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# Detection of statistically significant trends in the summer precipitation of mainland Spain

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In the context of global warming, it is a well-known fact that there is an increase in precipitation in middle latitudes. Convective phenomena have also been on the increase in the past few decades. It is gradually becoming more difficult to characterize climatic trends in middle latitudes. Data show that there may be different results depending on the study zones. Thus, it is interesting to study climatic changes in recent precipitation series, especially if we can have at our disposal a dense network of rainfall stations with reliable precipitation series.

The analysis of precipitation series in 333 rainfall stations from 1961 to 1990 has revealed that summer precipitation shows a statistically significant trend in wide areas of Mainland Spain. In the months of July and August, the precipitation is exclusively convective. In those months, the precipitation increased in 20% of the southern areas, that is, in those areas where temperatures are on average higher. June and September present different trends showing a decrease in precipitation in 10% of the territory.

*Keywords:* Trends; Precipitation; Summer precipitation

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## 1. Introduction

Over the 20th century, annual zonally averaged precipitation increased about 7% to 12% for the zones 30°N to 85°N in emerged landmasses in the Northern hemisphere,

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except in the Far East (IPCC, 2001). There is a general consensus about a number of changes in precipitation during the 20th century. It has also been noted that in middle latitudes—where most of the world's population lives—changes occur on a regional scale. However, in the zone between 10°N and 30°N the precipitation over emerged landmasses has decreased in 0.3%. In tropical latitudes, there seems to be an increase of approximately 0.2% to 0.3%. The data illustrate a number of changes that seem to be taking place. These changes are usually put down to global warming, which favors convectivity and distributes precipitation differently (Woodward and Gray, 1993; Hansen and Lebedeff, 1987).

Other authors such as Wetherald and Manabe (1995) present models pointing towards the existence of certain regions with summer droughts, where the drought may extend over other seasons of the year. This fact is especially important in those territories that are characteristic for their aridity.

In the Mediterranean area, precipitation is scarce and water requirements are increasing. Consequently, the amount of precipitated water is a very important variable within the sustainable development framework in the area. Some authors have found (Piervitali et al., 1998) a negative trend in precipitation from the 1950s in the Mediterranean Basin. The summer period is of special relevance because the precipitation is convective and the water requirements of the population and of agricultural and industrial activities are constantly increasing. The problem is more serious in the southwest of Europe, since the area is visited every summer by millions of tourists demanding large rates of water. Hence, it is important to establish trends of precipitation series during the summer months in Spain.

There has been a pattern of continued aridity since the late 1960s through North Africa south of Sahara. This effect is most persistent in the western region (Nicholson, 1993). Is this signal detected in the western Mediterranean region of Europe? The Iberian Peninsula is separated from the North of Africa by only a few kilometers and the question is: are there noticeable changes in the trends of summer precipitation in the Iberian Peninsula?

This paper presents an analysis of the trends of precipitation series in Mainland Spain between 1961 and 1990. In Spain, a vast network of rainfall stations records precipitation data on a daily basis. The orography varies a lot from one region to another and the mainland is influenced by either the Atlantic climate or by the Mediterranean climate. Taking into account this variability, the analysis was carried out using the data from as many different stations as possible. The aim is to study zones with/without climatic changes in summer precipitation. The paper describes the methodology used for the detection of the trends in the summer precipitation series and presents the results found. In addition, the paper includes the methodology employed to locate the regions with clear trends in monthly precipitation series in the period when the precipitation is convective.

## **2. Database**

### *2.1. Preliminary analysis*

The final aims stated, the first step is a preliminary analysis of precipitation series in Mainland Spain. Several criteria have to be taken into account in order to select the

stations with precipitation series that allow the identification of areas with climatic trends. This selection implies the following questions:

1. What are the criteria for relying on the precipitation series?
2. What spatial density of rainfall stations should be used?
3. What time period is it necessary to study in order to reach conclusions about recent climatic changes relating to precipitation?

Various facts have to be considered to find an answer to these questions:

1. The changes in precipitation trends have probably been more significant in the past few decades (IPCC, 2001).
2. Between 1961 and 1990, numerous rainfall stations measured precipitation. In the 1990s in Spain, most of the manually operated stations were replaced by automatic stations. Many old stations were not updated and simply closed down. So, the technological innovation brought with it the loss of many observation points.
3. A higher reliability will be assigned to those monthly precipitation series that come from stations that have been operating over the whole period of 30 years and whose data have been digitalized by the *Instituto Nacional de Meteorología* (Almarza et al., 1994, 2000).
4. Precipitation variation in Spain has been studied by different authors such as Rodríguez-Puebla et al. (1998). They all conclude that precipitation over the Iberian Peninsula has a strong seasonal character.
5. In Mainland Spain, the precipitation is convective in the summer months—July and August, stratiform between October and April, and of a mixed type the remaining months. The precipitation records show that the most rainy months are usually the ones in autumn and spring, while the months of July and August are the less rainy ones.
6. Summer rainfall is mainly caused by convective thunderstorms. In the Iberian Peninsula, thunderstorms usually affect extensions of several thousand square kilometers. It is therefore advisable to use a rainfall station density of at least one every 3000 or 4000 km<sup>2</sup> in order to reach conclusions about climatic trends in precipitation.
7. In this paper, we will consider the summer period as including the months of June, July, August and September. It has to be taken into account that in June and September in the northern latitudes of Mainland Spain the precipitation is of the mixed type: convective and stratiform. On the other hand, the precipitation over the whole territory in July and August is generally considered to be convective.

Keeping the previously mentioned facts in mind, we collected the digitalized monthly precipitation series recorded in 1500 rainfall stations. The series refer to the accumulated monthly precipitation in the months of June, July, August and September between 1961 and 1990.

At least one rainfall station every 3000 or 4000 km<sup>2</sup> was needed and for each rainfall station it was required that the monthly summer precipitation series be complete or with only one or two missing data. As a result of applying these conditions the number of stations was finally reduced to 345. So, for this study we have initially worked with the data from one rainfall station site every 1600 km<sup>2</sup> approximately. The selected stations present a fairly homogeneous spatial density distribution (see Fig. 1).

## *2.2. Constructing a database with complete monthly precipitation series*

Most of the 345 selected rainfall stations have complete data series. Nevertheless, in some cases it was necessary to fill in missing data in these series. Forty-two series had to be completed for the month of June, 54 for July, 46 for August and 51 for September. The interpolation method known as normal-ratio was used to fill in any missing values in the original series (Paulus and Kohler, 1952; Young, 1992; Potter, 1981). Each series with missing data was correlated with another three series from nearby rainfall stations. The correlation had to be significant at the 99% level. By applying this method, it was eventually possible to obtain 345 complete data series for each one of the months considered in this study.

The Kruskal–Wallis test was applied in order to verify the homogeneity of the data series. The monthly series of 333 rainfall stations were found homogeneous (significant at the 95% confidence level). In the 12 remaining stations, at least one of the precipitation series was identified inhomogeneity, so they did not fulfill the criteria to be included in this



Fig. 1. Dots represent the position of the 333 rainfall stations used for the analysis.

Table 1

For every month the table shows the number of rainfall stations with a statistically significant trend by applying the Man–Kendall test

Month	Trend	No. of rainfall stations with trend	Year at which a trend begins
June	Negative	33	1979
	Positive	0	–
July	Negative	0	–
	Positive	63	1975
August	Negative	2	1980
	Positive	59	1968
September	Negative	28	1973
	Positive	2	1973

The table shows also the first year of the trend put down to climatic reasons.

study. The precipitation series of the months June to September in the 333 rainfall stations selected do not contain abrupt changes due to non-climatic reasons, but may maintain climatic changes.

### 3. Detection of trends in precipitation series

Numerous authors like Steinberger and Gazit-Yaari (1996), Keim and Cruise (1998), Aizen et al. (1997) and Metcalfe et al. (1997) prefer to carry out a linear trend analysis to detect changes in the precipitation for an annual period or for a single season. The advantage of this method is its simplicity. However, it presents a great difficulty to establish the year in which the new trend began. Following Sneyers (1990), the Mann–Kendall (Kendall, 1975) test was used for this study because it determines whether there is a statistically significant trend, and it also establishes the approximate year at which a trend begins. This test sets up two series, a progressive one and a backward one. If they cross each other, and then diverge and acquire specific threshold values, then there is a statistically significant trend. The point where they cross each other indicates the approximate year at which the trend begins.

Table 1 shows the results found by applying this method. There is a considerable difference between the months of June/September and the months of July/August. In June/September, we can see that around 10% of the stations show negative trends and there are only two positive trends in September. In contrast, in July/August there are almost 20% of rainfall stations with a positive trend, and there are only two stations with a negative trend in August and none in July.

### 4. Areas showing the same trend

In climate research, it is important to have a reliable database. Considering the strict conditions imposed, the database used in this paper can be regarded as reliable. The

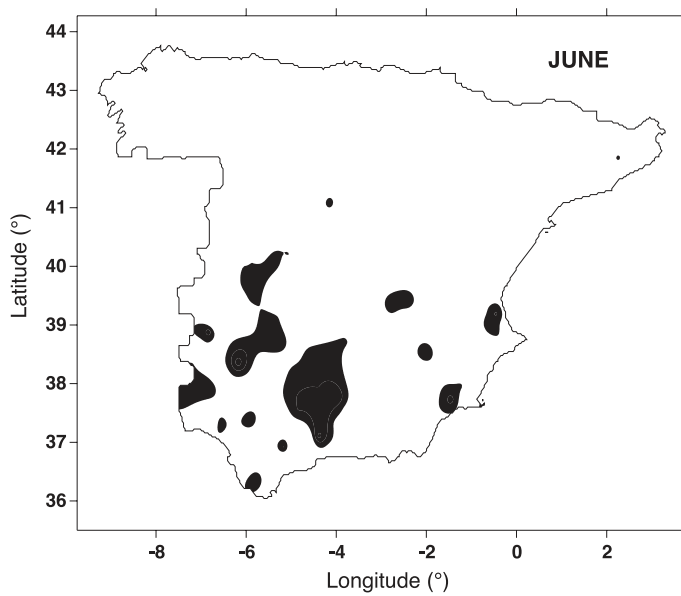


Fig. 2. The areas plotted in black show a negative trend in June during the period from 1961 to 1990.

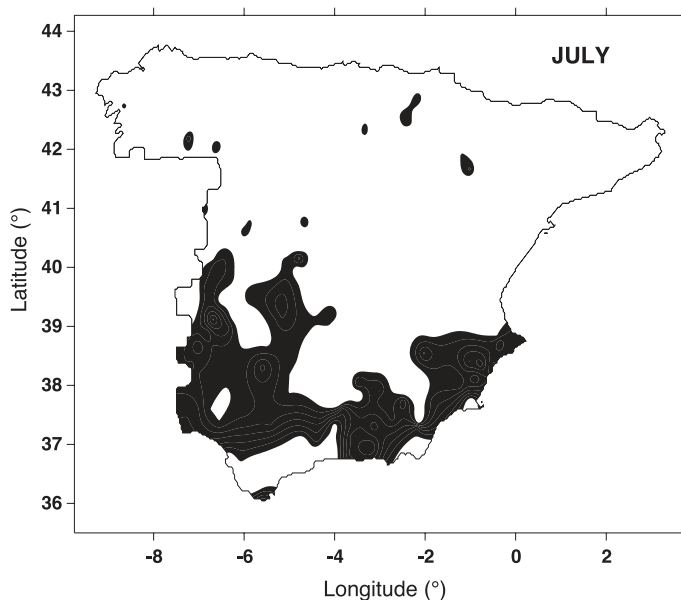


Fig. 3. The areas plotted in black show a positive trend in July during the period from 1961 to 1990.

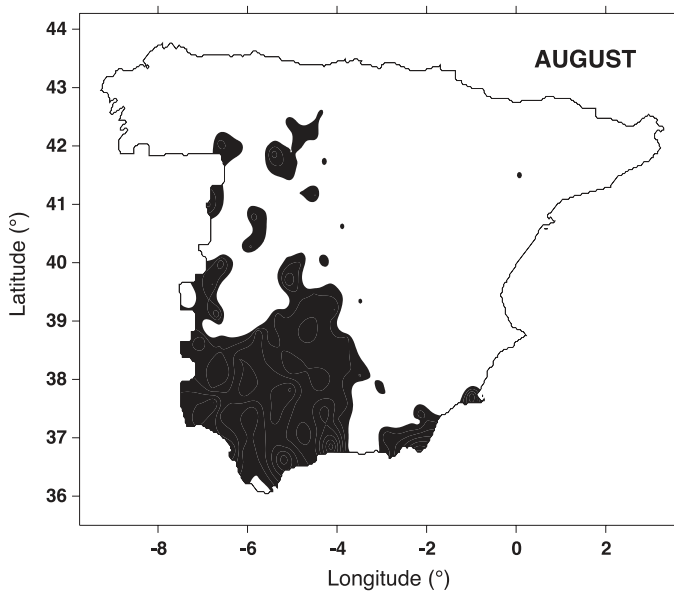


Fig. 4. The areas plotted in black show a positive trend in August during the period from 1961 to 1990.

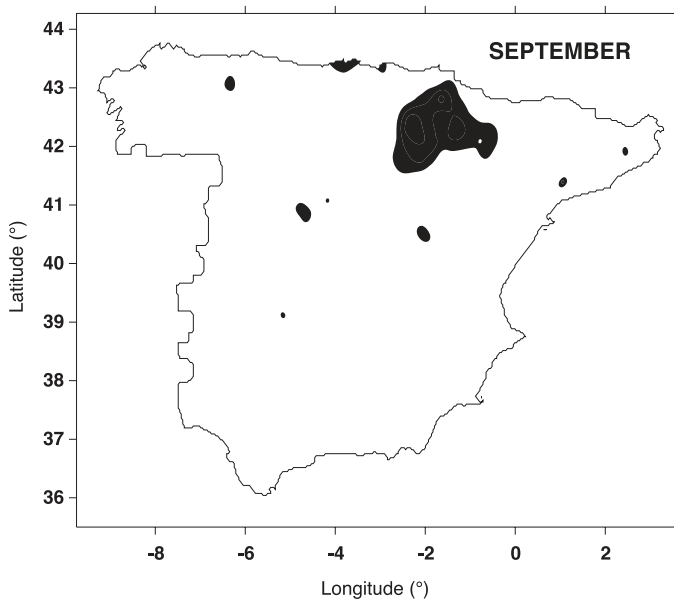


Fig. 5. The areas plotted in black show a negative trend in September during the period from 1961 to 1990.



Mann–Kendall test has revealed some series with well-defined trends. Whenever a particular trend has been found in the precipitation series in one time period, the same statistically significant trends would be expected in the precipitation series of nearby rainfall stations in the same time period. The rainfall stations density in this case is very high, so if one of the stations shows a trend towards more rain or towards less rain, then this same trend should appear in other stations situated close by. Nevertheless, there may also be effects on a very small scale that may alter this general rule.

The aim is to delimit areas with rainfall stations whose precipitation series show similar trends.

The Kriging method (Ripley, 1981; Isaaks and Srivastava, 1989) was used for this study. This method has advantages in that it constructs a model that joins points with similar features forming grid patterns. The method does not tend to generate “bull’s eye” patterns. The method generates an interpolated grid, estimating the values of the points at the grid nodes.

Three groups of regions have been established: regions showing positive trends, negative trends, and no trend at all. All these trends have to be statistically significant following the Man–Kendall test.

The results obtained by applying this technique are the plots shown in Figs. 2–5. The areas with two rainfall stations with positive trends in September and the two stations with negative trends in August have not been plotted, since they represent only 0.5% of the study zone.

## 5. Discussion

The results shown in the figures lead us to establish the following points:

1. In all cases the rainfall stations showing trends, be they positive or negative, tend to be grouped together and there are hardly any “bull’s eyes”. The change in climate trends tends to be gradual, so the fact that the stations with statistically significant trends are grouped together may indicate that the technique employed has been correct.
2. In the months of June and September, approximately 60,000 and 50,000 km<sup>2</sup>, respectively, show decreasing precipitation trends. In contrast, in the months of July and August, the precipitation trend shows an increase in 120,000 and 110,000 km<sup>2</sup>, respectively, which amounts to 20% of the territory.
3. In the months of June, July and August the regions showing trends are located to the south of the Iberian Peninsula, the area that is closer to Africa.
4. In the month of September, the one area that shows a particular trend is the Central Ebro Valley—to the NE of the Iberian Peninsula—with additional areas scattered around the rest of the territory. In this case, the south shows almost no trend at all.

How should these data be interpreted? It is necessary to analyze the type of precipitation before answering this question. In the Mediterranean region, there is a strong

seasonal variability. Serrano et al. (1999) carried out a month-to-month analysis of precipitation using PCA identifying seven meteorological patterns that cause precipitation. Only two of these patterns can be detected in Spain in the summer:

- Low pressure areas in the Cádiz Gulf moving east. There are also low pressure systems in the west of Portugal and Galicia.
- Polar maritime air masses coming from the Atlantic and associated to a high pressure area in the NW of the Iberian Peninsula, with low pressures in the Mediterranean, between Corsica and Sardinia.

In both cases, the meteorological effect is a growing instability favoring the occurrence of convective precipitation. This happens during warm months. In the whole of the Iberian Peninsula, the warm months are July and August. Between 1961 and 1990 in the months with convective precipitation there is a statistically significant trend of increasing precipitation in the south of Mainland Spain. We may thus conclude that the convective phenomena responsible for the precipitation have also increased in this time period, leading to a more frequent occurrence of thunderstorms. Table 1 shows that these changes begin in the 1970s. In conclusion, it seems that the climate change in convective precipitation affects only the southern regions that have a Mediterranean climate, the regions with the highest temperatures in the whole Iberian Peninsula.

The results found for the months of June and September are somewhat different. Rainfall stations showing statistically significant trends are grouped in a certain way: in June in the southern part of the territory and in September in the Ebro Valley (NE of the Iberian Peninsula). The first aspect that has to be pointed out is that in these months the precipitation is not always convective. Sometimes the fronts come from the Atlantic and in these cases they lead to stratiform precipitation. Besides, the months of July and August are the driest months in the year. This is why in the study zone the amount of convective precipitation is smaller than the amount of stratiform precipitation. The most plausible explanation for this trend in some regions is that in the months of June and September—with mixed precipitation, stratiform and convective—the increase of convective precipitation is being leveled out by a parallel decrease in stratiform precipitation. As a result, there is no trend in most of the territory, except for a few areas with negative trends.

The methodology employed has determined that in the period between 1961 and 1990 the monthly precipitation series start showing statistically significant trends in the 1970s, and that these trends tend to be grouped in certain areas of the study zone. Nonetheless, some “bull’s eyes” may be put down to regions with local effects leading to slight changes in the data series, or else to the fact that in those regions new statistically significant trends are being formed. It is essential now to follow closely the possible climatic changes that may be taking place in these regions within the study zone.

This division of the territory in two areas with different statistical trends has also been found in other regions of the Mediterranean. Steinberger and Gazit-Yaari (1996) found that in Israel annual precipitation in the south increased between 1960 and 1990.

In that particular area, the precipitation is more often convective than stratiform. Bücher and Dessens (1991) found in the Pyrenees that the mean annual temperature increased 0.83 °C during the period 1882–1970. In conclusion, the results found in this study are consistent with the idea that convective precipitation is on the rise within the context of a generalized increase in the surface temperature in an area of the Mediterranean region.

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