

SPATIAL DISTRIBUTION OF A DAILY PRECIPITATION CONCENTRATION INDEX IN PENINSULAR SPAIN

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ABSTRACT

Given its concentration in a few days and its modest total volume, knowledge about precipitation with daily resolution in Spain is highly important. In this article, a concentration index (CI) that evaluates the varying weight of daily precipitation, i.e. the contribution of the days of greatest rainfall to the total amount, is presented. The index is applied to exponential curves such as $Y = aX \exp(bX)$, which adjust the accumulated percentages of precipitation Y contributed by the accumulated percentage of days X on which it took place. The index was applied to 32 meteorological stations across peninsular Spain with quality data for the period 1951 to 1990, which enables the spatial patterns of daily pluviometric concentration in the territory to be determined. Copyright © 2004 Royal Meteorological Society.

KEY WORDS: concentration index; daily precipitation; exponential curves; peninsular Spain; regionalization

1. INTRODUCTION

The analysis of precipitation with daily resolution in Spain is a subject of great interest owing to the hydrological problems resulting from the high intensity and poor temporal distribution of rainfall in large areas of the Iberian Peninsula, these problems in turn being produced by the concentration of high percentages of the yearly total in a few very rainy days, separated by long periods of drought (Martin-Vide, 1994). This interest is not merely climatological; it also affects other areas of the environment and society. For example, the level of aggression of precipitation on the soil in environments with sparse vegetation, which is the case in many Iberian regions, is directly linked to its intensity and temporal distribution. Similarly, an important debate is currently under way regarding the development of Spain's National Water Plan, a high-cost series of hydraulic projects aimed at redistributing water resources between basins with highly different and variable flows and pluviometry.

However, the importance of daily precipitation has not been matched by sufficient scientific attention. A few articles have been published on the statistical structure of Spain's (or any of its regions') precipitation with daily resolution; see Martin-Vide (1987) and De Luis *et al.* (1997). In the first of these studies, the probabilities of a rainy day and of a rainy day being followed by a rainy day were shown for the 10 main meteorological stations along the Mediterranean coast of the Iberian Peninsula. The spatial pattern is not simple: the persistence of rainy days decreases from north to south along the eastern coast and increases from east to west along the southern coast. Most published articles only focus on extreme values (e.g. Elías and Ruiz, 1979; Estrela *et al.*, 2000; Egozcue and Ramis, 2001; Peñarrocha *et al.*, 2002). Some focus on the analysis of sequences of dry days (e.g. Lana and Burgueño, 1998a,b; Martin-Vide and Gómez, 1999), whereas others are forced to develop daily databases (Romero *et al.*, 1998) before conducting their analysis,

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thus illustrating the primitive state of the field. Other studies, conducted without a statistical aim, have used daily precipitation data in order to evaluate the weight of convective precipitation (Llasat and Puigcerver, 1997), to obtain a classification of atmospheric circulation patterns (Romero *et al.*, 1999), or to divide a certain area into several regions (Andrés *et al.*, 2000). The analysis of time-like tendencies and the development of scenarios for daily precipitation, which are of general interest in climate change, are almost unique in Spain's case (Goodess and Palutikof, 1998).

In terms of the statistical structure of daily precipitation, it is known that the distribution of its amount frequencies is, in general, adjustable by negative exponential distributions (Brooks and Carruthers, 1953). This is so because, in classifying and tabulating the daily precipitation amounts by length, their absolute frequencies decrease exponentially, starting with the lowest class. Therefore, in a given period and place, many small daily amounts of precipitation occur, whereas few large daily amounts do. These scarce large amounts may, nonetheless, have a considerable weight, i.e. represent a notable percentage in the total amount of the given place. Consequently, their occurrence in any given year may have a decisive effect on hydric input. In order to determine the relative or percentage impact of the different classes of daily precipitation and, especially, to evaluate the weight of the largest amounts in the total amount, this study analyses the accumulated percentages of precipitation Y contributed by the accumulated percentage of days X on which it took place. These percentages are related to positive exponential curves, termed normalized rainfall curves (Jolliffe and Hope, 1996). The work of Riehl (1949) and Olascoaga (1950) showed that such functions are of the kind

$$Y = aX \exp(bX) \quad (1)$$

where a and b are constants.

Applications of these curves in some Spanish regions have been conducted by Guilló and Puigcerver (1970), for 11 meteorological stations in Catalonia, and by Martin-Vide (1984), for 10 coastal Mediterranean stations. In the latter case, the highest weight of the largest daily amounts in the total amount was obtained in the south of the Gulf of Valencia (Figure 1). One way of adapting the above curves from Equation (1) is through the curves

$$Y = X \exp[-b(100 - X)^c] \quad (2)$$

where b and c are constants (Ananthakrishnan and Soman, 1989).

The proof that Equations (1) and (2) are probability distributions can be found in Jolliffe and Hope (1996), who demonstrated that such probability distributions are truncated, in the sense that rainfall values above and below certain thresholds have zero probability occurrence. They investigated the form of normalized rainfall curves for some standard probability distributions, such as gamma and Weibull, and concluded that there is no ideal solution to the problem of modelling them.

This paper attempts, methodologically, to further knowledge of the structure of the accumulated precipitation amounts contributed by the accumulated number of precipitation days (Section 2). To this end a concentration index (CI) is defined. This index, which is supported by exponential curves of the type given by Equation (1), evaluates the differences between the precipitation percentages contributed by the different classes. This method, already tested in some places along the Spanish Mediterranean coastline (Martin-Vide, 1994), will be extended here to 32 meteorological stations across peninsular Spain (Section 3). Its cartography divides the Iberian territory into two new pluviometric regions, very different from the ones according to the annual amount or other rainfall characteristics (Section 4). The concentration index is also an indicator of Mediterranean precipitation intensity and erosivity.

2. METHODOLOGY: DEFINITION OF CONCENTRATION OF DAILY PRECIPITATION AND A PROPOSAL FOR A CONCENTRATION INDEX (CI)

The methodology used, which includes a definition of concentration of daily precipitation and an index enabling it to be evaluated, will be illustrated through an example: Table I, data from the Valladolid station

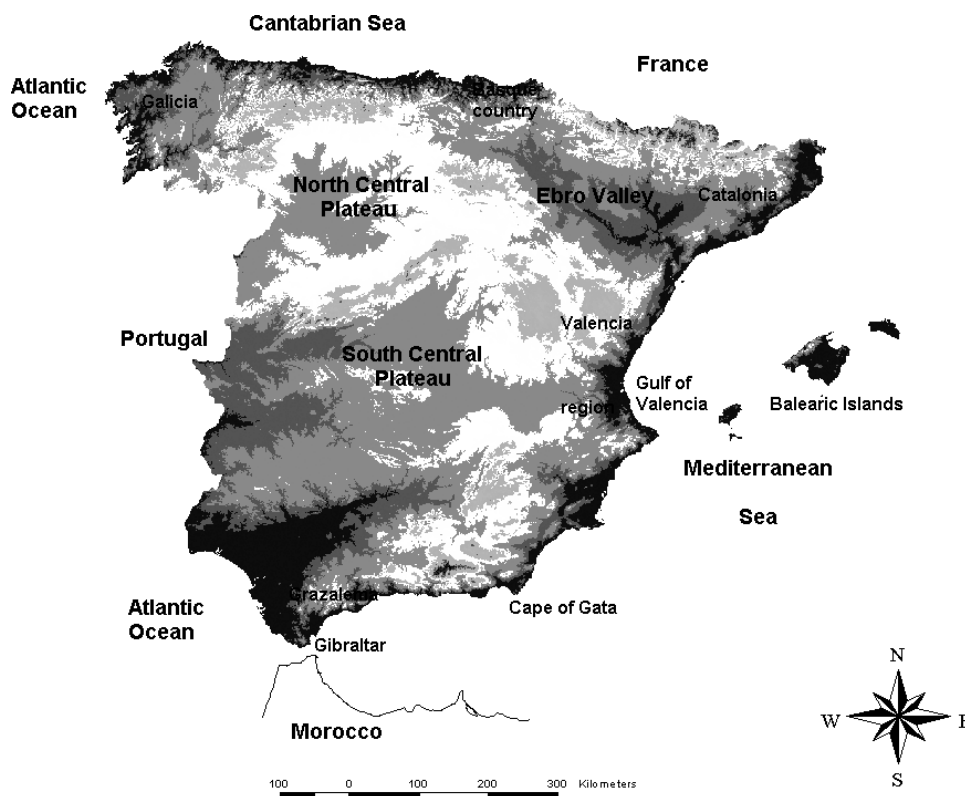


Figure 1. Locations of places named in the text

for the period 1951–90. This meteorological station does not present high daily precipitation values and, therefore, its frequency distribution can be presented in a moderate-length table.

In the first column of Table I the classes or class limits are presented in ascending order, and column two shows their midpoints. In the third column, labelled n_i , the number of recorded precipitation days in each class, or absolute frequency, is listed. Thus, for example, after 40 years (the period of the study), 1355 rainy days were recorded with amounts ranging from 0.1 to 0.9 mm; less than half of them (651) presented amounts ranging from 1.0 to 1.9 mm, etc. The rainiest day had between 82.0 and 82.9 mm. In total there were 4155 rainy days, the sum of the third column. The fourth column, labelled $\sum n_i$, shows the cumulative frequencies, obtained by adding the absolute frequencies of all the classes up to the one under consideration, the last one included (obviously, the value for the last class has to be the same as the total number of precipitation days). The fifth column, labelled P_i , is obtained by multiplying, class by class, the second column by the third one, which is each class's pluviometric total. Although substituting all the values of each class by its midpoint is only an approximation, it is sufficiently precise. In the sixth column, labelled $\sum P_i$, the values of the previous column are progressively added up; thus, the value of the last class is the total precipitation during the period of study, i.e. 17 634.5 mm. Finally, the percentages of columns four and six are presented in columns seven and eight respectively: in other words, the division of each value by the column's last value and multiplied by 100. The last two columns can be interpreted as follows: one-third of the rainy days, 32.6%, with 0.9 mm or less, represented only 3.8% of the total amount of precipitation, etc.

These results give the graphic representation shown in Figure 2: the cumulative percentage of rainy days (next-to-last column), $\sum n_i(\%)$ or X , is plotted against the cumulative percentage of rainfall amounts (last column), $\sum P_i(\%)$ or Y . Note that the resulting polygonal line is markedly exponential.

Let A and B be two fictitious stations (Figure 3) whose values have been chosen to illustrate the concept of concentration, with polygonal line similar to the previous real case. The bisector of the quadrant is

Table I. Frequency distribution in 1 mm classes, relative cumulative frequencies X and the corresponding percentages of the total precipitation Y in Valladolid (1951–90)

Class	Midpoint	n_i	$\sum n_i$	P_i	$\sum P_i$	$\sum n_i(\%) = X$	$\sum P_i(\%) = Y$
0.1–0.9	0.5	1355	1355	677.5	677.5	32.6	3.8
1.0–1.9	1.5	651	2006	976.5	1654	48.3	9.4
2.0–2.9	2.5	438	2444	1095	2749	58.8	15.6
3.0–3.9	3.5	326	2770	1141	3890	66.7	22.1
4.0–4.9	4.5	244	3014	1098	4988	72.5	28.3
5.0–5.9	5.5	212	3226	1166	6154	77.6	34.9
6.0–6.9	6.5	144	3370	936	7090	81.1	40.2
7.0–7.9	7.5	106	3476	795	7885	83.7	44.7
8.0–8.9	8.5	127	3603	1079.5	8964.5	86.7	50.8
9.0–9.9	9.5	70	3673	665	9629.5	88.4	54.6
10.0–10.9	10.5	77	3750	808.5	10438	90.3	59.2
11.0–11.9	11.5	67	3817	770.5	11208.5	91.9	63.6
12.0–12.9	12.5	49	3866	612.5	11821	93.0	67.0
13.0–13.9	13.5	38	3904	513	12334	94.0	69.9
14.0–14.9	14.5	36	3940	522	12856	94.8	72.9
15.0–15.9	15.5	27	3967	418.5	13274.5	95.5	75.3
16.0–16.9	16.5	18	3985	297	13571.5	95.9	77.0
17.0–17.9	17.5	26	4011	455	14026.5	96.5	79.5
18.0–18.9	18.5	24	4035	444	14470.5	97.1	82.1
19.0–19.9	19.5	21	4056	409.5	14880	97.6	84.4
20.0–20.9	20.5	14	4070	287	15167	98.0	86.0
21.0–21.9	21.5	16	4086	344	15511	98.3	88.0
22.0–22.9	22.5	5	4091	112.5	15623.5	98.5	88.6
23.0–23.9	23.5	8	4099	188	15811.5	98.7	89.7
24.0–24.9	24.5	8	4107	196	16007.5	98.8	90.8
25.0–25.9	25.5	7	4114	178.5	16186	99.0	91.8
26.0–26.9	26.5	4	4118	106	16292	99.1	92.4
27.0–27.9	27.5	2	4120	55	16347	99.2	92.7
28.0–28.9	28.5	6	4126	171	16518	99.3	93.7
29.0–29.9	29.5	3	4129	88.5	16606.5	99.4	94.2
30.0–30.9	30.5	4	4133	122	16728.5	99.5	94.9
31.0–31.9	31.5	1	4134	31.5	16760	99.5	95.0
32.0–32.9	32.5	3	4137	97.5	16857.5	99.6	95.6
33.0–33.9	33.5	2	4139	67	16924.5	99.6	96.0
34.0–34.9	34.5	2	4141	69	16993.5	99.7	96.4
35.0–35.9	35.5	1	4142	35.5	17029	99.7	96.6
36.0–36.9	36.5	2	4144	73	17102	99.7	97.0
38.0–38.9	38.5	1	4145	38.5	17140.5	99.8	97.2
39.0–39.9	39.5	1	4146	39.5	17180	99.8	97.4
41.0–41.9	41.5	1	4147	41.5	17221.5	99.8	97.7
42.0–42.9	42.5	1	4148	42.5	17264	99.8	97.9
43.0–43.9	43.5	2	4150	87	17351	99.9	98.4
46.0–46.9	46.5	1	4151	46.5	17397.5	99.9	98.7
49.0–49.9	49.5	1	4152	49.5	17447	99.9	98.9
50.0–50.9	50.5	1	4153	50.5	17497.5	100	99.2
54.0–54.9	54.5	1	4154	54.5	17552	100	99.5
82.0–82.9	82.5	1	4155	82.5	17634.5	100	100
Sum		4155		17634.5			

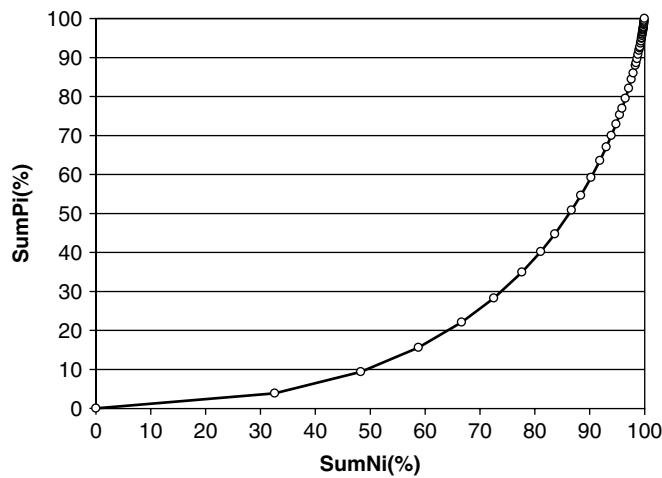


Figure 2. Accumulated number of precipitation days versus amount of accumulated precipitation in Valladolid (1951–90)

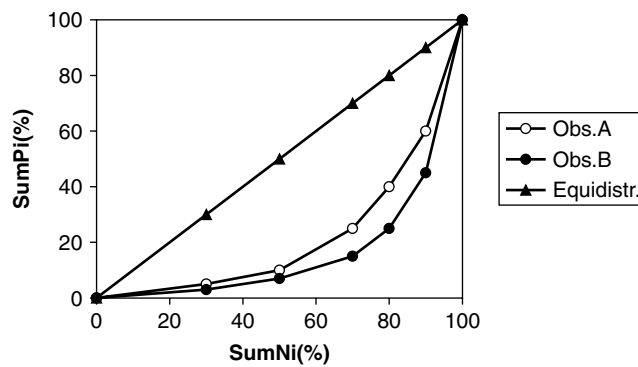


Figure 3. Concentration, or Lorenz, curves for two fictitious observatories (see text)

the equidistribution line (this is an ideal case) where the distribution of the daily precipitation is perfect. The concentration (or daily irregularity) can be considered to be a function of the relative separation of the equidistribution line. Thus, station B's polygonal line represents a region with greater concentration or irregularity than that of station A. Note that, according to station B, 10% of the rainiest days represent 55% of the total amount (90% of the days, after being sorted, account for 45% of the total), compared with 40% for station A (90% of the days account for 60% of the total). At station B, a given percentage of the rainiest days accounts for a higher percentage of the total annual amount than at station A. Consequently, the daily amounts of rain at station B are more disparate than those at station A.

The above-mentioned polygonal line is what is termed a concentration curve or Lorenz curve, widely used in many areas (Shaw and Wheeler, 1994). The area *S* enclosed by the bisector of the quadrant and the polygonal line provides a measure of concentration, because the greater the area, the greater the concentration. The Gini concentration index, defined by

$$\text{Gini index: } 2S/10\,000 \tag{3}$$

will serve to quantify it.

The concentration curve of the Valencia station is presented in Figure 4. This station has the highest daily precipitation amounts among those analysed. The cases of Valencia and Valladolid (shown in Figure 2) are equivalent to the fictitious cases presented in Figure 3.

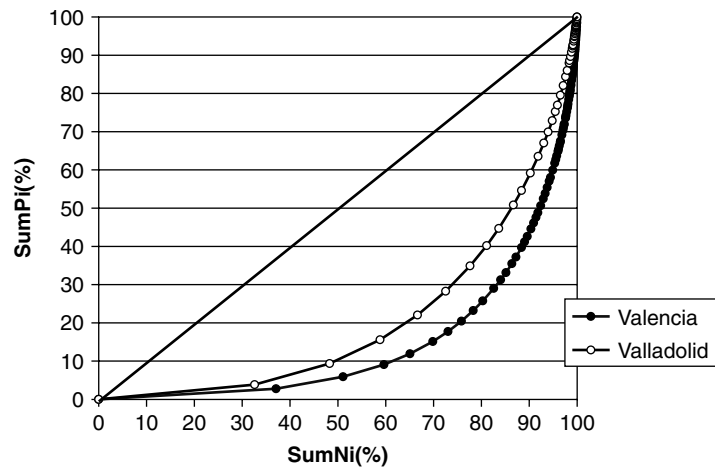


Figure 4. Concentration curves for Valencia and Valladolid (1951–90)

However, the above-mentioned method can be improved by substituting the polygonal lines by the exponential curves of the type in Equation (1). The determination of a and b , by means of the least-squares method, is simple but somewhat clumsy:

$$\ln a = \frac{\sum X_i^2 \sum \ln Y_i + \sum X_i \sum X_i \ln X_i - \sum X_i^2 \sum \ln X_i - \sum X_i \sum X_i \ln Y_i}{N \sum X_i^2 - (\sum X_i)^2} \tag{4}$$

$$b = \frac{N \sum X_i \ln Y_i + \sum X_i \sum \ln X_i - N \sum X_i \ln X_i - \sum X_i \sum \ln Y_i}{N \sum X_i^2 - (\sum X_i)^2} \tag{5}$$

Once both constants have been determined, the definite integral of the exponential curve between 0 and 100 is the area A' under the curve

$$A' = \left[\frac{a}{b} e^{bx} \left(x - \frac{1}{b} \right) \right]_0^{100} \tag{6}$$

The area S' compressed by the curve, the equidistribution line and $X = 100$ is the difference between 5000 and the value of Equation (6). From this value the following daily precipitation concentration index, which resembles that of Gini, can be defined:

$$CI = 2S'/10\,000 \tag{7}$$

or simply $CI = S'/5000$. Note that the value of the CI is the fraction of S' and the surface area of the lower triangle delimited by the equidistribution line.

In Valladolid's case, applying Equations (4) and (5) gives $a = 0.0398$ and $b = 0.0317$. Equation (7) gives $CI = 0.58$.

3. DAILY PRECIPITATION CONCENTRATION IN PENINSULAR SPAIN

Exponential curves of the type in Equation (1) were calculated for 32 meteorological stations across peninsular Spain, for the period 1951–90 (Table II and Figure 5). The stations selected, located in main cities, are those

Table II. Geographical coordinates, and annual mean precipitation P , coefficient of variation CV and mean number of rainy days N for 32 meteorological stations across peninsular Spain (period 1951–90)

Station (code map)	Latitude	Longitude	Altitude (m)	P (mm)	CV (%)	N
Albacete (AB)	38° 57'	1° 52'	704	374	28	74
Alicante (A)	38° 22'	0° 30'	82	365	32	60
Almería (AL)	36° 51'	2° 23'	21	218	42	44
Ávila (AV)	40° 39'	4° 42'	1130	370	27	101
Barcelona (B)	41° 18'	−2° 05'	6	604	25	78
Burgos (BU)	42° 21'	3° 37'	881	570	23	121
Cáceres (CC)	39° 28'	6° 20'	405	504	26	83
Ciudad Real (CR)	38° 59'	3° 55'	629	457	30	80
Córdoba (CO)	37° 51'	4° 51'	92	574	39	67
Cuenca (CU)	40° 04'	2° 18'	956	576	28	101
Girona (GI)	41° 54'	−2° 46'	129	817	32	88
Gijón (GJ)	43° 32'	5° 39'	10	979	16	167
Granada (GR)	37° 08'	3° 38'	680	398	24	75
Huelva (H)	37° 16'	6° 57'	26	511	32	67
Huesca (HU)	42° 05'	0° 20'	542	591	23	83
La Coruña (LC)	43° 22'	8° 25'	67	1028	17	168
León (LE)	42° 35'	5° 39'	913	581	23	104
Logroño (LO)	42° 27'	2° 20'	352	405	21	105
Madrid (M)	40° 25'	3° 41'	667	470	27	96
Murcia (MU)	37° 57'	1° 14'	75	303	37	54
Orense (OR)	42° 20'	7° 52'	150	801	25	116
Pamplona (P)	42° 46'	1° 38'	461	809	19	131
Salamanca (SA)	40° 57'	5° 30'	790	408	25	96
San Fernando (SF)	36° 28'	6° 12'	30	590	31	72
San Sebastián (SS)	43° 18'	2° 02'	259	1585	15	186
Seville (SE)	37° 25'	5° 54'	31	596	33	68
Soria (SO)	41° 46'	2° 29'	1080	540	21	114
Tortosa (TO)	40° 49'	−0° 29'	50	577	32	81
Valencia (V)	39° 29'	0° 23'	11	472	37	70
Valladolid (VA)	41° 39'	4° 46'	735	442	26	104
Vigo (VG)	42° 13'	8° 38'	255	2008	26	151
Zaragoza (Z)	41° 40'	1° 00'	240	335	26	75

with higher quality pluviometric records and are fairly regular, meaning that most of the days within the given period (14 610 days) are accounted for (Martin-Vide and Gómez, 1999). The values for constants a and b appear in Table III.

The adjustment of the exponential curves is acceptable in all cases, as, for example, is illustrated by the Valladolid and Valencia cases in Figures 6 and 7 respectively, where they overlap their respective concentration curves (obviously, however, point (100, 100) does not have to belong to the curves). The differences between the CI and the corresponding index calculated from the polygonal approach (Gini index) for Valladolid and Valencia are negligible: 0.004 and 0.007 respectively. Thus, of Equations (6) and (7) were used to determine the CI values for the 32 stations being studied. These data are shown in Table III.

The extreme CI values are: 0.55 in Orense (northwestern Spain), an area influenced by Atlantic disturbances; and 0.70 in Valencia (on the eastern side of the country), with precipitation characteristics marked by the Mediterranean Sea. Such a difference, which gives a 15% variation in the surface compressed by the exponentials of both stations and the equidistribution line is considerable, meaning that the daily pluviometric patterns are notably different.

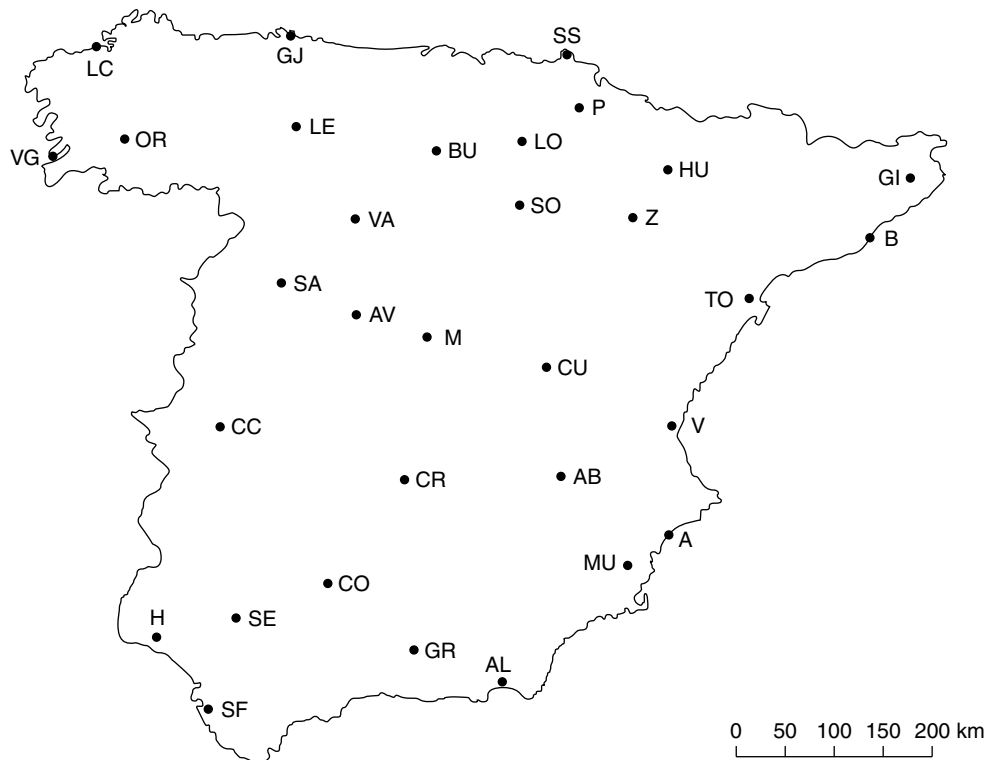


Figure 5. Location map of the 32 observatories analysed

Through the exponential concentration curves the percentage of precipitation contributed by 25% of the rainiest days, i.e. those with largest amounts, was calculated. The results are shown in Table III.

The extreme percentage values appear in the same stations: Valencia, with 78.8%, and Orense, with 64.9%. This is a variation of 13.9%, which shows notably different behaviour between the area of most concentrated rainfall and that with more regular daily amounts. Note that, in the first case, as in other stations (Tortosa, Alicante, Murcia) in eastern Spain, one-quarter of the rainiest days represents three-quarters, or more, of the total pluviometric amount. This leads to a marked uncertainty in terms of annual rainfall because, given the low number of rainy days per year (below 80 in most of the southern part of the Iberian Peninsula), any atmospheric circulation anomalies may greatly increase or drastically reduce the total yearly rainfall volume (regardless of whether the few days of heavy rain appear or not).

4. REGIONALIZATION OF PENINSULAR SPAIN BY MEANS OF CI

Annual precipitation amounts are generally modest in Spain (the average yearly precipitation is estimated to be scarcely 600 mm), although this fact conceals highly different extremes (Martin-Vide, 2000). In some northern provinces of the Iberian Peninsula (Galicia and the Basque country) and in one southern sierra (Grazalema), values may exceed 2500 mm, whereas in some far southeastern areas (Cape Gata — probably the driest place in continental Europe) amounts of only 150 mm are reached (Capel, 2000; Martin-Vide and Olcina, 2001). The time-like variability of precipitation on yearly, seasonal and monthly resolution is high in a large part of Spain. The coefficient of variation (standard deviation times 100 divided by the mean) of yearly precipitation is greater than 30% in many southern and eastern stations, and may reach 40% in others (Martin-Vide, 1994). However, a northern strip, adjacent to the Cantabrian Sea, presents low values (below 20%) consistent with mid-latitude marine west-coast pluviometry. The concentration of daily precipitation,

Table III. Values for constants a and b of exponential curves of the type given by Equation (1), CI and percentage of precipitation contributed by 25% of the rainiest days for 32 meteorological stations across peninsular Spain (period 1951–90)

Station (code map)	a	b	CI	Precipitation %
Albacete (AB)	0.0410	0.0312	0.59	68.1
Alicante (A)	0.0136	0.0415	0.68	77.1
Almería (AL)	0.0262	0.0354	0.63	72.0
Ávila (AV)	0.0328	0.0335	0.60	70.0
Barcelona (B)	0.0173	0.0397	0.65	74.5
Burgos (BU)	0.0400	0.0317	0.58	67.7
Cáceres (CC)	0.0447	0.0306	0.57	66.7
Ciudad Real (CR)	0.0521	0.0291	0.56	65.3
Córdoba (CO)	0.0455	0.0304	0.58	66.6
Cuenca (CU)	0.0470	0.0302	0.56	66.1
Girona (GI)	0.0268	0.0351	0.63	72.0
Gijón (GJ)	0.0347	0.0331	0.59	68.8
Granada (GR)	0.0524	0.0290	0.56	65.4
Huelva (H)	0.0319	0.0339	0.60	69.6
Huesca (HU)	0.0340	0.0333	0.60	69.0
La Coruña (LC)	0.0456	0.0305	0.56	66.3
León (LE)	0.0463	0.0302	0.57	66.6
Logroño (LO)	0.0375	0.0321	0.59	68.8
Madrid (M)	0.0305	0.0344	0.60	69.8
Murcia (MU)	0.0165	0.0397	0.67	75.7
Orense (OR)	0.0532	0.0290	0.55	64.9
Pamplona (P)	0.0405	0.0315	0.58	67.7
Salamanca (SA)	0.0485	0.0297	0.57	66.3
San Fernando (SF)	0.0352	0.0330	0.59	68.6
San Sebastián (SS)	0.0339	0.0334	0.59	68.9
Seville (SE)	0.0344	0.0332	0.59	68.9
Soria (SO)	0.0511	0.0292	0.56	65.8
Tortosa (TO)	0.0107	0.0441	0.69	78.1
Valencia (V)	0.0102	0.0443	0.70	78.8
Valladolid (VA)	0.0398	0.0317	0.58	67.8
Vigo (VG)	0.0367	0.0328	0.58	67.8
Zaragoza (Z)	0.0310	0.0338	0.62	70.7

studied through CI or simply the percentage of rain contributed by 25% of the rainiest days, is, as pointed out in Section 3, also high (although the values obtained show appreciable contrasts). Regardless of the variable or index analysed, the study of the peninsula's spatial patterns is necessary in order to understand the phenomenon completely. These patterns are usually complex because of: (1) the latitudinal situation, between the mid-latitude west-coast climate zone and the subtropical Mediterranean area, the latter predominating over the former; (2) its position between two continents, and above all, between two great water bodies (the Mediterranean and the Atlantic); and (3) a considerable variety in altitude, orientation and slope of its relief. The regionalization of Spain, according to several variables or index, is still a key objective for Spanish climatologists (e.g. Periago *et al.*, 1991; Martin-Vide and Gómez 1999; Serra de Larrocha *et al.*, 1999). Geographic and spatial patterns of the concentration of daily precipitation in peninsular Spain will now be analysed.

In a previous article (Martin-Vide, 1984), data from 10 meteorological stations on peninsular Spain's Mediterranean coast were used to show that the CI value increases along this coastline from north to south as far as the southern extreme of the Gulf of Valencia, this being due to the influence of the Mediterranean Sea;

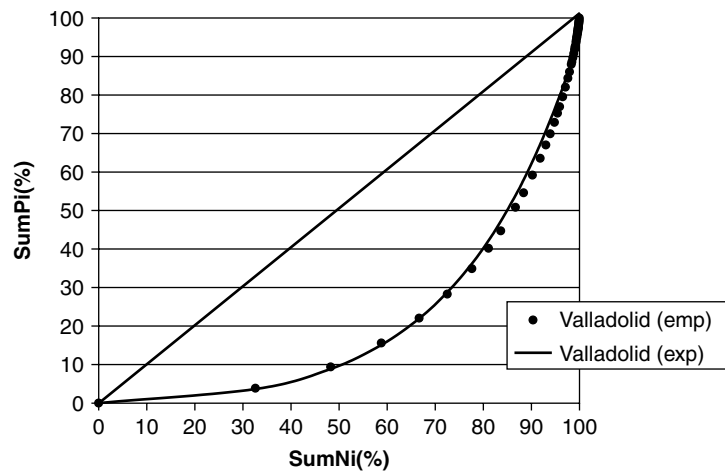


Figure 6. Empirical values (concentration curve) and exponential curve of type given by Equation (1) for Valladolid

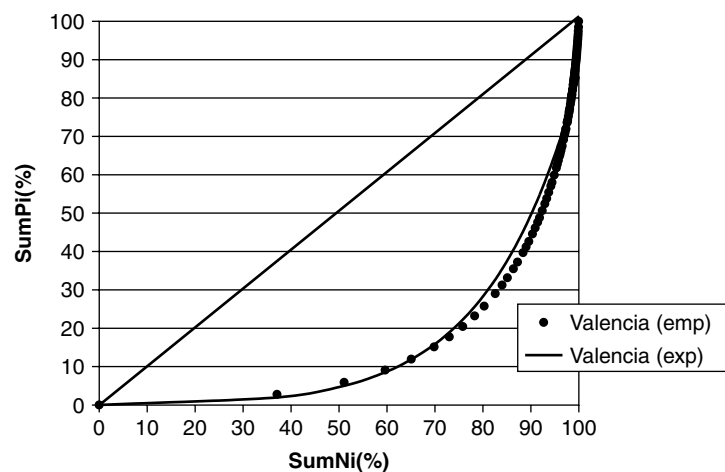


Figure 7. Empirical values (concentration curve) and exponential curve of type given by Equation (1) for Valencia

from there it decreases until it reaches Gibraltar, on account of the increasing influence of Atlantic storms, which become more regular on a daily basis. The spatial resolution in the Valencia region was increased by De Luis *et al.* (1997), and showed that the CI is an estimator of erosivity and aggressivity of rainfall, where precipitation records on hourly or minute resolution do not exist. Such a result makes the CI very useful in environmental studies whose aim is to estimate the risk of soil loss or evaluate the intensity of erosive processes.

The CI values in Table III are represented in Figure 8 through isopleths, and this enables the spatial patterns of daily precipitation concentration in a large part of the Iberian Peninsula to be determined. The eastern Mediterranean façade, where the highest values are achieved (up to 0.70 in Valencia), is perfectly outlined in the map. A high isopleth gradient defines very well the previously mentioned zone, from Catalonia (Barcelona) to Almería, with a significant turn towards the interior following the Ebro Valley (Zaragoza). The 0.61 isopleth is located at the threshold that discriminates the regions with high daily precipitation concentration, and thus with highly aggressive rainfall. In general, a value of 0.61 means that 70% of the total precipitation falls on 25% of the rainiest days. Beyond the area mentioned, no meteorological station reaches a value of 0.61. The eastern half of the two plateaux (Soria and Cuenca: 0.56) and Galicia (Orense,

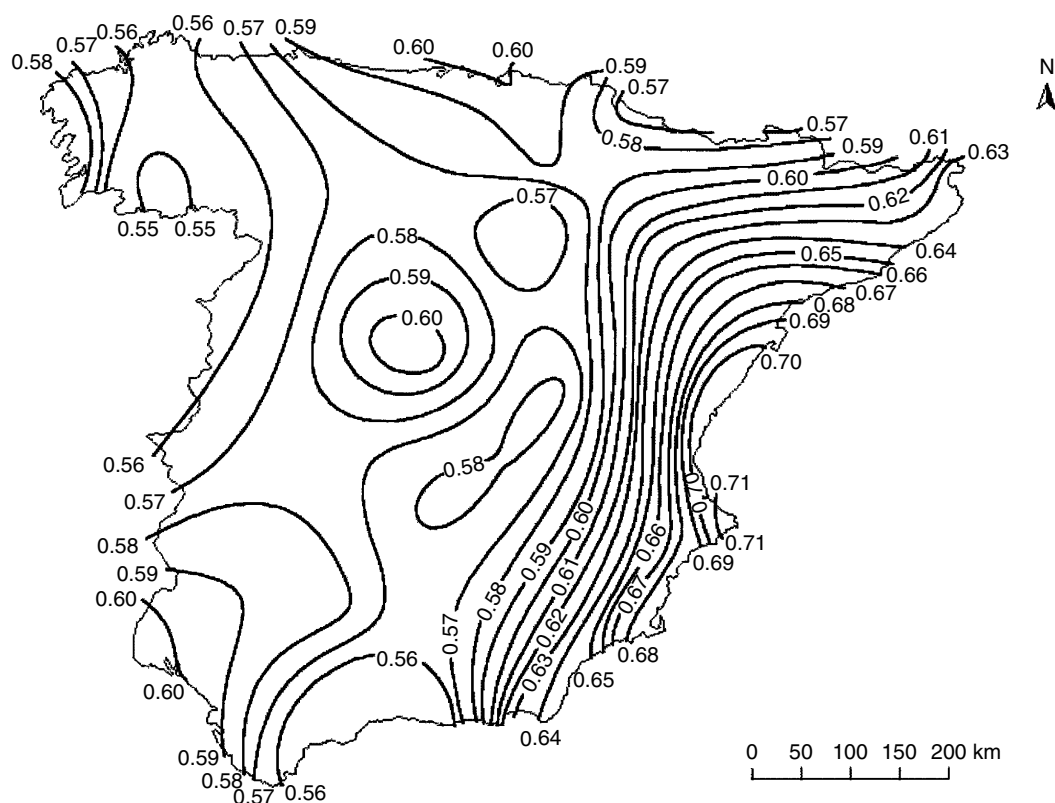


Figure 8. Isoleth map of CI (1951–90)

0.55; La Coruña, 0.56) are the regions with the lowest daily concentration, i.e. with the most regularity among the amounts of daily precipitation.

Although the CI appears to be randomly distributed in the central and western parts of the country, represented by the 24 meteorological stations with $CI < 0.61$ (mean 0.58), there are some spatially significant findings. Firstly, the northwestern area (extended somewhat to the south) stands out; this area comprises the meteorological stations of La Coruña, Vigo, Orense, León, Salamanca and Cáceres, and presents low values between 0.56 and 0.58 (mean 0.57). The east of the two plateaux also shows low values, e.g. Soria and Cuenca (both 0.56). In contrast, an area close to the centre of the country, comprising Madrid and Ávila (both 0.60), presents relatively high values, probably due to the mountain range separating the two plateaux. The eastern strip of land, with $CI > 0.61$, is represented by eight meteorological stations (mean 0.66). Within this area, and with the isopleth $CI = 0.66$, the sector with the greatest daily concentration of precipitation can be found, namely Murcia (0.67), Alicante (0.68), Tortosa (0.69) and Valencia (0.70). The value 0.66 corresponds approximately to 75% of the precipitation being contributed by 25% of the rainiest days.

The map analysed presents considerable geographic coherence, and identifies the area with the most daily rainfall contrast and the most critical intensity and aggressivity of rainfall. The country becomes distinctly divided into an eastern façade, where the Mediterranean depressions produce highly contrasting daily amounts (sometimes very large), and the rest of the territory, where the stronger influence of Atlantic disturbances produces more regular daily rainfall values. The Gulf of Valencia, the Spanish area with the highest daily and hourly pluviometric intensity (Elías and Ruiz, 1979), exceeds the peninsular southeast (Murcia, Almería), which is undergoing a severe desertification process due to its scarce annual precipitation.

The negative correlation between the CI and annual precipitation (i.e. the concentration of rain on a few very rainy days is apparently larger in places with low annual precipitation), which was expected to be high, was not observed at all. The value of Pearson's r (-0.23) is not significant. However, the correlation between

the CI and the annual coefficient of variation is significant and positive: $+0.52$ ($P < 0.01$). This result would seem to link pluviometric behaviour on an annual scale to that on daily scales, further supporting the thesis that a few very rainy days can change a year's pluviometric behaviour (dry or wet). In contrast to what occurs with annual precipitation, there is a significant and negative relationship between the annual number of rainy days and CI: -0.44 ($P < 0.05$).

5. CONCLUSIONS

The statistical analysis of daily data of areas like Spain, where monthly and yearly pluviometric amounts conceal highly different daily amounts of rain, is very interesting from a climatological point of view. The occurrence, or not, of one of these high daily amounts can change the character (dry or rainy) of any given month, season or year. This leads to considerable uncertainty in the average pluviometric contributions, which in turn has environmental and social repercussions.

The statistical structure of daily precipitation can be analysed by means of concentration curves that relate the accumulated percentages of precipitation Y contributed by the accumulated percentage of days X on which it took place. These curves are adjustable through exponential functions such as Equation (1). A concentration index CI, defined on the basis of these curves, enables the contrast or concentration of the different daily amounts to be evaluated.

The CI values obtained at 32 meteorological stations across peninsular Spain for the period 1951–90 range from 0.70 (Valencia) to 0.55 (Orense). CI clearly divides peninsular Spain into two regions: an eastern façade, which presents high concentration and where 25% of the rainiest days represent 70% or more of the annual total, and the rest of the country, which presents more regular daily amounts. The area with the highest daily concentration of rainfall is the south of the Gulf of Valencia, which is also the territory with the greatest daily and hourly pluviometric intensity in Spain. The CI correlates acceptably with the annual coefficient of variation (positive correlation) and with the annual number of rainy days (negative correlation) within the territory studied.

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REFERENCES

- Ananthkrishnan R, Soman MK. 1989. Statistical distribution of daily rainfall and its association with the coefficient of variation of rainfall series. *International Journal of Climatology* **9**: 485–500.
- Andrés M, Tomás C, De Pablo F. 2000. Spatial patterns of the daily non-convective rainfall in Castilla y León (Spain). *International Journal of Climatology* **20**: 1207–1224.
- Brooks CEP, Carruthers N. 1953. *Handbook of Statistical Methods in Meteorology*. Meteorological Office: London.
- Capel JJ. 2000. *El Clima de la Península Ibérica*. Ariel: Barcelona.
- De Luis M, González-Hidalgo JC, Raventós J, Sánchez JR, Cortina J. 1997. Distribución espacial de la concentración y agresividad de la lluvia en el territorio de la Comunidad Valenciana. *Cuaternario y Geomorfología* **11**(3–4): 33–44.
- Egozcue JJ, Ramis C. 2001. Bayesian hazard analysis of heavy precipitation in eastern Spain. *International Journal of Climatology* **21**: 1263–1279.
- Elías F, Ruiz L. 1979. *Precipitaciones Máximas en España. Estimaciones Basadas en Métodos Estadísticos*. Icona: Madrid.
- Estrela M, Peñarocha D, Pastor F, Millán M. 2000. Torrential events on the Spanish Mediterranean coast (Valencian region): spatial precipitation patterns and their relation to synoptic circulation. In *Mediterranean Storms. Proceedings of the EGS Plinius Conference*. Bios: Cosenza; 97–106.
- Goodess CM, Palutikof JP. 1998. Development of daily rainfall scenarios for southeast Spain using a circulation-type approach to downscaling. *International Journal of Climatology* **18**: 1051–1083.
- Guilló AM, Puigcerver M. 1970. Sobre las contribuciones relativas de las precipitaciones local y generalizada a la precipitación total en Cataluña. *Revista de Geofísica* **XXIX**(3): 203–215.

- Jolliffe IT, Hope PB. 1996. Representation of daily rainfall distributions using normalized rainfall curves. *International Journal of Climatology* **16**: 1157–1163.
- Lana X, Burgueño A. 1998a. Probabilities of repeated long dry episodes based on the Poisson distribution. An example for Catalonia (NE Spain). *Theoretical and Applied Climatology* **60**: 111–120.
- Lana X, Burgueño A. 1998b. Spatial and temporal characterization of annual extreme droughts in Catalonia (northeast Spain). *International Journal of Climatology* **18**: 93–110.
- Llasat MC, Puigcerver M. 1997. Total rainfall and convective rainfall in Catalonia, Spain. *International Journal of Climatology* **17**: 1683–1695.
- Martin-Vide J. 1984. Análisis de la irregularidad de la precipitación diaria en el litoral mediterráneo de la Península Ibérica. *Revista de Geofísica* **40**: 101–106.
- Martin-Vide J. 1987. *Característiques Pluviomètriques de la Precipitació a la Franja Costera Mediterrània de la Península Ibèrica*. Institut Cartogràfic de Catalunya: Barcelona.
- Martin-Vide J. 1994. Geographical factors in the pluviometry of Mediterranean Spain: drought and torrential rainfall. In *U.S.–Spain Workshop on Natural Hazards*. Iowa Institute of Hydraulic Research, The University of Iowa; 9–25.
- Martin-Vide J. 2000. The pluviometric diversity of Spain. In *Living with Diversity*, IGU Spanish Committee. AGE, RSG: Madrid; 415–424.
- Martin-Vide J, Gómez L. 1999. Regionalization of peninsular Spain based on the length of dry spells. *International Journal of Climatology* **19**: 537–555.
- Martin-Vide J, Olcina J. 2001. *Climas y Tiempos de España*. Alianza Editorial: Madrid.
- Olascoaga MJ. 1950. Some aspects of Argentine rainfall. *Tellus* **2**(4): 312.
- Peñarocha D, Estrela MJ, Millán M. 2002. Classification of daily rainfall patterns in a Mediterranean area with extreme intensity levels: the Valencia region. *International Journal of Climatology* **22**: 677–695.
- Periago MC, Lana X, Serra C, Fernández Mills G. 1991. Precipitation regionalization: an application using a meteorological network in Catalonia (NE Spain). *International Journal of Climatology* **11**: 529–543.
- Riehl H. 1949. Some aspects of Hawaiian rainfall. *Bulletin of the American Meteorological Society* **3**(5): 176.
- Romero R, Guijarro JA, Ramis C, Alonso S. 1998. A 30-year (1964–1993) daily rainfall data base for the Spanish Mediterranean regions: first exploratory study. *International Journal of Climatology* **18**: 541–560.
- Romero R, Sumner G, Ramis C, Genovés A. 1999. A classification of the atmospheric circulation patterns producing significant daily rainfall in the Spanish Mediterranean area. *International Journal of Climatology* **19**: 765–785.
- Serra de Larrocha C, Fernández Mills G, Lana X. 1999. Regionalización pluviométrica del NE de la Península Ibérica mediante análisis factorial y análisis espectral de los observatorios principales. In *La Climatología Española en los Albores del Siglo XXI*. Raso JM, Martín-Vide J (eds). Oikos-tau: Barcelona; 511–520.
- Shaw G, Wheeler D. 1994. *Statistical Techniques in Geographical Analysis*. Halsted Press: New York.