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A single scaling parameter as a first approximation to describe the rainfall pattern of a place: application on Catalonia

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Abstract

As well as in other natural processes, it has been frequently observed that the phenomenon arising from the rainfall generation process presents fractal self-similarity of statistical type, and thus, rainfall series generally show scaling properties. Based on this fact, there is a methodology, simple scaling, which is used quite broadly to find or reproduce the intensity–duration–frequency curves of a place. In the present work, the relationship of the simple scaling parameter with the characteristic rainfall pattern of the area of study has been investigated. The calculation of this scaling parameter has been performed from 147 daily rainfall selected series covering the temporal period between 1883 and 2016 over the Catalonian territory (Spain) and its nearby surroundings, and a discussion about the relationship between the scaling parameter spatial distribution and rainfall pattern, as well as about trends of this scaling parameter over the past decades possibly due to climate change, has been presented.

Keywords Simple scaling · Fractal analysis · Rainfall intensity · Intensity–duration–frequency curves · Climate change · Catalonia

Introduction

The intensity–duration–frequency curves (IDF curves), which have been a matter of considerable interest to engineers and hydrologists for over a century, remain nowadays as an important tool to analyze the risk of natural hazards for hydrological purposes. The mathematical relationships more often used to describe the IDF curves are empirical, sometimes in the form of a generalized equation for the rainfall intensity $I(t, T)$, valid for all durations t, and return periods T considered. This equation usually has the generalized form $\frac{a(T)}{b(t)}$, where $a(T)$ and $b(t)$ are functions independent of each other. The function $a(T)$ can be found empirically (Casas et al. 2004), although there are authors (Koutsoyiannis et al. 1998) who proposed the use of a function of statistical probability of the maximum rainfall intensity to determine it. Other authors (Burlando and Rosso 1996; Menabde et al. 1999) considered the fractal property of scale invariance of the rainfall series to find an analytical relationship for the IDF curves taking into account the scaling behavior. Burlando and Rosso (1996) were pioneers in applying scaling relationships to

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the statistical moments of the annual maximum rainfall series. There is also a methodology based on the property of scale invariance (Menabde et al. 1999; Yu et al. 2004; Desramaut 2008; Bara et al. 2010) to obtain IDF curves in those places where daily rainfall data are the only available. For instance, Aronica and Freni (2005) analyzed extreme rainfall data from a rain gauge network within the metropolitan area of Palermo (Italy) with the aim of combining and taking advantage of high-resolution rain gauges with a short working period along with low-resolution rain gauges with longer data records to obtain plausible depth-duration-frequency (DDF) curves. Applying this scaling approach, Aronica and Freni (2005) found better results than those coming from the classical sub-hourly rainfall regression formulas (Bell 1969; Ferreri and Ferro 1990). Likewise, studying the scaling properties of selected rainfall quantiles and applying this methodology, Bara et al. (2009) derived the IDF curves for durations shorter than a day, calculated from a historical data set covering the whole territory of Slovakia. In a recent paper, Rodríguez-Solà et al. (2017) used this methodology also to reproduce the well-known empirical IDF curves of three Spanish locations: Barcelona (Casas et al. 2004; Rodríguez et al. 2014), the Ebre Observatory (Pérez-Zanón et al. 2015), and Madrid (Casas-Castillo et al. 2016), taking into consideration the scaling behavior of rainfall. In addition, Rodríguez-Solà et al. (2017) obtained the IDF curves for a hundred of Spanish locations for which only daily rainfall data were available, and found a spatial distribution of the observed scaling behavior over Spain in concordance with the characteristic rainfall pattern in diverse areas. In this work, the influence of geographical location and the different mechanisms of rainfall generation in the scaling behavior has been investigated and discussed.

The simple scaling approach

Many atmospheric processes, rainfall generation among them, act in a wide temporal range giving rise to phenomena which accomplish self-similarity, i.e., that look the same regardless of the temporal scale at which they are observed. This kind of processes can be considered of fractal type, with properties manifesting power laws of the scale parameter λ, which is the ratio t/t_0 between any two durations t and t_0 within a scaling regime. In general, the fractal self-similarity of natural processes has a statistical nature; thus, the scaling properties of rainfall can be expressed by statistical relationships (Schertzer and Lovejoy 1987; Gupta and Waymire 1990; Schertzer and Lovejoy 2011). For instance, it has been widely observed (Koutsoyiannis and Foufoula-Georgiou 1993; Burlando and Rosso 1996; Menabde et al. 1999) that the probability distribution of the annual maximum rainfall intensity satisfies scale relationships, meaning that the probability distribution of the annual maximum intensity for a duration t, I_t, and the distribution at other time scale $t_0 = \lambda t$, $I_{\lambda t}$, can be related by a factor that is a power function of the scale parameter λ. This property, usually referred as "simple scaling in the strict sense" (Gupta and Waymire 1990; Yu et al. 2004), can be expressed by Eq. (1):

$$I_t \overset{\text{dist}}{=} \lambda^{\beta} I_{\lambda t} \tag{1}$$

where the symbol $\overset{dist}{=}$ indicates equality of probability distributions, and β is a scaling parameter. This equation implies that the statistical moments of these two distributions fulfill the equality, as well as their quantiles and the rest of statistical features. In terms of the statistical moments of order q of the rainfall intensity for a duration t, $\langle I_t^q \rangle$ [Eq. (2)], the scaling relationship can be expressed as Eq. (3):

$$\langle I_t^q \rangle = \frac{\sum_{i=1}^{n} I_{t_i}^q}{n} \tag{2}$$

$$\langle I_t^q \rangle = \lambda^{\beta q} \langle I_{\lambda t}^q \rangle. \tag{3}$$

The exponent βq can be considered as the linear case of a general scaling function $K(q)$, a function resulting nonlinear in the multifractal case. The simplest procedure to determine the scaling parameter β from daily data is to calculate the statistical moments using Eq. (2) of maximum annual series calculated by aggregation from daily series (with rainfall amounts for 2, 3, 4… days) for different values of the order q, and perform a linear regression between the logarithmic values of these moments and the logarithm of the duration t for every value of q. The straight lines obtained, each one of them with a slope of value βq, evidence scale invariance.

The equality of the quantiles of the probability distributions of Eq. (1) implies that these quantiles may also be related by the same scaling relationship. In particular, the scaling relationship which corresponds to an extreme rainfall intensity $I(t, T)$, with a return period T, and a duration t, i.e., IDF curves, can be expressed by Eq. (4), where daily duration appears as a reference duration $t_0 = 24$ h:

$$I(t, T) = \left(\frac{t}{24}\right)^{\beta} I(24, T). \tag{4}$$

Once known the scaling parameter β, Eq. (4) can be used to downscale daily values $I(24, T)$ to IDF values for sub-daily durations t, under the assumption that the simple scaling relationship is fulfilled by sub-daily durations, which can only be considered as an approximation. Rodríguez-Solà et al. (2017) applied this technique to reproduce the well-known IDF curves of three Spanish locations, which were very satisfactorily reproduced by

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downscaling daily records for durations above 1 h, with mean relative differences lower than 7%. Discrepancies between the downscaled values and the known values $I(t,T)$ for durations shorter than 1 h resulted slightly higher (around 20% in the worst cases) and seemed to depend on the kind of measuring instrument.

Because of its definition, the values of the simple scaling parameter are expected to be higher than − 1. The limit value of $\beta = -1$ would correspond to rainfall samples with isolated annual maximum values; in the case of daily rainfall, a maximum value for a specific day P_1 surrounded by dry days. Thus, the process aggregation leads to series where the precipitation for n days, P_n, is the same. Then, in terms of intensity, $I_n = I_1/n$, which corresponds to a scaling exponent of $\beta = -1$ compared to the scaling relationship for $q = 1$ (mean), $I_1/n = n^{\beta}\ I_1$. The opposite (and hypothetical) case would be a totally regular sample where all days (within the n-aggregation) present the same rainfall amount, which implies the same intensity for all durations, and consequently, $\beta = 0$. In real rainfall cases, the scaling parameter ranges between $\beta = -1$ and a value close to $\beta = -0.5$. It seems reasonable then to expect some relationship between the scaling parameter values and rainfall series regularity, with the lowest values close to − 1 corresponding to areas where rainfall is usually very irregular, with sudden isolated maximum values, and higher values for rainy areas with a more regular rainfall pattern. For instance, Menabde et al. (1999) compared two sets of rainfall data representing two examples of quite different climate types, and found a scaling exponent of −0.65 for Melbourne (Australia), a city with a mid-latitude temperate climate and rainfall throughout the year, and a value of − 0.76 for Warmbaths (South Africa), having a semiarid climate with summer convective rainfall, and concluded that the scaling exponent appears to be dependent on the rainfall/climate characteristics. In addition, Bara et al. (2009) found scaling exponents around − 0.75 for three locations representing the western (Kuchyňa–Nový Dvor), central (Liptovský Hrádok), and eastern (Humenné) areas of Slovakia, and Yu et al. (2004) found three types of rainfall scaling behavior over northern Taiwan, related to the change in topography and the influence of the northeast monsoon. Rodríguez-Solà et al. (2017) found a general concordance between the spatial distribution of β over the Iberian Peninsula and the mean annual precipitation distribution, with high values between − 0.55 and − 0.66 in rainy areas and low between − 0.84 and − 0.92 for the dry ones, with some discrepancies related to the kind of precipitation contributing to high rainfall amounts and the proportion of convective rainfall in total. In particular for Catalonia, Rodríguez-Solà et al. (2017) assigned a range of the scaling parameter between − 0.77 and − 0.83, based on the analysis of series from few stations located in this area. To investigate, in more detail for this area, the influence of geographical location and the different mechanisms of rainfall generation in the scaling behavior, a new calculation of the simple scaling parameter has been performed in this work from 147 daily rainfall series registered in the Catalonian territory (Spain) and surroundings, and a spatial distribution of its values has been presented and analyzed.

Rainfall series scaling analysis

The scaling analysis presented has been performed from the available rainfall database of the Servei Meteorològic de Catalunya (SMC) after a rigorous quality control based on a relative comparison between daily values measured at candidate stations and selected reference stations according to their distance, difference in elevation and daily correlation. Previously to the daily comparison, each series had been classified according to its absolute quality by an index which was designed to take into consideration the most common problems that daily rainfall series could present (errors from the digitization process, encoding errors, etc.). In this way, the daily comparison is performed selecting series of initially very probable high quality, when available. Figure 1 shows the temporal evolution of the number of series available from the SMC database (2142 in total). In this figure, blue line indicates a first selection of high-quality series (1817) which accomplished a completeness of 100% and less than 5% of data errors detected. Among the latter, the most restrictive black line corresponds to those series with length longer than 30 years of high-quality data, which are the 147 series used in the present work. These 147 daily selected series cover the whole Catalonian territory and its nearby surroundings during the temporal period between 1883 and 2016, with a higher density of measuring sites (over 50 series used per year) in the period 1942–2006. The whole set has a mean of 45.8 years of data per series.

By aggregation from the selected daily data, series of annual maximum of accumulated rainfall on 1–15 days have been obtained and analyzed. The q order statistical moments of rainfall intensities have been calculated [Eq. (2)] for values of q of 0.5, 1, 1.5, 2, 2.5 and 3, and a linear regression between their logarithmic values and the logarithm of the duration t has been performed for every value of q with the aim to evidence scale invariance and to find the value of the scaling parameter β in every case. The empirical β values found in this study range between − 0.87 and − 0.65 for Catalonia and they have been spatially analyzed to obtain its dependence to geographical and climatic features.

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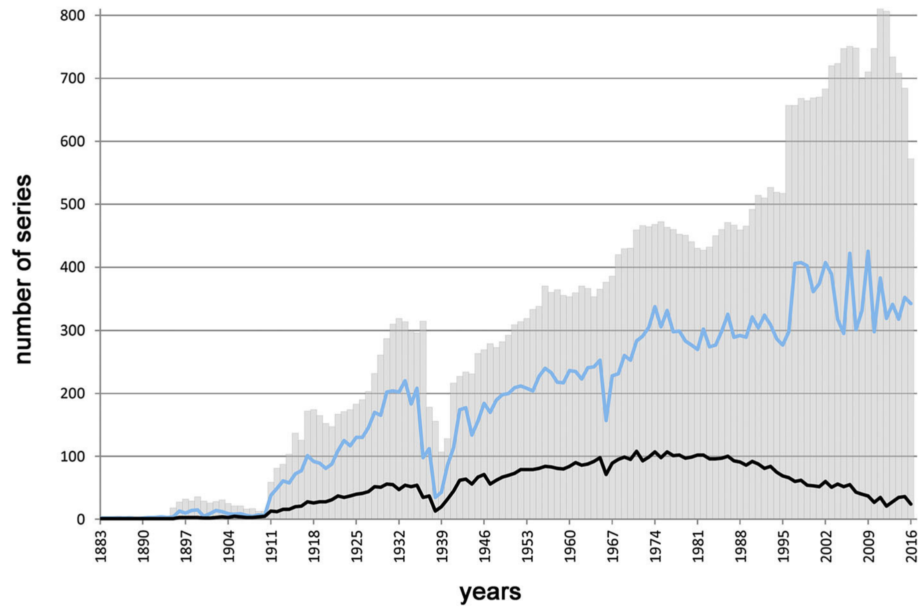

Fig. 1 Number of rainfall series over the temporal period 1883–2016. Grey bars indicate the total available series from the SMC database (2142), blue line those with high annual quality (1817), and the more restrictive black line corresponds to series used in the present work (147)

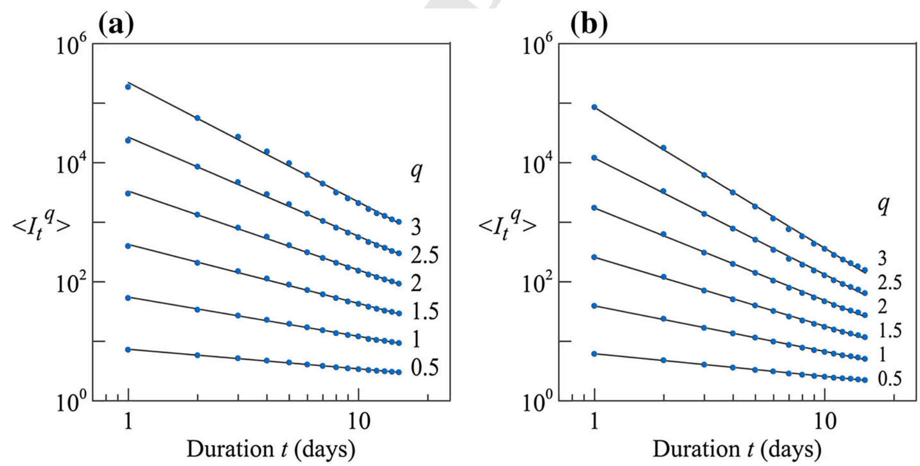

Fig. 2 Statistical moments for different values of q of the annual maximum intensity calculated for the aggregated series from: **a** Vielha and **b** Lleida. Straight lines indicate scale invariance over a temporal range from 1 to 15 days, with slopes determining the scaling function K(q)

As an example, Fig. 2 shows the log–log plots of the statistical moments against duration corresponding to two stations: Vielha (VA010) and Lleida (SE020). These two stations have been selected, because they correspond to two different climates in Catalonia and they present quite different values of empirical β (Vielha with -0.71 and Lleida -0.83). Vielha is located in the Val d'Aran County, a part of Catalonia where the Atlantic influence dominates over the Mediterranean and its climate is characterized by a regular precipitation through the year with high accumulated total amounts. On the other hand, Lleida's climate, in Segrià County, is classified as Dry Continental Mediterranean and rainfall characteristics imply low annual amounts in an irregular pattern with seasonal maxima in spring and autumn. In Fig. 2, straight lines fitted by linear regression, each of them with a slope of value $K(q)$, indicate scaling invariance. The values of these slopes have been displayed in Fig. 3, where the linear behavior of the scaling function $K(q)$ ($-0.71\ q$ for Vielha station and $-0.83\ q$ for Lleida) shows the monofractal or simple scaling behavior of these two specific series, which is a general result for all the analyzed stations.

The empirical results found for β show a wide variability within a short distance with a standard deviation value of 0.04 for the whole territory. The observed variability might be caused by the fact that different series have a different number of years available, being the series with just 30 years more influenced by particular episodes. However, the performed spatial analysis yields a certain pattern, namely higher values mainly concentrated in the northwest. While the 90% of the empirical values range between -0.84 and -0.70 and have a mean of -0.79, there are two distinct zones which have been detected: (1) a northern area with a mean value of -0.75, matching a mountainous area with some Atlantic influence at its most northwestern end, and (2) a western area with a mean value

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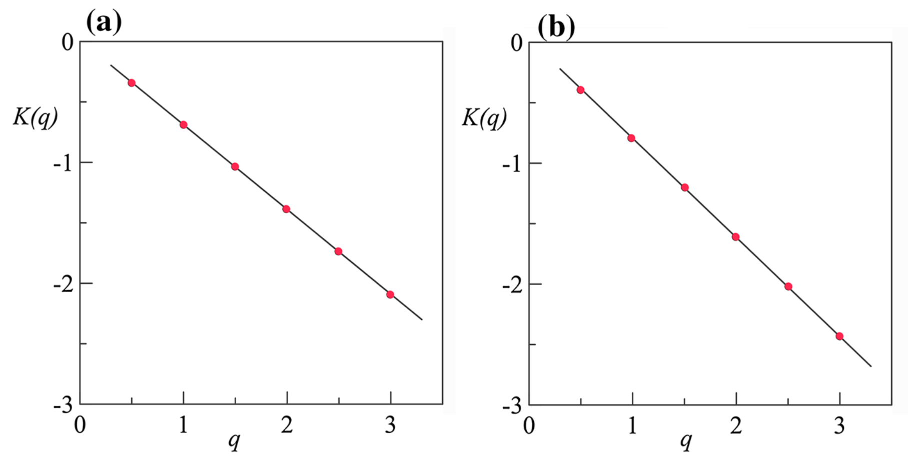

Fig. 3 Linear scaling functions K(q) for **a** Vielha (− 0.71 q) and **b** Lleida (− 0.83 q)

of β of − 0.81, in great concordance with the driest areas in Catalonia. Indeed, a statistical analysis of the values obtained in these zones, i.e., Kolmogorov–Smirnov test for two samples, shows that the northern zone (Zone N in Fig. 4) and the western zone (Zone W) come from different distributions, and hence, the samples are distinct. The different results of β values in these two distinct zones can be seen in Fig. 4 where empirical values are shown grouped in boxplots according to the detected zones.

The northern zone has higher β values at its most northwestern corner where some features of Atlantic climate are observed. In the northwestern area of Catalonia, the climate is less influenced by the Mediterranean because of its distance to the coastline and the blockage of the high mountains of the Pyrenees. Moreover, the northwestern corner is often influenced by Atlantic fronts and its climate is characterized by high amounts of rain collected regularly through the year.

On the other hand, Zone W has a climate characterized by scarce rainfall, recorded mainly during Autumn and Spring. This western dry area presents some of the lowest β values obtained over Catalonia supporting its climatic observations of irregular rainfall patterns. Not so differently from the Zone N, the Zone W is not extremely influenced by the Mediterranean, being far from the coastline, it has a more continental climate than other areas in Catalonia; the main difference with the Zone N is the dryness regarding total annual amounts and the irregularity of the rainfall pattern with two seasons where the most part of the rain is collected.

Nevertheless, the pattern of β values empirically obtained shows other areas characterized by high or low values, such as low values in the eastern coastline where the rainfall pattern is known to be irregular, but these areas are more difficult to spot because of the high variability of the empirical results. To better analyze the spatial pattern of scaling parameter and its relationship to climatic characteristics, the empirical values have been interpolated. The interpolation has been performed using a simple kriging technique through a wave exponential model to fit the variogram (see Fig. 5 for fitting details).

The spatial distribution of β after interpolation is shown in Fig. 6. The distinct zones previously discussed (namely, Zone N of high β values and Zone W of low β values) are clearly captured by the interpolation, being the distinction between the northwestern area and the western zone the most clear feature. Moreover, a third zone in the east, near the north part of Catalonia's Mediterranean coast, presents

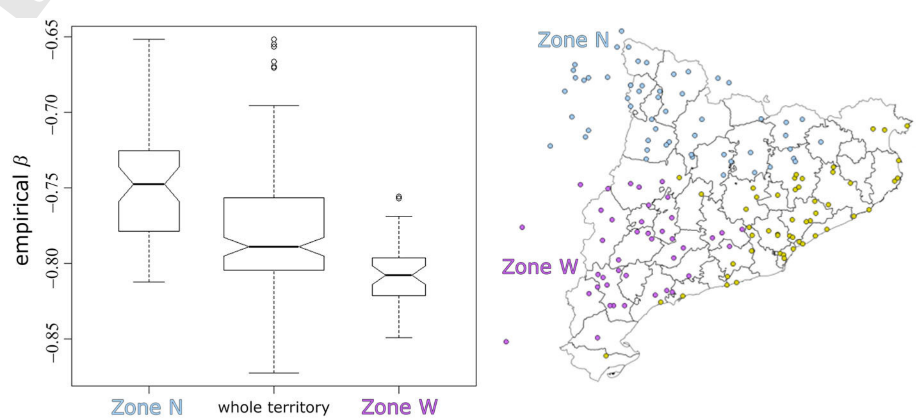

Fig. 4 Empirical values of the β parameter grouped in boxplots according to the North (Zone N) and West (Zone W) of Catalonia

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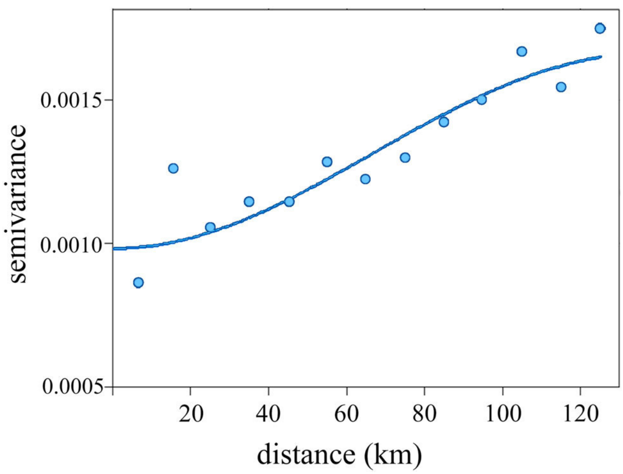

Fig. 5 Kriging variogram

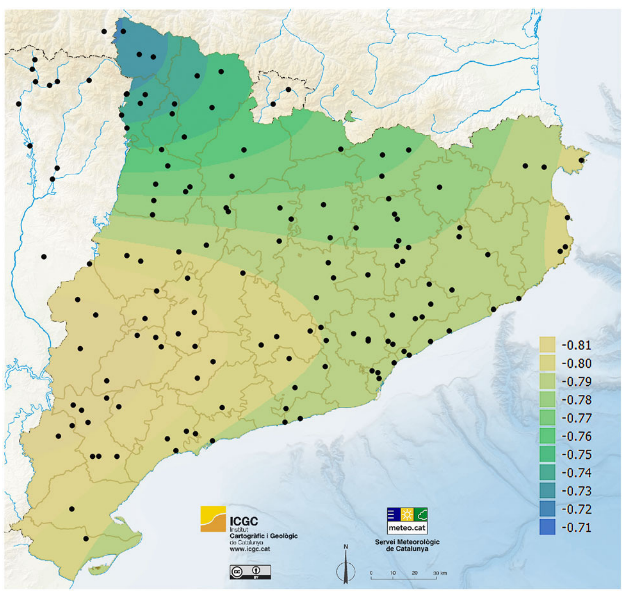

Fig. 6 Spatial distribution of the scaling parameter β over Catalonia

low values of interpolated β. The eastern coastline is clearly influenced by the Mediterranean and heavy rain episodes occur often associated with Mediterranean low-pressure systems that bring wet eastern winds to this area. The rainfall pattern of this eastern area is characterized by low total annual amounts collected mainly in Autumn. Therefore, the climatic characteristics of this area support the rainfall irregularity suggested by the empirical β values.

Overall, a negative gradient of β values is observed to increase towards the coastline where the rainfall pattern becomes more influenced by the Mediterranean Sea, with the exceptions of the central and southern coastline in its most proximity to the Sea. This exception is actually caused by an area of lower β values in the west associated with an irregularity of the rainfall pattern not caused, in this case, by the Mediterranean influence but by the droughtiness of the region. The regularity of the rainfall pattern associated with high β values is clearly supported by the climatic rainfall characteristics of the northwestern area.

As it can be seen in Fig. 7a, a significant correlation between the scaling parameter and mean annual rainfall can be observed, β increasing with mean annual rainfall. This correlation has been especially noticed in the two distinct zones highlighted before (high β values and annual rainfall amounts in the NW in contrast to western low β values and dry areas). Figure 7b shows that β increases with the percentage of annual precipitation amount that occurs during the maximum rainfall day. This contribution of the maximum rainfall day to the total amount is related with rainfall irregularity. Figure 8a, b shows that no dependence has been observed between β and longitude, whereas there is some correlation with latitude, β increasing towards north. There is also some correlation with altitude (Fig. 9a), β being higher to greater height, and with the distance to coastline (Fig. 9b).

Climate trends of the scaling parameter β

It is commonly assumed that one of the consequences of global warming will be an intensification of the hydrological cycle (Huntington 2006) which may lead to an increase of precipitation, among other hydrological variables. In fact, an increase in total rainfall in the last decades has been reported in middle and high latitudes (IPCC 2007). Despite of this, several studies have evidenced a decreasing trend of total precipitation over the Mediterranean area: one of the conclusions of the Regional Climate Change Report of the CLIVAR-Spain network (Pérez and Boscolo 2010) was that in the last decades, the annual precipitation in the Iberian Peninsula has significantly decreased compared to the 1960s and 1970s, especially at the end of winter, whereas an increase of extreme rainfall was observed. Some regional climate model projections pointed a potential increase in intensity and frequency of heavy and torrential rainfall in many areas of Europe for the 21st century (Christensen and Christensen 2003), despite a general decreasing trend in average summer precipitation. Buonomo et al. (2007) found also an increase of extreme rainfall over Europe, greater as both the return period of the rainfall becomes longer and the duration considered becomes shorter, and Rodríguez et al. (2014) obtained a slightly higher increase of the expected hourly rainfall in Barcelona (Catalonia, Spain) compared to daily rainfall increase. Due to its apparent connection to rainfall pattern characteristics, some changes in the rainfall scaling behavior are expected to be detected along with this

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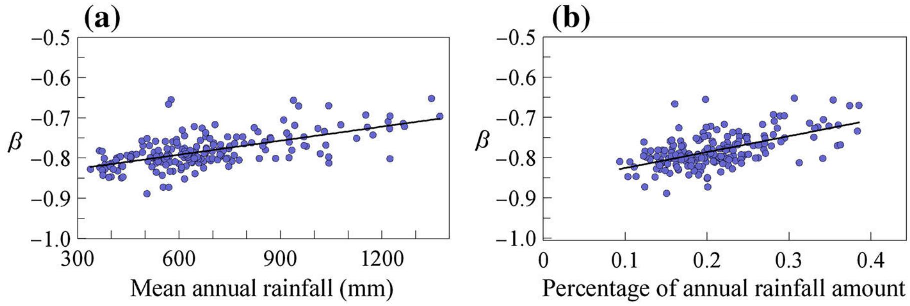

Fig. 7 Dependence of the scaling parameter β on **a** mean annual rainfall and **b** ratio between the maximum daily and mean annual rainfall

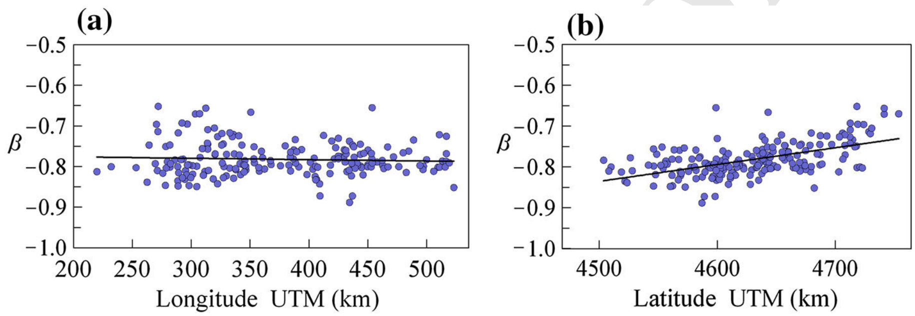

Fig. 8 Dependence of the scaling parameter β on **a** longitude and **b** latitude

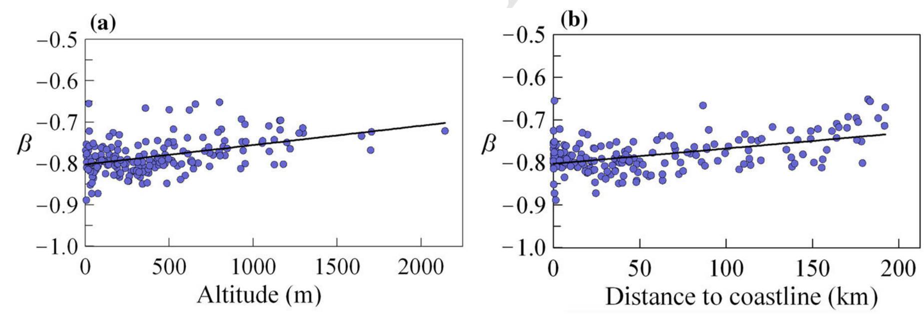

Fig. 9 Dependence of the scaling parameter β on **a** altitude above sea level and **b** distance to coastline

assumed trend of decrease in annual precipitation and relative increase in extreme rainfall.

To analyze the temporal evolution of the scale parameter β during the twentieth century and the beginning of the current century, the values of this parameter have been calculated by taking sliding intervals of 30 years varying the temporal range in 1 year. The mean value of the β parameter of the set of stations in Catalonia has been slightly decreasing as the 20th century progressed (Fig. 10), although only in the Western Pyrenees area, the downward trend has statistical significance for a 95% confidence level ($p < 0.05$) according to the non-parametric method of Mann–Kendall (Mann 1945; Kendall 1975) (Fig. 11). In the sequence corresponding to the Western Pyrenees, there is a greater decrease of the β parameter from the second half of the 20th century. This result seems compatible with the reduction of the amount of annual rainfall detected since 1950 in some studies carried out in Catalonia and nearby areas (SMC 2016; Esteban et al. 2013). The Annual Bulletin of Climate

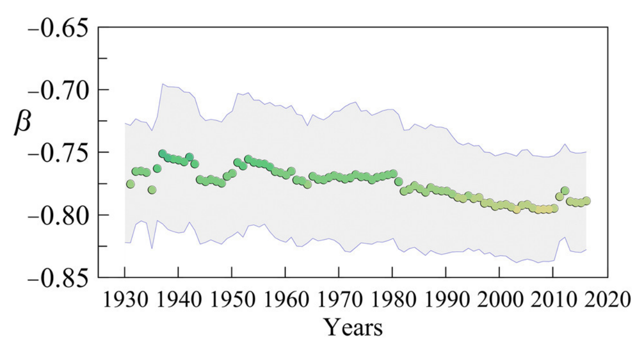

Fig. 10 Temporal evolution of the scaling parameter β in Catalonia. Points show the mean of all values; shaded areas represent data dispersion (± σ)

Indicators (SMC 2016) shows that almost all the territory of Catalonia has registered a slight decreasing trend of precipitation since 1950, but the rainfall decline only exceeds the threshold of statistical significance in some areas of the Pyrenees, the Pre-Pyrenees, and the center of the territory. The SMC (2016) study shows also that the

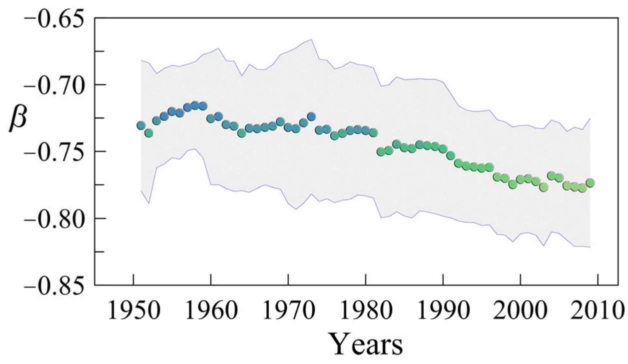

Fig. 11 Temporal evolution of the scaling parameter β in Western Pyrenees. Points show the mean of all values; shaded areas represent data dispersion ($\pm\,\sigma$)

SDII climate index (annual total precipitation divided by the number of days with precipitation higher than 1 mm) in the area of the Pyrenees presents a statistically significant positive trend which indicates that annual precipitation is divided by fewer days of precipitation. In the same area, the CWD index (maximum number of consecutive days in a year with precipitation equal to or greater than 1 mm) shows a trend with statistical significance towards the decrease. Esteban et al. (2013) also recorded a significant fall in annual rainfall in Andorra (Pyrenees) for the second half of the 20th century and the beginning of the current century.

It is remarkable that the β sequence obtained from the centennial daily rainfall series registered at the Ebre Observatory (1905–1916) clearly shows a decreasing trend with statistical significance (Fig. 12). The Ebre Observatory is located in the south of Catalonia, in a region with values of β lower than $-\,0.80$. The temporal evolution of the climate index SDII in the Ebre Observatory shows a gradual increase of +0.14 mm/day per decade, at the limit of the statistical significance ($p = 0.05$) (SMC 2016).

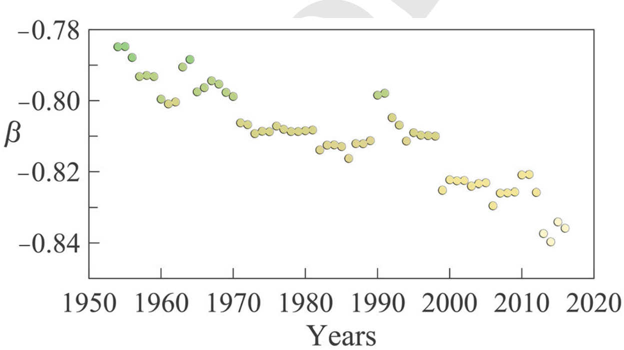

Fig. 12 Temporal evolution of the scaling parameter β in the Ebre Observatory

Conclusions

In most part of the Catalonian territory, the empirical values of the scaling parameter β range between $-\,0.84$ and $-\,0.70$, with a mean of $-\,0.79$. Despite of the high variability of this parameter, which seems to depend on the longitude of the sample and the presence of particular high intense episodes in it, a spatial analysis yields a certain configuration which can be related to some specific climatic rainfall characteristics. Analyzing the spatial distribution of this parameter, two distinct zones have been detected: (1) a northern area with a mean value of $-\,0.75$, matching a mountainous area with some Atlantic influence at its most northwestern end, and (2) a western area with a mean value of $-\,0.81$, in great concordance with the driest areas in Catalonia. Apart from these distinct zones, at the East, low β values are distributed over areas of clear Mediterranean influence where convective rainfall occurs often. On the other hand, the highest values of β are found mainly in the NW where large rainfall accumulations are most often caused by episodes of continuous rain. This results are in agreement with those obtained by Rodríguez-Solà et al. (2017), who found a general concordance between the spatial distribution of β over the Iberian Peninsula and the mean annual precipitation distribution, with high values in rainy areas and low for the dry ones, with some discrepancies related to the kind of precipitation contributing to high rainfall events and the proportion of convective rainfall in total. Thus, a good correlation between the scaling parameter and mean annual rainfall has been observed, β increasing with mean annual rainfall. This correlation has been especially noticed in the two distinct zones highlighted before (high β values and annual rainfall amounts in the NW in contrast to western low β values and dry areas). However, an increase of the value of β with the percentage of annual precipitation amount that occurs during the maximum rainfall day has been observed also; an expected result, since the contribution of the maximum rainfall day to the total amount is related with rainfall irregularity. No dependence has been observed between β and longitude, whereas there is some correlation with latitude, β increasing northward. As expected, there is also some correlation, with altitude, β being higher at greater elevation, and with the distance to coastline attributed to the influence of the Mediterranean Sea. A general negative gradient of β values is observed to increase towards the coastline, with the exceptions of central and southern coast due to the low β values observed in the arid western area of Catalonia. The regularity of the rainfall pattern associated with high β values is clearly supported by the climatic rainfall characteristics of the northwestern area.

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The analysis of the temporal evolution of the scaling parameter β during the 20th century has allowed us to detect some remarkable changes in the rainfall scaling behavior in Catalonia. The mean value of the scaling parameter β for all stations shows a slight decreasing trend over the past century and the beginning of the current one. This trend is statistically significant in the Western Pyrenees, where the greater decrease of β has been found from the second half of the 20th century, in concordance with the decreasing trend of the annual precipitation detected in this area since 1950. In addition, in the southern area of the Catalonian territory where values of β are mostly lower than -0.80, the sequencing of β obtained from the centennial daily rainfall series registered at the Ebre Observatory (1905–1916) clearly shows a decreasing trend with statistical significance during the second half of the 20th century. These results are compatible with the expected trend of decrease in annual precipitation and relative increase in extreme rainfall in many areas of Europe projected by several regional climate models for the 21st century (Pérez and Boscolo 2010; Christensen and Christensen 2003).

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Compliance with ethical standards

Conflicts of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

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