A review of statistical analyses on monthly and daily rainfall in Catalonia

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Abstract

A review on recent studies about monthly and daily rainfall in Catalonia is presented. Monthly rainfall is analysed along the west Mediterranean Coast and in Catalonia, quantifying aspects as the irregularity of monthly amounts and the spatial distribution of the Standard Precipitation Index. Several statistics are applied to daily rainfall series such as their extreme value and intra-annual spatial distributions, the variability of the average and standard deviation rain amounts for each month, their amount and time distributions, and time trends affecting four pluviometric indices for different percentiles and class intervals. All these different analyses constitute the continuity of the scientific study of Catalan rainfall, which started about a century ago.

Key words: monthly and daily rainfall, spatial and time distributions, pluviometric indices, time trends, Catalonia

1 Introduction

The results of the first monthly rainfall network in Catalonia were compiled by Febrer (1930), with measurements of different lengths from 314 rain gauges covering the period from 1861 to 1925. The results included the first monthly average rainfall maps. A complete relation of preliminary contributions can be found in Albentosa (1980). With a similar objective, Clavero et al. (1996) published a more detailed spatial distribution of the monthly average rainfall from close to 300 gauges, with at least 20 years of recordings since 1940 up to 1980. With the statistical description in mind and taking advantage of the data available, the authors of this review have analysed particular spatial properties of monthly and daily rain amounts in Catalonia, in a century in which detection of the human influence on precipitation trends for the earth has been recently proven (Zhang et al., 2007). Previous research in this domain cover different scopes as the contribution of the convective rainfall to the annual amount (Guilló and Puigcerver, 1970; Puigcerver and Guilló, 1971; Llasat and Puigcerver, 1997; Llasat, 2001), the dynamical and statistical analysis of flood events (Llasat and Puigcerver, 1992, 1994; Llasat and Rodríguez, 1992; Ramis et al., 1994; Llasat et al., 1996), the prediction of a mesoscale convective system

by a nested numerical model (Codina et al., 1997), the climatological analysis of the dry-wet time series (Martín-Vide, 1984; Burgueño, 1991) the regionalization of the precipitation by means of Principal Component Analysis (Fernández-Mills et al., 1994; Serra et al., 1998), and the Gumbel distribution of extreme rain amounts (Casas et al., 2007).

According to Kiktev et al. (2003), for middle latitudes (30° - 60°N) and the period from 1950-1995, most of Europe and East Asia are characterized by a positive trend in the annual maximum of consecutive days with daily precipitation below 1.0 mm, with a negative trend in the number of rainy days. This general behavior becomes of larger relevance for the Mediterranean area, where an increase of extreme daily rainfall has been observed during 1951-1995, in spite of a decrease in total amounts (Trigo et al., 2000; Alpert et al., 2002). Thus, in the Mediterranean area, the prospect is for a larger frequency of drought periods, with associated impacts on agriculture, on the exploitation of water resources and also on socio-economic activities. In the Iberian Peninsula, different trend analyses of daily rainfall point to an increase of light rainfall events at the cost of a decrease of more intense events (Goodess and Jones, 2002; Gallego et al., 2006; Rodrigo and Trigo, 2007). Different regional climate models, as also global models considering different scenarios of
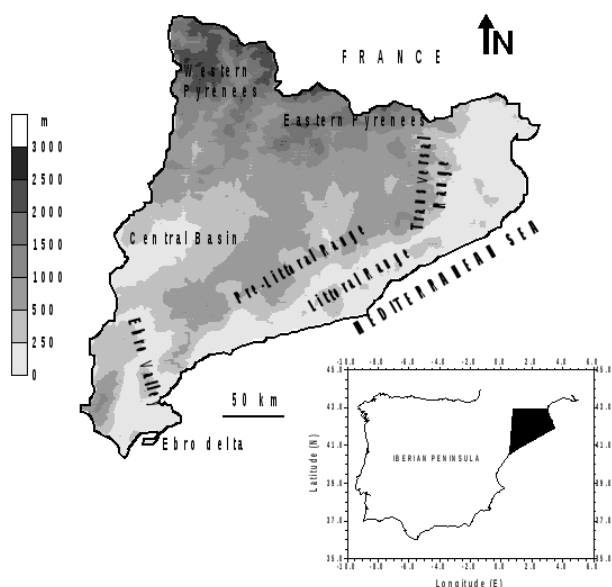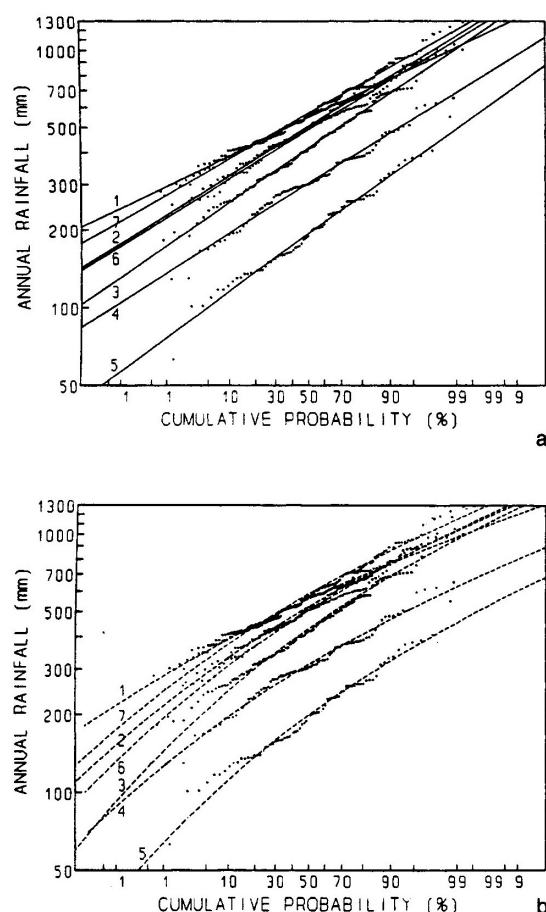
Figure 1. Main orographic features of Catalonia and its emplacement in the Iberian Peninsula.
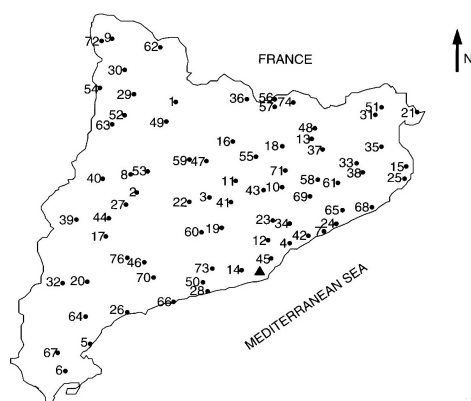
Figure 2. Spatial distribution of the 75 rain gauges belonging to the *Agencia Estatal de Meteorología*, with inclusion of the Fabra Observatory, which is represented by a solid triangle.

Figure 3. Probability plot of cumulative functions for empirical annual rainfall compared with a) the log-normal distribution, and b) the gamma distribution. Numbers 1 to 7 design gauges ordered in decreasing latitude. (Source: Lana and Burgueño, 2000a).

greenhouse gas emissions applied to the Mediterranean region, point to a lengthening of the long dry spells, due to a reduction in the rain amount during the 21st century (Ghan and Shippert, 2006), particularly in the summer season (Voss et al., 2002; Gibelin and Déqué, 2003; Räisänen et al., 2004; Sánchez et al., 2004; Kundzewicz et al., 2006).

These observed shifts in the spatial and temporal rainfall distribution are connected to the dynamical effects of the enhanced greenhouse gases and sulphate aerosols in the atmosphere. Thus, on the extratropical cyclone activity, Geng and Sugi (2003) deduced that the total cyclone density will decrease significantly around the year 2050 in the middle latitudes of the Northern Hemisphere during December-January and February (DJF) and June-July-August (JJA) seasons. Moreover, while a reduction of weak and medium-strength cyclone is foreseen, the density of strong cyclones will increase by more than 20% in JJA. These changes are linked to the decrease of baroclinicity in the lower troposphere, mainly caused by the decrease of meridional temperature gradient. Previous studies on cyclones over the North Atlantic by Knippertz et al. (2000) also pointed towards a reduction of the number of total cyclones and an increase of strong cyclones, with a poleward and eastward shift of their track. This shift of the storm tracks has also been found by other authors (Ulbrich and Christoph, 1999; Pinto et al., 2007). This behavior is consistent with the 1948-2002 arctic cyclone activity (60° - 90°N), which shows that the number and intensity of cyclones entering the Arctic from midlatitudes have increased, thus suggesting a shift of storm tracks into the Arctic, particularly in summer (McCabe et al., 2001; Zhang et al., 2004). The Mediterranean Basin would also suffer a decrease of the overall cyclone activity and an increase of
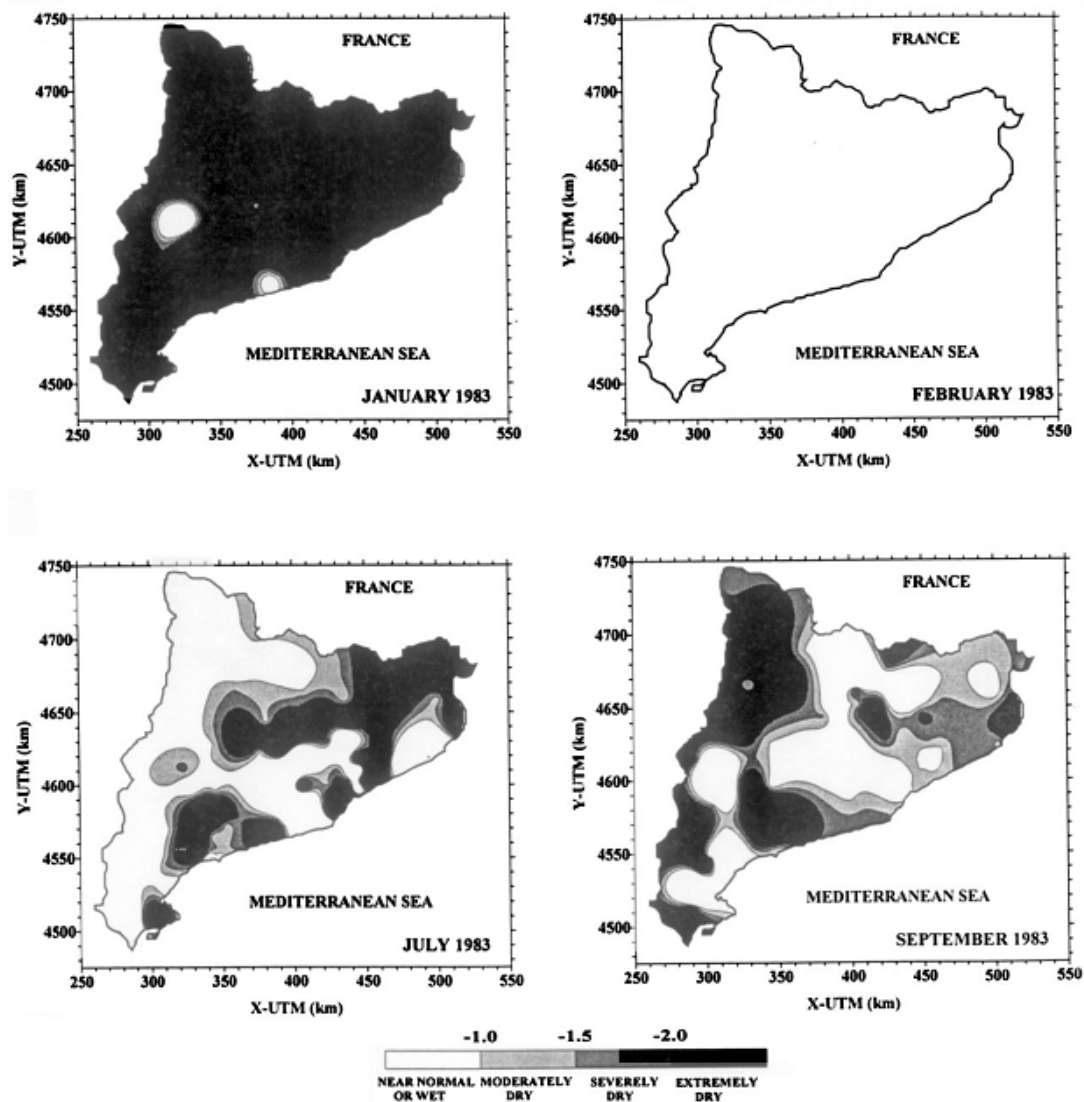
Figure 4. Spatial distribution of monthly Standardized Precipitation Indexes (SPI) for January, February, July and September of 1983. White areas correspond to zones with rain gauges reaching annual SPIs greater than -1.0. (Source: Lana et al., 2001)

deep cyclones in a doubled CO_2 climate scenario (Lionello et al., 2002). As a second order consequence, the observed northward shift of storm tracks supports more stable circulation conditions over Europe, manifested in a higher persistence of atmospheric circulation in last decades, with the consequent exacerbation of impacts on the occurrence and severity of temperature extremes (Kyselý and Domonkos, 2006; Kyselý, 2007).

In the present changing rainfall conditions, statistics on a regional scale are of value, given that these may supply an objective analysis that will become an aid to check any future rainfall scenario. The contents of this review cover the monthly and daily rain amounts statistics in Catalonia developed during the last 14 years by the authors, paying particular attention to their spatial distribution, statistical distributions and time trends.

2 Study area, databases and regional climate

2.1 Study area

Catalonia extends over a surface of 32.000 km^2 at the NE of the Iberian Peninsula, with nearly 400 km of Mediterranean coast (Figure 1). As main orographic characteristics, it is worth mentioning the Pyrenees and Pre-Pyrenees Ranges, which mitigate the effects of northern advections for the rest of the region; the Littoral and Pre-Littoral Ranges, sheltering the Central Basin against eastern advections and, at the same time, enhancing their effects on the Littoral and Pre-Littoral domains; and the Central Basin itself, subject to the effects of frontal passages and western advections, mitigated by the remoteness to the Atlantic coast. Within the Pyrenees Range, distinctions have to be made between the

Eastern Pyrenees regime, strongly influenced by the vicinity to the Mediterranean Sea, and the north face of the Western Pyrenees, with clear signs of Atlantic influence.

The Mediterranean regime is mainly governed by the influence of westerlies in winter and the subtropical anticyclone in summer. The vicinity of the sea and neighboring high relief lands produce a great regional variety of weather and climate. In the West Mediterranean, a large majority of the depressions are originated in the same region. These are the Saharan and Genoa type depressions (Barry and Chorley, 2003; Jansà et al., 2001). Unlike the central area and southwest coast of the Iberian Peninsula, with winter precipitation mainly explained by the North Atlantic Oscillation, the eastern Iberian Peninsula keeps a negative correlation with the Western Mediterranean Oscillation (Martín-Vide and López-Bustins, 2006).

2.2 Databases

The monthly precipitation along the Spanish Mediterranean and nearby Atlantic coasts, as also the monthly and daily rain amounts recorded in Catalonia have been obtained from the *Agencia Estatal de Meteorología*, former *Instituto Nacional de Meteorología*. The length and size of the databases have changed along the years on account of the different kinds of studies. While in Lana and Burgueño (2000a) the mean data length of seven rain gauges was longer than a century, in Lana and Burgueño (1998) data were obtained from 74 rain gauges, with lengths ranging from 30 to 76 years; in Lana et al. (2001), from 99 rain gauges for the years 1961 to 1990; and in Burgueño et al. (2005), from 75 gauges covering the period between 1950-2000 (Figure 2). For this last database, the homogeneity of every rain gauge record and a certain lack of data from some gauges have been extensively analyzed, quantified and discussed by Lana et al. (2004) and Burgueño et al. (2005). Missing data in some gauges can reach 10 years, usually not distributed in very short gaps, but in continuous periods close to 1 year. Missing daily data could have been estimated by considering statistical methods and data corresponding to neighboring gauges. Nevertheless, the strong spatial variability of the daily pluviometric regime of Catalonia (Lana et al., 2004) advises against the substitution of missing data. In spite of the low number of data series in the Western Pyrenees Range, the recording continuity of the remaining gauges is good.

2.3 Regional climate

The closeness to a warm sea and the distant Atlantic Ocean, together with a complex orography, produce a particular scenario for the spatial distribution of rainfall amounts, in which eastern and southern advections are the most significant contributors in spring and especially in autumn. They mainly affect the littoral and pre-littoral domains, but sometimes extend further inland.

The Föhn effect through the Iberian Peninsula under the western advections and through the Pyrenees under north-
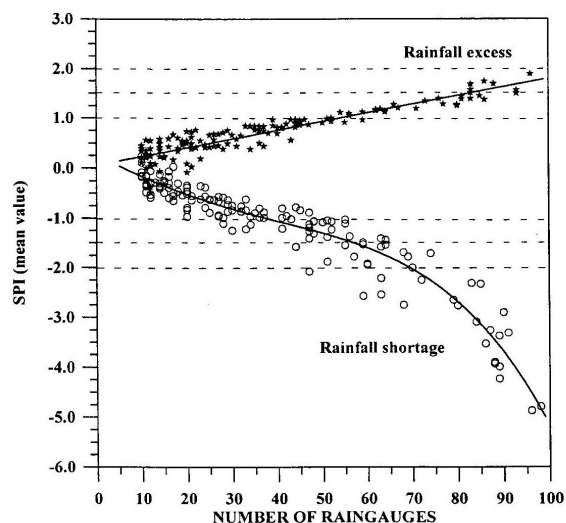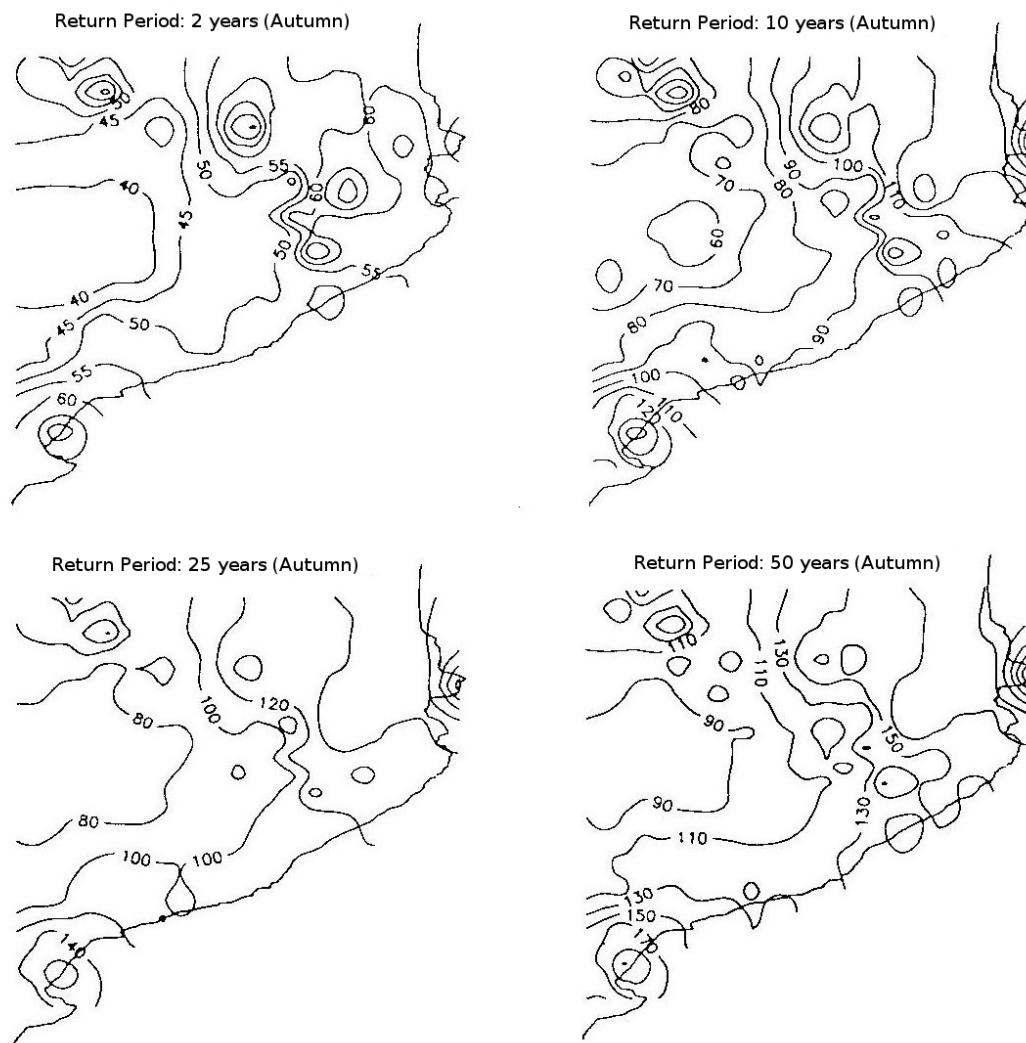

Figure 5. Evolution of the spatial-averaged SPI in terms of the number of rain gauges where rainfall shortage or excess is detected. Open circles and stars depict empirical values and solid lines the best fit by means of a straight line and a polynomial respectively. (Source: Lana et al., 2001)
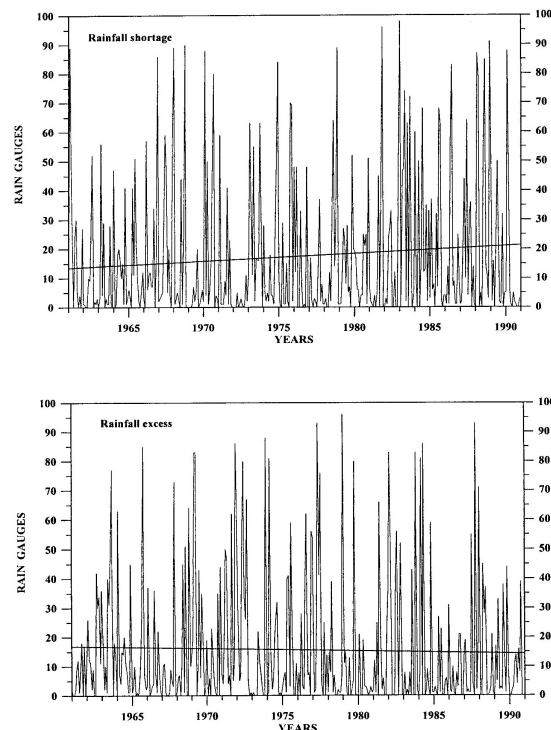
Figure 6. Evolution of the number of rain gauges detected each month with SPIs less than -1.0 (rainfall shortage) and greater than 1.0 (rainfall excess). Straight lines depict linear trends along the recording period of 30 years. (Source: Lana et al., 2001)

Return Period: 2 years (Autumn)

Return Period: 10 years (Autumn)

Return Period: 25 years (Autumn)

Return Period: 50 years (Autumn)

Figure 7. Spatial distribution of predicted daily precipitation maxima (mm), corresponding to Autumn, for return periods of 2, 10, 25 and 50 years. (Source: Lana et al., 1995)

ern and northwestern circulations would explain the null or scarce rainfall under these synoptic situations in some areas of Catalonia, except for the north face of Western Pyrenees. On the other hand, when a nucleus of low-pressure crosses Catalonia, the rain amounts are relevant. Moreover, these systems are sometimes reactivated when they reach the Mediterranean Sea and can generate eastern advections.

Long dry spells usually occur in the hot and cold seasons because of anticyclonic persistence which often affects the whole region. Along the hot seasons, the income of humid air from the Mediterranean together with cold air masses at high levels of the troposphere can interrupt summer droughts in mountain ranges such as the Pyrenees and Pre-Pyrenees by convective phenomena.

3 Monthly rainfall

3.1 Pluviometric irregularity for the Spanish Mediterranean Coast

Seven long-term series of monthly rain amounts (Table 1), two of them in the Catalan coast, were used to study the irregularity of the pluviometric regime along the Spanish Mediterranean and nearby Atlantic coasts (Lana and Burgueño, 2000a). Three statistical functions (gamma, lognormal and a combination of Poisson and gamma distributions) and moment-ratio diagrams were used to model the monthly and annual empirical distributions of precipitation amounts, each distribution being tested by means of the Kolmogorov-Smirnov test. It is noteworthy that, whereas most of the monthly cases required the gamma distribution, the pluviometric behavior of the summer months was well

Table 1. List of Mediterranean and Atlantic gauges with their latitude, longitude, recording period, available years, sample mean annual rainfall, m, its standard deviation, s, number of years to achieve stationary values, ns, and coefficient of variation, CV. (Source: Lana and Burgueño, 2000a)

Station	Latitude	Longitude	Recording period	Years	m (mm)	s (mm)	ns (years)	CV (%)
Barcelona	41°23'N	2°10'E	1860-1987	128	573.0	150.5	100	26.3
Tortosa	40°49'N	0°29'E	1906-1994	89	542.3	177.2	65	32.7
Valencia	39°29'N	0°21'W	1864-1994	129	452.0	178.1	65	39.4
Alicante	38°22'N	0°30'W	1909-1994	86	324.6	108.3	60	33.4
Almería	36°50'N	2°29'W	1913-1994	75	212.2	85.9	50	40.5
Málaga	36°39'N	4°29'W	1906-1994	80	532.4	186.0	65	34.9
San Fernando	36°28'N	5°45'W	1839-1994	151	608.7	195.8	80	32.2

described by the Poisson-gamma distribution. Consequently, monthly rainfall amounts are not identically distributed along the year for each gauge. Moreover, both the log-normal and the gamma distributions satisfactorily model empirical annual amounts (Figure 3). Second, temporal trends deduced for annual and seasonal amounts were computed and their statistical significance evaluated. The most notable fact is that, although some linear trends are close to 1 mm year^{-1}, their significance levels exceed the assumed threshold value and, excepting the winter season for Barcelona, they were considered non-significant from a statistical point of view. Finally, by using monthly and annual amounts again, three temporal irregularity indexes were computed for each pluviometric series, the temporal disparity of the rainfall patterns of the Mediterranean region being enhanced as a result. In addition to the temporal irregularity, a change with latitude was observed both in the parameters of the statistical distributions and the temporal irregularity indexes for the rain gauges analysed. The two most southerly rain gauges constitute a special case in comparison with the remaining stations, because they also receive the Atlantic influences due to their proximity to this ocean.

A spectral analysis of rainfall anomalies (Lana and Burgueño, 2000b) for the Barcelona monthly amount series (1860-1987) also received special attention, taking profit of its data length.

## 3.2 Monthly rainfall shortage and excess in terms of the Standard Precipitation Index

Spatial and time behaviors of rainfall shortage and excess were analysed using a database obtained from 99 rain gauges with monthly totals collected from 1961 to 1990 (Lana et al., 2001). The distribution of monthly amounts for each rain gauge was modelled by means of the gamma or Poisson-gamma distributions. Then, using an equiprobable transformation, monthly amounts described by these distributions were substituted by values given by the Standardized Precipitation Index, SPI, which follows a standardized normal distribution and provides a unique pluviometric scale (Figure 4). After that, principal component analysis, PCA,
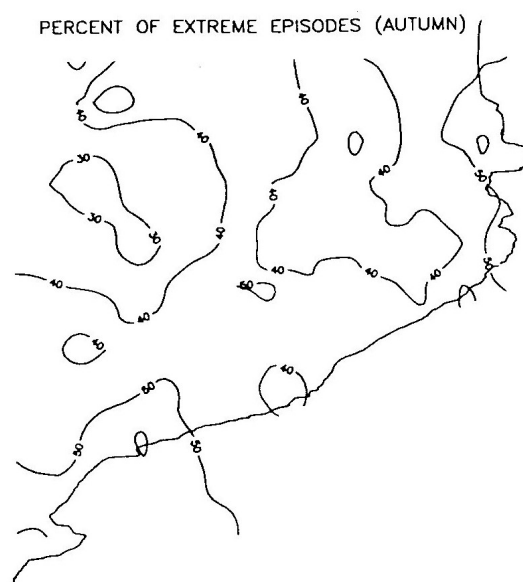
Figure 8. Percentage occurrence of the annual extremes in Autumn. (Source: Lana et al., 1995)

was applied to the set of monthly SPIs. A double regionalization of the 99 rain gauges, distinguishing between episodes of rainfall shortage and excess, was achieved by taking into account the rotated factor loadings, RFL, correlating rain gauges and principal components, PC. A time classification of rainfall shortage and excess episodes was also established, considering in this case the factor scores, FS, obtained after a PCA of variables based on monthly SPIs.

The spatial regionalization achieved became a rough picture of the different topographic domains (Pyrenees, Pre-Pyrenees, Central Basin, Littoral and Pre-Littoral chains and Mediterranean Coast), the climatic diversity of Catalonia being enhanced by these results. The time clustering suggested a quite complex behavior of the rainfall shortage and excess episodes. Moreover, the spatial distribu-
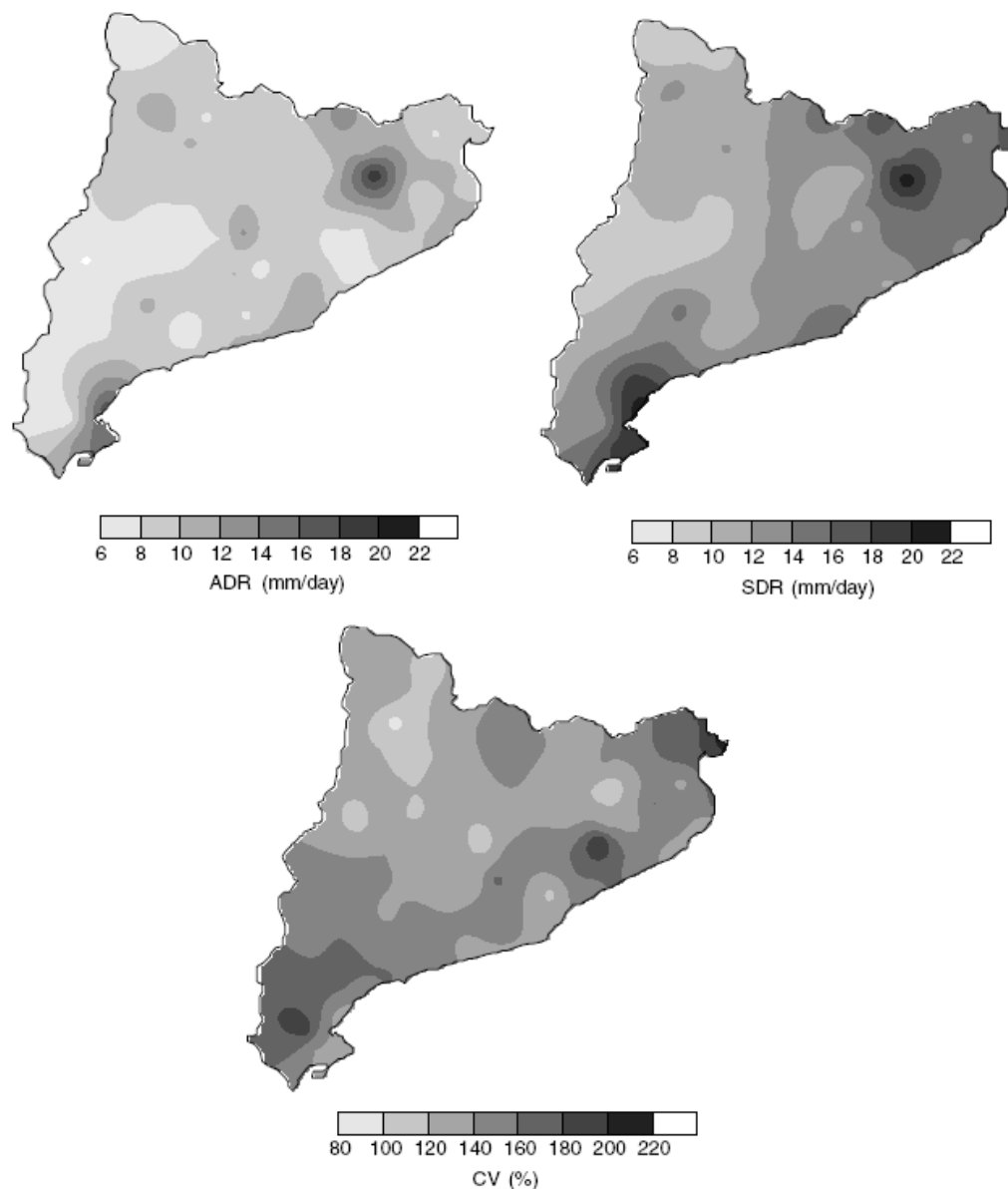
Figure 9. Averages daily rainfall (ADR), standards deviation (SDR) and coefficients of variation (CV) evaluated by considering the whole recording period of every rain gauge. (Source: Lana et al., 2004)

tion of these time clusters was very dispersed, in such a way that monthly shortage and excess sometimes affect the whole of Catalonia and sometimes just a small area. Besides results obtained from PCA and clustering algorithms, it is worth noticing that the severity of the episodes increased remarkably only for rainfall shortage (Figure 5). In addition, an analysis of the number of rain gauges affected by monthly shortage and excess showed an interesting fact: whereas the number of rain gauges associated with a shortage had an increasing tendency, an outstanding decreasing tendency for excess was detected in the period of 1961-1990 (Figure 6).

4 Daily rainfall

4.1 Daily precipitation maxima

The spatial distribution of expected daily precipitation maxima was investigated for several return periods (Lana et al., 1995). The process was applied to the four traditional seasons and for the whole year by assuming the classical Gumbel theory of extremes (Gumbel I distribution), which was confirmed by the reasonable fit between predicted and empirical extremes. The analysis pointed towards a combination of several factors controlling the extreme daily amounts distribution in Catalonia, such as the complex orography, the
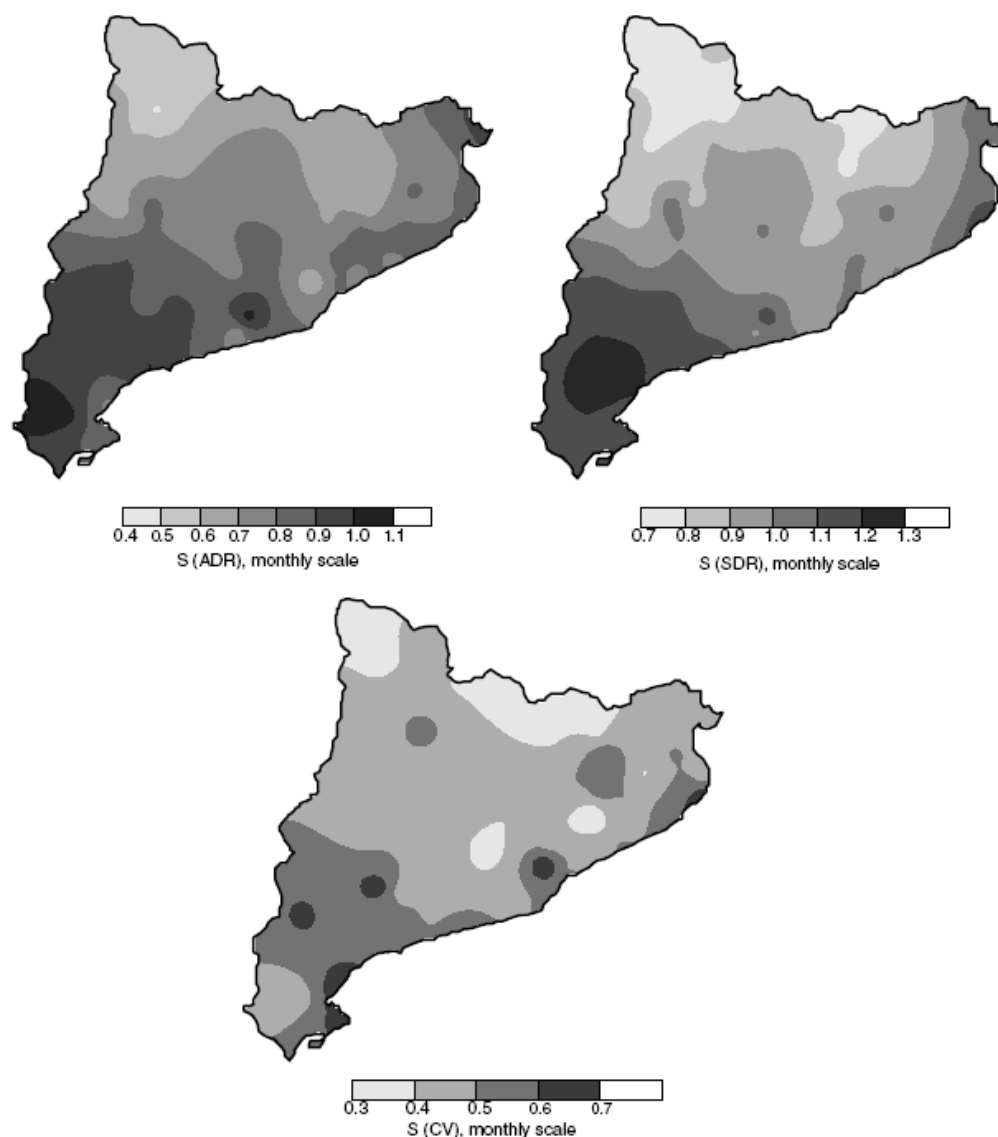
Figure 10. Spatial distribution of the temporal irregularity for the monthly series of ADR, SDR and CV. (Source: Lana et al., 2004)

proximity of the Mediterranean Sea, the significant convective activity, and the dominant surface circulation.

The records belonged to 74 rain gauges covering the whole region, with observational data of different record lengths. The stations were selected from 350 rain gauges observing two conditions. On the one hand, their seasonal and extreme data must be without significant time trend. On the other hand, the number of available extremes must be greater than 30. The resulting observational data length ranged from 30 to 76 years.

Figure 7 illustrates the behavior of the precipitation maxima corresponding to Autumn (September, October and November), and Figure 8 the occurrence in percentage of the seasonal extremes in Autumn. The most significant feature is the predominance of extreme events recorded in this sea-

son. As can be noted, the largest daily maxima are observed in the two outermost corners of the littoral. Recently, a more detailed analysis (Casas et al., 2007) has been obtained by using 145 rain gauges, which has permitted the objective estimation of the maximum daily precipitation at 1 km^2 spatial resolution.

The precipitation measurements of the different gauges, together to a Jardí gauge and a siphon gauge, installed at the Fabra Observatory and in different emplacements of Barcelona respectively, have made it possible to obtain the extreme amounts collected for a wide range of durations, from 1 to 730 consecutive days. As expected, the results obtained satisfy a power law between the duration and the extreme amount collected, which remains below the values obtained for United Kingdom (Burgueño et al., 1998).
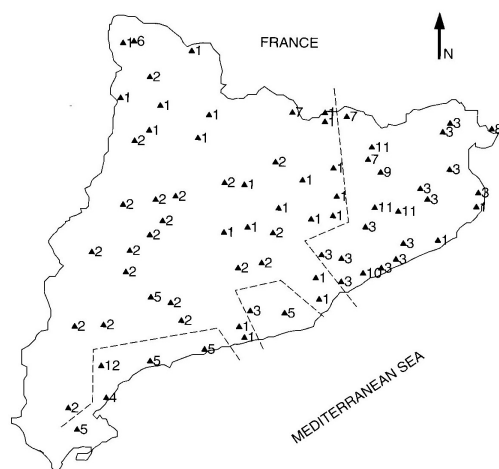
Figure 11. Spatial distribution of the 12 clusters obtained after the application of the AL clustering algorithm to the resulting FSCs, obtained by PCA applied to 12 monthly average ADRs and 12 SDRs for the 75 rain gauges considered. (Source: Lana et al., 2004)

4.2 Spatial and temporal variability of the daily rainfall

Spatial and temporal patterns in the daily rainfall regime of Catalonia recorded for the 1950-2000 period were analyzed from several points of view, including the irregularity of the time series in terms of entropy, the Mann-Kendall test for time trends, a PCA, an average linkage, AL, clustering algorithm and, finally, a power spectrum analysis, which included a comparison of white-noise and Markovian red-noise hypotheses (Lana et al., 2004). The analyses were based on three monthly variables derived from the amounts recorded on a daily basis: the average daily rainfall, ADR, and the standard deviation, SDR, of the daily rainfall for each month, together with the corresponding coefficient of variation, CV. Figure 9 shows the spatial distribution of these three statistics when applied to the whole recording period of every rain gauge. The temporal variability was manifested by the irregularity index, S:

$$S = \frac{1}{N-1} \sum_{i=1}^{N-1} \left| \log\left(\frac{X_{i+1}}{X_i} \right) \right| \qquad (1)$$

of a time series of N values of X. The spatial variability of S was characterized by relevant values in all cases and gradients from the north to the south and to the Mediterranean coast (Figure 10).

The interpretation of the factor scores derived from the PCA and of the clusters obtained from the AL algorithm also described the complex spatial distribution of the daily rainfall regime, given that the effects of atmospheric circulation patterns on rainfall regimes are conditioned by the complex orography of Catalonia and its proximity to the Mediterranean Sea. Figure 11 shows the spatial distribution of the different clusters, together with indication of two main areas
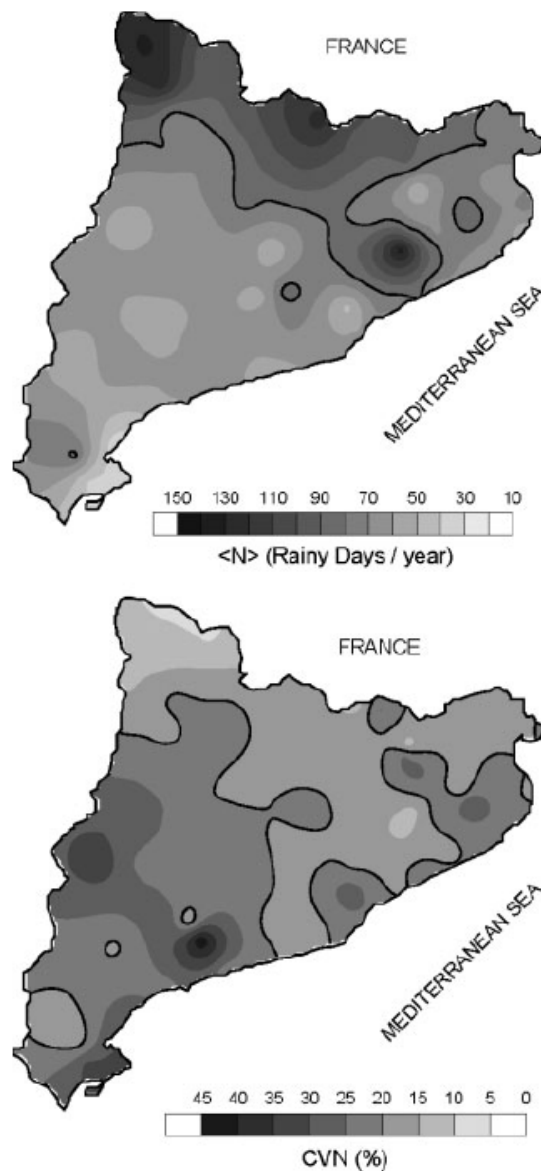
Figure 12. Spatial distribution of the average number of rainy days per year and of its coefficient of variation. Outlined isolines correspond to 80 rainy days per year and 20% of CVN. (Source: Burgueño et al., 2005)

by means of a dashed line. The largest contains mostly clusters 1 and 2, while the rest of clusters are spread close to the littoral. The factors loadings associated with the PCA also suggested a distinction between hot, cold and mild seasons. Finally, it is worth mentioning that monthly series were usually accompanied by white background noise and, in a few cases, signs of Markovian behavior and some significant periodicities, which were generally shorter than 10 months and changing from one cluster to another.
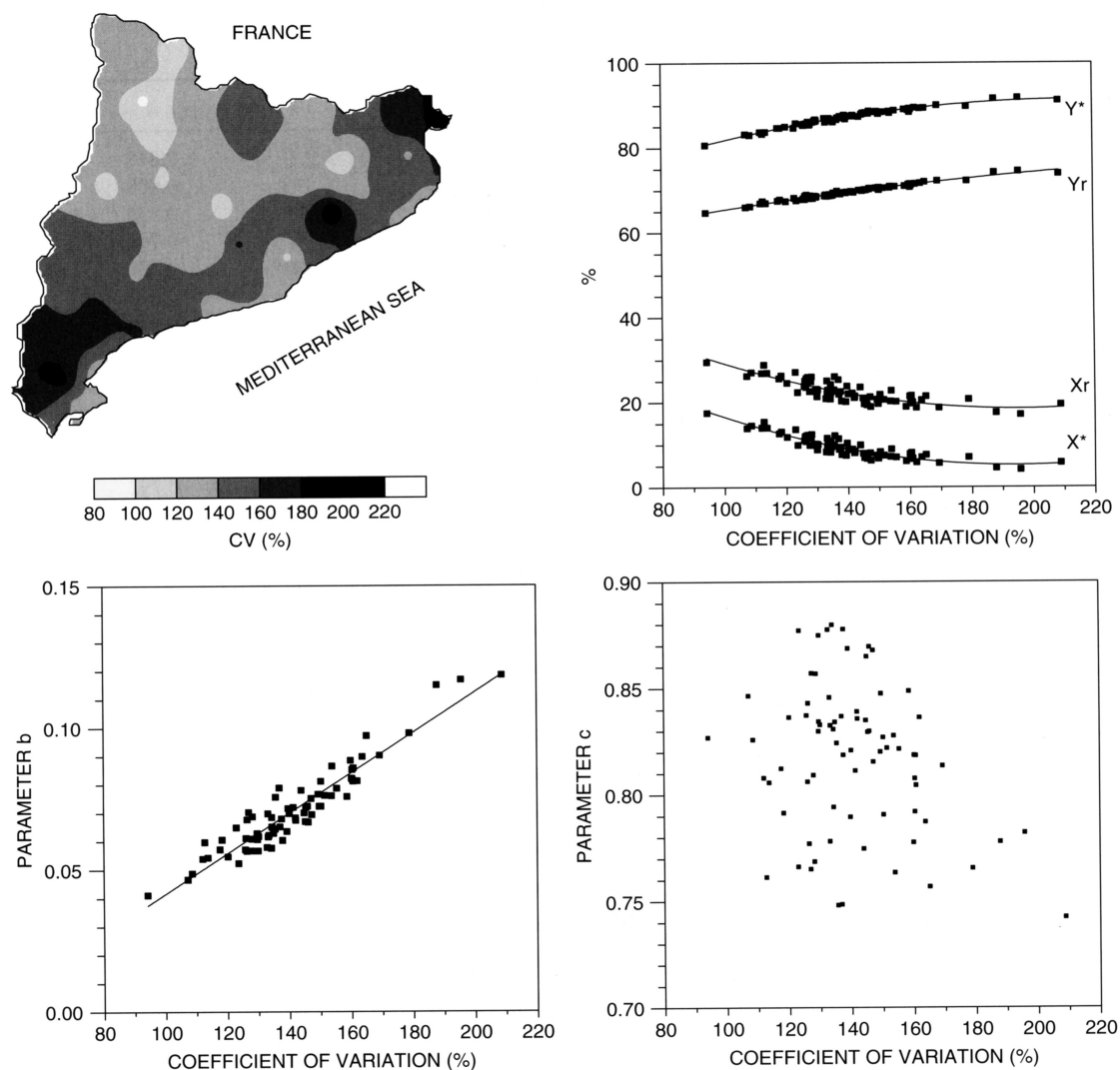
Figure 13. Dependence of parameters X_r, Y_r, X^*, Y^*, b and c on the CV of daily rain amounts. The geographical scattering of the CVs is depicted in the attached map. (Source: Burgueño et al., 2005)

4.3 Statistical distributions of the daily rainfall regime

A relatively dense network of 75 gauges provided a database of daily rainfall from 1950 to 2000, which allowed the corroboration of other analyses of the pluviometric regime in Catalonia relative to the average daily rainfall, its standard deviation and its coefficient of variation (Burgueño et al., 2005). A similar and more detailed research had been applied before to the Fabra Observatory data series, years 1917-1999 (Burgueño et al., 2004).

The average annual number, $<N>$, of rain days is shown in Figure 12, together to its coefficient of variation, CVN. The first remarkable feature is the wide range obtained for $<N>$, from 30 to 140 rainy days per year, and the relatively narrow band of values of CVN, from 5 to 45%, considerable lower than those derived for CVs of the daily

rain amounts Lana et al. (2004). Another noticeable fact is the clear decreasing (increasing) tendency in $<N>$ (CVN) from north to south, with some striking gradients of $<N>$ in areas of the Pyrenees and Transversal Ranges, and of CVN near the Mediterranean coast. The annual number of rainy days had no field significant trend for the whole region, even though 23 of the 75 gauges had significant trends.

The daily amounts distributions, X, were well modelled by an exponential distribution, while the time distributions, Y, mostly accepted the Weibull model. A few gauges did not follow either of the two models, 25 just followed just one model and 42 gauges fitted both models. The parameter of the exponential distribution adopted a relevant gradient from east to west, which pointed to the influence of Mediterranean advection on the average rain amount.
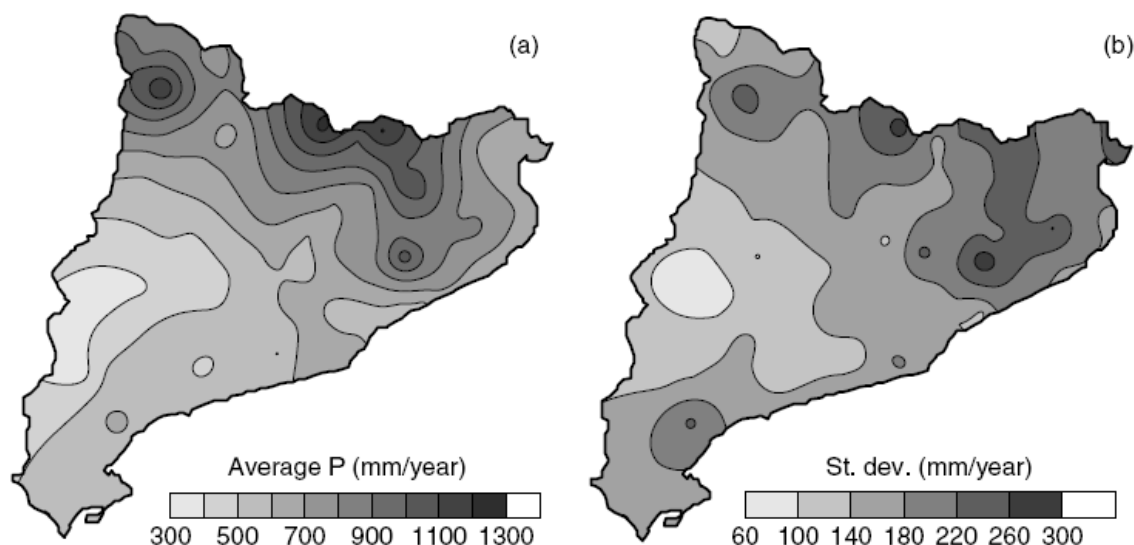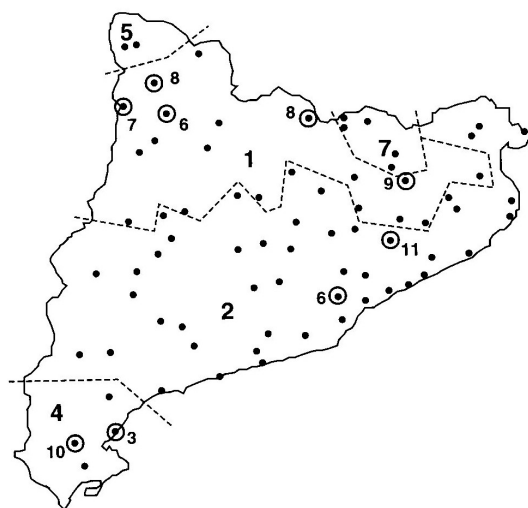
Figure 14. Spatial distribution of a) the average and b) the standard deviation of index P (mm year^{-1}). (Source: Martínez et al., 2007)
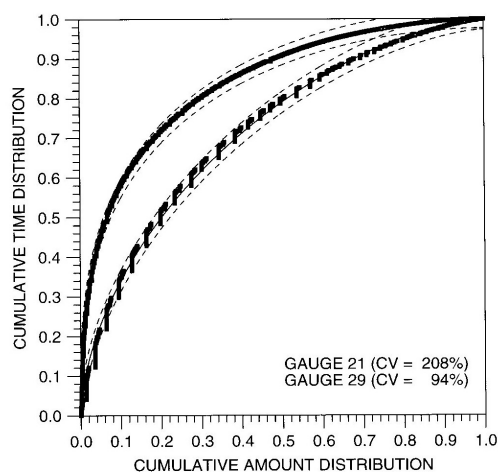
Figure 15. Two examples of the NRCs for rain gauges associated with the largest and smallest CVs of daily rain amounts, accompanied by the 95% confidence bands of the Kolmogorov-Smirnov test. (Source: Burgueño et al., 2005)


Figure 16. The 11 clusters of rain gauges after the application of the AL algorithm to the FSCs derived after applying the PCA to 17 variables (four pluviometric indices for the different percentiles and class intervals). (Source: Martínez et al., 2007)

The normalized rainfall curves, NRC, were obtained, expressing X in function of Y, irrespective of previous success in the distribution modelling. The parameters X_r, Y_r, X^*, Y^*, corresponding to the coordinates of the points of the NRC with slope equal to unity, and to the points with coordinates $(0.5, Y^*)$ and $(X^*, 0.5)$, were determined and related to the CV of the daily rain amounts (Figure 13). The NRCs can be fitted to the law:

$$X = Y \exp\left[-b(1-Y)^c\right] \qquad (2)$$

as also to a beta distribution. The set of NRCs deduced corresponds to coefficients of variation of daily amounts ranging from 94 to 208% (Figure 15). The parameters of the empirical fit and of the beta distribution kept their dependence on the coefficient of variation of daily rain amounts, and the NRCs obtained did not differ remarkably, for instance, with respect to Indian gauges in the monsoon season.

A close revision of coordinates $(1-X_r, 1-Y_r)$, derived from the NRCs, manifested that a very large fraction of rain-
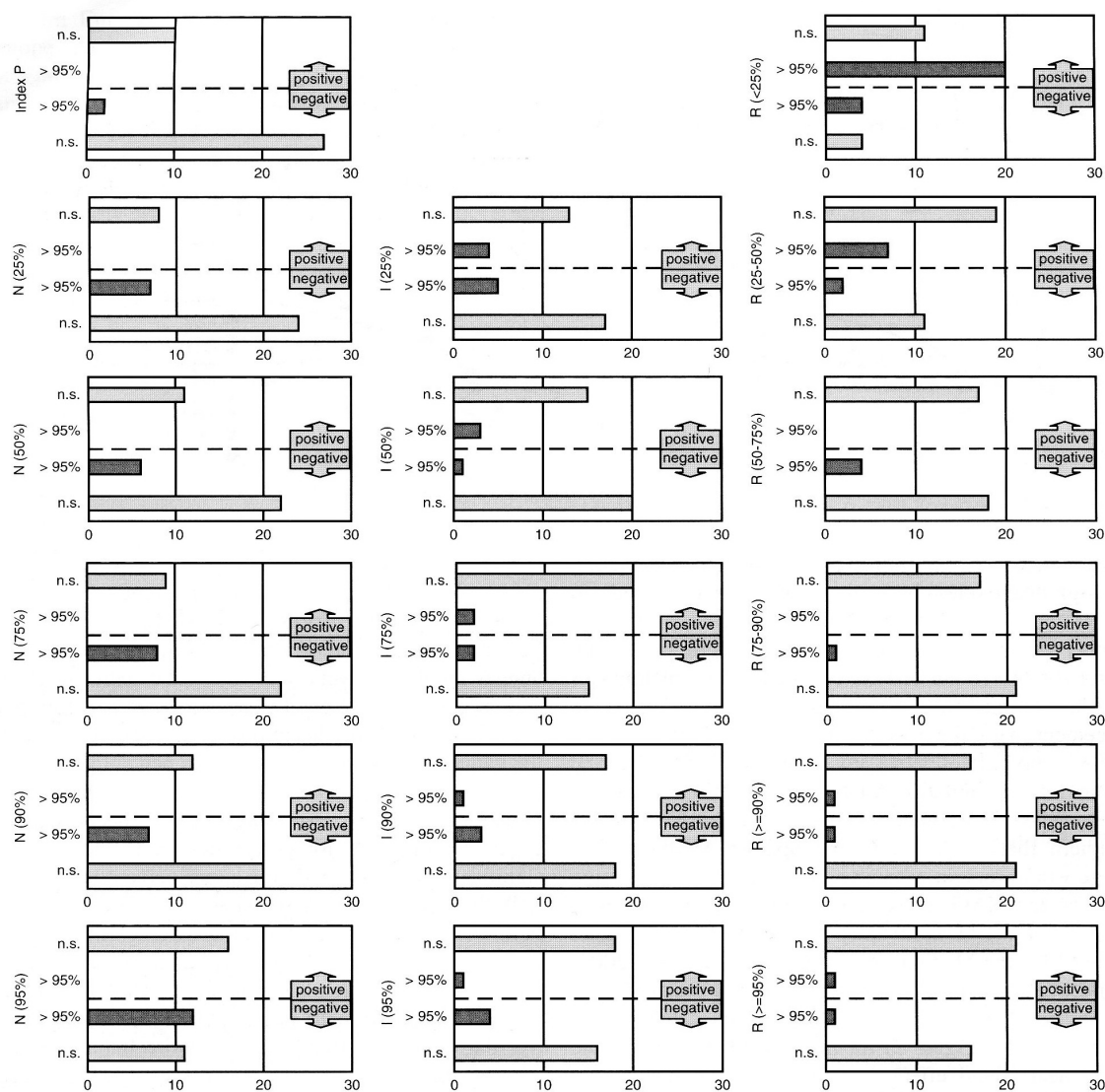
Figure 17. Histograms of the number of significant and non-significant positive and negative time trends for all the indices and the selected percentiles. (Source: Martínez et al., 2007)

fall amounts is explained by quite a low number of daily episodes with remarkable totals that exceed the average daily rainfall. In this way, the uneven character of the daily pluviometric regime in Catalonia was clearly shown.

4.4 Daily rainfall regime derived from four precipitation indices

Annual rainfall amount, P, number of rainy days per year, N, average daily intensity in a year, I, and relevance, R, of the contribution of a rainfall class interval to the annual amount were used as pluviometric indices to deeply analyze the description of the complex behavior of daily rainfall regime of Catalonia (Martínez et al., 2007). These same precipitation indices had been previously applied to the Fabra

Observatory (1917-1999) data series at seasonal and annual scales (Lana et al., 2003), while the research on their periodicities and irregularities had also been studied (Lana et al., 2005).

For this analysis, daily amounts of rainfall from 75 rain gauges for the period 1950-2000 were considered. Indices N and I were analyzed by distinguishing five percentiles (25th, 50th, 75th, 90th and 95th) of the daily rainfall amounts. Index R was evaluated taking into account $<25\%$, 25 - 50%, 50 - 75%, 75 - 90%, $\geq 90\%$ and $\geq 95\%$ class intervals. All these indices were described by their mean annual values, standard deviations (see Figure 14 as an example) and consecutive temporal irregularities (Equation 1). Besides the complex orography of the region, effects of the influence
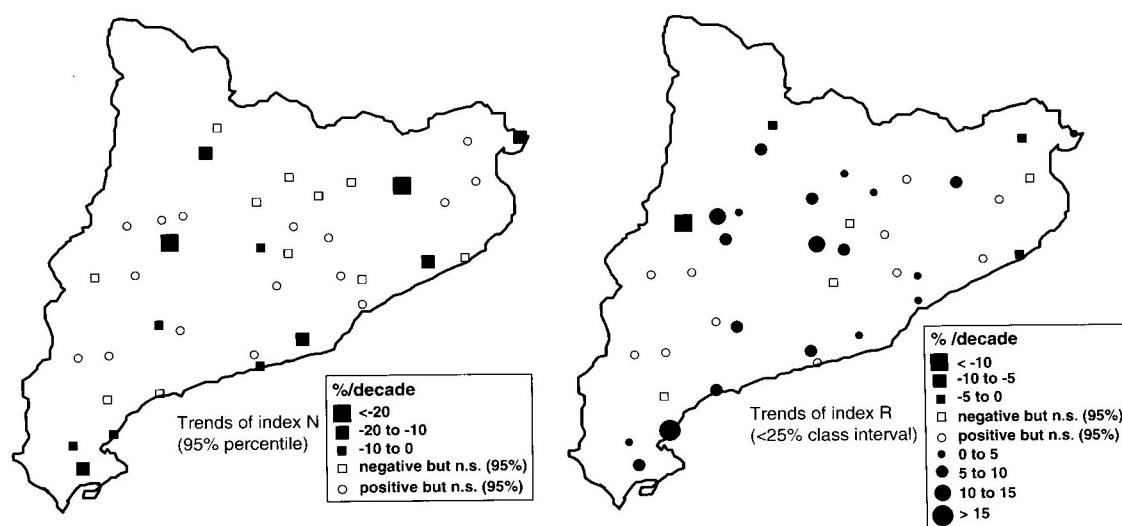
Figure 18. Time trends of index N (95th percentile) and index R ($<25\%$ class interval), given in percentage of averaged value per decade. (Source: Martínez et al., 2007)

of the Mediterranean regime and remoteness of the area of study to the Atlantic coast were detected in the diversity of spatial patterns of the indices. The influence of the Atlantic regime was also found at some places in the Pyrenees, especially those faced north. All these features were described through a PCA, which was applied to average annual values of the pluviometric indices, and the subsequent clustering process (Figure 16). Additionally, time trends of the annual indices were analyzed for a selected set of 39 rain gauges with an optimum recording continuity. Trends were derived from linear regression, and local statistical significances at the 95% confidence level were established using the Mann-Kendall test. Field significant trends were investigated by means of Monte Carlo simulations (Figure 17). It is worth mentioning that field significant trends were detected in the number of rainy days for percentiles up to 75th, all local trends being negative. Field significant trends were also detected in daily intensity, whatever the threshold level, with positive and negative local trends. The relevance index R depicted field significant trends for the first three class intervals, with a predominance of positive local trends in the first two, thus indicating an increasing contribution of light and moderate daily episodes to the annual amounts (Figure 18).

5   Conclusions

Several studies manifest the complex behavior of daily rainfall in Catalonia, result of the orography, the atmospheric circulation patterns and the proximity to the Mediterranean Sea. As has been mentioned in Section 2, rainfall amounts strongly depend on Mediterranean cyclogenesis in spring and, especially, in autumn, and on convective phenomena in summer. Frontal passages from the Atlantic are not so

important, except for the north face of the Pyrenees Range. Consequently, anomalies in these circulation patterns could imply relevant changes on rain amounts.

The monthly amounts recorded in seven emplacements of the west Mediterranean and nearby Atlantic coasts have been successfully described by the gamma and Poisson gamma distribution, while the annual amounts precise both the gamma and the log-normal distributions. Strictly for Catalonia, the monthly amounts have been substituted by values of the SPI, which follows a standardized normal distribution, and the spatial behavior of the shortage and excess episodes have been described through PCA and clustering algorithms. As a collateral result, the number of gauges affected by a monthly shortage shows a positive trend in the measurement period.

Daily precipitation maxima have been analyzed through the Gumbel I distribution. Autumn is the season of the year with a larger percentage of annual extremes, getting up to 50% in the north and south extremes of the Catalan coast. The monthly ADR and SDR have been submitted to PCA and posterior AL procedure. The resulting clustering permits to differentiate the Mediterranean Coast and north-eastern Catalonia from the rest of the region. When all the rain gauges are considered, field significant trends for monthly ADR, SDR and CV must be discarded. A similar result is obtained for the annual number of rainy days. The empirical amount and time distributions of daily amounts have been modelled by the exponential and Weibull distributions, both of them being functionally related. In general, the pluviometric regime assigns a very large fraction of rainfall amounts to a quite low number of daily episodes, as is characteristic of the Mediterranean climate. The trend analysis has been extended to four indices, named P, N, I and R, of the precipitation process. It is worth mentioning that all the significant local trends derived for the annual number of rainy days are negative, whatever the percentile. This feature is

especially remarkable when considering the number of very wet days (95th percentile), as their contribution to the annual amounts is very relevant. These negative local trends, mostly distributed throughout the area, are of a clear Mediterranean influence. Consequently, a noticeable change in the pluviometric regime should be the decreasing number of copious daily episodes in areas of Mediterranean influence.

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