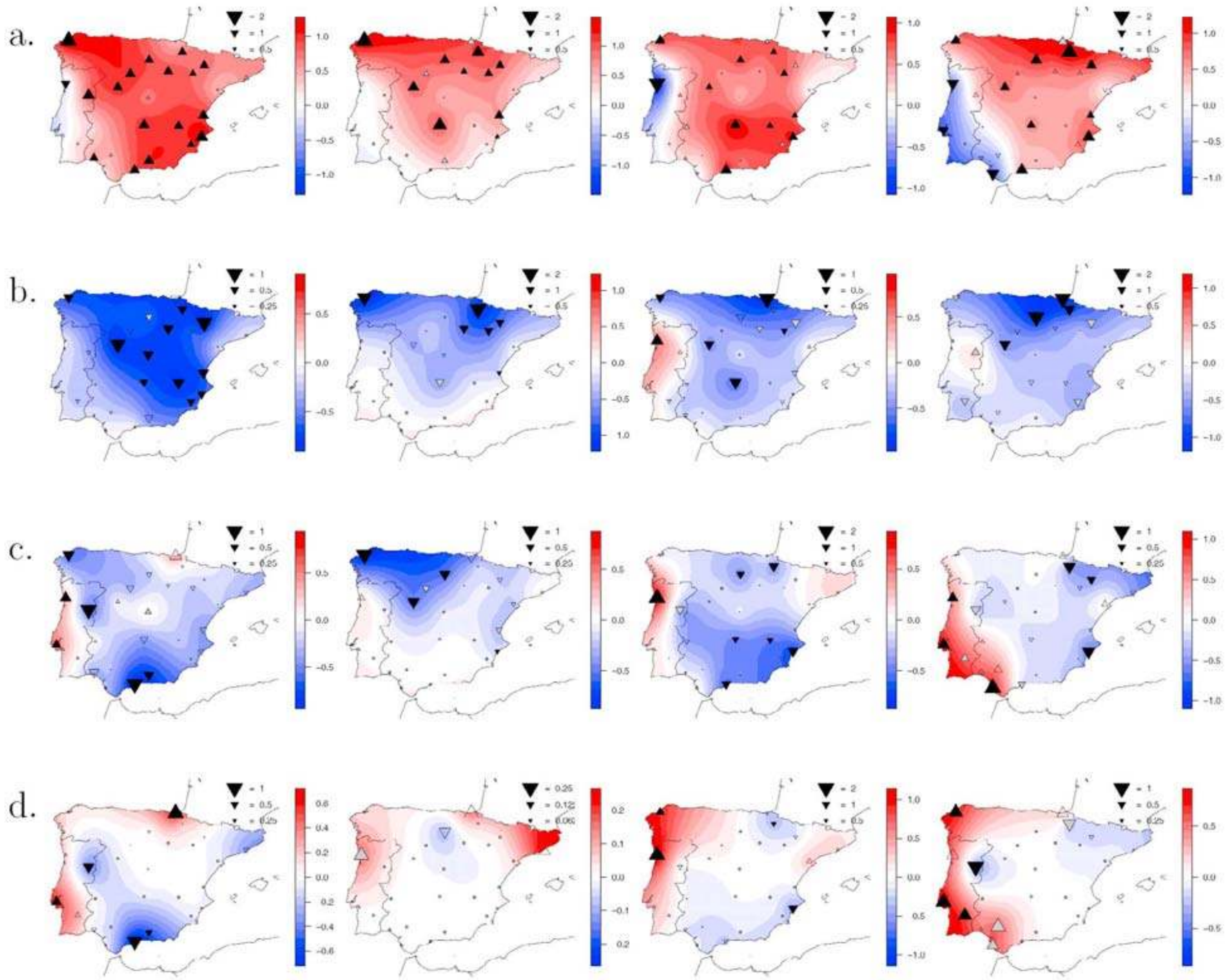

**Figure 10.** Mann-Kendall test for proportion of rainy days in each rainfall category with respect to the total in (from left to right) spring, summer, fall, and winter: (a) light, (b) moderate, (c) intense, and (d) very intense. Upward-pointing triangles represent increasing trends, and downward-pointing triangles represent decreasing trends. The size of each triangle is proportional to the magnitude of the normalized trend (normalized by the standard deviation). Solid black triangles represent trends significant at the 5% level, and solid gray triangles indicate trends significant at the 10% level. Isolines correspond to interpolated values of the normalized trend (in percentage). Circles show trends with absolute value of <0.125. Period is 1903–2003.

[42] The spatial distribution of trends for P2 is displayed in Figure 12. Here, the category of light rainfall is experiencing an increase relatively generalized to the whole IP, with a high number of significant positive trends (Table 5) in spring and winter. The picture becomes more bipolar in summer and fall, where we have an increase in the southeast and east of the IP and a light decrease in the rest of the peninsula. The moderate rain category presents decreases in spring in the interior, east, and south and in summer in the eastern half of the IP. A decrease dominates also in the fall in the eastern half, except in Barcelona (where a light increase appears) and over almost the entire IP in winter. Increase trends for the moderate category are mostly restricted to the western (summer) and northwestern (fall) sectors. For the intense rain category we can observe widespread decreases in the whole of the IP, with small positive trend exceptions being restricted to the Iberian System and Valencian coast (spring), the Cantabrian and Portuguese coasts (summer), the western coast (fall), and the eastern coast (winter). The very intense rain category appears to be generally characterized by patterns very similar to those depicted for the intense rain in spring, fall, and winter. However, summer presents negative trends restricted only to two northern observatories: Burgos and Huesca.

## 5. Summary and Conclusions

[43] In this work, we have examined the trends in three indices designed to highlight changes in the frequency of precipitation at 27 stations covering the IP for the complete period 1903–2003 and the two subperiods 1903–1953 and 1954–2003. These indices were evaluated seasonally in five

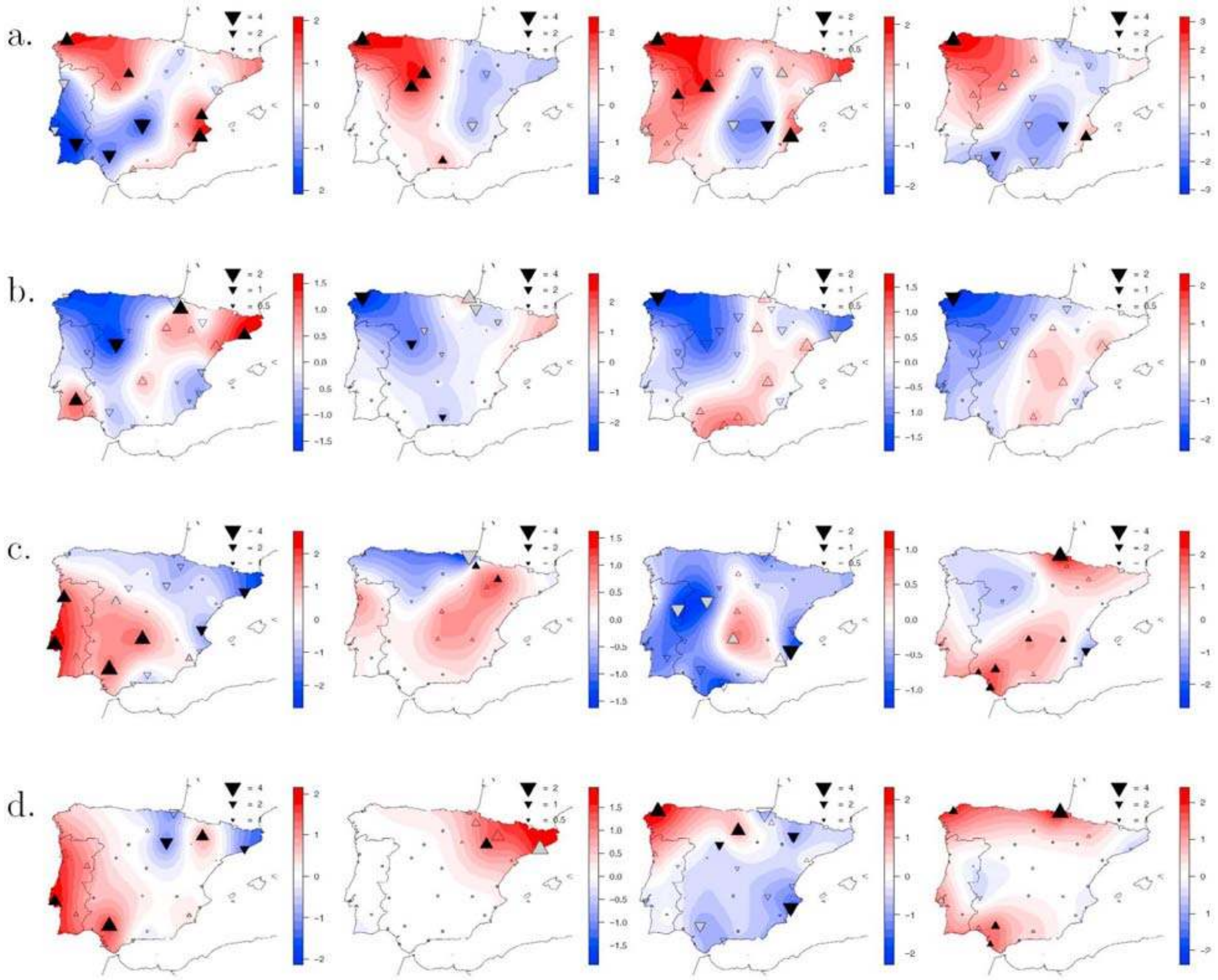

**Figure 11.** Mann-Kendall test for proportion of rainy days in each rainfall category with respect to the total as in Figure 10. Period is 1903–1953.

rainfall categories, chosen specifically to take the rainfall regime of this region into account. Hence the work involved the study of a great number of series in order to determine the evolution of the daily precipitation characteristics and the spatial distribution of the trends that were found over the cited period. The results showed statistically significant and spatially coherent trends for some of the analyzed indices. Our findings are internally coherent, and they correspond well with what has been reported by other researchers in more global or regional studies. The patterns of behavior can be summarized as follows.

[44] For the complete period 1903–2003, we have found that the total number of rainy days and of light rainfall days are increasing at many observatories over the IP and for all seasons, except in the western zone of Portugal and the Cádiz gulf, where they are decreasing. Coherent with the previous finding, maxima of dry spells are diminishing for most observatories over the IP throughout the year, with the exceptions concentrated again over Portugal and the Cádiz gulf, where they are increasing. Moreover, results show that the rain events are becoming less and less intense in the whole IP in all the seasons except in the previously mentioned regions of Portugal and the Cádiz gulf, where they are intensifying.

[45] When one looks in more detail at each subperiod, the behavior of the trends seems to be less generalized. Nevertheless, it is possible to extract some important features. When the second 50 year period is analyzed, a completely different picture emerges from the first period. For this first subperiod (1903–1953), we can find an almost generalized decrease in the number of rainy days in the fall for all the rainfall categories. In contrast, for the second subperiod (1954–2003), we find the opposite pattern: an increase of the number of rainy days in the fall for all the categories of rainfall, especially for total and light rain. In spring, an increase in the number of rainy days is found mainly for total, moderate, and intense categories for the first subperiod and a slight decrease is found for the second. In winter, we can notice a clearer decrease in the number of rainy days mainly for total, moderate, and intense rainfall categories in the second subperiod. In the case of the maxima of dry spells for both subperiods, there are many observatories that

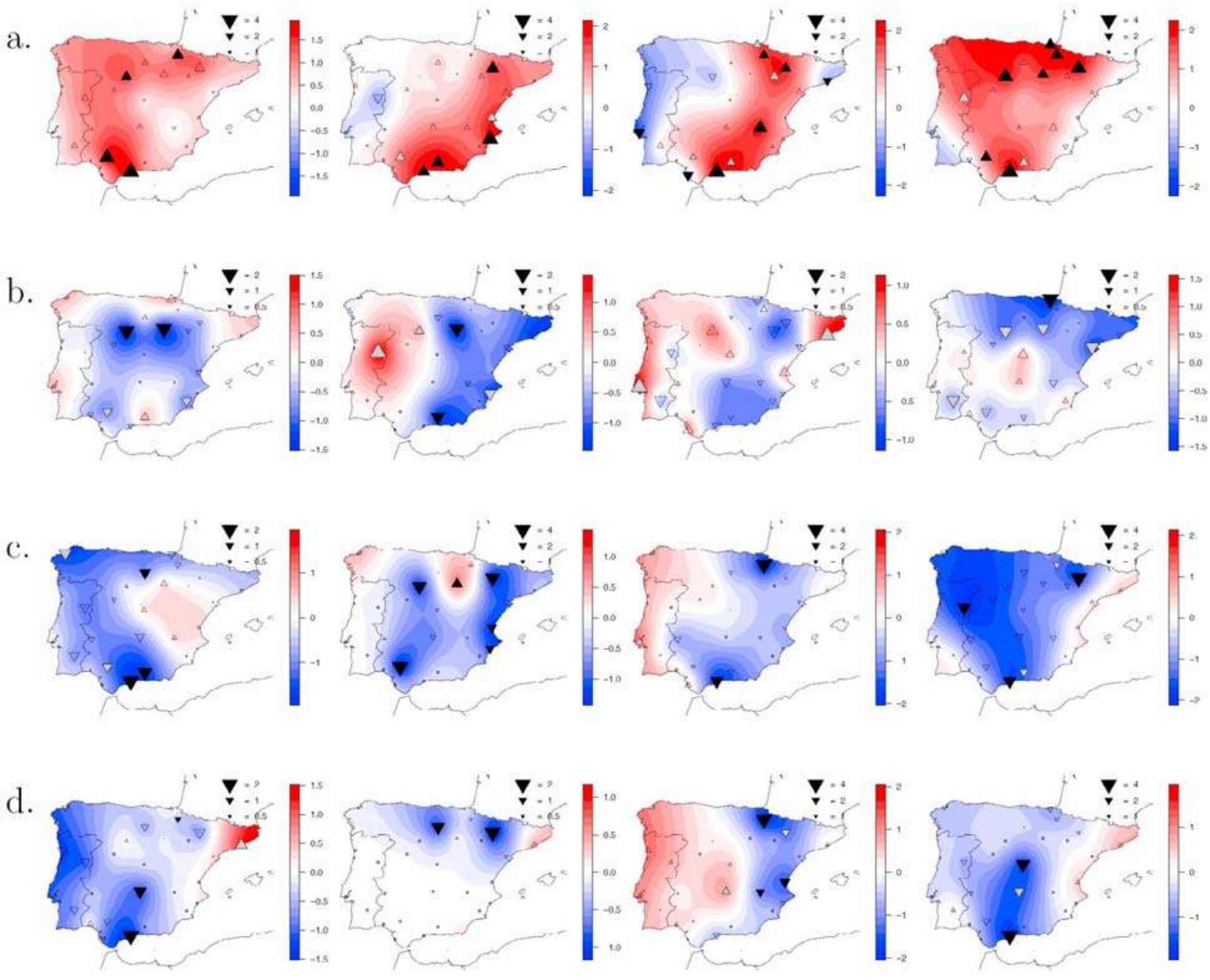

**Figure 12.** Mann-Kendall test for proportion of rainy days in each rainfall category with respect to the total as in Figure 10. Period is 1954–2003.

show significant trends opposite those of the total number of rainy days. This was to be expected, since the two indices can be regarded as complementary. A proof of the consistency of our results is the similarity of the behavior found here for the last subperiod to the one described by *Gallego et al.* [2006] for a slightly different network and period (1958–1997).

[46] This decrease in precipitation observed during P2 may be partially due to the significant increase of the Arctic Oscillation and NAO indices throughout the second half of the twentieth century [*Hurrell*, 1995; *Trigo et al.*, 2004; *Lopez-Bustins et al.*, 2008]. Generally, positive trends of these indices are consistent with the reduction in winter precipitation over the western Mediterranean area (including the IP) during this subperiod [*Trigo et al.*, 2004]. *Esteban et al.* [2006] have found a significant positive trend for the daily circulation type entitled “Central Europe high” for the period 1960–2001. This relatively dry pattern corresponds to an anticyclone over central Europe connected with the Azores high pressure. In fact, several authors have indicated that the decrease in frequency of “wet” weather types (Cyclonic C, or those with a western component W, SW) was the main driver of the precipitation decline observed in Portugal during the second half of the twentieth century [*Corte-Real et al.*, 1998; *Trigo and DaCamara*, 2000]. In the same tone, *Vicente-Serrano and López-Moreno* [2006] found a general positive trend in the frequency of the weather types prone to dry conditions over the IP (A, SE, and E) and a general negative trend of cyclonic and west weather types (SW, W, and NW) in the same period. These trends found in the weather types that affect the IP can explain the decrease in precipitation and the increase in length of dry spells found for P2.

[47] Recent works have stressed that some anthropogenic factors can affect the pluviometric regime of a certain region, namely the construction of dams with large irrigated areas. The IP is characterized by an irregular hydrological regime particularly prone to large droughts and wet periods [e.g., *Trigo et al.*, 2004; *Vicente-Serrano and López-Moreno*, 2006]. In order to relieve the disastrous consequences of these phenomena and to guarantee water resources for the economic activities, a large number of dams have been erected since 1950 throughout the whole of the IP.

**Table 5.** Number of Significant Trends Found in Series of Seasonal Proportion of Rainy Days for Each Rainfall Category[a]

| | 1903–2003 (PT) | | | 1903–1953 (P1) | | | 1954–2003 (P2) | | |
|---|---|---|---|---|---|---|---|---|---|
| | Negative | Positive | WT | Negative | Positive | WT | Negative | Positive | WT |
| | | | | *Spring* | | | | | |
| Light | 2 | 17 | 8 | 5 | 4 | 18 | 0 | 4 | 23 |
| Moderate | 12 | 0 | 15 | 1 | 3 | 23 | 4 | 0 | 23 |
| Intense | 4 | 3 | 20 | 2 | 6 | 19 | 5 | 0 | 22 |
| Very intense | 3 | 3 | 21 | 2 | 4 | 21 | 3 | 1 | 23 |
| | | | | *Summer* | | | | | |
| Light | 0 | 13 | 14 | 1 | 4 | 22 | 0 | 7 | 20 |
| Moderate | 7 | 1 | 19 | 6 | 2 | 19 | 3 | 2 | 22 |
| Intense | 6 | 0 | 21 | 1 | 2 | 24 | 7 | 1 | 19 |
| Very intense | 0 | 1 | 26 | 0 | 2 | 25 | 5 | 1 | 21 |
| | | | | *Fall* | | | | | |
| Light | 2 | 14 | 11 | 2 | 7 | 18 | 3 | 8 | 16 |
| Moderate | 7 | 2 | 18 | 2 | 0 | 25 | 0 | 2 | 25 |
| Intense | 7 | 1 | 19 | 3 | 1 | 23 | 2 | 1 | 24 |
| Very intense | 2 | 2 | 23 | 4 | 2 | 21 | 4 | 1 | 22 |
| | | | | *Winter* | | | | | |
| Light | 3 | 10 | 14 | 6 | 5 | 16 | 0 | 9 | 18 |
| Moderate | 9 | 1 | 17 | 2 | 0 | 25 | 5 | 0 | 22 |
| Intense | 5 | 4 | 18 | 1 | 6 | 20 | 5 | 0 | 22 |
| Very intense | 2 | 5 | 20 | 1 | 7 | 19 | 3 | 0 | 24 |

[a] WT, without significant trend.

[48] We believe that the three periods analyzed provide complementary information. On the one hand several significant trends obtained for the entire period are not monotonic and can often be concentrated in just part of the time series. In fact, we have found a large number of regions where positive (negative) trends in the first half are followed by negative (positive) trends in the second period.

[49] To the best of our knowledge this study provides one of the first long-term assessments (centennial scale) on changes of precipitation associated with different rainfall categories over such a large area as the IP. The contrasting evolution of trends between the first and second halves of the twentieth century could only be characterized following the current availability of recently digitized station data from both Portugal and Spain.

[50] Although the authors have not engaged in a comprehensive assessment on the detection and attribution of the changes obtained in this study, the fact remains that recent literature has mentioned possible links. Among these theories, it is worth mentioning the construction of large dams that can be associated with significant changes of land use in the surrounding area and may induce important changes in the hydrological cycle [*Hossain et al.*, 2009]. The overall impact of such dams is not yet clear, with some authors detecting an intensification of the hydrological cycle and the occurrence of extreme events downstream [*Hossain*, 2010], while others have noted that the draining of swamps can result in decreased precipitation through a negative feedback mechanism [*Pielke et al.*, 1999]. This last phenomenon could be happening over some regions of the IP, where the number of large reservoirs has increased significantly during the second half of the twentieth century.

[51] **Acknowledgments.** Long-term series of observed data were obtained through the Portuguese project SIGN (SIGNatures of environmental change in the observations of the Geophysical Institutes) under the POCTI/CTA/47803/2002 project. M. Cruz Gallego received support from the Junta de Extremadura-FEDER Funds (GRU09080 and IB10077), and Ricardo M. Trigo received support from the EU 6th Framework Program (CIRCE). Manola Brunet and Javier Sigró are supported by the Spanish-funded CLICAL (Comisión Interministerial de Ciencia y Tecnología: CGL2006-13327-C04-03/CLI) and CAFIDEXPI (Comisión Interministerial de Ciencia y Tecnología: CGL2007-65546-C03-02) projects.

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