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Homogeneity of monthly precipitation data in the Iberian Peninsula

F. Gonzalez-Rouco, E. Zorita

32 pages with 12 figures and 3 tables

Abstract

The homogeneity of time series of monthly precipitation in the Iberian Peninsula, Southern France and Northern Africa in the last 90 years has been analyzed. The original time series present severe homogeneity problems that could be corrected by applying outlier correction, homogeneization and spatial interpolationalgorithms.

It has been found that climate variability is more important for the presence of outliers than measurements errors. The impact of the correction procedures on the estimated long-term precipitaiontrends has also been studied.

Homogenisierung monatlicher Niederschlagssummen auf der Iberischen Halbinsel

Zusammenfassung

90 Jahre lange Zeitserien monatlicher Niederschlagssummen von der Iberischen Halbinsel, aus Südfrankreich und Nordafrika wurden auf Homogenität untersucht. Die Originalzeitserien weisen Inhomogenitäten auf, die durch die Korrektur von Ausrutschern und durch Anwendung von Homogenitäts- und Interpolationsalgorithmen aufgehoben werden konnten.

Es wurde gefunden, daß natürliche Klimavariabilität eine wichtigere Ursache für Ausrutscher ist als Meßfehler. Der Einfluß der angewandten Homogenisierungsalgorithmen auf die langfristigen Trends wurde untersucht.

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1 Introduction

In the last few decades there has been an increasing concern regarding the changes in climate caused by anthropogenic emissions of greenhouse gases and aerosols (Houghton et al. 1992; Houghton et al. 1995). This interest has been mainly based on the results of climate models. In a similar fashion, there has been a rise in the activity directed towards the detection of the expected climate change signal in observed data (Santer et al. 1995; Hegerl et al. 1996). It is essential for this purpose to use good quality observations and thus outliers and homogeneization arise as important points to deal with.

Outliers are observations very distant from the mean value which can cause important biases in the estimation of the sample statistics (Barnett and Lewis 1994). They can be due to measurement errors or to some unknown extreme phenomenology. When they undoubtedly belong to the first class those extreme data can be rejected, otherwise they can be substituted by some value that keeps the information of an extreme event and yet does not have such an important influence on the statistics estimation.

A homogeneous climate series is defined as one where variations are caused only by changes in weather and climate (Conrad and Pollak 1950). This would mean that the measurements have been consistently registered by the same method, with the same instrumentation, at the same time-of-day and place and in the same environment. Unfortunately, this is seldom the case and at most old observatories, instruments, location, observer or other environmental factors have been altered (Jones et al. 1985; Karl and Williams 1987; Peterson et al. 1998). In the case of precipitation, progressive improvements of instrumentation can also introduce artificial systematic increases (Hanssen-Bauer and Førland 1994), and thus long-term variations and trends should be interpreted cautiously (Houghton et al. 1992). For long-term climate analysis to be accurate, the climate data must be homogeneous, thus, inhomogeneities must be detected and inhomogeneous series be excluded or corrected.

Several statistical tests have been developed that allow detection of inhomogeneities in time series. Some depend on the metadata (Karl and Williams 1987; Rhoades and Salinger 1993) and others use them as additional information when the station history is poorly documented or missing at all (Buishand 1982; Alexanderson 1986). Some tests are univariant, while others use information from reference time series which are compared with the test series to decide upon its quality. A comprehensive review on this topic has been presented by (Peterson et al. 1998b).

Considerable research has been accomplished on the characteristics of low frequency climate variability of precipitation in the western Mediterranean (Maheras 1988; Valero et al. 1993; Zorita et al. 1992; Fernández-Mills 1995; Valero et al. 1996b; Rodriguez-Puebla et al. 1998). However, homogeneity assesments of historical precipitation data during the 20th century have seldom been performed (Almarza et al. 1996; Esteban-Parra et al. 1998). Thus, a description of a close insight into this problem from the perspective of an objective methodology and where all the information from a high number of stations is taken into account is still to come. In this work, we focus on the detection and correction of outliers and inhomogeneities in a data set of precipitation in the southwest of Europe. The correction of outliers has been performed by taking into account dispersion in the time series by means of windsorization, this is, trimming the values that exceed a certain threshold (Barnett and Lewis 1994). For the correction of inhomogeneities we have used a procedure based upon the Standard Normal Homogeneity

Test developed by Alexanderson (1986). This method assumes invariance of the ratio of the values of the test series and those of a reference series built using information from several neighbouring stations. An inhomogeneity in the test series will be revealed by a systematic change in this ratio. However, it there exists no *a priori* knowledge of which ones are the homogeneous time series, the test has to be applied several times to decide which stations have good quality records and can be used as a reference. We have followed a procedure divided in six steps, which allows identifying reference series and correcting inhomogeneous ones. The first five steps follow those of Hanssen-Bauer and Førland (1994) and the sixth one has been added to account for series with two inhomogeneities.

Data are described in the next section. A description of the methodology is presented in Sect. 3. Results are presented in the following section and finally conclusions are summed up and discussed.

2 Data

We have used long time series of monthly precipitation totals (mm) covering most of the Iberian Peninsula (IP hereafter), south of France and north of Africa and spanning the period 1899 to 1989. Iberian rain gauge data were provided by the Instituto Nacional de Meteorología (Spain). The Carbon Dioxide Information Analysis Centre (USA) and Metéofrance (France) supplied north-african and french precipitation data, respectively. Figure 1 shows the spatial distribution of the 95 observatories; the corresponding names and lengths of the associated time series are listed in Table 1. We have selected the period 1899 to 1989 for this first version of the data set which will be refered to as SED (Southwestern European Data set) hereafter.

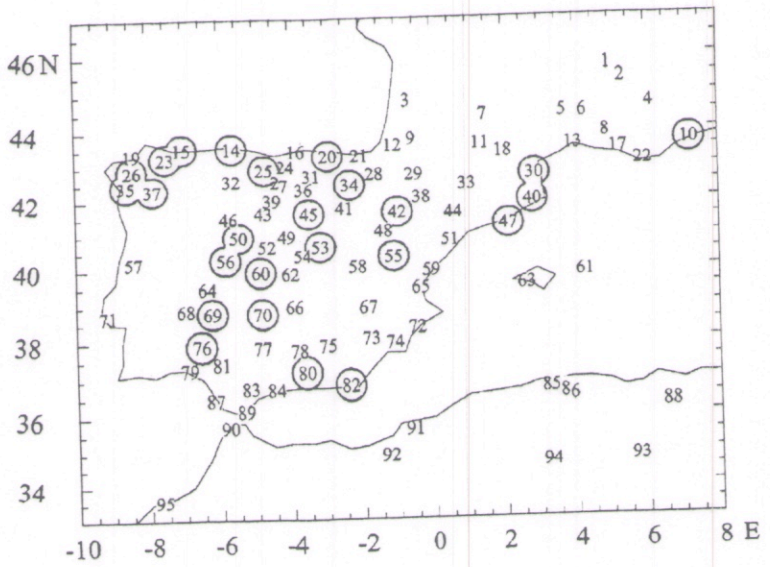


Figure 1: Spatial distribution of SED stations. Numbers reffer to those of Table1. Circles point time series in which information from secondary sites was used.

Non circled numbers in Fig. 1 stand for sites in which time series were used unchanged to apply the procedures described in the next section. In some cases (circled identifiers in Fig. 1) long data gaps were present and/or temporal extension of the time series was desirable. In order to improve the quality of these records and also the spatial coverage of the data set additional information from 43 secondary sites (non-numbered rows in Table 1) was used. Thus, initial corrections following the ratio method (Mitchell et al. 1966) were calculated and applied using data from the overlapping periods between the base stations and the additional observatories. The lower threshold value for correlation between the base station time series and the time series of a candidate secondary site to be used for data interpolation was 0.8.

N°	Name	Period	Corr	N°	Name	Period	Corr
1	LYON	1841-1994		25	CAMPORREDONDO	1917-1992	
2	GRENOBLE	1833-1976		26	SANTIAGO	1906-1993	
3	BOURDEAUX	1899-1994			Universidad	1899-1950	0.89
4	GAP	1899-1992		27	CERV. PISUERGA	1912-1986	
5	BAGNOLS-L-B	1899-1993		28	PAMPLONA	1899-1993	
6	JOYEUSE	1900-1993		29	CANFRANC	1910-1994	
	Service des crues	1900-1930	0.98	30	PERPIGNAN	1899-1993	
7	CAHORS	1899-1993			Pont Rouge	1899-1923	0.98
8	AVIÑON	1899-1993		31	OÑA	1900-1994	
9	SAINT SERVER	1899-1993		32	LEON	1904-1993	
10	NICE	1899-1993		33	CAPDELLA	1915-1991	
	Rue Gioffredo	1891-1920	0.90	34	LOGROÑO	1911-1994	
11	TOULOUSE	1899-1994			Instituto	1911-1947	0.85
12	PEIREHORADE	1851-1992		35	PONTEVEDRA	1899-1994	
13	MONTPELLIER	1899-1993			Salcedo	1949-1985	0.96
14	GIJON	1913-1994		36	BURGOS	1899-1991	
	Cabo Peñas	1914-1922	0.76	37	ORENSE (Granja)	1899-1994	
15	CASTROPOL	1907-1994			Santuario Molas	1924-1925	0.90
	Tapia de Casariego	1907-1925	0.80		Beariz	1926-1935	0.87
	Castropol	1923-1972	0.95		Villamayor	1937-1950	0.90
16	SANTANDER	1912-1991			Ginzo	1969-1972	0.91
17	MARSELLE	1899-1994		38	HUESCA	1899-1994	
18	REVEL	1899-1973		39	PALENCIA	1913-1988	
19	CORUÑA	1899-1993		40	GERONA	1911-1991	
20	BILBAO SONDICA	1899-1993			Instituto	1911-1969	0.89
	Guernica	1925-1930	0.86	41	SORIA	1899-1994	
	Larrasquitu	1925-1946	0.86	42	ZARAGOZA	1899-1994	
	Machichaco	1913-1930	0.77		Facultad de ciencias	1899-1941	0.89
	Basauri	1940-1950	0.93	43	VALLADOLID	1899-1994	
21	SAN SEBASTIAN	1899-1993		44	LERIDA	1913-1991	
22	TOULON	1899-1994		45	VID DE ARANDA	1899-1994	
23	LUGO	1913-1994			Col. Franciscanos	1914-1939	0.85
	Mundín	1913-1921	0.92		Aranda del Duero	1943-1994	0.84
	Brigós	1922-1939	0.94	46	ZAMORA	1909-1994	
	Sarria	1952-1966	0.91	47	BARCELONA	1899-1994	
24	REINOSA	1911-1991			Universidad	1899-1937	0.91

Table 1: Names and periods of the time series used in the compilation of SED. Numbers match those in Figure 1. Correlation values between main sites and additional secondary observatories are also shown.

N°	Name	Period	Corr	N°	Name	Period	Corr
48	DAROCA	1899-1993		70	ALMADEN	1913-1994	
49	SEGOVIA	1899-1994			Pozoblanco	1936-1994	0.84
50	SALAMANCA	1899-1993		71	LISBOA	1899-1989	
	Observatorio	1899-1944	0.94	72	ALICANTE	1899-1993	
51	TORTOSA	1899-1991		73	CEHEGIM	1913-1994	
52	AVILA	1900-1994		74	MURCIA	1899-1993	
53	GUADALAJARA	1912-1991		75	CAZORLA	1911-1994	
	Atienza	1937-1945	0.81	76	ARACENA	1913-1994	
54	MADRID	1899-1994			Galaroza	1960-1994	0.95
55	TERUEL	1899-1994			Valdeazufre	1964-1994	0.96
	Ariño	1936-1943	0.90	77	CORDOBA	1911-1994	
56	HERVAS	1913-1994		78	JAEN	1899-1993	
	Bejar	1913-1979	0.90	79	HUELVA	1903-1994	
	Aldea del Camino	1951-1954	0.90	80	GRANADA	1899-1993	
57	COIMBRA	1899-1989			Alhendim	1977-1990	0.93
58	CUENCA	1908-1990		81	SEVILLA	1899-1994	
59	CASTELLÓN	1911-1993		82	ALMERIA	1910-1994	
60	TALAVERA	1913-1990			Estación sismológica	1909-1932	0.89
	Candeleda	1936-1940	0.90		Ciudad Jardín	1933-1967	0.89
	Robledillo de la Vera	1940-1942	0.91	83	GRAZALEMA	1912-1994	
	Marrupe	1944-1947	0.87	84	MALAGA	1900-1995	
	Alcañizo	1959-1962	0.96	85	DAR-EL-BEIDA	1838-1994	
	Cabañuelas	1989-1990	0.85	86	ALGIERS	1889-1994	
61	MAHÓN	1899-1994		87	SAN FERNANDO	1899-1989	
62	TOLEDO	1908-1991		88	CONSTANTINOPLA	1899-1994	
63	PALMA MALLORCA	1899-1993		89	GIBRALTAR	1899-1994	
64	CACERES	1904-1991		90	TANGER	1899-1989	
65	VALENCIA	1899-1994		91	ORAN	1899-1994	
66	CIUDAD REAL	1904-1991		92	TLEMCEM	1899-1989	
67	ALBACETE	1899-1991		93	BISKRA	1902-1994	
68	BADAJOZ	1899-1994		94	DJELFA	1899-1994	
69	ALANGE	1913-1994		95	CASABLANCA	1902-1989	
	Valencia del Ventoso	1913-1934	0.89				
	Miajadas	1917-1950	0.91				

Table 1: Table 1 continued.

3 Methodology

In this section a brief description is provided on the development of outlier and homogeneity corrections.

3.1 Outliers

Historically, the identification of outliers has been the primary emphasis of quality control work (Grant and Leavenworth 1972). In this work outliers were identified as those values traspasing a maximum threshold for each time series (Trenberth and Paolino 1980; Peterson et al. 1998) defined by:

$$P_{out} = q_{0.75} + 3IQR, \quad (1)$$

where $q_{0.75}$ is the third quartile and IQR the interquartilic range. The IQR has been used in quality control of climate data (Eischeid et al. 1995) because it is resistant to outliers. Values

over P_{out} were substituted, trimmed, by this limit. This way of proceeding reduces the bias caused by outliers and yet keeps the information of extreme events (Barnett and Lewis 1994).

3.2 Homogeneization

3.2.1 The standard normal homogeneity test

The homogeneization procedure is based on the application of the Standard Normal Homogeneity Test, SNHT (Alexanderson 1986). This test is based on the assumption that precipitation amounts at the station being tested (test station) and some regional average values are proportional to each other. This relationship is expressed in terms of the ratio q between the test station normalized precipitation values and those of a regional time series defined as a weighted average of several neighboring reference stations. Thus, the ratio q in a specific year may be denoted as:

$$q_i = \frac{F_i}{G_i}, \quad i = 1, \ldots, n \tag{2}$$

n being the number of timesteps and F_i and G_i functions of the precipitation at the test and reference stations which are defined as:

$$\begin{aligned} F_i &= \frac{P_i}{\overline{P}} \\ G_i &= \frac{\sum_{j=1}^{k_i} v_j \frac{Q_{ij}}{\overline{Q_j}}}{\sum_{j=1}^{k_i} v_j}, \end{aligned} \tag{3}$$

P_i being the precipitation at the test station, Q_{ij} the precipitation at the j^{th} reference station and v_j a weight factor for the j^{th} reference station. In this work v_j was defined as the square of the correlation coefficient between the test series and the j^{th} reference series. k_i is the number of reference sites used in time step i which varies as a result of different length of time series and the existence of missing data. Overbars denote averages throughout the observational period.

In order to apply the test the q_i values are standardized by their sample mean, $\overline{q}$, and standard deviation, s_q:

$$z_i = \frac{(q_i - \overline{q})}{s_q}$$

This series has zero mean and unit standard deviation and is assumed to be normally distributed, N(0,1). An inhomogeneity in the test series would affect the series of ratios and thus z_i. Therefore, the homogeneity test is based on the definition of the following hypothesis:

Null hypothesis, (H_0): The test series is homogeneous. Any subset of z_i is distributed as N(0,1).

Alternative hypothesis, (H_1): The test series is inhomogeneous. There is an inhomogeneity in year m such that the m first years of the z_i have mean value μ_1 and the $(n-m)$ last years have mean value μ_2, being the standard deviation 1 in both temporal segments.

This definitions enable the test to detect and correct only one inhomogeneity in the original test series. A test statistic, T_m, is computed for each of the n-1 possible change points:

$$T_m = m\overline{z}_1^2 + (n-m)\overline{z}_2^2, \quad m = 1, \ldots, n-1, \tag{4}$$

where $\overline{z}_1$ and $\overline{z}_2$ are the mean values of z_i during the m first and the $(n-m)$ last years, respectively. A high T value in year m implies that μ_1 and μ_2 depart significantly from zero, making H_0 unlikely.

The maximum T_m value in the time series will be denoted by T_x. The probability that T_x exceeds a certain value if H_0 is correct depends only on the length of the time series. The critical T values for the 5% and 10% significance levels (T_{95} and T_{90}, respectively) are given by Alexanderson (1986). In practice, the test is applied making use also of the existing information about the history of the station, the metadata. A precipitation series is then classified as inhomogeneous when: *i*) it contains an inhomogeneity significant at the 5% level five years or more from either end of the series, *ii*) the series contains an inhomogeneity significant at the 10% level, which is explainable by metadata.

Hanssen-Bauer and Førland (1994) recommended to interact with the metadata information at the 10% level to reduce the posibilities of rejecting as inhomogeneous a true homogeneous series. The reason for not accepting unexplained inhomogeneities close to the ends of the series is an increased probability for high T values near the ends (Hawkins 1977).

Once a series is identified as inhomogeneous, the data before the inhomogeneity date are corrected through multiplying them by:

$$f = \frac{q_a}{q_b}, \tag{5}$$

where q_a and q_b are the mean values of q_i after and before the inhomogeneity. The date of change was taken to be that in the metadata when a matching with the historical records ocurred. Otherwise, the year corresponding to T_x was assumed.

Equations (2) and (3) can also be used for interpolating missing data (Alexanderson 1986; Valero et al. 1997a). Assuming $q(t) \simeq \overline{q} = 1$ for missing data, the estimations of the missing F_i values, $\widehat{F}_i$, can be obtained from

$$\widehat{F}_i = q_i\, G_i \simeq \overline{q}\, G_i = G_i \tag{6}$$

and thus precipitation for the test station can be estimated from

$$\widehat{P}_i = \overline{P} G_i \tag{7}$$

3.2.2 Selection of reference stations

The above description states how correction factors can be calculated for a test series by using information of several reference stations. However, usually no *a priory* knowledge exists on which ones are the reference series and the test has to be run in an iterative way several times to decide upon which ones are the best-quality series. We have followed the same procedure as Hanssen-Bauer and Førland (1994) for this purpose. We have added one step to their procedure in order to account also for the correction of series with two inhomogeneities. Figure 2 highlights the steps of the method which is described in this section.

In step 1 the test is applied to each time series. All series are considered as potentially

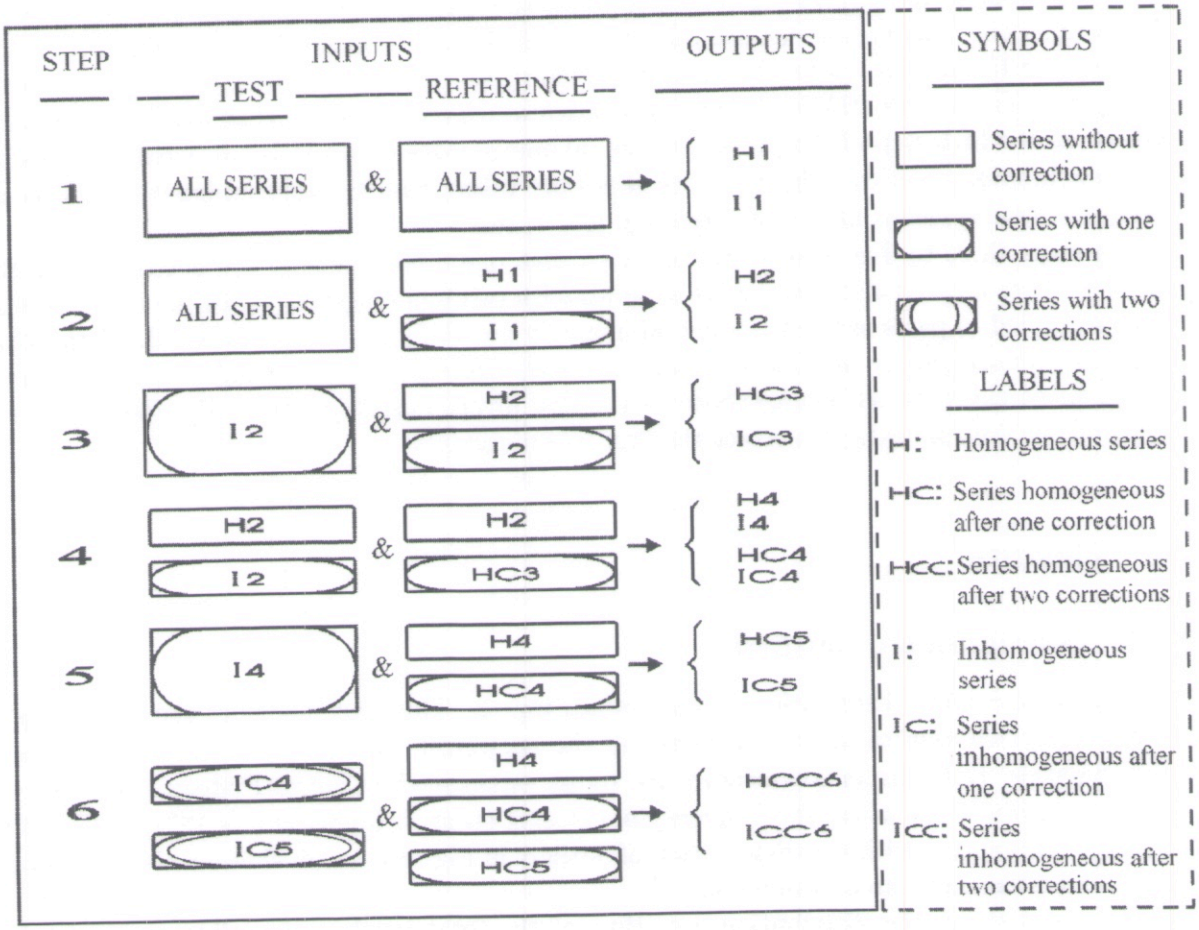


Figure 2: Diagram showing the six steps of the homogeneization procedure (after Hanssen-Bauer and Førland (1994)). Test series are tested by comparing with reference series and sorted into output groups at each step of the procedure for subsequent use. The output groups are identified by the result of the test (H for homogeneous and I for inhomogeneous), by the number of corrections applied to the input test-series (C for one correction and CC for two corrections) and by the number of the step in which the test is performed. Independently of this convention sybols indicate the number of corrections applied to any input series.

homogeneous and those which correlate best with the test station are chosen as the reference ones. The result is a first classification of homogeneous (H1) and inhomogeneous (I1) series. In step 2 corrections are applied to the I1 set following Eq. 5. Subsequently the test is applied to each time series again though using an improved data set as reference series: the H1 group and the just corrected I1 series. This produces a new, somewhat optimized, classification into homogeneous (H2) and inhomogeneous (I2) series. In the third step the I2 group is corrected and then the test is applied only to these modified time series; the pool of possible reference stations is built with the H2 set and the corrected I2 stations. The result is a group of homogeneous time series corrected once (HC3) and a subset of series with more than one inhomogeneity (IC3).

In the previous steps the procedure basically improves the quality of the reference series. Under the fourth step all series are checked again: the homogeneous H2 group and the corrected I2 group. The reference series are only those which have proved their homogeneity so far, namely the H2 and HC3 sets. The H2 set provides two new subsets after applying the test, a group of homogeneous (H4) and a group of series which contain more than one inhomogeneity (IC4). In the fifth step of the procedure the inhomogeneous group I4 is corrected and checked for new inhomogeneities. The reference series are taken from the just updated homogeneous (H4) and homogeneous after one correction (HC4) sets.

In steps three to five corrections for series with one inhomogeneity are developed. In this work we have applied also corrections to series with two inhomogeneities. In the sixth step the test is applied to parts of the series containing only one inhomogeneity. Firstly the data before the first inhomogeneity are omitted and the remaining data are corrected using as reference series those classified as homogeneous in the five preceeding steps; secondly, the test is run with all the data in order to correct the first inhomogeneity.

4 Results

4.1 Distribution of outliers

Figure 3a shows the distribution of P_{out} values Eq. 1. This plot describes the variability of the data, which reaches maximum values in the northwest and south of the IP and most of the Pyrenees. Data dispersion achieves its lowest values in the Central Plateau and along the Mediterranean Coast where the frequency of extreme events is higher (Linés 1970; Valero et al. 1997b). This agrees with the distribution of outliers in Fig. 3b, which shows a clear maximum in the mediterranean area of influence.

Figure 4 shows the distribution over time of the total number of outliers in this region. Figure 4a describes the yearly evolution through this century. We can appreciate some inter-annual variability and also a long term trend: the linear fit in exhibits a significant increase of 0.36 dec^{-1}. The total number of corrected values was 519: 12% of them were produced in spring, 3% in summer, 52% in autumn and 33% in winter. Figure 4b shows the corresponding monthly distribution, characterized by a maximum in October and a minimum in the summer.

The spatial distributions of the number of outliers for each season (not shown here) reveals that maxima are located in the east coast in spring and autumn in a similar fashion as Figure 3b. In winter they spread over the west and south of the IP and for the summer months there

is no apparent structure but isolated cases in the Central Plateau.

The overall agreement of the areas and timing of outliers with those of extreme events suports the idea of physical mechanisms as causes for the detected anomalous data rather than human induced errors.

4.2 Homogeneization

For this first version of SED homogeneity corrections were developed from the annually averaged time series and subsequently applied to monthly data. Results obtained by ussing annual averages should not differ substantially from results obtained by using monthly values (Alexanderson 1986), the latter being more sensitive to displacements of the mean value that could lead incorrectly to identify a series as inhomogeneous. Such is the behavior of the $q(t)$ series in dry months that can produce distortions in the test. Since this is the case of numerous stations in the south of the IP and north of Africa, the annual option was chosen.

a)

b)

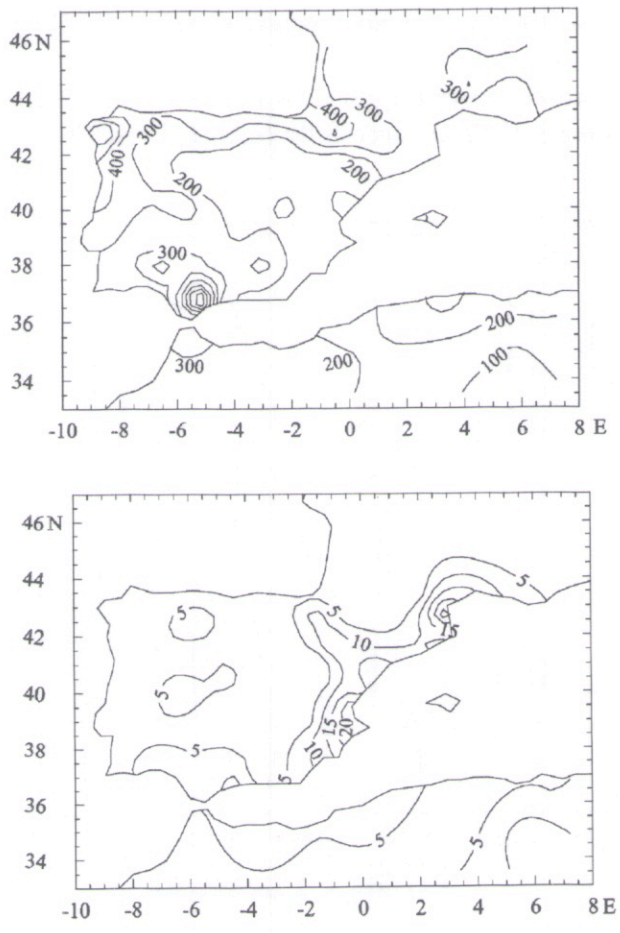


Figure 3: (a) Spatial distribution of P_{out} (mm) values.(b) Spatial distribution of the absolute number of outliers in each station.

Table 2 shows the number and type of series involved in each step (column 1) of the homogeneization procedure. The number of time series tested in each step is shown in column 2 and the number of series making part of the reference group appears in column 3. The quantity of resulting homogeneous (H) or inhomogeneous (I) time series are indicated in columns 4 to 9, either after one (HC, IC) or after two (HCC, ICC) corrections.

In the two first steps almost the same results are obtained. The most relevant changes are shifts in the classification of some series which switch from homogeneous in step 1 (H1) to inhomogeneous in step 2 (I2) (stations 42, 51, 72 and 90) or viceversa (stations 13, 23, 34, 79 and 94). In the third stage the 53 inhomogeneous series obtained in step 2 are corrected and tested producing a subset of 45 homogeneous after one correction (HC3) and 8 inhomogeneous (IC3) series.

Following the methodology previously described, in the fourth step the subset of 42 homogeneous series in step 2 (H2) was tested and provided 38 purely homogeneous series without any corrections (H4) and 4 series which contain at least one inhomogeneity (I4). The 53 I2 series were corrected and tested again and provided 44 series homogeneous after one correction (HC4) and 9 series with at least two inhomogeneities (IC4).

During the fifth stage of the method the 4 I4-type series obtained in step 4 were corrected and tested. The output was a set of 3 homogeneous series (HC5) and 1 with at least two inhomogeneities (IC5).

In the last step, the procedure was applied to the 10 series with more than one inhomogeneity (IC4 and IC5) being 9 of them succesfully corrected (HCC6) and only one (station 69,

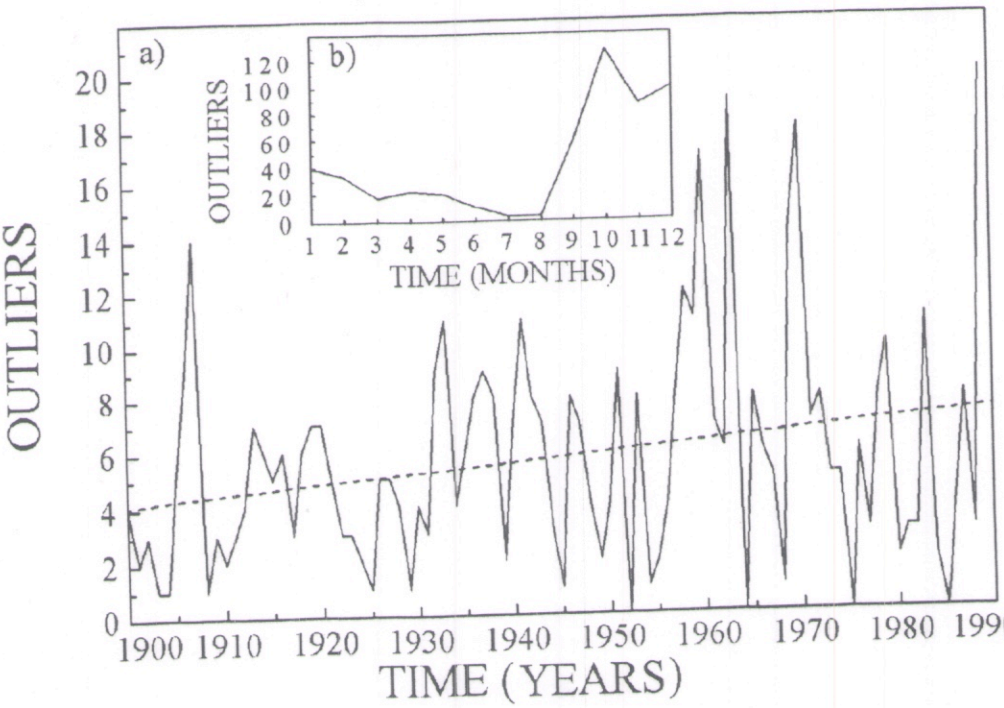


Figure 4: Time evolution of the absolute number of outliers in the area of interest: (a) annual and (b) monthly totals. The dashed line shows the linear fit to the data ($0.36dec^{-1}$).

Alange) showed more than two inhomogeneities (ICC6). This last station was rejected from the data set. 40% of the series were homogeneous, 49.5 became homogeneous after one adjustment and 9.5% after two corrections.

Figure 5a describes the type (symbols) of inhomogeneity of each time series.

It can be appreciated that there is no evident spatial structure in the distribution of inhomogeneities. The same figure shows the number of reference stations used for the analysis of each series (solid lines). This number was imposed to be always between 5 and 10 and was chosen as a function of the correlation (always higher than 0.5) between the test station and any candidate reference station. There is a clear structure, with the highest values in the west of the IP and the south of France where correlations between pairs of time series are also higher than in any other area. This also corresponds with the areas of highest correlation values between the F and the G series (Eq. 3) which are shown in Figure 5b. The high correlations between F and G also support our criterium for selecting reference stations.

Figure 6 shows the temporal distribution of correction factors. Inhomogeneities which are not supported by metadata are identified with a cross sign and those which agree with the history of the station with a circle or a triangle corresponding to a relocation or a change in height, respectively. The histogram shows the distribution of the changes during the century, both for the detected inhomogeneities (black bars) and for the changes registered in the metadata (white bars).

More complete history files of stations would be desirable to discuss the potential influence of changes in instrumentation, observer and others upon the quality of SED. Unfortunately, only relocation and changes in the height of a few stations could be related to a group of inhomogeneities (30% of the total). The cases in which data from external sites were used to fill gaps in the time series, both at the early stages of this work and by the original sources (see section 2) have also been considered as a type of relocation in the comparison of inhomogeneities and metadata. Relocation can lead to inhomogeneities as a result of the difference in annual precipitation in both the old and the new position as well as differences in sheltering conditions. In 70% of the inhomogeneities identified as relocations an increase of catchment (factor > 1) has been produced. However, the mean of all correction factors in Figure 6 does not depart significantly from one, therefore, there is no bias in the occurrence of inhomogeneities either to increase or decrease precipitation means on the whole data set. This is due to the fact that unknown changes (crosses in Fig. 6) have led to a decrease in catchment (factor < 1) in 66% of the cases. Nevertheless, changes in specific sites have played a decisive role as it will be shown later.

The three changes in height (triangles) seem to agree somehow in the type of inhomogeneity. The two first ones occur in La Coruña (1916) and in San Sebastián (1918) and reveal an increase

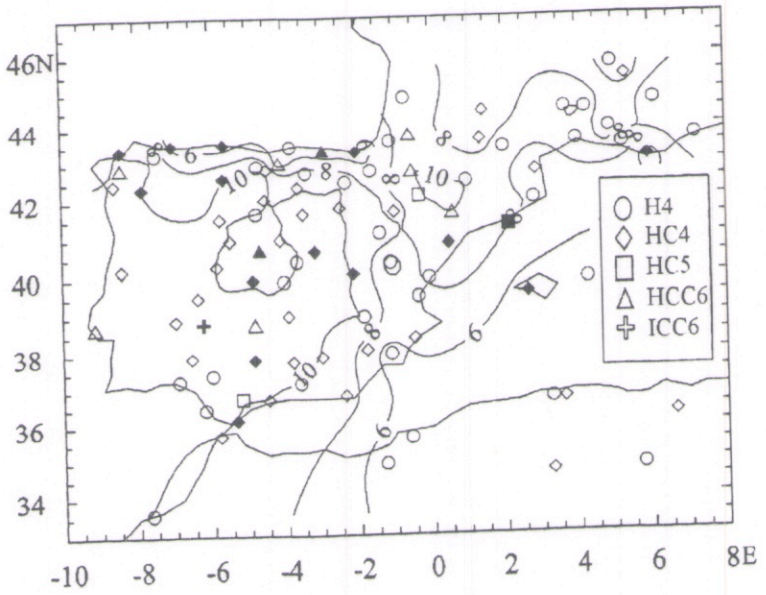
	INPUT SERIES		OUTPUT SERIES					
Step	Test	Ref.	H	HC	HCC	I	IC	ICC
1	95	95	43	-	-	52	-	-
2	95	95	42	-	-	53	-	-
3	53	95	-	45	-	-	8	-
4	95	87	38	44	-	4	9	-
5	4	82	-	3	-	-	1	-
6	10	85	-	-	9	-	-	1

Table 2: Number and type of series involved in each step of the homogeneization procedure.

in catchment related to a new position of the pluviometer in a lower and probably more sheltered location. The third one (Gibraltar in 1935) corresponds to a change of the pluviometer to a higher position, in principle less sheltered, and thus favouring a decrease in catchement.

Finally it is also worth pointing out that 80% of the inhomogeneities occur before 1950. Such a bias is also present in the histogram of the medatata (white bars). Though the metadata

a)



b)

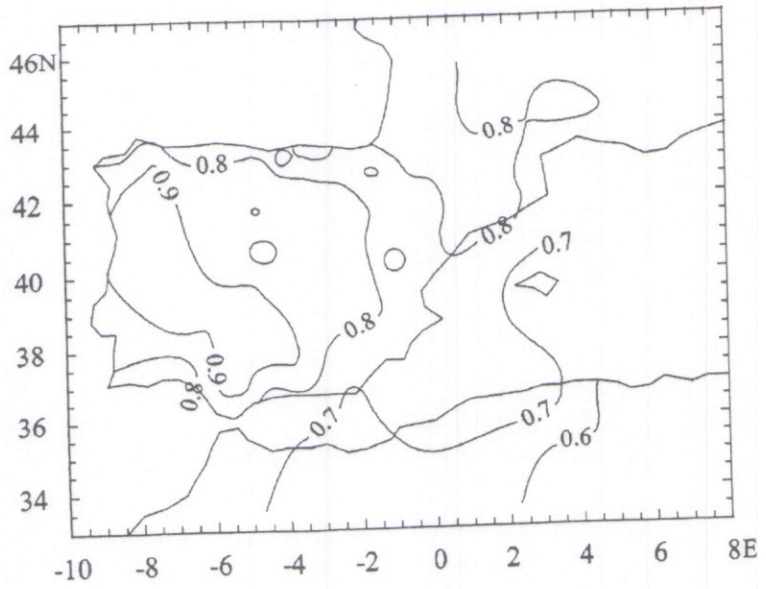


Figure 5: (a) Type of time series after applying the homogeneization procedure: homogeneous (H), homogeneous after one (HC) or two (HCC) corrections and inhomogeneous after two corrections (ICC). Numbers in the legend stand for the step of the procedure. Solid symbols indicate agreement with metadata. Isolines indicate the number of reference stations used. (b) Correlation values between F and G (see Eq. 3)

archives are scarce they can be taken as an indication that there have been less changes in the last decades. This supports the smaller amount of inhomogeneitipies after 1950.

Figures 7 to 9 give some typical examples of the application of the SNHT to several types of time series showing values for the T statistic (Eq. 4) and the series of ratios q_i (Eq. 2). Figure 7 displays results for Murcia (station number 74) and Palma de Mallorca (number 63). Murcia, classified as homogeneous in the fourth step of the procedure (H4) shows no significant changes in the T statistic; there is a secondary maximum in 1955 that seems to agree with a change in the position of the rain gauge registered in the metadata. The series of ratios, q, does not show apparent displacements from the mean value. Palma de Mallorca is an example of homogeneous after one correction series (HC4). In step 2 of the procedure (dots), the test reveals a wide T maximum centered in 1940, possibly related to a change in the position of the rain gauge in 1937. This maximun disappears after the correction factor is applied to the values before 1937. The q values also reveal this inhomogeneity: non-corrected values in dots cluster above (below) 1 for most years before (after) the change while the corrected ones, continous line, do not show this step-like behaviour.

An example (Figure 8) of homogeneous series after applying one correction is La Coruña (number 19). In this case the test statistic shows several significant maxima. The most important one takes place in 1915 and agrees with a change in the height of the rain gauge; the

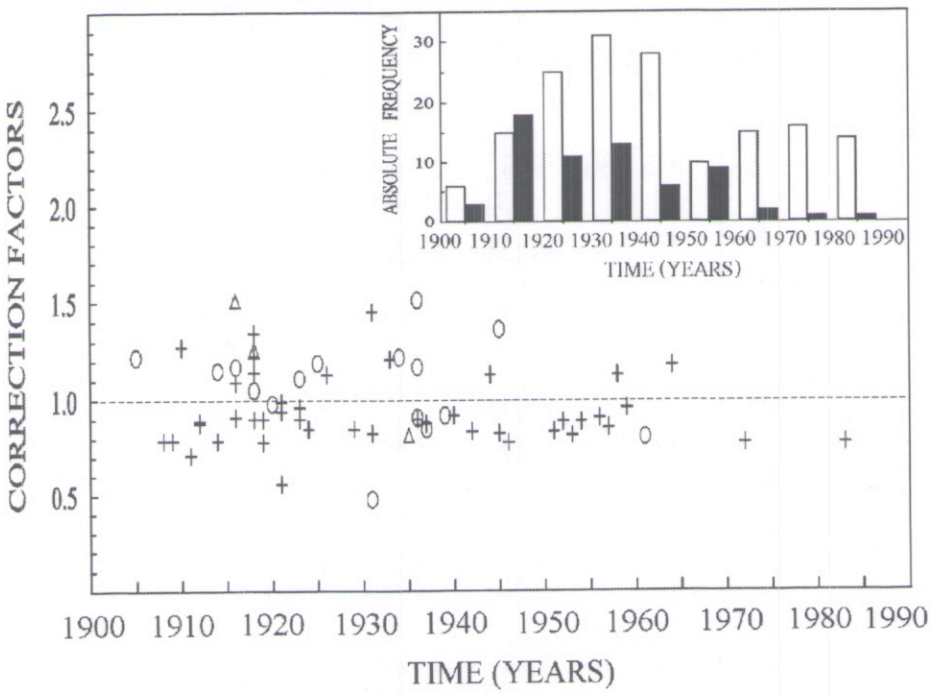


Figure 6: Distribution of correction factors within the studied period. Crosses stand for inhomogeneities of unknown origin, circles correspond to relocations or interpolations of data from distant sites and triangles to changes in height. The upper panel shows the histogram of inhomogeneity dates both for the detected changes (black bars) and those registered in the metadata (white bars).

second peak occurs in 1942 and does not match with any entrance in the historical records. The first peak disappears and the second one is not significant after applying the correction factor to the data before 1915. The q series shows some displacement from the mean value before 1915 (dots in the oval) which also disappears after the correction is applied. Hervás (number 56), one of the series reconstructed for the data set, is an example of HC4-type series. The T statistic shows (Figure 8) a low amplitude maximum in 1983 not supported by the available metadata which drops out in step 4 of the procedure.

Bilbao (number 20), described by Figure 9 is an example of series that became homogeneous after two corrections. The values of the T statistic in the second step (hollow dots) show a maximum centered in 1946 wich agrees with a reference in the metadata in 1945. After the correction of this inhomogeneity, a second maximum rises over the significance level in the fourth step (solid dots). This peak agrees with a change in the position of the rain gauge

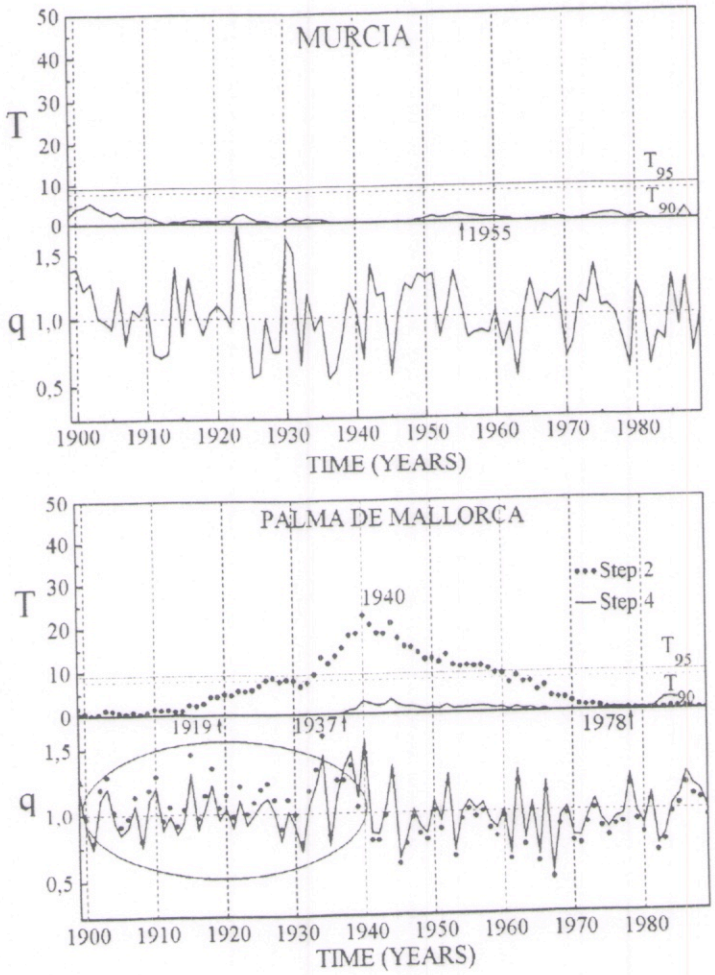


Figure 7: Values of T and q for Murcia (upper panel) and Palma de Mallorca (lower panel). For Palma de Mallorca results are shown before (dots, step 2) and after (solid line, step 4) the application of correction factors. Dates of metadata are indicated with arrows in the horizontal axis. q data before the inhomogeneity are highlighted in the oval.

in 1920. In the sixth step both inhomogeneities are corrected and the T statistic shows no important peaks. The q values also show these changes: it can be noticed how non corrected data (dots) depart more strongly from unity than the corrected ones (solid line), particularly during the period between both inhomogeneities (highlighted with the oval).

Finally, results for Alange (number 69) are shown also in Figure 9. This is the only station which remained inhomogeneous after two corrections (ICC). The T values exhibit significant maximae in years 1934, 1917 and 1955 corresponding to the steps 2, 4 and 6 of the procedure, respectively. The series of q ratios show an appreciable displacement from the mean value only in step2 (hollow dots in the oval). The inhomogeneity in 1917 is supported by only a single peak value and the maximun in step 6 hardly reaches the T_{95} significance level. This accounts for the low magnitude of these inhomogeneities and their lack of evidence in the series of ratios for steps 4 and 6. The three inhomogneities are probably related to data interpolations from the secondary sites.

Table 3 groups some results for the cases just described. In the first block of information, the reference stations used for each test station are listed. Since the criterium for choosing them

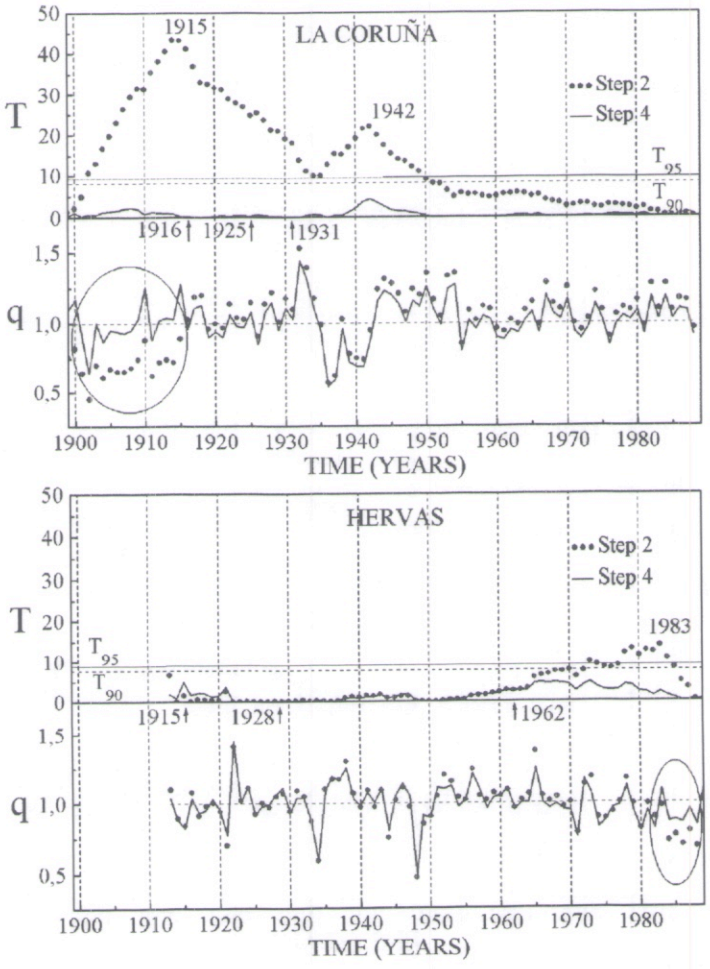


Figure 8: Same as Figure 7 for La Coruña and Hervás

was based on the correlation coefficient between the latter and all candidate reference stations and not in the geographical distance, the chosen sites are not necessarily the neighbouring ones.

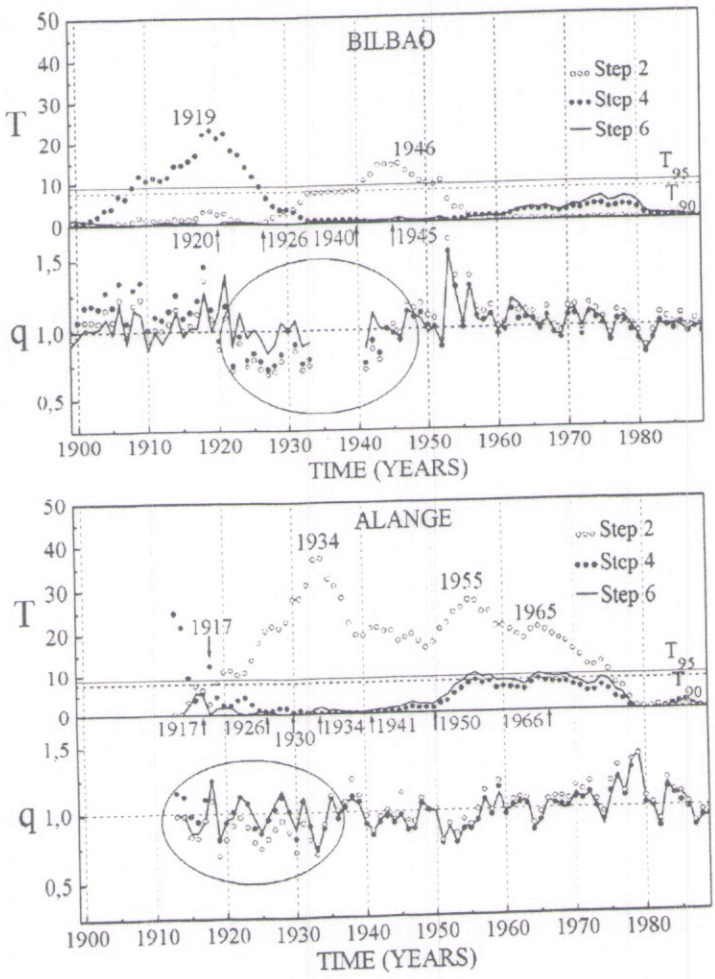


Figure 9: Same as Figure 7 for Bilbao and Alange

In the second block of the table, critical values for the T_m statistic (T_{90} and T_{95}) in each case are given and below them the maximum values of T which were reached in each step as well as the associated dates. The type of series is also indicated for each case. Finally, in the lower panels we show the percentages of change in q ($\Delta\overline{q}$) and the correction factors (f, Eq. 5). $\Delta\overline{q}$ is defined as

$$\Delta\overline{q} = \frac{\overline{q}_a - \overline{q}_b}{\overline{q}_a} \cdot 100$$

where $\overline{q}_b$ and $\overline{q}_a$ are the mean values of q before and after the correction, respectively. The correction factors and $\Delta\overline{q}$ change in accordance. When the latter are negative (positive) the data before the inhomogeneity have a higher (lower) mean value than the rest of the series and the correction factor for them is consequently lower (higher) than 1.

T values for Murcia never exceed the critical ones. $\Delta\overline{q}$ values are also low in the two first steps of the homogeneization (6.7% and 0.7%) and high in the fourth step (30%). This last feature is probably due to the unreliability of the test close to the end of the series. In Palma, La Coruña and Hervás significant T values are obtained in steps 1 and 2 in 1940, 1916 and 1979/83, respectively. After applying the correction factors they show non-significant maxima in 1944, 1942 and 1915. $\Delta\overline{q}$ values are also high in steps 1 and 2 (between 21% and 36%) but in steps 3 and 4 they are corrected producing low values (between 6% and 8%) in the dates mentioned above.

Bilbao and Alange were corrected twice. T values are over the significance level in steps 1

	MURCIA 1899-1989	**PALMA de M.** 1899-1989	**CORUÑA** 1899-1989	**HERVAS** 1913-1989	**BILBAO** 1899-1989	**ALANGE** 1913-1989
			REFERENCE STATION NAMES (number)			
1	Cehegim (73)	Mahón (61)	Pontevedra (35)	Coimbra (57)	San Sebastián (21)	Badajoz (68)
2	Alicante (72)	D. Beida (85)	Lugo (23)	Campor. (25)	Santander (16)	Sevilla (81)
3	Almería (82)	Murcia (74)	V. Aranda (45)	Lugo (23)	Perpignan (30)	Cordoba (77)
4	Castellón (59)	Barcelona (47)	Coimbra (57)	Segovia (49)	Peirehorade (12)	Talavera (60)
5	Albacete (67)	Albacete (67)	Orense (37)	Capdella (33)	Bourdeaux (3)	C. Real (66)
6			Salamanca (50)	Soria (41)		Tanger (90)
7			Palencia (39)	Lisboa (71)		Madrid (54)
8			Pisuerga (27)	Burgos (36)		Jaén (78)
9			Campor. (25)	Pisuerga (27)		S. Fern. (87)
10			León (32)	Zamora (46)		Cuenca (58)
			T_{90} / T_{95}			
	7.7 / 9.1	7.7 / 9.1	7.7 / 9.1	7.6 / 8.9	7.7 / 9.1	7.6 / 8.9

Table 3: Homogeneization results for Murcia, Palma de Mallorca, La Coruña, Hervás, Bilbao and Alange.

	MURCIA	PALMA de M.	CORUÑA	HERVAS	BILBAO	ALANGE
STEP			T_x (year)			
1:	2.1 (1974)	23.9 (1940)	40.5 (1916)	14.8 (1979)	11.9 (1918)	36.4 (1934)
2:	2.5 (1987)	22.4 (1940)	43.3 (1916)	13.7 (1983)	14.2 (1946)	36.9 (1934)
3:	- -	3.3 (1944)	4.3 (1942)	4.8 (1915)	24.8 (1919)	14.6 (1918)
4:	5.2 (1902)	3.3 (1944)	3.8 (1942)	4.8 (1915)	23.1 (1919)	24.8 (1918)
5:	-	-	-	-	-	-
6:	- -	- -	- -	- -	5.4 (1975)	9.8 (1956)
			TYPE OF SERIES			
	H4	HC4	HC4	HC4	HCC6	ICC6
STEP			$\Delta\overline{q}$(%)			
1:	6.7	-22.6	32.6	-24.6	-14.8	17.5
2:	0.7	-21.6	36.0	-28.1	11.7	17.5
3:	-	-6.8	6.15	7.7	-19.9	-15.6
4:	-30.0	-6.8	6.13	7.7	-19.4	-15.8
5:	-	-	-	-	-	-
6:	-	-	-	-	-7.8	7.8
STEP			f			
1:	- -	0.85 (1940)	1.51 (1916)	0.78 (1975)	1.36 (1946)	1.22 (1934)
2:	- -	- -	- -	- -	1 (1920)	1 (1918)

Table 3: Table3 continued.

and 2. After these first corrections the second pair of inhomogeneities arises in steps 3 and 4. The values of $\Delta\overline{q}$ do not become lower after the first corrections were applied to the data before 1946 (Bilbao) and 1934 (Alange). In the sixth step the data before the first inhomogeneity (1919 and 1918, respectively) in each station were handled as missing and corrections were obtained and applied to the periods 1921-46 and 1919-34. Once this was done, the data before the first inhomogeneity were replaced and corrections developed for them. Then, the T values get lower becoming not significant for Bilbao and remaining over the significance level for Alange. The values of $\Delta\overline{q}$ are also reduced for both cases: -7.8% and 7.8% (notice that having the same absolute value, the change is significant only in Alange, due to the lower variability of data in this station).

The correction factors deduced from the analysis of the annual data were applied to the monthly data and interpolation for missing values was also accomplished following Eqs. (6) and (7). Figure 10 shows the temporal distribution of missing values in the data set. The highest percentages are reached at the beginning of the century due to the lower amount of stations at this time. There is a secondary maximum at the 1970's and 1980's due to the shut down of measurements in some stations. A small maximum close to 1940 related to the Spanish Civil War (1936-1939) can also be appreciated. After the interpolation was accomplished Camporredondo (number 25) and Algiers (number 86) were eliminated from the

data set because of the long data gaps present and neighboring stations that can describe appropiatedly the local climate features were available in both cases.

4.3 Trends

In this section, the effect of homogeneization and windsorization (outliers corrections) on precipitation trends are described.

Trends are obtained through the calculation of least-square linear regressions of precipitation data against time. A significance t-test (Snedecor and Cochran 1972) for constant precipitation is applied. The effective sample size and autocorrelation in the residuals are also taken into account. As precipitation time series often show high autocorrelation, values are not independent of each other and the effective number of data has also been used in the testing of significance (Trenberth 1984; Zwiers and von Storch 1995). Also, residuals resulting from the

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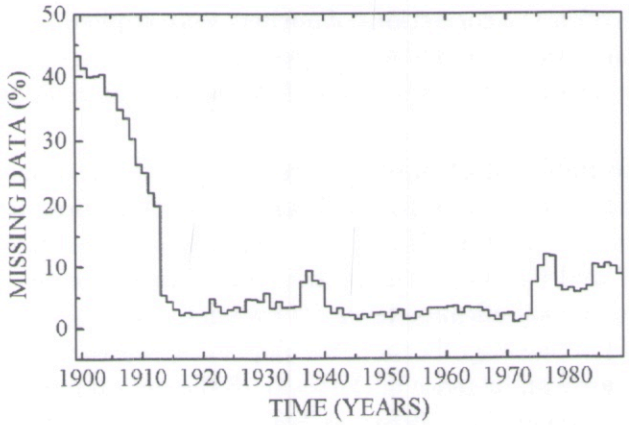

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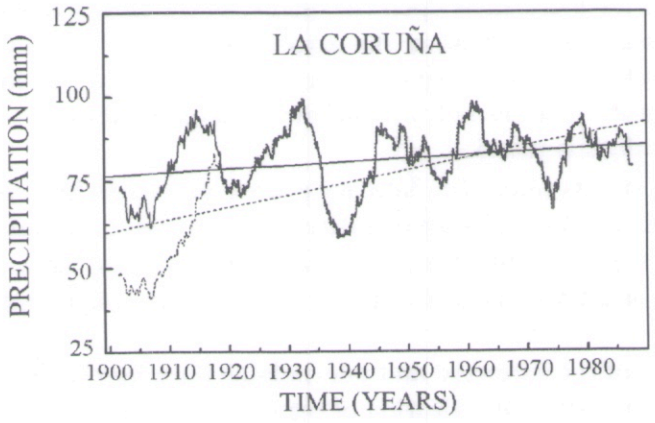

Figure 10: (a)Temporal distribution of the annual percentage of missing data in SED. (b)Trends and outputs of a centered five year moving average for monthly precipitation values in La Coruña before (dashed line) and after (solid line) the homogeneity correction.

least square regression are usually assumed to be white noise, but this is not often the case. When residuals show autocorrelation both the slope and its error are badly estimated. We have used a Durbin-Watson method (Durbin and Watson 1971; Valero et al. 1996a) to account for the existence of autocorrelation in the residuals. An AR(1) model has been assumed for the errors of the least square regression whenever significant autocorrelations were detected.

Figure 10b shows the effect of the homogeneity correction for the time series from La Coruña. The solid lines correspond to a low pass filter output and a linear fit to the corrected data; the dashed line is similarly obtained from the original series. The linear fit to non-corrected data shows a significant ($\alpha = 0.05$) slope of 3.6 $mm/decade$ which is reduced to a non-significant value of 0.9 $mm/decade$ after the correction.

Figure 11a shows trends for the original data (without corrections). Results for each case correspond only to the period of existence of data within the time interval 1899 to 1989 (i. e., Grenoble: 1899 to 1976, see Table 1). 30% of the trends are significant. In general, positive trends seem to dominate, particularly in the north of the IP. However, interpreting spatial structures from these plots should be done with caution since the time span of the time series can change from site to site.

Fig. 11b shows trends after the corrections of outliers were applied. Nearly the same pattern is obtained, except in some specific cases where changes in the magnitude and significance of slopes arise; examples for this are the time series of Perpignan (number 30), Palencia (39) and Castellón (50).

In order to check the influence of outlier corrections in the homogeneization procedure, step 1 in Fig. 2 was rerun with the original data without outlier corrections. The test results were different in 8 cases: stations 38, 43, 47, 71 and 84 switched from inhomogeneous to homogeneous and 72, 87 and 94 from homogeneous to inhomogeneous. In all these cases T values were very close to the significance level. If outliers were not trimmed the series were pushed to the significance or non-significance side depending on the specific characteristics of the time series. Outliers cause an increase in the mean of the period in which they occur. If this rise in mean sharpens (shortens) the differences between the period before and after a given change, it will increase (decrease) the T values and the significance of the change. The authors consider that it is safer to take decisions upon the quality of the time series that depend mostly on its overall characteristics rather than on the extreme behaviour of a few data. This is also valid for the calculation of trends, since we are interested in results that describe the long term behaviour of the time series and are not so sensitive to individual data. Therefore we think that the use of trimmed data is justified.

Fig. 11c shows the trends after the data have been corrected for outliers and inhomogeneities. If we compare it to Fig. 11b we can describe the changes as dramatic. Significance is reached in only 8 sites and the picture is more uniform. In most sites the value of trends is neglible and there are almost no negative trends left; positive trends in the north of the IP still remain.

Fig. 11d shows trends of the corrected and interpolated data for the period 1899 to 1989. A solid zero line is plotted for easier visualization of regions of diferent sign. Though significance is reached only in a few stations, a highly coherent spatial behaviour arises in this plot. All stations close to the Atlantic coast show positive trends. In the north of the IP this also happens inland further south and also with the french stations, which only show negative trends on the Mediterranean Coast. On the east coast of the IP, positive values also arise. The Pyrenees,

the french Mediterranean Coast, north of Africa and quite a few stations in the middle and south of Spain show negative values.

These annual trends show the average behaviour of seasonal trends. Some insight into the

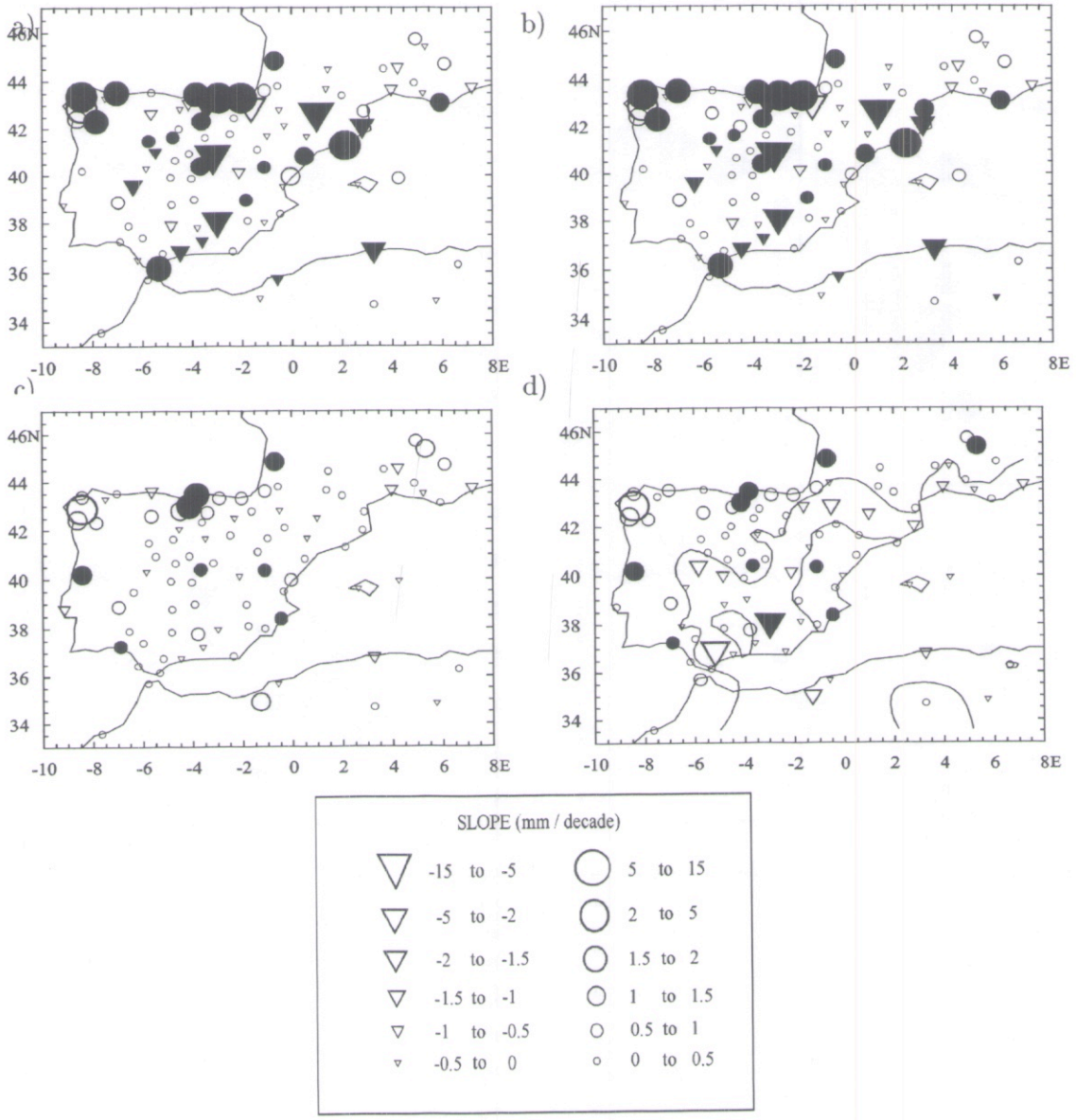

Figure 11: Trends in the (a) original data set, (b) after correcting outliers, (c) after correcting outliers and inhomogeneities. Annual means for the periods of existence of data in each station have been used for the calculations.(d) Trends in the final data set for the period 1899 to 1989 (inputs were also annual means). A solid line for value cero is plotted for easy visualization of different regions.

latter is obtained from Figure 12. Slopes have been obtained using monthly anomalies for each season (winter: December to February; spring: March to June; summer: July to September; autumn: October to December). Anomalies were calculated by substracting the long term monthly means to filter out the mean annual cicle.

Trends in winter (Fig. 12a) show positive values nearly over all the area except for the north of Africa. Significance is reached in 40% of the trends. In spring (Fig. 12b) the positive

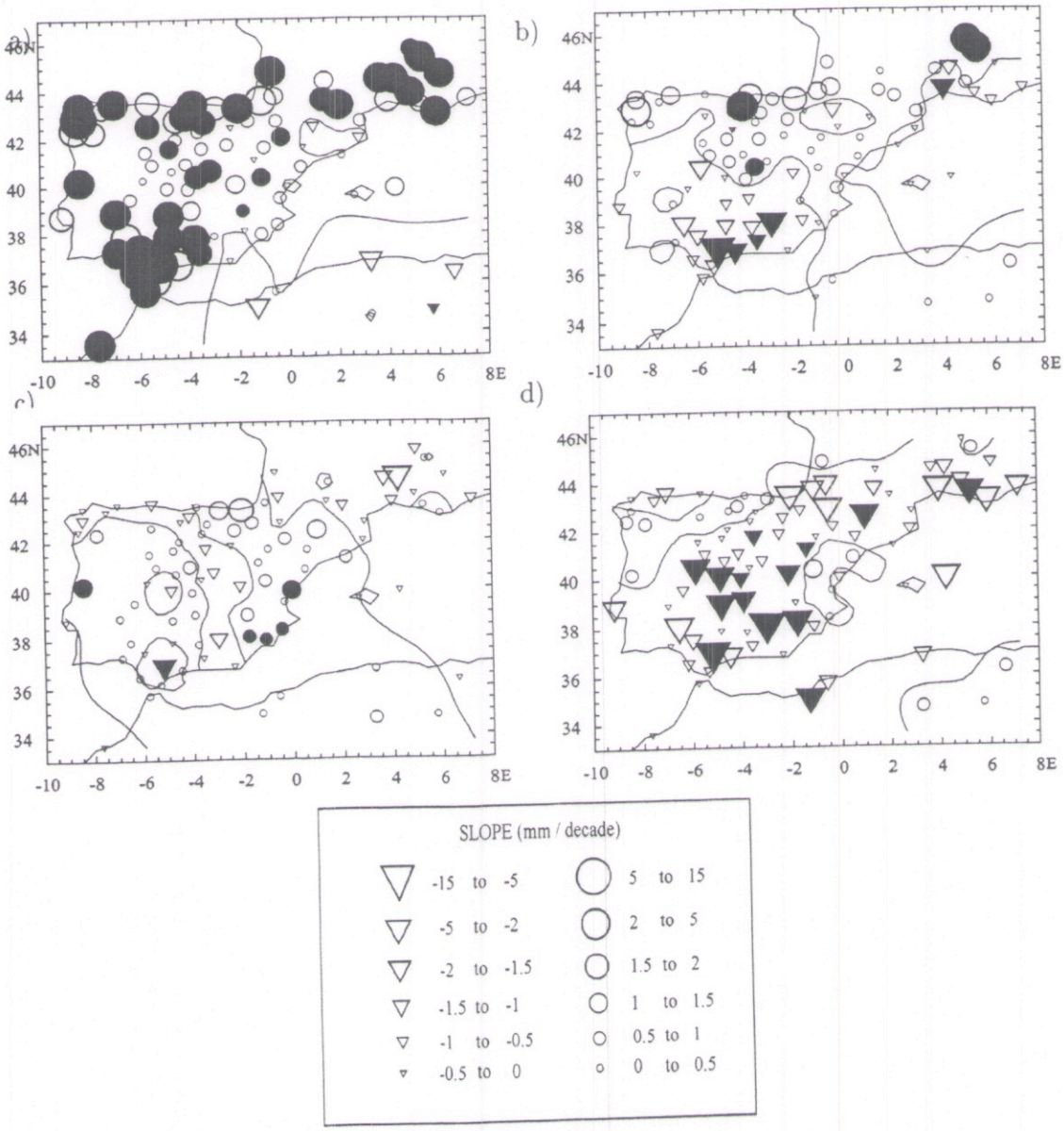

Figure 12: Trends in the final data set for (a) winter, (b) spring, (c) summer and (d) fall. Monthly data for each season were used as inputs. A solid line for value cero is plotted for easy visualization of different regions.

trends loose significance in the northern half of the IP and give way to negative trends in the southern half. In the summer (Fig. 12c) the pattern alternates areas of positive and negative values. In autumn (Fig. 12d), negative, often significant, precipitation values are obtained nearly everywhere except for some sites on the east coast and in the northwest. The decrease of precipitation in autumn and spring and increase in winter indicates strengthening of the annual cycle. These results agree with those of other authors that report a significant downward trend during this century, both in the intensity of the zonal circulation in the North Atlantic and in the amplitude of its the annual cycle, these being described by changes in the North Atlantic Oscillation (NAO) index (Lamb and Peppler 1987; Hurrel 1996). When the NAO index annual amplitude is less than normal , i. e., when smaller autumn-winter and/or greater NAO for summer is observed (Makrogiannis et al. 1991) the amplitude of the annual wave in precipitation in the IP increases (Valero et al. 1996b).

5 Discussion and conclusions

A quality control procedure has been applied to a data set consisting of 95 precipitation time series in the southwest of Europe. For this, outliers and inhomogeneities have been taken into account as potential quality problems.

The spatial and temporal distributions of extreme data match the areas and times of the year of extreme phenomenology. Therefore we should reject human errors as major causes to these extreme data. By correcting outliers we still keep their character of extreme values and reduce the posible biases they can cause in statistics estimations.

The effects of outlier corrections on trend estimation and homogeneity corrections have been shown to be of minor importance. However, by handling outlier-corrected data, results rely more on the long term behaviour of the series than on the marginal extreme properties of a few points.

After analysing the homogeneity of the time series, 40% of them were homogeneous, 49.5% were homogeneous after applying one correction factor and 9.5% after applying two correction factors. In 30% of the cases the inhomogeneities could be linked to some historical change in the rain gauge, in spite of the metadata being scarce. Examples have been presented that provide evidence that precipitation records from the area of study show severe homogeneity problems. There is a considerable influence of homogeneity corrections in the estimation of trends which points out that any long term variability study from this area can potentially lead to very different results depending on the use of homogenized or non-homogenized data.

Trends for corrected data present great regional agreement. Winter values show positive and ussually significant trends over most of the area of study. Significant negative trends show up mainly in spring and autumn. This trends seem to agree with those described in the literature for the zonal circulation in the Norht Atlantic (Makrogiannis et al. 1991; Valero et al. 1996b). Future work will focus on the behaviour of these long term trends, also in conection with the large scale circulation.

The SNHT is based on the hypothesis that the ratios between the test-station values and some regional precipition average should be constant. It is posible that this underlying assumption leads to removing distinct local trends in stations imbeded in microclimates and not necesarily related inhomogenity problems. It should also be pointed that the output of such

a quality control procedure does not intend to be an error-free data set, but one where the quality of the time series has been significantly improved. On the other hand, different methodologies can lead to partially different results, as not only the error subject to any homogeneity test adds uncertainty but also the various methods and criteria that can be chosen for the selection of reference stations. Different countries and institutions have chosen methodologies that specifically suit their purposes (Peterson et al. 1998b). In this sense, work intercomparing different methods would be desired and is still to come.

6 Acknowledgments

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References

Alexanderson, H. A., 1986: A homogeneity test applied to precipitation data, *J. Climatol*, **6**, 661–675.

Almarza, C., J. A. López, and C. Flores, 1996: *Homogeneidad y variabilidad de los registros históricos de precipitación de España*, Tech. rept. A-143. Instituto Nacional de Meteorología, Madrid.

Barnett, V., and T. Lewis, 1994: *Outliers in Statistical Data*. 3rd. edn.. Chischester: J. Willey and Sons.

Buishand, T. A., 1982: Some methods for testing the homogeneity of rainfall records, *J. Hydrol.*, **58**, 11–27.

Conrad, V., and C. Pollak, 1950: *Methods in Climatology*. Cambridge, MA: Harvard University Press.

Durbin, J., and G. S. Watson, 1971: Testing for serial correlation in least squares regression, III, *Biometrika*, **37**, 1–19.

Eischeid, J., C. B. Baker, T. Karl, and H. F. Díaz, 1995: The quality control of long-term climatological data using objective data analysis, *J. Appl. Meteorol.*, **34**, 2787–2795.

Esteban-Parra, M. J., F. S. Rodrigo, and J. Castro-Diez, 1998: Spatial and temporal patterns of precipitation in Spain for the period 1880-1992, *Int. J. Climatol*, **18**, 1557–1574.

Fernández-Mills, G., 1995: Principal component analysis of precipitation and rainfall regionalization in Spain, *Theor. Appl. Climatol.*, **50**, 117–131.

Grant, E. L., and R. S. Leavenworth, 1972: *Statistical Quality Control*. New York: McGraw-Hill Book Company.

Hanssen-Bauer, I., and J. Førland, 1994: Homogenizing long norwegian precipitation series, *J. Climate*, **7**, 1001–1013.

Hawkins, P. M., 1977: Testing a sequence of observations for a shift in location, *J. Am. Stat. Assoc.*, **72**, 180–186.

Hegerl, G. C., H. von Storch, K. Hasselmann, B. D. Santer, U. Cubasch, and P. D. Jones, 1996: Detecting anthropogenic climate change with an optimal fingerprint method, *J. Climate*, **9**, 2281–2306.

J. Houghton, B.A. Callendar and S.K. Varney (Eds.), 1992: *Climate Change: the Supplemntary Report to the IPCC Scientific Assesment*, Cambridge University Press.

J. Houghton, L. G. Meira Filho, B. A. Callander, N. Harris, A. Kattenberg and K. Maskell . (Eds.), 1995: *Climate Change, 1995: The Science of Climate Change*, Cambridge University Press.

Hurrel, J. W., 1996: Decadal trends in the North Atlantic Oscillation: regional temperatures and precipitation, *Science*, **269**, 676–679.

Jones, P., B. Raper, B. Santer, B. Cherry, C. Goodess, M. Kelly, T. Wigley, S. Bradley, and H. Díaz, 1985: *A Grid Point Surface Air Temperature Data Set for the Northern Hemisphere*, Tech. rept. Department of Energy, Washington.

Karl, T. R., and C. N. Williams, 1987: An approach to adjusting climatological time series for discontinuous inhomogeneities, *J. Climate. Appl. Meteor.*, **26**, 1744–1763.

Lamb, P. J., and R. Peppler, 1987: North Atlantic Oscillation: concept and application, *Bull. Am. Meteorol. Soc.*, **68**, 1218–1225.

Linés, A., 1970: *Climates of Northern and Western Europe*, C Wallen (ed.). World Survey of Climatology, vol. 5, Amsterdam-London-New York: Elsevier Publishing, Chap. The Climate of the Iberian Peninsula, pages 195–239.

Maheras, P., 1988: Changes in precipitation conditions in the western Mediterranean over the last century, *J. Climatol.*, **8**, 179–189.

Makrogiannis, T. J., H. S. Sahsamanoglou, A. A. Flocas, and A. Bloutsos, 1991: Analysis of the monthly zonal index values and longterm changes in the North Atlantic and Europe, *Int. J. Climatol.*, **11**, 493–503.

Mitchell, J. M., B. Dzerdzeevski, H. Flohn, W. L. Hofmeyr, H. H. Lamb, K. N. Rao, and C. C. Wallen, 1966: *Climate change*, Tech. rept. 79. WMO, Geneve.

Peterson, T. C., R. Vose, R. Schmoyer, and V. Razuvaev, 1998: Global Historical Climatology Network (GHCN) quality control of monthly temperature data, *Int. J. Climatol*, **18**(1169-1179).

Peterson, T. C., D. R. Easterling, T. R. Karl, P. Groisman, N. Nicholls, N. Plummer, S. Torok, I. Auer, R. Boehm, D. Gullett, L. Vincent, R. Heino, H. Tuomenvirta, O. Mestre, T. Szentimrey, J. Salinger, E. J. Førland, I. Hanssen-Bauer, H. Alexanderson, P. Jones, and D. Parker, 1998b: Homogeneity adjustments of *in situ* atmospheric climate data: a review, *Int. J. Climatol*, **18**(1493-1517).

Rhoades, D. A., and M. J. Salinger, 1993: Adjustment of temperature and rainfall records for site changes, *Int. J. Climatol.*, **13**(899-913).

Rodriguez-Puebla, C., A. H. Encinas, S. Nieto, and J. Garmendia, 1998: Spatial and temporal patterns of annual precipitation varibility over the Iberian Peninsula, *Int. J. Climatol.*, **18**(299-316).

Santer, B. D., K. E. Taylor, T. M. Wigley, J. E. Penner, P. D. Jones, and U. Cubash, 1995: Towards the detection and attribution of an anthropogenic effect on climate, *Clim. Dyn*, **12**(77-100).

Snedecor, G. W., and W. G. Cochran, 1972: *Statistical Methods*. 6th edn.. Iowa State University Press.

Trenberth, K. E., 1984: Some effects of finite sample size and persistence on meteorological statistics. Part I: autocorrelations, *Mon. Wea. Rev.*, **112**, 2359–2368.

Trenberth, K. E., and D. A. Paolino, 1980: The Norther Hemisphere sea-level pressure data set: trends, errors and discontinuities, *Mon. Wea. Rev.*, **108**, 856–872.

Valero, F., J. A. García-Miguel, M. L. Martín, and Y. Luna, 1993: Detecting long-term variations in precipitation in the souteastern Iberian Peninsula, *Ann. Geophysicae*, **11**, 837–845.

Valero, F., J. F. González, F. J. Doblas, and J. A. García-Miguel, 1996a: A method for the reconstruction and temporal extension of climatological time series, *Int. J. Climatol.*, **16**, 213–227.

Valero, F., F. J. Doblas, J. F. González, and J. A. García-Miguel, 1996b: On long-term evolution of seasonal precipitation in southwestern Europe, *Ann. Geophysicae*, **14**, 976–985.

Valero, F., R. M. Rodríguez, and J. A. García-Miguel, 1997a: Filling data algorithms in urban air pollution monitoring networks, *J. Environ. Eng-ASCE*, **103**, 395–403.

Valero, F., M.Y.Luna, and M. Martin, 1997b: An overwiew of a heavy rain event in Southeastern Ibe ria: the role of large-scale meteorological conditions, *Ann. Geophysicae*, **15**, 494–502.

Zorita, E., V. Kharin, and H. von Storch, 1992: The atmospheric circulation and sea surface temperature in the North Atlantic area in winter: their interaction and relevance for Iberian precipitation, *J. Climate*, **5**, 1097–1108.

Zwiers, F. W., and H. von Storch, 1995: Taking serieal correlations into account in tests of the mean, *J. Climate*, **8**, 336–351.