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Daily rainfall trend in the Valencia Region of Spain

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With 6 Figures

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Summary

We have analyzed daily rainfall trends throughout the second half of the 20th century in the western Mediterranean basin (Valencia Region, E of Spain). The area is characterized by high torrentiality, and during the second half of the 20th century some of the highest daily rainfall values in the Mediterranean basin have been recorded. In this area, mean annual rainfall varies between 500 and 300 mm and is overwhelmingly dependent on just a few days of rain. Daily maximum rainfall varies on average from 120 mm day^{-1} to 50 mm day^{-1}, and represents a mean of 17% (coastland) to 9% (inland) of annual rainfall. The 10 days in each year with the heaviest rainfall (called ‘‘higher events’’) provide over 50% of the annual rainfall and can reach more than 400 mm on average. We compared the annual rainfall trend and the trend of higher and minor events defined by percentiles, both in volume and variability. We, therefore, tested whether annual rainfall changes depend on the trend of the higher (rainfall) events.

To overlap spatial distribution of trends (i.e.: positive, no significant and negative trends) we have used cross-tab analysis. The results confirm the hypothesis that annual rainfall changes depend on changes found in just a few rainy events. Furthermore, in spite of their negative trend, higher events have increased their contribution to annual rainfall.

As a consequence, although torrential events may have diminished in magnitude, future scenarios seem to be controlled by a limited number of rainy events which will become more and more variable year on year. The high spatial density of data used in this work, (97 observatories per 24.000 km^2, overall mean 1 observatory per 200 km^2), suggests to us that extreme caution should be applied when analyzing regional and sub-regional changes in rainfall using GCM output, especially in areas of high torrentiality.

1. Introduction

Downscaling climate change processes has heightened the need for accurate information about distribution of climate variables on different time and space scales. In the case of precipitation detailed analysis is needed, because precipitation is more variable than other climate variables, and because from regional to global scale data are needed for model evaluation and for the construction of climate scenarios for climate change impact studies (New et al., 2002).

Simulation of GCMs, forced with increasing atmospheric concentrations of greenhouse gases, indicates an increase in extreme daily rainfall events on a global (Zwiers and Kharin, 1999; Meehl et al., 2000) and regional scale (Hennessy et al., 1997; McGuffie et al., 1999). Although models still have limitations that affect the simulations of the extreme events in terms of spatial resolution, it is recognized that changes in daily precipitation regimes are dependent on local

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factors (Bhaskharan and Mitchell, 1998). On the other hand, there is evidence in some areas of the increasing frequency of wet days and an increased proportion of total precipitation occurring during the heaviest events (Brunetti et al., 2001a and b; Groissman et al., 1999; Karl and Knight, 1998), but only few areas have been studied on a daily basis because high quality data are necessary, these data are not, in general, available (Brunetti et al., 2001b) and because there are difficulties determining trends of very rare events (Frei and Schär, 2001).

In this context, the relationship between annual rainfall and daily rainfall events is a priority research task in environments with scarce rainfall and where temporal rainfall variability is high, such as Mediterranean climate areas. In these environments the annual maximum rainy day (or a few) is able to produce enormous quantities; a few events can drastically modify the monthly, seasonal or annual rainfall, and all of them are able to affect the water cycle and environmental processes (Delitala et al., 2000).

In this paper, we study the relationships between the annual rainfall and daily rainfall trends during the second half of the 20^{th} century by using a dense network of rainfall observatories (1 observatory per 200 km^2 in mean). The study area is located in the western Mediterranean basin (Valencia Region, E of Spain), characterized by torrential precipitation, decrease in the mean annual rainfall and changes in variability and seasonal distribution (De Luís et al., 2000; González Hidalgo et al., 2001).

2. Study area

The Valencia Region is located in the western Mediterranean basin (East Coast of Iberian Peninsula, Spain, Fig. 1), and comprises an area extending between 38° and 40° N (24.000 km^2). It is a key area in understanding the spatial patterns of rainfall distribution along the Mediterranean coast of the Iberian Peninsula, because it is the transitional area between Atlantic influences from SW–W during the cooler part of the year and Mediterranean conditions from E–NE (Martín Vide, 1984). These combined effects produce a general rainy season from September to April, but the actual months of peak precipitation vary from location to location (Sumner et al., 2000) and usually depend on few rainy days.

Rainfall-generating processes in the area have been explained by Peñarrocha et al. (2002), Sumner et al. (2000), Camarasa (1993), Wheeler and Martín Vide (1992) and Martín Vide (1984) among others. All of them emphasize the effect that the temperature of the Mediterranean Sea, topography and synoptic circulation patterns have on the generation of severe storms.

Torrentiality along the East Coast of the Iberian Peninsula and particularly in the Valencia Region is notable (Martin-Vide, 1984; Camarasa, 1993; De Luís et al., 1996; Romero et al., 1998, 1999). In this area, there have been some of the highest rainfall events of 20^{th} century in the Mediterranean Basin (Peñarrocha et al., 2002). Table 1 shows some selected daily values of extreme events in different parts of the

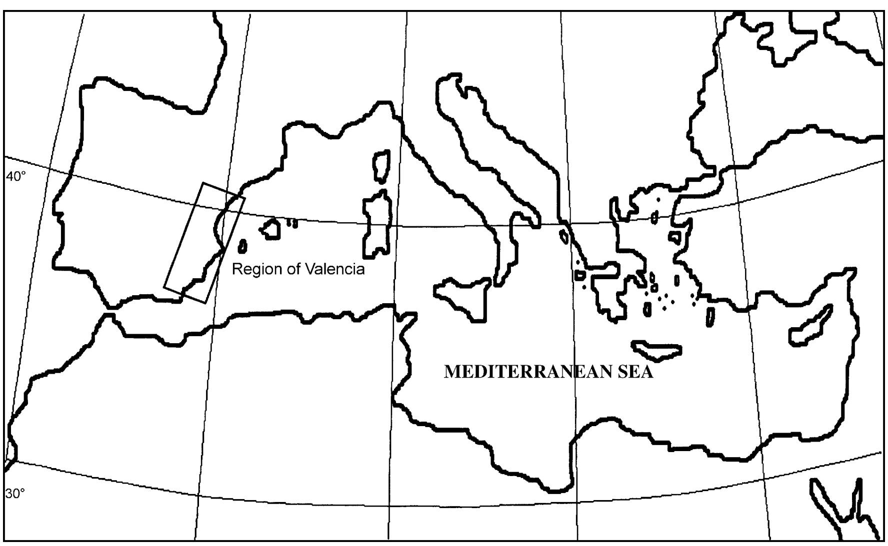


Fig. 1. Mediterranean Basin and Valencia Region location

Table 1. Selected values of extreme rainfall events in the Mediterranean coast of Iberian Peninsula (Region of Valencia)

Location	mm	Time	Date	Location	mm	Time	Date
Cap San A.	410	24	Oct. 1957[1]	Alzira	200	24	Oct. 1977[1]
Denia	343	24	Oct. 1957[3]	Pobla del Duc	>1000	72	Nov. 1977[1]
Valencia	350	24	Oct. 1957[1]	Denia	377	24	Nov. 1977[1]
Xabia	878	24	Oct. 1957[1]	Gandia	720	24	Nov. 1977[1]
Callosa	253	24	Oct. 1971[2]	Cofrentes	426	24	Oct. 1982[3]
Benisa	249	24	Oct. 1971[2]	Alicante	220	24	Oct. 1982[3]
Pego	204	24	Oct. 1971[2]	Verger	242	24	Sep. 1987[1]
Xalò	226	24	Oct. 1971[2]	Orihuela	316	30	Nov. 1987[1]
Tarbena	210	24	Oct. 1971[2]	Oliva	817	24	Nov. 1987[1]

Time in hours. [1]López Bermúdez and Soriano (1992). [2]Olcina (1994a, p. 82). [3]Olcina (1994b, p. 45, 46, 55, 92). In October 2000 rainfall was >500 mm in 24 hours in Fredes. A global Mediterranean basin review can be found in Poesen and Hooke (1997)

Valencia Region recorded during the last 50 years. Return period analysis indicates that more than 100 mm day^{-1} can be expected anywhere in the region (Egozcue and Ramis, 2002; De Luís et al., 2001).

In the study area mean annual rainfall varies between 500 mm year^{-1} to less than 300 mm year^{-1}, and follows a complex spatial pattern N–S/E–W. Relief is one of the most prominent factors in such spatial distribution. Daily maximum rainfall varies on average between 120 mm day^{-1} to 50 mm day^{-1}, and represents a mean of 17% (coastland) to 9% (inland) of annual rainfall. The 10 days of heaviest rainfall in a year provide over 50% of annual rainfall and can reach more than 400 mm on average.

Annual rainfall trends in the area show a decrease in annual values and an increase in variability (De Luís et al., 2000). However, a high spatial heterogeneity exists, which makes it difficult to establish an overall pattern.

The Valencia Region is densely populated on the coastal fringe, where tourism (more than 2,000,000 visitors per year) and specialized agriculture demand large amounts of water. Meanwhile, inland areas have been severely depopulated, and changes in land use and the rural exodus have increased the intensity and frequency of forest fires (Vallejo, 1997).

3. Data and method

3.1 General background

We used daily rain-gauge data sets from 97 meteorological stations. The original source (Pérez Cueva, 1994) comprising 210 station, was checked for inhomogeneities using metadata information and linear regression methods. From these, only complete and homogeneous series covering at least WMO 1961–1990 are used. These stations are distributed irregularly throughout the Valencia Region and represent the longest period available for the highest quality data covering the area (Pérez Cueva, 1994). The overall density is 1 observatory per 200 km^2.

The selection of daily events poses problems in the definition of an extreme event. Karl et al. (1995) and Yu and Neil (1993) identify those events as being over 50.8 (2 inches) and 40 mm day^{-1} respectively. Brunetti et al. (2001b and 2000), Ramos (2001) and Osborn et al. (2000) use percentiles, and Iwashima and Yamamoto (1993) and Suppiah and Hennessy (1998), consider the absolute maximum, the second largest, the third, and so on instead of a threshold by volume, for this study this last criterion was selected. To calculate higher events defined in this way, the daily values in each year were ranked from highest to lowest by volume. Then the 10 days of heaviest rainfall in a year (from now on called "higher/highest events") were selected as the most extreme events because in the Valencia Region they represent on average 50% of annual rainfall (De Luís, 2000). Computed as before the 10th highest value was the 97th percentile (threshold exceeded or equaled by the top ≈3% of events). Using the same procedure, we considered the 11th, 12th, and soon to be minor events. To test for trends in higher and minor events, we used the Spearman non-parametric test at 95% confidence level. Trends in the contribution of higher and minor events to total annual rainfall were analyzed by using annual contribution series.

Changes in inter-annual variability of higher and minor events have been evaluated by using standardized values of absolute anomaly series. General procedures of trend and spatial analysis can be found in De Luís et al. (2000).

3.2 Spatial association of rainfall trends

To overlap the spatial distribution of rainfall trends we have applied the cross-tables analysis (contingency tables, see Fienberg (1994) for a general description of cross-tables analysis), in which "the sample data randomness selected" is the meteorological station (total 97) and the "characteristics" evaluated are the signs of rainfall trend (i.e.: positive, no significant and negative). We compared the distribution of the annual rainfall trend and the trend of higher and minor events, defined as before, both in volume and variability. A list of pair-wise-evaluated comparisons is shown in Table 2 with their acronyms.

We tested the independence of each frequency distribution by using the χ^2 test. Given that trends can only be positive, not significant, and negative ($p < 0.05$, Spearman rank test, see De Luís, 2000), contingency table structure is 3×3 (row $\times$ column). The contingency tables were manipulated as a transition frequency matrix, with a row and column for each trend category to test for significance of the expected transition frequency matrix as follows (Swan and Sandilans, 1995, pp. 215–221):

Step 1. We constructed the contingency table counting transition trends following the results of trend analysis (see trend maps and Table 3 for Cross Tab structure).

Step 2. Dividing elements by row totals we obtained the observed transition probability matrix. The information of this matrix allows us to elucidate the nature of change between compared trends.

Table 2. List of rainfall trends compared pair-wise and their acronyms

Annual rainfall – Higher rainfall	AVOL–HIVOL
Annual rainfall – Minor rainfall	AVOL–MIVOL
Interannual variability – Higher interannual variability	AVAR–HIVAR
Interannual variability – Minor interannual variability	AVAR–MIVAR
Annual rainfall – Higher (as annual %)	AVOL–HI %

Table 3. Cross tab analysis structure

		Trend b			
		+	ns	-	Sum
Trend a	+	n_{++}	n_{+ns}	n_{+-}	$n_{+..}$
	ns	n_{ns+}	$n_{ns\,ns}$	n_{ns-}	$n_{ns..}$
	-	n_{-+}	n_{-ns}	n_{--}	$n_{-..}$
	Sum	$n_{..+}$	$n_{..ns}$	$n_{..-}$	$n_{....} = n$

Step 3. Dividing each column total of the observed transition frequency matrix by the total number of transitions, we calculated the fixed probability vector, i.e. the probability of going "to" each trend sign compared to if that probability is independent of the "from" state. The expected random transition probability matrix is then determined by these probabilities.

Step 4. We converted into expected counts by multiplying by row totals from the observed transition frequency matrix to give the expected random transition frequency matrix.

Step 5. The observed and expected counts can then be compared using χ^2.

The H_0 hypothesis is that data comes from a population with random transitions. And H_1 is "the data comes from a population of transitions that are not-random". Degrees of freedom were calculated with $(r-1)^2$ and the signification probability level was assessed by the Montecarlo running model for two-sided with SPSS™ package, after Yates correction, given that 0 frequencies were present in some cases.

The previous test outline establishes whether or not there is a relationship between the two variables compared. When the alternative hypothesis (H_1) is confirmed, it does not provide a measure of the strength of the relationship. In such a case we calculated the Contingency

Coefficient (CC) (Clark and Hosking, 1986, pp. 265–266), as follows:

$$CC = \sqrt{\frac{\chi^2}{n + \chi^2}}$$

with (n) the absolute frequency. Such statistics do not assume any prior distribution of the variable (Downie and Heath, 1986, p. 246), and the maximum value is calculated as follows (Sachs, 1978, pp. 402–403):

$$CC_{max} = \sqrt{\frac{K - 1}{K}}$$

which in cross tables (3×3) is 0.82 $(K = \text{rows})$. In each case we calculated the ratio CC/CC_{max}.

Finally, to characterize the overlap of trends, we tested the symmetry of cross-tab using the Bowker test. Null hypothesis (H_0) (symmetry), was:

$$B_{ij} = B_{ji},$$

with B_{ij} = observed frequency at i-th row with j-th column, and B_{ji} = the frequency observed at the j-th row with i-th column, calculating χ^2_{sim} as follows:

$$\chi^2_{sim} = \sum_{j=1}^{r-1} \sum_{i>j} = \frac{(B_{ij} - B_{ji})^2}{B_{ij} + B_{ji}}$$

Table 4. Annual rainfall trends. Number of rainfall observatories by rainfall trends

Trend	Positive	Not significant	Negative
Annual Rainfall	11	42	44
Annual variability	39	52	6

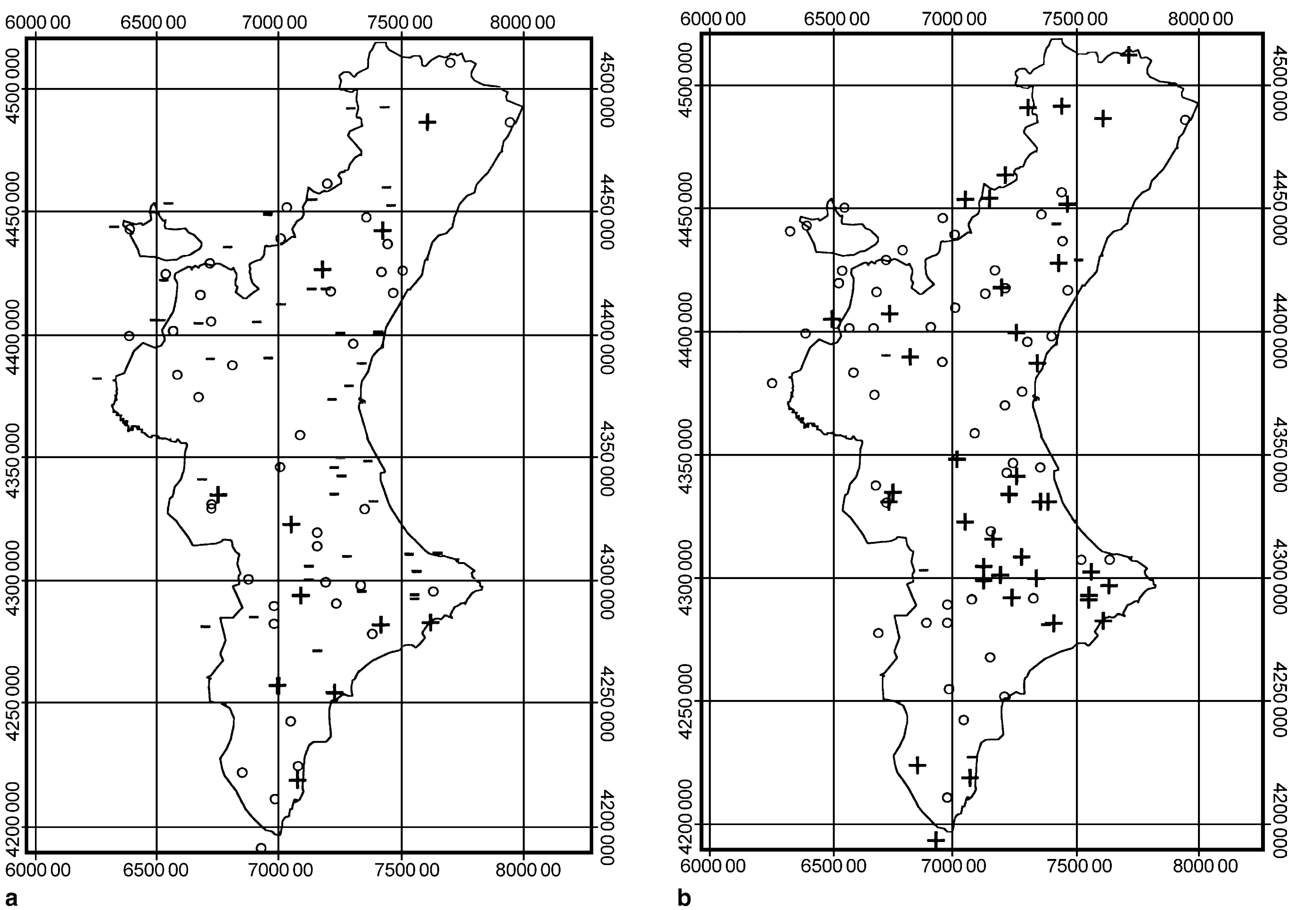


Fig. 2. (**a**) Annual rainfall trends by volume. (+) positive, (○) not significant, (–) negative. Probability level $p < 0.05$ (Spearman rank test). (Figure 6a, in De Luís et al., 2000, with modification). (**b**) Interannual rainfall variability trends. (+) positive, (○) not significant, (–) negative. Probability level $p < 0.05$ (Spearman rank test). (Figure 7a, in De Luís et al., 2000, with modification). UTM projection, units in meters, grid 50×50 km

Degrees of freedom were $= (r(r-1))/2$, and estimated probability level 0.05. The alternative hypothesis (H_1) was asymmetry. Further information about this test can be found in Sachs (1978, pp. 407–408).

We used the combined analysis of independence, empirical probability transition matrix, association and symmetry to evaluate the change between each trend.

4. Results

4.1 General background

Overall results that summarize general information about annual trend analysis are shown in Table 4, which gives the number of observatories by each trend category.

The spatial distribution of annual trends is presented in Fig. 2. A detailed description of these results can be found in De Luis et al. (2000).

4.2 Rainfall trends of higher and minor rainfall events

Higher rainfall events have increased in magnitude in 16 observatories. In 39 cases, rainfall from higher events has decreased and no

Table 5. Daily trend analyses. Number of rainfall observatories by rainfall trends

Trend	Positive	Not significant	Negative
Highest events (volume)	16	42	39
Highest events (variability)	44	39	14
Highest as annual %	32	52	13
Minor events (volume)	9	46	42
Minor events (variability)	42	42	13

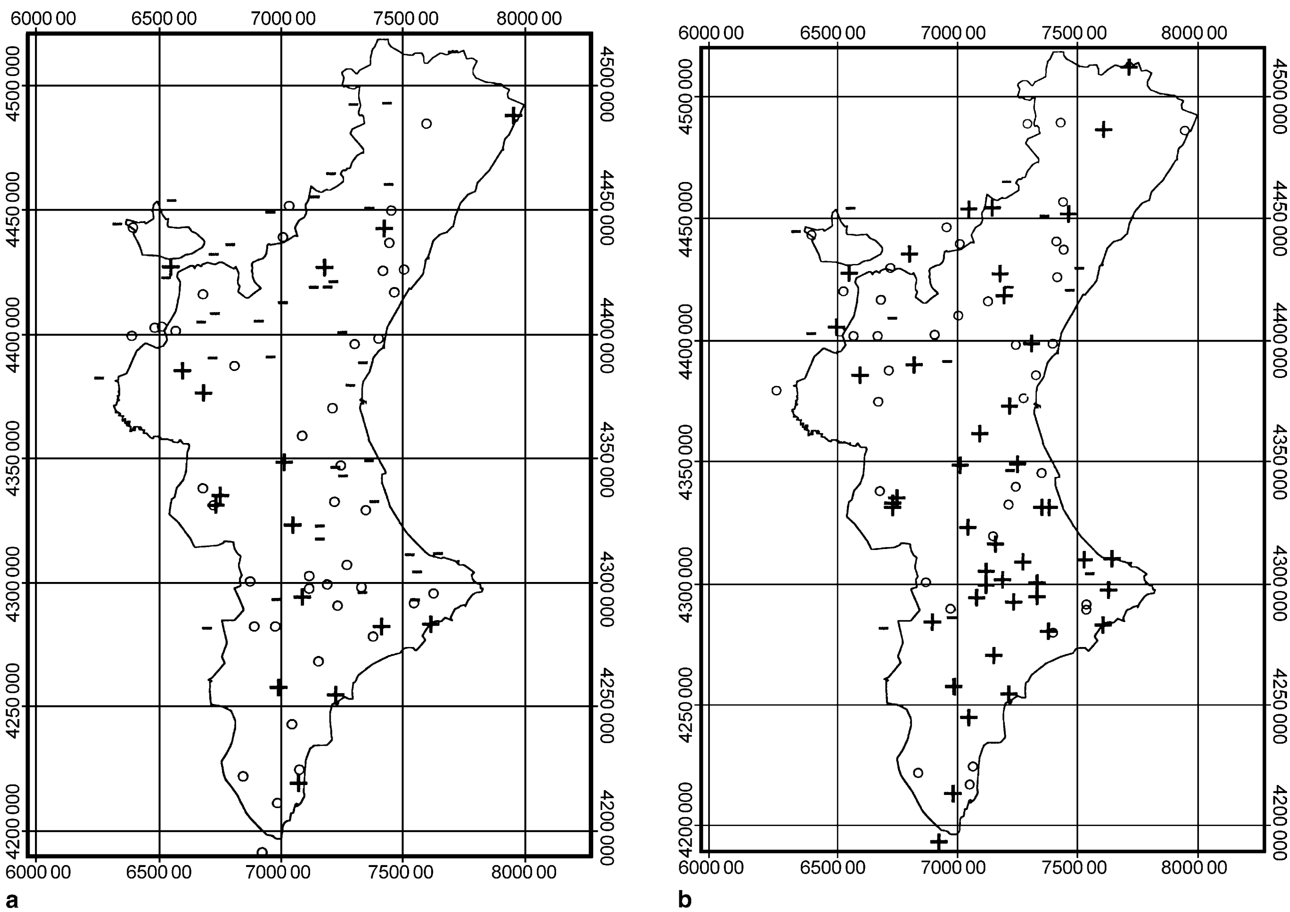


Fig. 3. (**a**) Higher events rainfall trends by volume. (+) positive, (○) not significant, (−) negative. Probability level $p < 0.05$ (Spearman rank test). (Figure 16a, in González Hidalgo et al., 2001, with modification). (**b**) Trends of Higher rainfall events variability. (+) positive, (○) not significant, (−) negative. Probability level $p < 0.05$ (Spearman rank test). (Figure 16b, in González Hidalgo et al., 2001 with modification). UTM projection, units in meters, grid 50 × 50 km

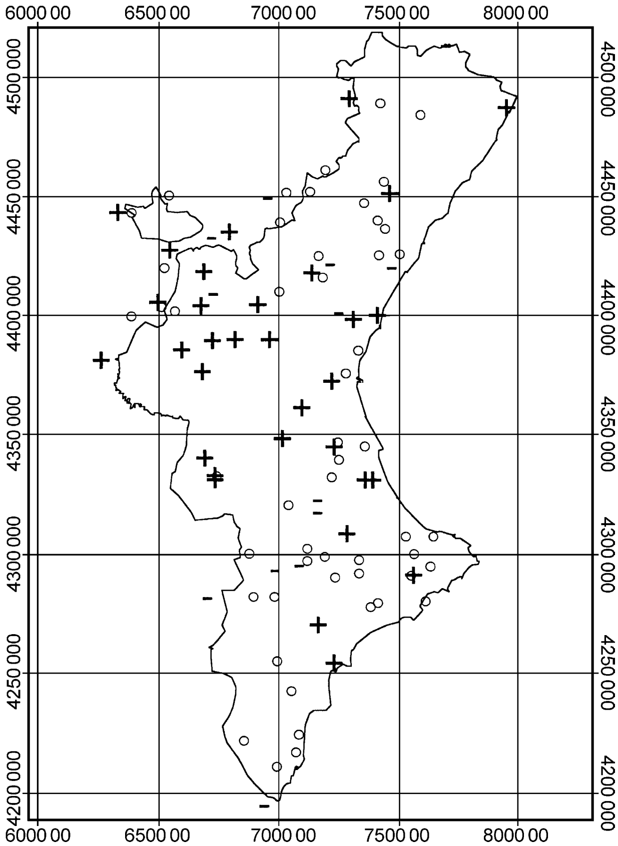


Fig. 4. Trend of higher rainfall events as percentage over annual rainfall. (+) positive, (○) not significant, (−) negative. Probability level $p < 0.05$ (Spearman rank test). (Figure 16c, in González Hidalgo et al., 2001, with modification). UTM projection, units in meters, grid 50 × 50 km

significant trend was found in 42 (Table 5). The spatial distribution of signs is shown in Fig. 3a. The contribution of these higher events as a percentage over annual rainfall has increased in 32 locations, remained steady in 52 and decreased in 13. The spatial analysis of these contributions indicates that no significant trends predominate in the north and south, while a positive trend predominates in central areas (Fig. 4).

The inter-annual variability of these events has increased in 44 locations, decreased in 14 and was not significant in 39 cases. Increase in rainfall variability is especially evident in southern areas of the Valencia Region (Fig. 3b).

Finally, rain falling in minor events increased for only 9 observatories, in 42 cases decreased and no significant trends were found in 46 cases (Fig. 5a). Their variability increased in 42 cases, was negative in 13 cases and was not significant in 42 (Fig. 5b).

4.3 Annual rainfall versus higher events rainfall

Contingency tables (cross tab) between annual rainfall trends and higher and minor events are shown in Table 6 with the empirical transition probability matrix (e.t.p.) (see Figs. 2a, 3a, and 5a).

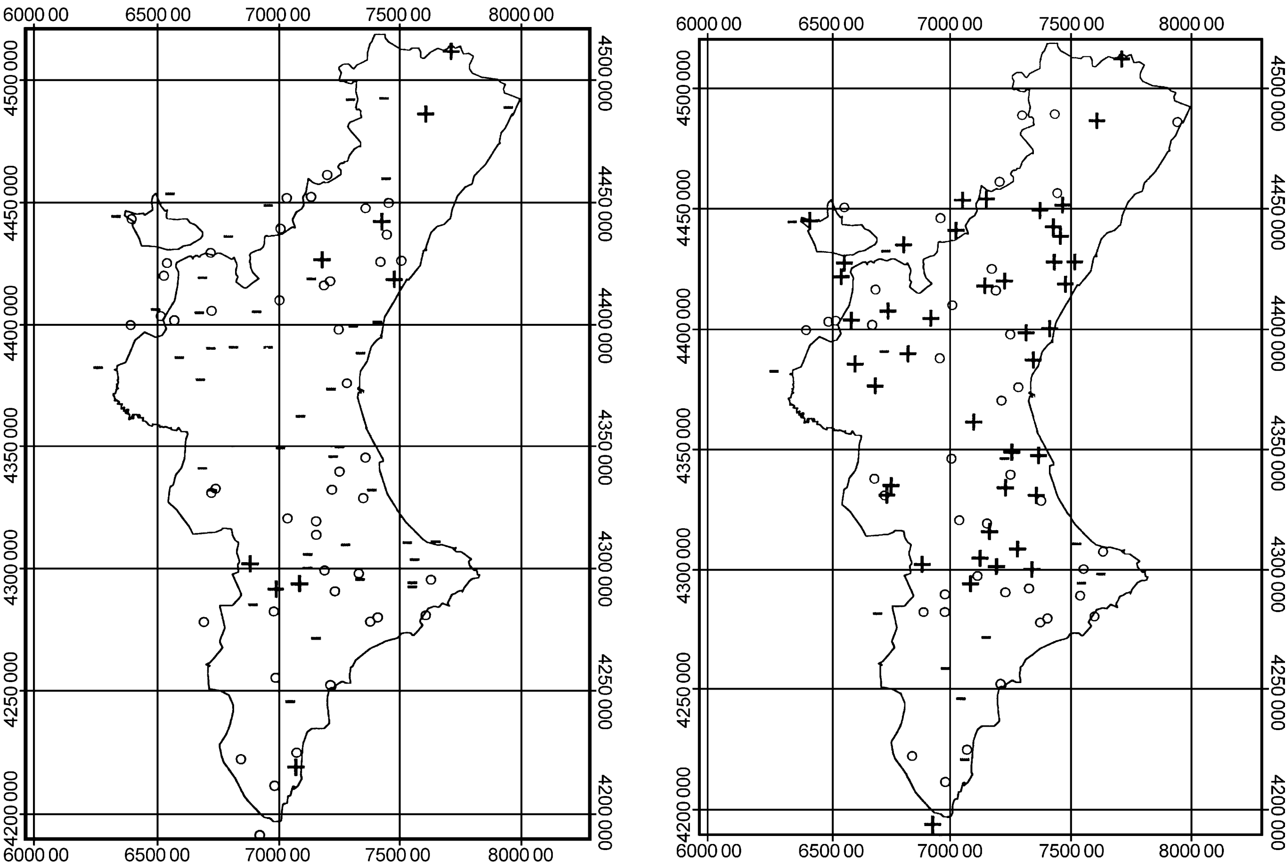
Annual rainfall changes seem to be highly and directly related with observed changes in higher rainfall events (Table 7: AVOL-HIVOL, χ^2 69.56, $p < 0.000$; CC_{max} 78.8%). Transitions produce a symmetric matrix (χ^2 4.66, n.s.) and changes between trends are direct. The main diagonal groups 67 observatories (Fig. 6). Annual rainfall and higher events decreased at the same time in 30 cases (empirical transition probability 0.769, Table 6).

Minor event rainfall trends are also spatially related to annual rainfall trends (χ^2 44.01, $p < 0.000$), although the CC (68.2% CC_{max}) shows their lesser importance on annual volume. Their cross tab is symmetrical and 65 observatories have the same trends. No significant aggregation was detected between the highest and minor events (HIVOL and MIVOL, data not shown, χ^2 7.85, n.s.). This suggests that spatial variations between them are random.

4.4 Inter-annual variability rainfall changes

The relationship between inter-annual variability of annual rainfall and inter-annual variability of highest and minor event are shown in Table 8 (see Figs. 2b, 3b, and 5b).

Annual trend variability is not related to higher and minor variability trends (AVAR-HIVAR, χ^2 8.42, p 0.076; AVAR-MIVAR, χ^2 2.34, p 0.707, Table 9). In both cases cross-tables are symmetrical and the main diagonals show direct relationships between trends (48 cases in higher and 43 cases in minor events, see Table 8). Such results suggest that the annual variability trend is affected spatially at random by the variability of higher and minor events. There is no aggregation between the variability trends of highest and minor e-vents, (HIVAR-MIVAR, χ^2 2.19, ns, data not shown).



a b

Fig. 5. (**a**) Trends of minor rainfall volume. (+) positive, (○) not significant, (−) negative. Probability level $p < 0.05$ (Spearman rank test). (**b**) Trends of Minor rainfall variability. (+) positive, (○) not significant, (−) negative. Probability level $p < 0.05$ (Spearman rank test). UTM projection, units in meters, grid 50×50 km

Table 6. Cross tab analysis. Annual rainfall trend versus higher and minor event trends

		AVOL						AVOL (e.t.p.)		
		+	ns	-				+	ns	-
HIVOL	+	10	6	0	16	e.t.p.	+	0.625	0.375	0.000
	ns	1	27	14	42		ns	0.024	0.643	0.333
	-	0	9	30	39		-	0.000	0.231	0.769
		11	42	44	97					

		+	ns	-				+	ns	-
MIVOL	+	5	4	0	9	e.t.p.	+	0.556	0.444	0.000
	ns	6	28	12	46		ns	0.130	0.609	0.261
	-	0	10	32	42		-	0.000	0.238	0.762
		11	42	42	97					

Table 7. Independence and symmetry test results. Annual rainfall and higher and minor trends

Comparison	Independence				Symmetry		
	g.l. $(3-1)^2$, crit. 9.48				g.l. $(3\times(3-1))/2$, crit. 7.815		
	χ^2	p	CC	% CC_{max}	χ^2	p	Diagonal
AVOL–HIVOL	69.56	0.000	0.646	78.8	4.66	n.s.	\
AVOL–MIVOL	44.01	0.000	0.559	68.2	0.58	n.s.	\

We included CC value and the percentage over maximum (% CC_{max}). Also we indicated by (/, \) the main diagonal to perform the symmetry test. It informs us about the dominant changes and their direction. n.s.: not significant

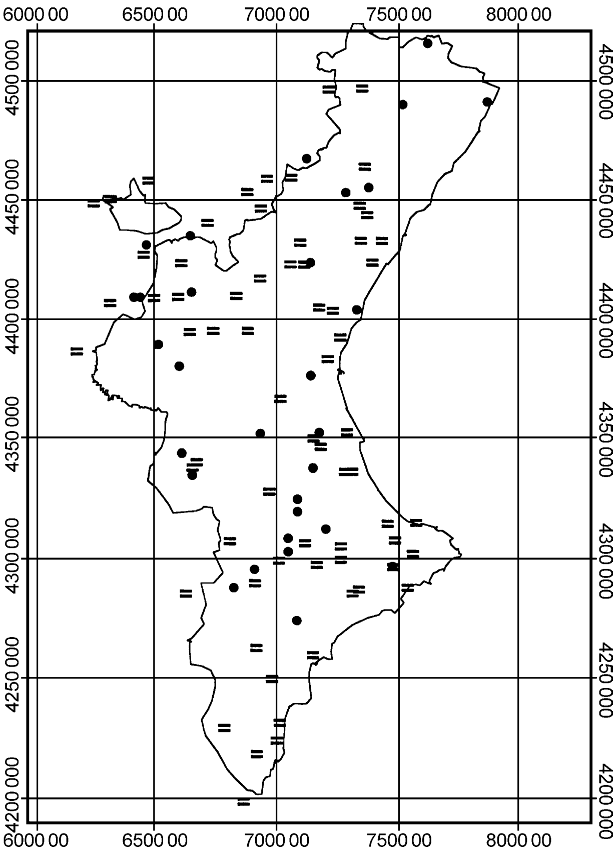


Fig. 6. Overlapping of trends between annual rainfall trend and trend of Highest events. (=) The same trend. (●) Different trend. UTM projection, units in meters, grid 50 × 50 km

4.5 Annual rainfall trend and contribution of higher events as a percentage

Finally, the relationship between the annual rainfall trend and the trend of higher events as a percentage of annual rainfall is shown in Table 10 (see Fig. 4).

Spatial distribution of the trend of higher events as a percentage of total annual rainfall is not clearly aggregated with the annual rainfall trend (AVOL-HI%, χ^2 8.97, p = 0.060; C_{max} 35.5%, Table 11). The transition pattern is complex, the matrix is symmetrical and the main diagonal includes 41 observatories, but changes are not direct. In general where annual rainfall decreased, the higher event contribution (as percentage) remained steady (22 cases) or increased (19 cases).

The results suggest that decreases in annual rainfall (44 cases) and decreases in higher events (32 observatories) happen at different rates. Where the contribution of higher events increased (32 cases, 1/3 of the total), annual rainfall mainly decreased (19 cases). As a consequence, rainfall during minor events has decreased more than in higher ones, so the contribution of higher events has increased in percentage terms, although the trend is negative.

5. Discussion

The integrated hierarchy of global simulation of climate variability, regional climate changes and extreme events has recently been indicated as vital research to improve the subregional analysis of climate change and downscaling processes by the IPCC 2001 report (Parry, 2001). For variables like precipitation, that do not adapt well to a normal distribution, the analysis is difficult to do. It requires long-term, good quality daily data which are not available for many regions (New et al., 2002; Brunetti et al., 2001b), and because changes in the frequency of maximums can be surprisingly large for seemingly modest mean changes (Trenberth and Owen, 1999; Nicholls and Murray, 1999; Folland et al., 1999). Last but not least, on a regional scale the results of IPCC are affected by much more uncertainty, and in the Mediterranean Basin it is difficult to foresee the trends owing to its latitudinal position (Brunetti et al., 2001a).

Recent works have demonstrated that, given no change in the frequency of precipitation, a

Table 8. Cross tab analysis. Annual rainfall variability trend versus higher and minor variability trends

AVAR

HIVAR	+	ns	-			e.t.p.	+	ns	-
+	24	19	1	44		+	0.545	0.432	0.023
ns	12	23	4	39		ns	0.308	0.590	0.103
-	3	10	1	14		-	0.214	0.714	0.071
	39	52	6	97					

MIVAR	+	ns	-			e.t.p.	+	ns	-
+	19	20	3	42		+	0.452	0.476	0.071
ns	17	23	2	42		ns	0.405	0.548	0.048
-	3	9	1	13		-	0.231	0.692	0.077
	39	52	6	97					

Table 9. Independence and symmetry test results. Annual rainfall variability trend and higher and minor variability trends

Comparison	Independence				Symmetry		
	g.l. $(3-1)^2$, crit. 9.48				g.l. $(3 \times (3-1))/2$, crit. 7.815		
	χ^2	p	CC	% CC_{max}	χ^2	p	Diagonal
AVAR–HIVAR	8.42	0.076	–	–	4.15	n.s.	\
AVAR–MIVAR	2.34	0.707	–	–	4.70	n.s.	\

We included CC value and the percentage over maximum (% CC_{max}). Also we indicated by (/, \) the main diagonal to perform the symmetry test. It informs us about the dominant changes and their direction. n.s.: not significant

Table 10. Cross tab analysis. Annual rainfall trend versus higher rainfall trend (as %)

AVOL

HIVOL	+	ns	-			e.t.p.	+	ns	-
+	1	12	19	32		+	0.031	0.375	0.594
ns	9	21	22	52		ns	0.173	0.404	0.423
-	1	9	3	13		-	0.077	0.692	0.231
	11	42	44	97					

Table 11. Independence and symmetry test results. Annual rainfall trend versus higher rainfall trend (as %)

Comparison	Independence				Symmetry		
	g.l. $(3-1)^2$, crit. 9.48				g.l. $(3 \times (3-1))/2$, crit. 7.815		
	χ^2	p	CC	% CC_{max}	χ^2	p	Diagonal
AVOL–HI%	8.97	0.060	0.291	35.5	3.94	n.s.	/

We included CC value and the percentage over maximum (% CC_{max}). Also we indicated by (/, \) the main diagonal to perform the symmetry test. It informs us about the dominant changes and their direction. n.s.: not significant

10% change in the mean annual rainfall is amplified for heavy precipitation rates (Groissman et al., 1999). For many regions, it seems that the changes in the frequency or probability of precipitation are either small or expressed in high rainfall rates (Karl and Knight, 1998). But many areas have not been analyzed so this research is an urgent task, particularly in environments where rainfall is characterized by high torrentiality.

In the study area of the western Mediterranean basin, annual rainfall is overwhelmingly dependent on a few days of rain. Higher events contribute on average 1/10 of annual rainfall, and the 10 annual higher events contribute over 50% of annual rainfall (De Luís, 2000). For this reason, the hypothesis that the annual rainfall trend and its variability depends on the trend of a highest event is relevant. Our results confirm the first hypothesis. The strong association between annual rainfall trend and the trend of higher events suggests that, during the second half of the 20th century, annual rainfall trends have depended on the trends of a few rainy days, a result which is consistent with the high value that they represent over annual rainfall.

Our second hypothesis is not confirmed. The inter annual variability trend (AVAR) is not related spatially to the variability of either higher or minor events. Therefore, the effects of variability of both higher and minor events on annual variability seem to be spatially at random.

Previous analyses in different parts of the World suggested that, in areas with increased annual rainfall, heavy precipitation has been significantly larger (Karl and Knight, 1998; Plummer et al., 1999; Osborn et al., 2000). Karl and Knight (1998) reported a 10% increase in annual precipitation with over half this trend being caused by increases in the upper 10th percentile of daily precipitation events. But also, in some areas, an increase in heavy precipitation has been documented, despite a decrease in mean rainfall values (Plummer et al., 1999; Tarhule and Woo, 1998; Groissman et al., 1999). In the Western Mediterranean Basin, Brunetti et al. (2000, 2001a and b) have found a negative trend for the number of wet days and annual rainfall in Italy, while the heaviest events class interval show positive trends; similar results were found in two long observatories by Ramos (2001) in NE inland of Spain. In both cases the increase of contribution of heaviest events start at the end of 20th century.

In our case we found a relationship characterized by a decrease in annual rainfall volume and that of the 10th highest events, although these seem to be increasing their contribution to annual rainfall because of the effects of a greater decrease in minor events. On the other hand, changes in rainfall variability of higher and minor rainfall events might threaten extreme situations which could suggest that an increase in the magnitude of extreme events is occurring, both in terms of torrential rainfall events and drought intensity. Perhaps future research will resolve this hypothesis.

The nature of different rates of rainfall decrease in higher and minor events is difficult to assess. In Italy Brunetti et al. (2001b) have suggested that the observed increasing precipitation intensity could be due to a general enhancement of the hydrological cycle, caused by increases in the surface temperature, and the reduction of the number of wet days from 1951 to 1996 have been consistent with the variation of the atmospheric circulation, with persistence of subtropical anticyclones over Mediterranean Basin during more recent years. In the study area rainfall is produced by SW–W flows during the cold season, and E–NE flows in autumn. These E–NE flows are independent of general western circulation and they are clearly related to higher events (Llasat, 2001; Sumner et al., 2000; Martín Vide, 1984), while SW–W flows are associated mainly with minor events (but the relationship is not exact, see Peñarrocha et al., 2002). Given that western flows are associated with the NAO teleconnection pattern, the positive phase dominant during the last 15 years could be responsible for higher rates of decrease in minor events. Further analysis must be done on such questions.

As a consequence, in environments where the annual rainfall trend depends on a few days of rain that are increasing in variability, extreme caution must be taken in downscaling processes before accepting any regional prediction from GCM output.

6. Conclusions

Daily rainfall analysis of a dense data set in the western Mediterranean basin (Valencia Region, eastern coast of Spain), during the second half of the 20th century, indicates that the annual rainfall trend depends on the trend of a very few rainy days.

On the other hand, the positive trend of highest events as a percentage of annual rainfall, in spite of their negative trend by volume, suggests that minor events have decreased more intensely, probably associated with NAO teleconnection values over the last 15 years.

Spatial variability found between annual and daily rainfall trends suggests that annual rainfall trends could depend on local factors that affect extreme events.

The results suggest that, although torrential events may have diminished in magnitude, future scenarios could be controlled by a limited number of rainy events which will become more and more variable year on year. The high spatial density of data used in this work, suggests to us that extreme caution should be applied when analyzing regional and sub-regional changes in rainfall using GCM output, especially in areas of high torrentiality.

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