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# Máster en Cambio Global

# 2013-2014

# Thermo-pluviometric characterization of Peninsular Spain and the Balearic Islands during the period 1958-2007.

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ABSTRACT

A dense daily data base of precipitation, maximum and minimum temperatures extending from 1950 to 2008 called Spain02 was used to perform a climatic study for Peninsular Spain and the Balearic Islands. The thermo-pluviometric characterization has identified different and diverse climates in the region under study. A detailed analysis of two consecutive periods has allowed us to look for evidence of climate change in the region. A generalized and significant increase in daily maximum and minimum temperatures has been detected for the entire region. Furthermore, a change in the pattern of rainfall has also been observed. Changes in precipitation of opposite sign have been detected depending on the zone. These changes were found for the amount of rainfall, number of rainy days, consecutive periods of rain, and extreme events of precipitation. The region under study is shown to be greatly affected by climate change. The database, being so extensive and reaching virtually the present, has allowed to make estimates of return periods using statistical modeling of extreme values based on the Generalized Pareto Family distribution. The resulting return period maps highlight the coastal areas of Valencia region as the most affected by torrential daily rainfalls, of 600mm or more, which occur every 100 years on average.

## 1. INTRODUCTION

The climate has always been a concern for the societies. Some sectors such as agriculture and fishing have always been conditioned by this aspect. Currently there are many other sectors, such as tourism, infrastructure construction or urban planning, that depend directly on climate. Due to this interest on climate, there has always been an interest in developing the necessary instruments and the technology for measuring weather variables in order to characterize it. And with the appearance of new technologies especially, the most developed societies have acquired a great ability to record the most relevant meteorological variables. Large databases that are now available are of great academic interest as well as for planning and land management.

Currently, in Spain many long series of meteorological variables are available that allow us to characterize the climate. Since these series have temporal and spatial discontinuities, specific products have been developed, such as the Spain02 database (Herrera et al. 2012) to group all these series together, correct errors and inconsistencies and distribute the data into a regular grid throughout the country.

This paper attempts to study the climate of the Spanish Peninsular region and the Balearic Islands. For this purpose, the maximum daily temperature, minimum daily temperature and daily precipitation variables have been used. These have been obtained from the Spain02 database.

With these data at hand three different objectives were pursued: (i) to make a characterization of the climate, (ii) to look for evidence of climate change, and (iii) to study the extremes of the series.

The characterization of the climate of Peninsular Spain and the Balearic Islands follows a thermo-pluviometric characterization. To make this, we have chosen a sufficiently long period that begins in 1958 and ends in 2007. This period is considered appropriate because it comprises 50 years of data, a long enough period. Thirty years is usually considered enough to characterize the climate of a region. For the thermo-pluviometric characterization, the variables of daily maximum and minimum temperatures and daily precipitation were considered separately. The generated results are annual and seasonal averages of different kinds of climatic products and indices (see next section), appropriate to analyze the different behaviors of the climate of the region.

According to the latest IPCC report some of the consequences of climate change have already been observed. The warming in the climate system is unequivocal and changes since 1950 are unprecedented in our recent past. Following the increase in the concentrations of greenhouse gases, the atmosphere and ocean have warmed, the snow-covered and ice extent have decreased and sea level has risen (Stocket et al. 2013). Because of this evidence on a global scale, it seems interesting to see if in the region under study evidence of climate change can also be observed. Specifically for Spain, there several published works is in this field. Some studies related to precipitation have shown that extreme precipitation indices have declined in recent decades (Valencia et al. 2012). A study about trends and extreme drought indices show a clear trend towards drier conditions during the 20th century in most western Mediterranean regions (Sousa et al. 2011). In other studies about temperature, some results indicating a significant increase in the frequency and intensity of most of the extreme hot temperature have been published (El Kenawi et al. 2011). In addition, the Mediterranean emerges as one of the most prominent regional climate change hotspots in response to intermediate and high levels of forcing (Diffenbaugh and Giorgi 2012). Therefore, it is expected that the temperature of the area under study is affected.

The novelty of the work presented here is the use of the same high quality database for searching evidence of the climatic changes on three of the most relevant variables. This database extends to 2008 so we are going to do an updated climatic characterization in the region under study and generate maps with very current return periods that reflect the latest trends in changes of extreme events. Thus, in this work, new products are analyzed on a high resolution grid using data of Span02.

With this aim, two periods are defined and statistically significant differences between them are sought. The two periods are from 1958 to 1982 and from 1983 to 2007. The results generated are of the same type as those generated for the characterization of the full period. To study the significance a test on the averages with a level of 90% significance was chosen.

Characterization of the extremes of the series is presented in a different section with the aim of detecting and analyzing the extreme climatic events in the region. A meteorological or climate extreme event is defined as the occurrence of a value of a meteorological variable above (or below) a threshold value near the upper (or lower) end of the distribution of observed values for the variable in question (Field et al. 2012).

For this study we have calculated the probabilities of occurrence of extreme values for maximum and minimum temperature, and daily precipitation, using a Generalized Pareto Distribution model adjusted using the values above the $90^{th}$ percentile. In order to express the results I have used maps of return periods for critical values of both maximum and minimum temperature, and precipitation. The study of these distributions of extreme values is of great interest because these events are the cause of big loss of property and even loss of human lives.

## 2. MATERIALS AND METHODS

### 2.1. Study area

The area covered by this study includes the part of the Iberian Peninsula that is Spanish territory as well as the Balearic Islands. This region was chosen because it is covered by the Spain02 database.

The Peninsular Spain is located in southwestern Europe. It is a region with a complex orography influenced by the Atlantic and Mediterranean climates. The influence of both climates, combined with the orography, cause a wide range of climates in the region with a strong North-South gradient, both on precipitation (Herrera et al. 2012) and temperature. The Balearic Islands are located to the east of the Iberian Peninsula, in the western Mediterranean region. The islands emerge abruptly from the sea with a complex and prominent orography. Although the islands are relatively small, there is also a north-south gradient in both temperature and precipitation.

In our study region different types of climate are present. According to the Köppen-Geiger classification (AEMET, 2011), we find:

- BWh (hot desert) and BWk (cold desert) located in small areas of the southeast of the Iberian Peninsula in the Spanish provinces of Almeria, Murcia and Alicante, with minimum peninsular rainfall.
- BSh (warm steppe) and BSk (cold steppe) which is widely spread over the southeast of the peninsula and the Ebro Valley.
- Csa (temperate with dry or hot summer): this is the variety of climate that covers a larger area of the Iberian Peninsula and the Balearic Islands, occupying about 40% of its surface. This climate characterizes most of the southern half of the Peninsula and Mediterranean coastal regions, except for the arid southeast.
- Csb (temperate with dry or temperate summer), covering most of the northwestern peninsula and many mountainous areas of the interior.
- Cfa (temperate with a dry season and hot summer): this is seen mainly in the northeast of the Peninsula, in zones of moderate altitude surrounding the Pyrenees and the Iberian System.
- Cfb (temperate with a dry season and temperate summer) located in the Cantabrian region, in the Iberian System, part of the northern plateau and much of the Pyrenees.
- Dsb (cold with temperate and dry summer) and Dsc (cold with dry and fresh summer) that are located in small high mountain areas of the Cantabrian Mountains, Iberian and Central systems and Sierra Nevada.
- Dfb (cold without dry season and temperate summer) and Dfc (cold with a dry season and fresh summer) located in areas of high Pyrenees and some small high mountain areas of the Cantabrian Mountains and the Iberian System.
- Even ET (tundra) is present only in small areas in the high mountains of the Central Pyrenees, coinciding with the highest altitudes of the ridges.

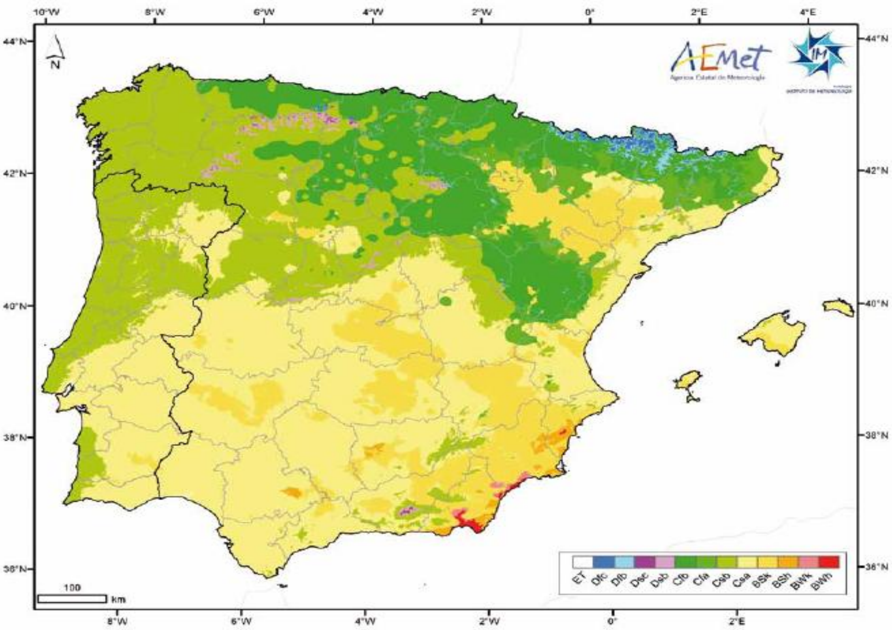


Figure 1: Map of Köppen-Geiger classification for the Iberian Peninsula and the Balearic Islands. Source: AEMET.

As seen in figure 1, the diversity in climatology of the region makes it interesting to see what part of this complexity can be effectively captured by the database. In the classification we are pursuing we expect to find the main thermo-pluviometric characteristics of the different classes of behaviors that cover large subdomains of the territory, although it will be difficult to distinguish between all these climatic subtypes.

## 2.2. SPAIN02 Database

Spain02 (version 2.0) is a series of high-resolution daily precipitation and maximum and minimum temperature gridded data sets developed for peninsular Spain and the Balearic islands. A dense network of ~2500 quality controlled stations (~250 for temperatures) for the period 1950-2007 was selected from the Spanish Meteorological Agency (AEMET) in order to build the gridded products for version 2.0 (0.2º resolution regular grid).

The variables provided are: precipitation amount in units of kg/m² (i.e. mm), maximum surface air temperature in units of Celsius degrees and minimum surface air temperature in units of Celsius degrees. These variables have a daily frequency. Daily precipitation records (and the resulting gridded values) for any given day n correspond to the precipitation registered between 0700UTC of day n and 0700UTC of day n+1 (see http://www.meteo.unican.es/es/datasets/spain02).

In this work, Spain02 was used to extract the necessary data to make the thermo-pluviometric analysis of the region, to search changes in the climate between 1958-1982 and 1983-2007, and to study the extreme events.

Spain 02 database comprises the period from January 1950 to March 2008. When analysed carefully, we observed that in the first few years there have been some values outside the expected range, probably as a consequence of the lack of quality data. Therefore some years from the initial period have not been considered (the first 7 years for the characterization and search of changes, and the first 10 for the study of extremes). Finally, 2008 has not been considered because we wanted to work with complete years.

### 2.3. Characterization

For the thermo-pluviometric characterization we have focused on the period between 1958 and 2007. This period of 50 years should allow us to extract climatic conclusions.

All the products that are calculated have been generated with programs specifically created for this task, using the programming language *C*. All these programs have the same structure. Initially, the data is read from Spain02 files in text format (.*tx*t). Next, the relevant products are calculated. And finally, the programs sort the result in the correct format so that it can be read with the graphical representation program called *Surfer*. With *Surfer* I have generated all the figures to summarize the results in the form of maps.

The products generated are many and varied. They intend to represent the variability of the system, as faithfully as possible. The products are grouped, for clarity, by the primitive variables (both daily temperatures and the daily precipitation) used to calculate them, because these have been considered separately in each case.

For the maximum daily temperature, the average has been calculated considering every day of the year, and also taking into account only the days for each season. The seasons are defined as follows to simplify calculations: winter includes the months of January, February and March, spring includes the months of April, May and June, summer includes July, August and September and autumn includes October, November and December. For the maximum daily temperature, in addition to annual and seasonal averages, we calculated both the average number of days per year that 30 degrees Celsius are exceeded and the average length (in days) of consecutive periods in which the daily maximum temperature exceeds 30 degrees.

For the daily minimum temperature, I have also calculated the averages considering every day of the year, and taking into account the seasons separately. In addition, it has been calculated the average number of days (per year) in which the minimum temperatures do not exceed 0 degrees and 3 degrees Celsius. Besides, I have calculated the average length (in days) of consecutive periods in which the minimum temperatures lie below 0 and 3 degrees Celsius.

For the daily precipitation, I have calculated the average daily precipitation and the mean for each season. In addition, calculating the average rainfall of rainy days, taking into account only those days (annually or seasonally) when it rains has been considered of interest. Another product generated was the number of days, during the study period, in which 100 and 200 mm of rain were surpassed. Again, it has been calculated for the entire year and for each season separately.

I also calculated the number of rainy days per year, and the number of rainy days in each season. Similarly I calculated the number of days per year without rain, and the number of days when it didn't rain for each season. And finally, other products that have been considered enlightening are: the average length (in days) in a row of rainy days (and also for dry periods) per year, and considering the seasons separately. I will refer to these products as mean duration of wet and dry episodes, respectively, to simplify in the following sections.

Below a summary table with the products [units] generated in this section for each variable is shown.

| Maximum daily temperature. | Minimum daily temperature. | Daily precipitation. | | |
|---|---|---|---|---|
| The average of maximum daily temperature.[Celsius Degrees] | The average of minimum daily temperature. [Celsius Degrees] | The average daily precipitation.[mm] | Number the days during the study period that it rains more than 100mm and 200mm. [days] | The average length of wet episodes for winter, spring, summer and autumn. [days] |
| The average of maximum daily temperature for winter, spring, summer and autumn. [Celsius Degrees] | The average of minimum daily temperature for winter, spring, summer and autumn. [Celsius Degrees] | The average daily precipitation for winter, spring, summer and autumn. [mm] | Number the days during the study period that rains more than100mm and 200mm for winter, spring, summer and autumn. [days] | The average length of dry episodes for winter, spring, summer and autumn. [days] |
| The days that 30 degrees Celsius is exceeded: the average number of days per year. [days] | The days that the minimum temperature is not exceeded 0 and 3 degrees: the average number of days per year. [days] | The average daily precipitation of rainy days. [days] | The number of days per year of rain for winter, spring, summer and autumn. [days] | |
| The days that 30 degrees Celsius is exceeded: the average length of consecutive days. [days] | The days that the minimum temperature is not exceeded 0 and 3degrees: the average length of consecutive days. [days] | The average daily precipitation of rainy days for winter, spring, summer and autumn. [days] | The number days per year without rain for winter, spring, summer and autumn. [days] | |

Table 1: Summary of products generated for the characterization section.

## 2.4. Search for evidence of climate change.

In this section the objective was to detect changes between two recent periods. In order to do this we have divided the period used for the characterization into two sub-periods. The first one covers from 1958 to 1982 and the second from 1983-2007. The aim is to detect statistically significant changes. These changes are calculated for the same products listed in the previous section.

As in the case of the global characterization, specific programs for each product analysis using the programming language C have been created. All these programs have the same structure. First, they read the data of the variables for the first set of 25 years and calculated the relevant result. Then, they read the data of the variables for the following 25 years and recalculate the results. Next, they calculate the difference between the results of the second and first periods. Thus we obtain the change in the climatic index between the two studied periods. The next step consists in calculating the statistical significance of the change found. This calculation is performed by means of the comparison of the average test. Finally the results are arranged so that they can be represented in the form of spatial maps with Surfer.

The test of average comparison is a statistical test that can be performed to assess if differences exist between two given periods. The analysis consists in applying the following formula:

$$C = \frac{|M_2 - M_1|}{\sqrt{{\sigma_2}^2/n_2 + {\sigma_1}^2/n_1}}$$

where C is the parameter which is to be determined. $M_1$ is the result for the average of the variable in period 1, $\sigma_1^2$ is the variance of this average and $n_1$ is the number of elements in the series for period 1. $M_2$ is the result for the average in period 2, $\sigma_2^2$ is the variance of this average and $n_2$ is the number of elements included in the series for the period 2.

A significance level of 90% was chosen for this work. If the parameter C is lower than 1.645, the two averages will be similar to a significance level of 0.1. In these circumstances, it is considered that the two values are similar and there has been no change between the two periods. Otherwise, if C is greater than or equal to 1.645, the two averages will be different at that level of significance, and so it will mean a real change in the results for the two periods studied.

Keep in mind that this test of significance cannot be applied to all products. For products which consist of a simple average, as is the case of number of days per year (or per period), it does not make sense to apply this test. For them the change was calculated, that is to say, the difference between the result of the period 2 and the result of period 1, and represented without the consideration of the statistical significance.

In the results section, figures summarizing evidence of climate change will only represent values of change that are statistically significant according to the applied test and criteria. The results that are not significant at the 0.1 level will be considered nulls. When the test has not been applied owing to the nature of the climatic product, all the changes will be represented.

Below there is a summary table with the products [units] generated for each variable is shown in this section.

| Maximum daily temperature. | Minimum daily temperature. | Daily precipitation. | |
|---|---|---|---|
| Change between the average of maximum daily temperature. [Celsius Degrees] | Change between the average of minimum daily temperature. [Celsius Degrees] | Change between the average daily precipitation for winter, spring, summer and autumn. [mm] | Change between the number of days per year without rain for winter, spring, summer and autumn. ** [days] |
| Change between the average of maximum daily temperature for winter, spring, summer and autumn. [Celsius Degrees] | Change between the average of minimum daily temperature for winter, spring, summer and autumn. [Celsius Degrees] | Change between the average daily precipitation of rainy days. [mm] | Change between the average length of wet episodes for winter, spring, summer and autumn. [days] |
| Change between the days that 30 degrees Celsius is exceeded. The average number of days per year**. [days] | Change between the days that the minimum temperature does is not exceeded 0 and 3 degrees. The average number of days per year. **[days] | Change between the number of days during the study period that rains more than 100mm and 200mm. ** [days] | Change between the average length of dry episodes for winter, spring, summer and autumn. [days] |
| Change between the days that 30 degrees Celsius is exceeded. The average length of consecutive days. [days] | Change between the days that the minimum temperature does is not exceeded 0 and 3 degrees. The average length of consecutive days. [days] | Change between the number of days per year of rain for winter, spring, summer and autumn. ** [days] | |

Table 2: Summary of products generated to search for evidence of the climate change section. The products in which significance tests have not been applied are marked with **.

## 2.5. Calculation of return periods.

The aim of the characterization for the extremes of the series is to develop maps of return periods. The return period is the expected time, or average time, between the occurrence of two events of low probability. Therefore, these maps of return periods consist of a graphical representation of these occurrences of low probability but with high impact on society. Having this type of information at hand is of great interest, as it allows exploring those parts of the region more exposed to this type of phenomena.

In this paper, these calculations were performed with *R*. *R* is a programming language and software development environment for performing calculations and statistical graphics. Of the many libraries that are available for *R*, one has been used for the work with extremes: *extRemes*. For this library *extremes.gui*, a graphical interface that facilitates the use of the package, is available.

One option that allows us to use this environment to calculate the probability of occurrence of extreme events is the Generalized Pareto Distributions. This family of distributions is the one that was the most suitable to our case.

All the results of the **Generalized Pareto Distributions** are contained in the following theorem.

Let $X_1$ , $X_2$ , .... be a sequence of independent random variables with common distribution F, and let $M_n = max\{X_1, X_2, \dots, X_n\}$. Denote an arbitrary term in the Xi sequence by X, and suppose that F is a member of the GEV(Generalized Extreme Value distribution) family :

$$G(z) = e^{\left\{-\left[1+\xi\left(\frac{z-\mu}{\sigma}\right)^{-1/\xi}\right]\right\}}$$

defined on $\left\{z: 1 + \frac{\xi(z-\mu)}{\sigma} > 0\right\}$, where $-\infty < \mu < \infty$ , $\sigma > 0$ and $-\infty < \xi < \infty$ .

So if G(z) is a GEV that, for large n, $\Pr\{(Mz \leq z)\} \approx G(z)$, where $G(z) = e^{\left\{-\left[1+\xi\left(\frac{z-\mu}{\sigma}\right)^{-1/\xi}\right]\right\}}$ for some μ, σ>0 and ξ. Then, for large enough u, the distribution function of (X-u), conditional on X>u, is appropriately described by

$$H(y) = 1 - \left(1 + \frac{\xi\, y}{\tau}\right)^{-1/\xi}$$

defined on {y: y>0 and ( 1 + ξ y / τ )>0}, where τ = σ + ξ (u- μ).

This theorem implies that, if block maxima have approximating distribution G, then threshold excesses have a corresponding approximate distribution within the generalized Pareto family. Moreover, the parameters of the generalized Pareto distribution of threshold excesses are uniquely determined by those of the associated

GEV distribution of block maxima. In particular, the parameter ξ is equal to that of corresponding GEV distribution. Choosing a different, but still large, block size n would affect the values of the GEV parameters, but not those of the corresponding generalized Pareto distribution of threshold excesses: ξ is invariant to block size, while the calculation of τ is unperturbed by the changes in μ and σ which are self-compensating **(**Coles, Stuart, et al 2001**).**

This calculation is applied to daily maximum temperature, daily minimum temperature and daily precipitation for the period between 1960 and 2007. The Generalized Pareto Distributions gives us the probability of occurrence, which is simply the inverse of the return period.

The calculation of the probability using Generalized Pareto Distributions is only applicable, according to theory, for the maximum values of the series. Thus it can be applied directly to the maximum temperature and precipitation. In the case of the minimum temperature I must introduce a sign change in the initial data, so that the upper extremes of the new series correspond now to the lowest temperatures.

On the other hand, the threshold used to adjust the GPD to the tail of the series was set at 90th percentile for the maximum and minimum daily temperature, and the daily precipitation. This threshold means that only values above this threshold will be used and fitted to the GPD.

Below is a summary table with the products[units] generated in this section for each variable is shown.

| Maximum daily temperature. | Minimum daily temperature. | Daily precipitation. | |
|---|---|---|---|
| Return periods corresponding to 30ºC. | Return periods corresponding to -5ºC. | Return periods corresponding to 100mm. | Return periods corresponding to 200mm. |
| Return periods corresponding to 35 ºC. | Return periods corresponding to -10ºC. | Return periods corresponding to 300mm. | Return periods corresponding to 400mm. |
| Return periods corresponding to 40 ºC. | Return periods corresponding to -15ºC. | Return periods corresponding to 500mm. | Return periods corresponding to 600mm. |
| Return periods corresponding to 45 ºC. | Return periods corresponding to -20ºC. | | |

Table 3: Summary of products generated for the return periods section

# 3. RESULTS

In this section the most relevant results obtained are shown. The results shown below are represented geographically for a better understanding. Thus, we have a spatial distribution of each product.

## 3.1. CHARACTERIZATION.

This section was intended to make a thermo-pluviometric climatic characterization in Peninsular Spain and the Balearic Islands. To achieve our goal, the results obtained for the various products of daily maximum and minimum temperature and precipitation are discussed.

### 3.1.1. Maximum daily temperature.

The representation of the average to maximum daily temperature lets you see the warmest and the coldest places in the region.

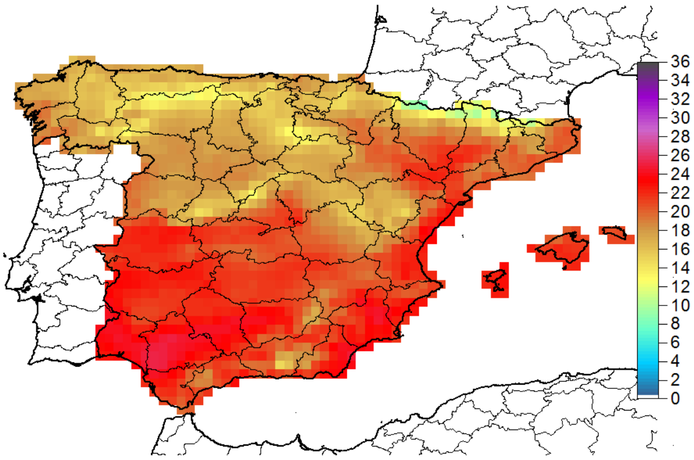


Figure 2: The average of maximum daily temperature(in ºC).

Figure 2 shows that a marked north-south gradient is patent. Approximately, we find the highest maximum temperatures from the south of Madrid downwards, with the exception of mountain areas. The whole of the Atlantic coast and the northern Peninsula have more moderate temperatures in general. The lowest maximum temperatures are obtained in the high mountain areas of the Pyrenees. Note that the temperatures in the Ebro Valley are higher than those of its surroundings.

Then, this same product is displayed separately for each season. The mean annual values could soften the behavior of this variable to a large extent. A seasonal representation allows us to see the characteristics of each season.

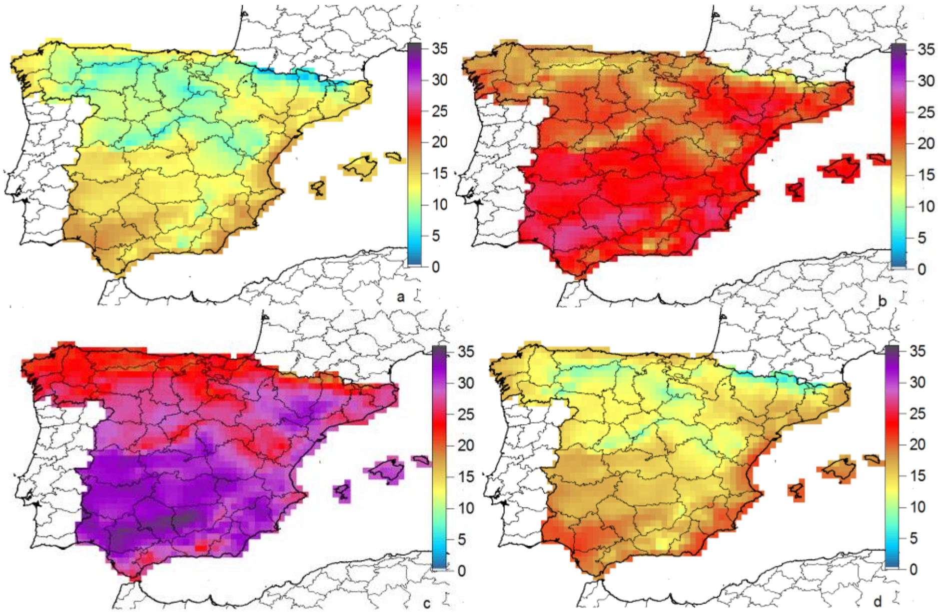

Figure 3: The average of maximum daily temperature(in ºC) for winter(a), spring(b), summer(c) and autumn(d).

The first thing we notice is a marked seasonality in the daily maximum temperature. This result is typical of the tropics where the 4 seasons are very distinct. We see that the north-south gradient is maintained in all seasons. The Mediterranean coast has a very warm summer and mild winter. The Atlantic coast, conversely, has both a mild summer and a winter. We can see that the central plateau, with the Pyrenees, is one of the places where maximum temperatures remain lower throughout the year. The depression of the Guadalquivir is where the highest maximum temperatures are recorded throughout the year. It can also be noted that the east coast of the peninsula, along with the island of Ibiza and the Guadalquivir depression, is where the highest maximum temperatures are recorded in autumn.

Figure 4 shows the distribution and the characteristics of the episodes of intense heat. This type of product allows us to see the areas which are most affected by these high temperatures.

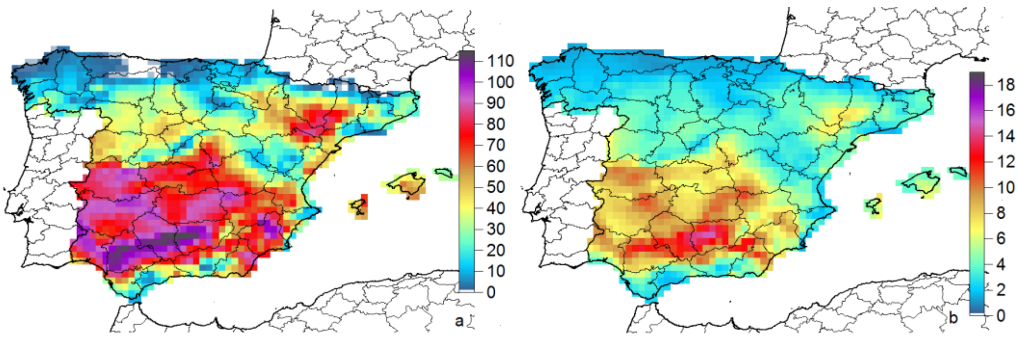

Figure 4: The days that 30 degrees Celsius is exceeded: (a) the average number of days per year; (b) The average length of consecutive days.

In Figure 4 (a) we can observe that the depression of the Guadalquivir has almost a third of the days each year with a temperature above 30 degrees. In the more central parts of this region, in Jaén, these episodes over 30 graphs are given on average about 18 consecutive days. The people of this region, and generally the whole of the southern part of the peninsula, with the exception of the coast, are severely affected by these days with maximum temperatures above 30 degrees.

In contrast, the Atlantic coast and the Pyrenees have very few days a year over 30 degrees of maximum; in some places, none. And these days only occur one at a time.

Balearic Islands and the Ebro basin have an intermediate situation. These areas have a temperature above 30 degrees Celsius between 60 and 80 days per year, but these episodes do not last longer than a week in a row on average.

### 3.1.2. Minimum daily temperature.

The mean of the daily minimum temperature allows us to see the places most affected by cold temperatures, where the best conditions for frost or snow are found. This average distribution generally lets us identify areas in the region under study with a cold climate throughout the year, with cold winters and mild summers. It also allows us to distinguish those areas ones that have a warmer climate with warm summers and mild winters.

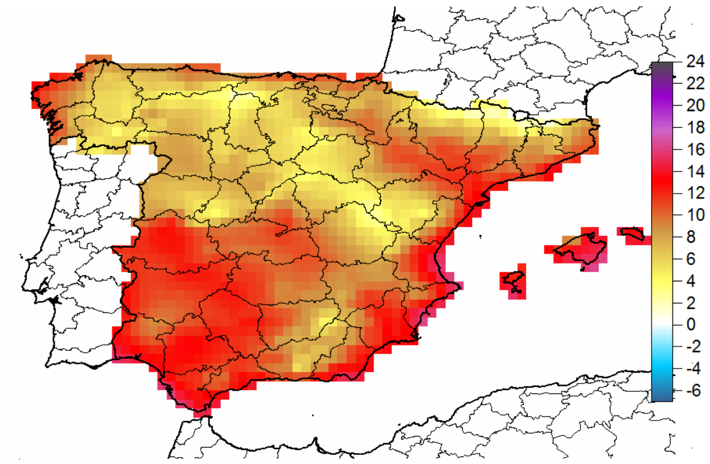


Figure 5: The average of minimum daily temperature(in ºC).

If we look at Figure 5, the annual average allows us to identify two major areas. The Northern Peninsula and Betic System have lower minimum temperatures than the other regions. The southern half of the peninsula, however, displays higher minimum temperatures. It is also remarkable that some points on the coast, including those in the north, have temperatures above those around them.

This effect of the coast, due to the proximity to the sea, softens winters. The proximity to the sea causes more stable minimum temperatures preventing frost and extreme low minimum temperatures.

It is interesting to examine, again, the average by season as it provides us with a larger amount of information.

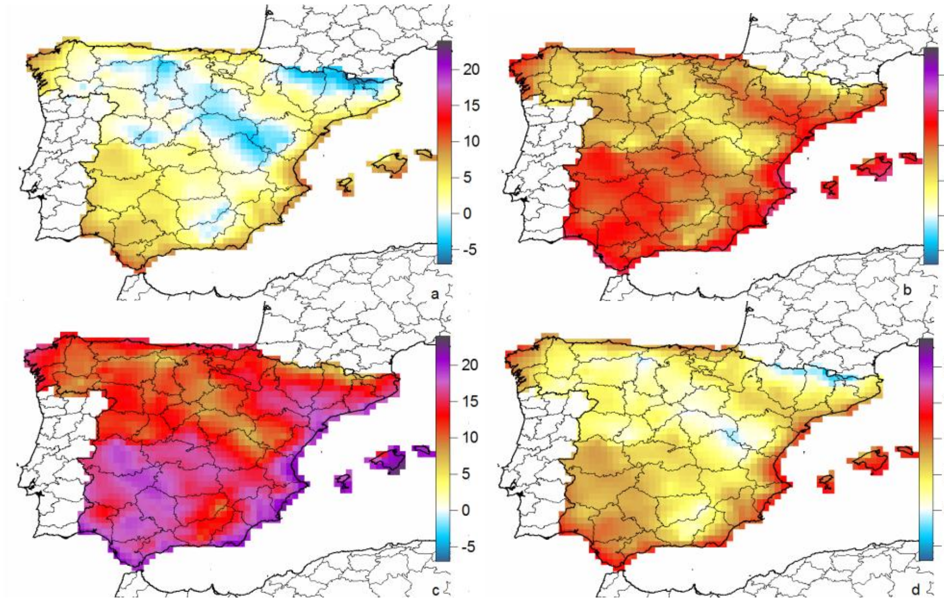
Figure 6: The average of minimum daily temperature(in ºC) for winter(a), spring(b), summer(c) and autumn(d).

In Figure 6 we can see that the cooler areas during all seasons coincide with those of the annual average.

The areas with the highest minimum temperatures generally coincide with those with the highest maximum temperatures (see figure 3). We can see that while in almost the entire peninsula, the spring is warmer than the autumn; this is not the case for the Balearics. In the Balearic Islands, the minimum temperature is very similar during spring and autumn.

One of the consequences of climate change that is expected to affect the region under study is the decrease in the number of frost days. It is therefore interesting to identify areas of the region where this phenomenon occurs. Very low minimum temperatures are essential for this phenomenon to occur. In order to identify these locations, Figure 7 shows the distribution of the episodes of extremely cold days, compared to low temperatures. Although the product was generated to 3 and 0 ° C, only the product for 0 ° C is shown because both essentially display the same distribution. You can see the results for 3 º C in the appendix.

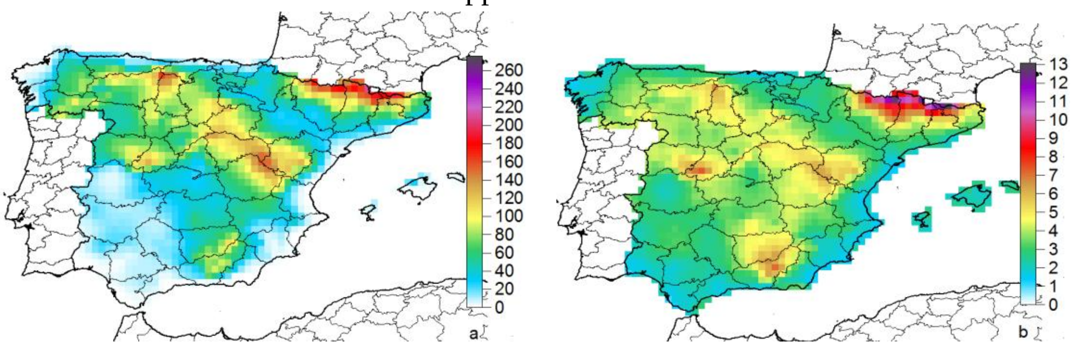
Figure 7: The days that the minimum temperature is not exceeded 0 degrees: (a) the average number of days per year; (b) the average length of consecutive days.

The days with a minimum below zero are found in points of high altitudes and they are mostly concentrated in the Pyrenees. Also in the Pyrenees it is where more days with these features occur in a row. Note that, in coastal areas and in Extremadura and the valley of the Guadalquivir, between 0 and 10 days per year with minimum temperatures below 0 º C are occurring. These days with temperatures below 0º C take place one at a time, or two consecutive ones. These places have very mild winters with little frost and snow, which do not last for long.

### 3.1.3. Precipitation.

Along with temperatures, precipitation determines the type of vegetation in a region. It is a very important resource for society and a change in its distribution due to climate change is anticipated. In order to examine the effect of this change in the different environments of the area under study it is important to study its distribution.

A product to highlight is the daily average rainfall in each season, which are represented in Figure 8.

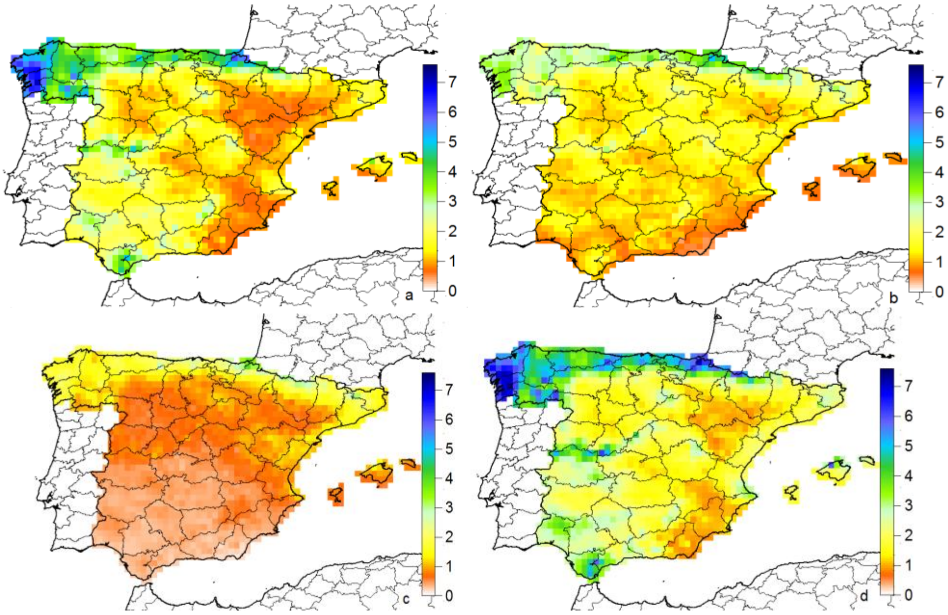

Figure 8: The average daily precipitation(in mm) for winter(a), spring(b), summer(c) and autumn(d).

The regions with more precipitation are consistent throughout the year: the Atlantic coast and Galicia. Some places like the east coast of the Peninsula, the Sierra de Tramuntana in Mallorca, Cadiz and the Central system, among others, have more precipitation than their surrounding areas. The annual average of daily rainfall is not shown in this section since it essentially behaves as in autumn, the season dominating the average (see the appendix).

Another interesting product of this variable is the average of precipitation for rainy days. This product lets us know the kind of rain that a region has. It is this feature of the precipitation that determines whether it is possible to take advantage of the resource.

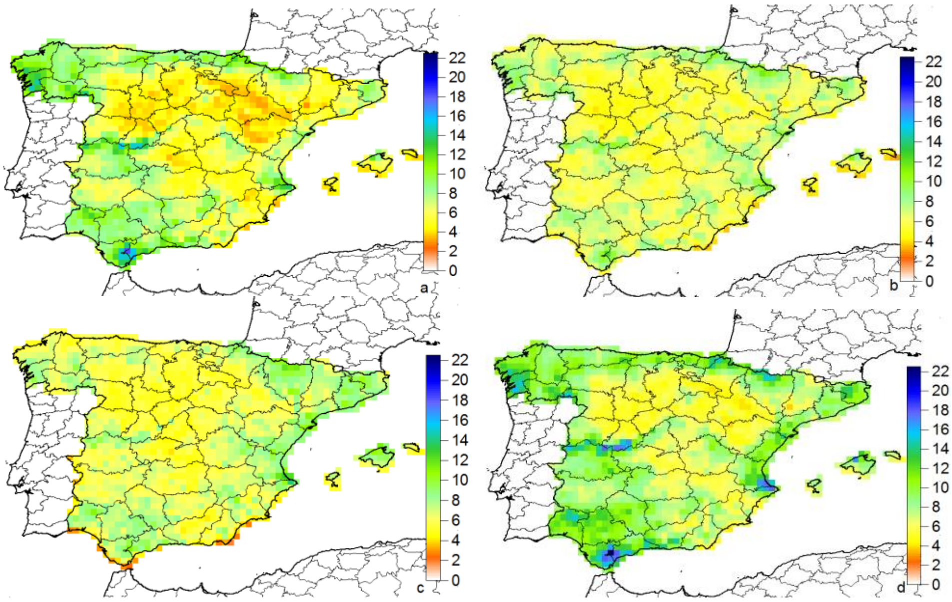

Figure 9: The average daily precipitation(in mm) of rainy days for winter(a), spring(b), summer(c) and autumn(d).

Figure 9 shows that the places where it rains more on average (Figure 8) and those where it rains more on rainy days do not match. Galicia and Cantabria’s mountain ranges, which hold the highest amount of average daily rainfall and have intermediate and low values of average rain on rainy days. This indicates that even if it rains for many days, the precipitation is small each day. Places like Cadiz and the Sierra de Aitana have the highest torrential rain. Torrential rain is one of the main characteristics of the Mediterranean climate. This consists of a few rain events with very high intensity, mostly concentrated in autumn, although some also take place in winter. The Sierra de Tramuntana also presents these heavy events. The average daily precipitation of days of annual rainfall is not shown in this section as it essentially behaves as in autumn, the season that dominates the average again. The corresponding map can be seen in the appendix.

A very interesting product that can be calculated is the number of days that have reached very high precipitation values. Such events can cause damage and high economic losses. Interestingly, in the 50 years studied here, we can analyze how many times these events have taken place and where they have occurred. The distribution of these events will provide information about the type of regional weather and vulnerability to large floods or flash floods.

The values of precipitation chosen are 100 and 200 mm. Figure 10 displays the number of days, in the 50 years under study, in which there has been a rain event equal to or greater than 100 and 200 mm, respectively.

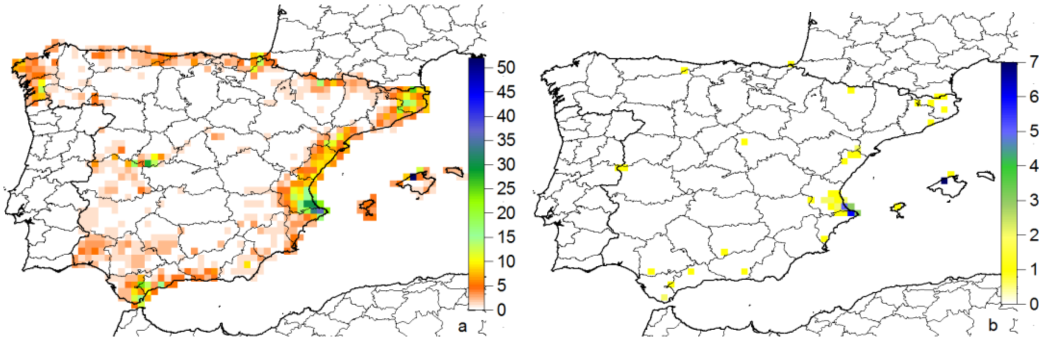


Figure 10: Number of days during the period under study that it rains more than (a) 100mm and (b) 200mm.

Figure 10 shows that, as expected, episodes of 100 mm are much more abundant than those of 200 mm, in the order of 7 times more abundant. Another noticeable feature is that both events of 100 mm and 200mm are mostly found on the coast and a few in the central system.

The Valencian and Catalan coast, along with the Balearic Islands, hold a large concentration of events of 100mm and also a large amount of events of 200mm. On the other hand, Malaga and Cadiz, which have a high density of 100mm events, have no 200 mm events. The 200 mm events are more scattered in the Penibetic System than the 100mm events.

The Pyrenees also have 100mm events, but the 200mm events in that area have only occurred in the area of Girona, heavily influenced by the Tramuntana (name given to the area for the strong winds from the north).

The two most prominent areas are consistent in both maps: the Sierra de Aitana in Alicante and the Tramuntana mountain range in Mallorca. The point with the highest number of 200mm events listed in Mallorca, in the Sierra de Tramuntana, coinciding with one of the places with the highest daily rainfall in the region under study.

As in the previous cases, the seasonality of these events is interesting to examine.

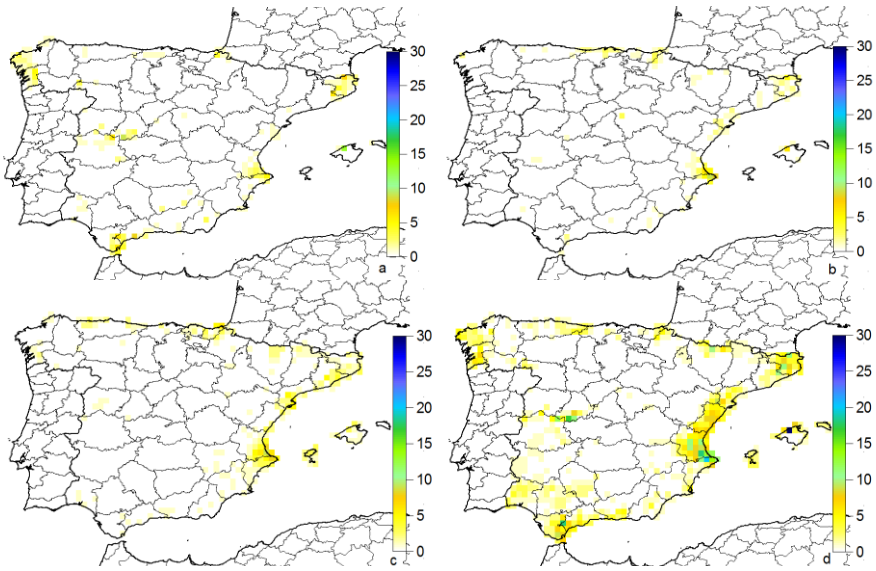


Figure 11: Number of days during the study period that it rains more than100mm for winter(a), spring(b), summer(c) and autumn(d).

It is easily seen that the season that dominates this product is autumn. The distribution of events in autumn is almost the same as the annual distribution. For winter, spring and summer, the locations with the largest number of events are the same again, although these were produced significantly less often. Just note that in winter and autumn events occur in Galicia, in the provinces of La Coruña and Pontevedra, which do not appear in summer or spring.

For events of more than 200mm (shown in the appendix), most of them occur in autumn, especially in areas with a Mediterranean climate. This distribution demonstrates the typical feature of Mediterranean torrential rainfall. It occurs mostly in summer in the Sierra de Aitana. In winter, we can highlight the central part of the Sierra de Tamuntana, Mallorca as an important point displaying these events. In spring, there has practically been no event of this magnitude.

The number of rainy days per year is a result which, again, allows us to see how precipitation in the region under study is distributed.

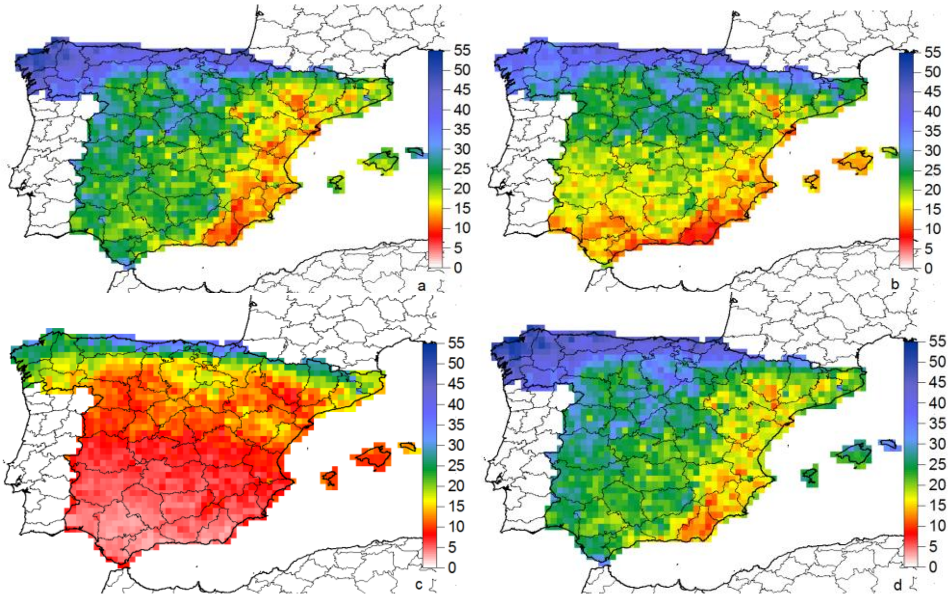


Figure 12: The number of days per year of rain for winter(a), spring(b), summer(c) and autumn(d).

In Figure 12, a clear difference in the precipitation regime shows. Whereas on the Atlantic coast and the Pyrenees rain happens repeatedly and constant during all seasons, in the rest of the peninsula there is a large difference in the number of rainy days between seasons.

Areas with less rainy days are the Mediterranean coast of the peninsula and the Ebro Valley. In these areas it rains for less days than it its surroundings, in all seasons. In summer very few rainy days are found. Andalucía is worth mentioning for having some points with an average of rainy days close to zero during the summer.

The figures corresponding to the number of days a year that it does not rain are complementary to those of days a year that it rains. These figures are available in the appendix and show exactly the same information as Figure 12.

To complement Figure 12, we want to observe these rainy days in a row: we want to see if they occur and, when they occur, how long these periods are.

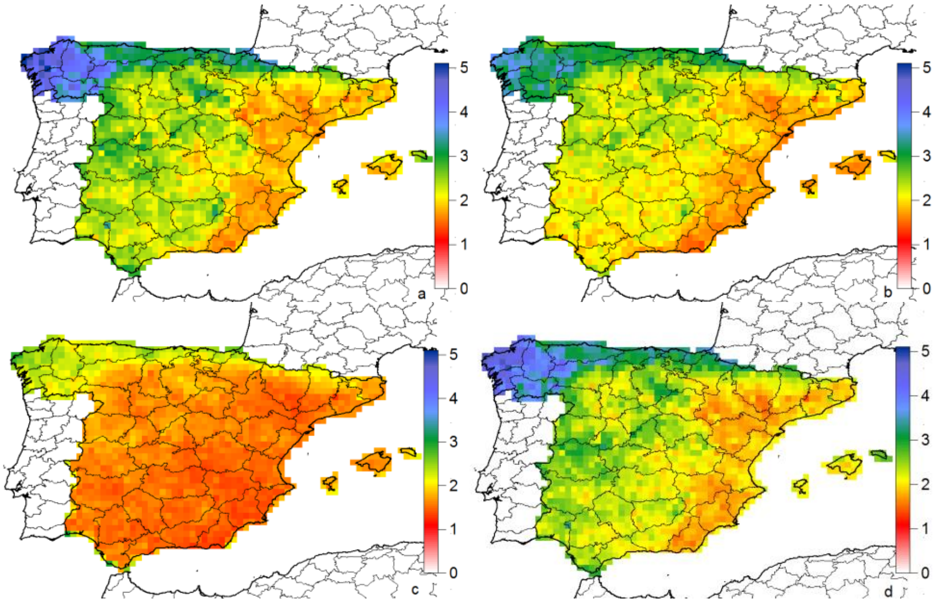


Figure 13: The average length of wet episodes for winter(a), spring(b), summer(c) and autumn(d).

The duration of consecutive days with precipitation is shorter in summer. In the east of the Peninsula and the Balearics, these episodes last less than in the rest of the country for all seasons. On the other hand, the sequences of consecutive rainy days are longer in Galicia and the Atlantic coast in all seasons.

In order to complement this, the average length of days without rain is interesting to analyze. This product can determine such important things as the viability of certain crops or the forest type because the duration of periods without rain may determine the type of vegetation that can survive.

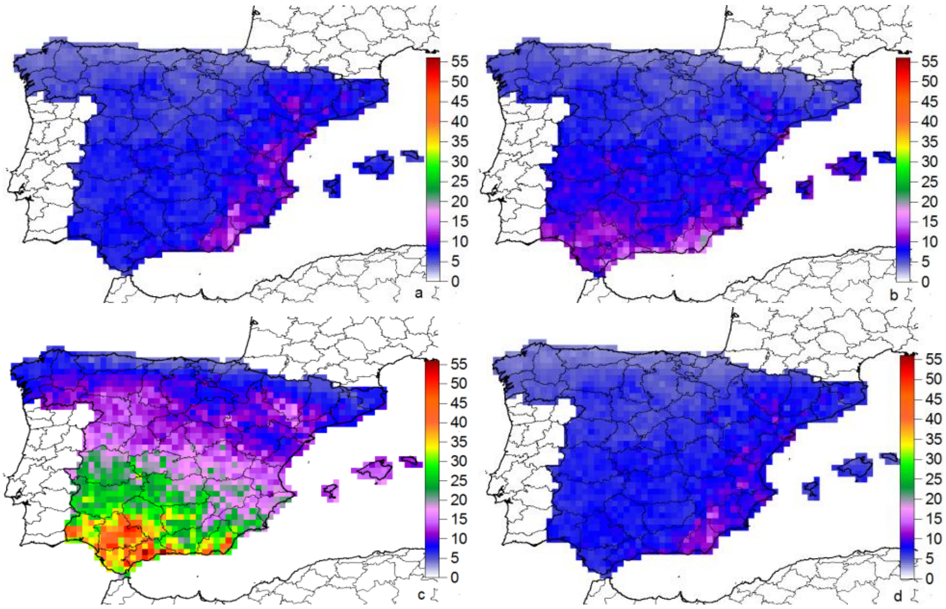


Figure 14: The average length of dry episodes for winter(a), spring(b), summer(c) and autumn(d).

Figure 14 shows that the gusts of dry days last up to 10 days for the entire Peninsula, except in summer. In summer we see a very different distribution. In the southern part of the Peninsula, in Andalusia, many days in a row without rain are found. In some places this average reaches up to 55 days. This result clearly shows that the depression of the Guadalquivir and its surroundings has much less precipitation in summer than the rest of the region under study.

## 3.2. SEARCH FOR EVIDENCE OF CLIMATE CHANGE.

We should bear in mind that, for the period between 1958 and 2007, two equal periods of 25 years are defined. The first period extends from 1958 to 1982 whereas the second period extends from 1983 to 2007. Variables of interest for these two periods have been calculated. In the figures the difference between periods (i.e. the second period minus the first period) are represented. This representation helps us to assess changes over time with respect to the variables. Furthermore, for results where it makes sense, a test of significance on the mean with a significance of 90% has been run. For these results, only differences which are statistically significant are shown.

### 3.2.1. Maximum daily temperature.

One of the effects of climate change that has already been experimentally measured is the warming of the atmosphere and the sea. It is interesting to see if that actually happens to the temperature in the region under study.

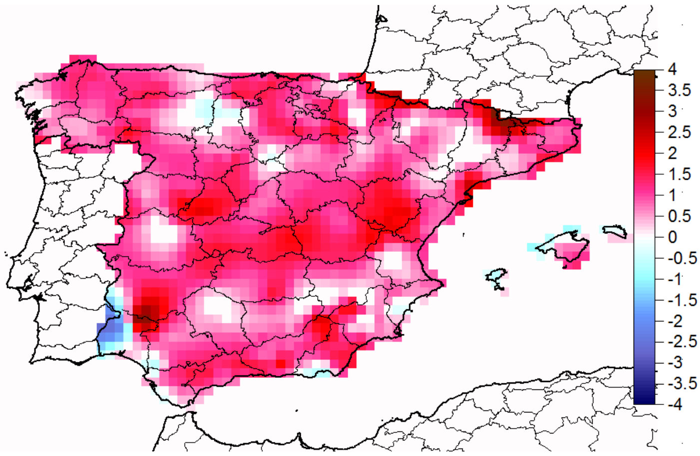


Figure 15: Change between the average of maximum daily temperature(in ºC), with a significance of 90%.

In Figure 15, where significant changes in the daily maximum temperature are represented, an increase in temperature is observed in virtually the entire region and some small cooling zones appear. Some of these cooling zones have a strange distribution. In the case of the region near the south of Portugal they are not believable to be true although they are statistically significant. This cooling may be due to a problem in defining the environs of the database, because the orography is not the reason to explain this effect. We should keep in mind that the database is a product, not actual measurements, so it may be defective and this looks like one of their defects. The other points of cooling may show a reality because the difference is one of very few degrees and the points are located near the sea, which makes it feasible. Cooling also appears off the coast, in Leon, coinciding with a portion of the Cantabrian mountain range, but is very little intensity.

Once this change is seen in the daily average over the year, we could ask what happens in every season, whether the results are equally significant and whether the direction of change is the same throughout the year.

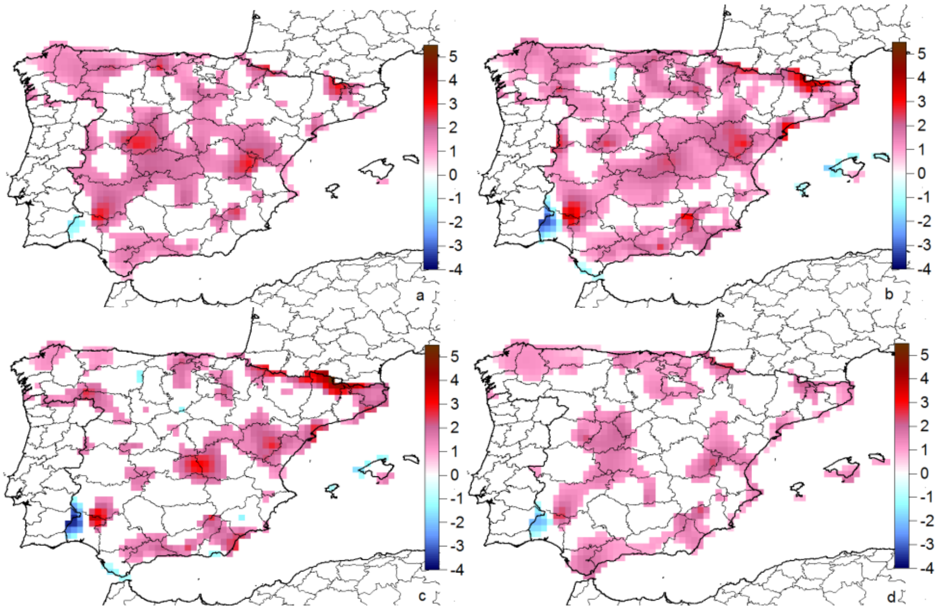

Figure 16: Change between the average of maximum daily temperature(in ºC) for winter(a), spring(b), summer(c) and autumn(d) , with a significance of 90%.

In Figure 16 we can see that the change is not equally significant for each season. However, the direction of change is the same. In winter and spring is when most part of the region has experienced a significant increase in the maximum temperatures. In summer the warming has been less significant, but places like the Pyrenees and the southern plateau have had a strong average warming of maximum temperatures of up to 5 degrees. In autumn, a significant warming is found in some areas but it only consists of 1 degree on average.

The anomaly that has been detected in southern Portugal is consistent on all maps. This feature leads us to think that actually it is due to a defect in the database. The other two declines that were observable in Figure 15 are displayed here as well. A decrease in the daily maximum is noticeable here, in northern Balearic during spring and summer, just as seen in León. We should note that in the map for summer some pixels of decline appear for the maximum daily temperature.

Another result of the changes we expect to find is in the number of days over 30 degrees.

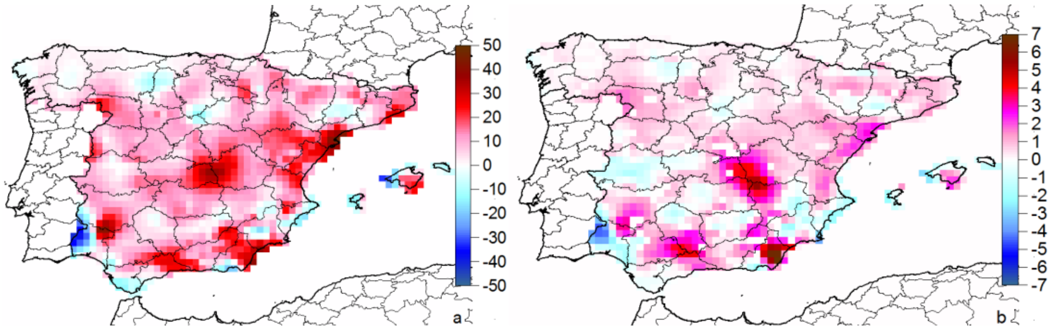

Figure 17: Change between the days that 30 degrees Celsius is exceeded: (a) the average number of days per year; (b) the average length of consecutive days, with a significance of 90%.

We can see that the number of days per year with a maximum temperature above 30 degrees has increased significantly in areas of the Mediterranean coast and south of Madrid. Conversely, it has decreased slightly in some regions. The Atlantic coast has remained unchanged. Regarding the change in the length of consecutive days with these features, there was a large significant increase in south of Madrid, coinciding with the Southern Plateau as well as in Almeria.

A reduction appears in some areas of both products but it is shorter and of less intensity than the increments. The anomaly observed in Portugal and its surroundings is found again.

### 3.2.2. Minimum daily temperature.

If there has been a warming of the atmosphere, it should be noticeable in a decrease of the minimum daily temperatures. Therefore, studying the changes in daily minimum temperatures between the two periods of study is relevant for our study.

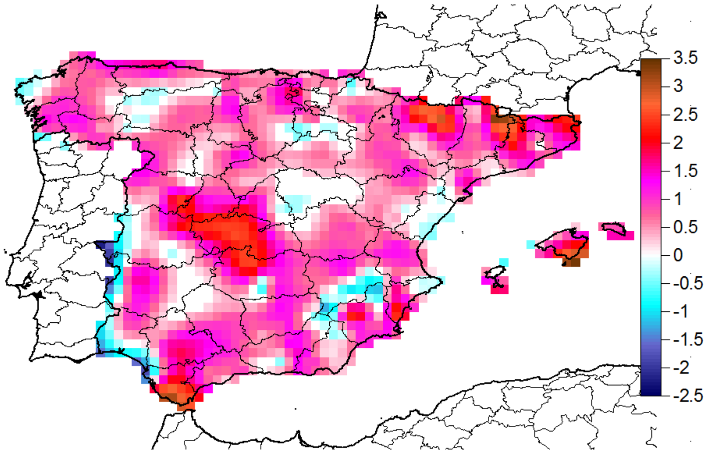

Figure 18: Change between the averages of minimum daily temperature(in ºC), with a significance of 90%.

In Figure 18 we see that the greatest changes in the minimum occur in the Pyrenees, the southern plateau, Cadiz and the Balearics. In these regions there has been an increase of up to 3 degrees of the average in the minimum throughout the year. Although there are regions where the minimum temperature has slightly decreased, the direction of change is mostly positive. I mean, there has been a significant increase in daily minimum temperatures in most of our area under study.

On the border with Portugal a problem appears, in the same way as it had been detected with the maximum. This anomaly appears in all the results for temperatures and we will therefore not comment on this issue any further.

Again, it will be interesting to check if these changes occur in the same direction during different seasons. We will also see if changes and abnormalities are equally significant across seasons.

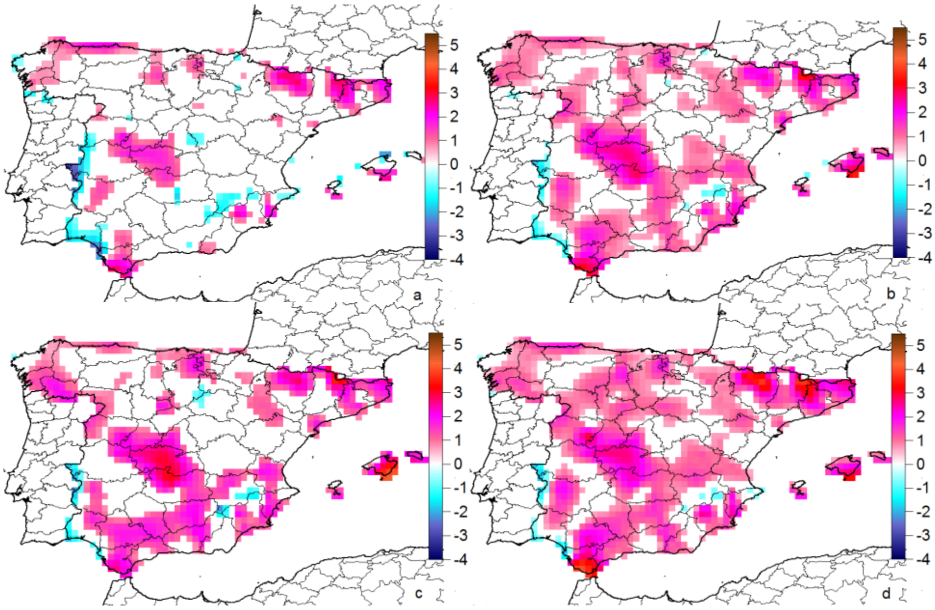


Figure 19: Change between the average of minimum daily temperature(in ºC) for winter(a), spring(b), summer(c) and autumn(d) , with a significance of 90%.

In winter, significant changes occur in significantly fewer regions. In spring and autumn, the affected region for these significant changes is quite similar, as is observable in Figure 18. In summer an intermediate situation occurs. The remarkable thing is that changes occur mostly in the same direction, towards an increase in minimum daily temperatures. The few places that experience a cooling with respect to the minimum appear in winter. We should mark the fact that in the sub-Betic mountain range a statistically significant decrease occurs in all seasons and in the annual average.

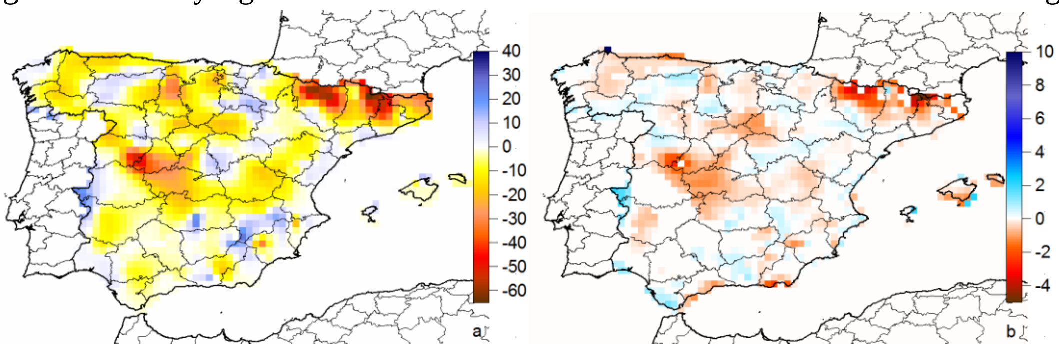


Figure 20: Change between the days that the minimum temperature does is not exceeded 0 degrees: (a) the average number of days per year; (b) the average length of consecutive days, with a significance of 90%.

Figure 20 represents the results for days with a minimum temperature below 0 degrees Celsius. We notice that the annual number of days in Figure 20 (a) most of the results have decreased. The region most affected by the reduction of days below 0 degrees is the Pyrenees. In the duration of consecutive days with a minimum below 0, the Pyrenees is the most affected region with a statistically significant decrease in most of the region they occupy, and up to 4 days in a row. An increase in the number of consecutive days is only significant for small areas and with values of 1 day.

### 3.2.3. Precipitation.

Precipitation is a meteorological variable that strongly determines the climate.

In order to check if there have been any changes in the climate of the region under study, we have to look for a statistically significant change in the results concerning this variable. Unlike for temperature, for precipitation it is not quite agreed how it would be affected by global warming. It is important to examine not only if there are any significant changes but also in which direction.

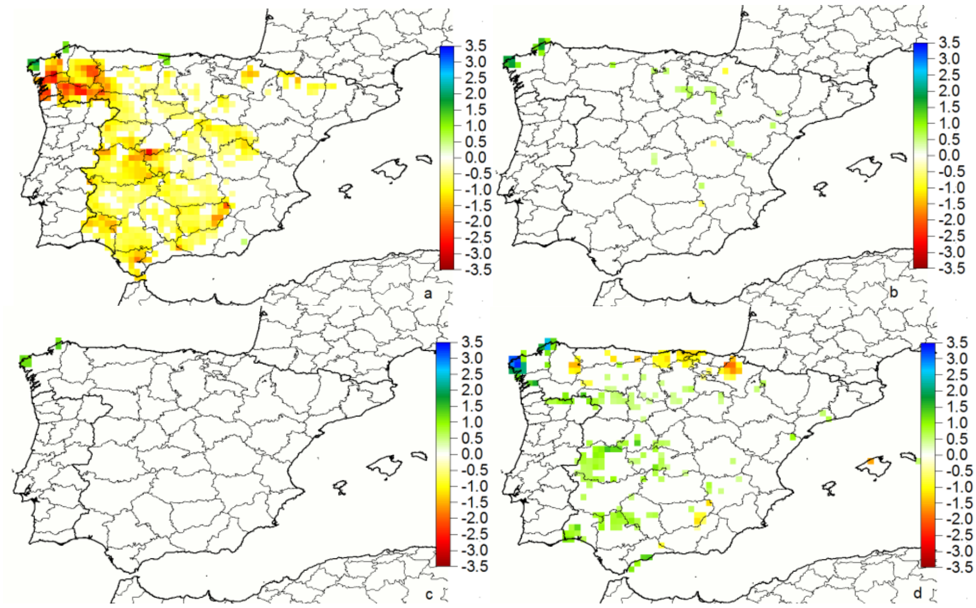


Figure 21: The change between the average daily precipitation(in mm) for winter(a), spring(b), summer(c) and autumn(d) , with a significance of 90%.

The figure above clearly shows that the changes are only significant for winter and autumn but especially in winter. We can therefore say that no change is observable in the average daily precipitation in summer or spring, except in some points of the Galician coast. The exceptions are the areas of Cape Finisterre and Ortegal, which show a significant increase in the average daily precipitation for all seasons. In winter, the statistically significant changes are found in the western half of the Peninsula. These changes imply a decrease in daily precipitation. In autumn, the changes are scattered throughout the Peninsula. In regions where the change is significant, this is an increase in precipitation. However, a decrease takes place in the Cantabrian coast.

The result corresponding to the daily average for the full year is not shown because it is dominated by winter and it is almost the same (available in the appendix). The only highlight of the results for the full year is a significant increase in the east coast that is not reflected in any of the seasons.

The change in the daily average and the average of the days when it rains does not seem to be similar. What follows is an analysis of the distribution of these results.

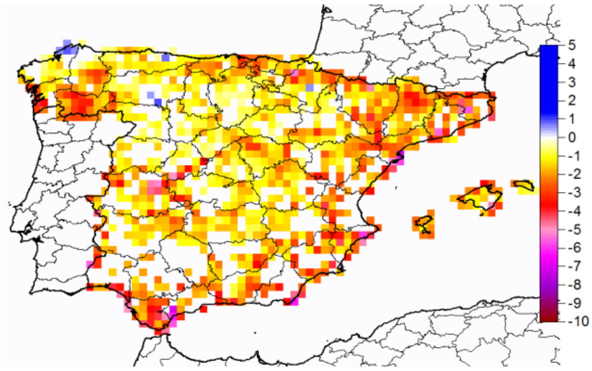


Figure 22: Change between the average daily precipitation(in mm) of rainy days, with a significance of 90%.

The first fact that stands out is that the significance of the changes is quite widespread. This is not the case when we have a look at the seasonal results. The direction of this change is always negative, except for a few scattered pixels. As for seasonal changes, they are only statistically significant for winter and autumn. Nevertheless, they are significant in a few pixels and all in a negative direction; they imply a decrease (see the appendix).

Another result that we have calculated is the difference in the number of days between two periods of 25 years, which have surpassed a daily rainfall of 100 and 200mm.

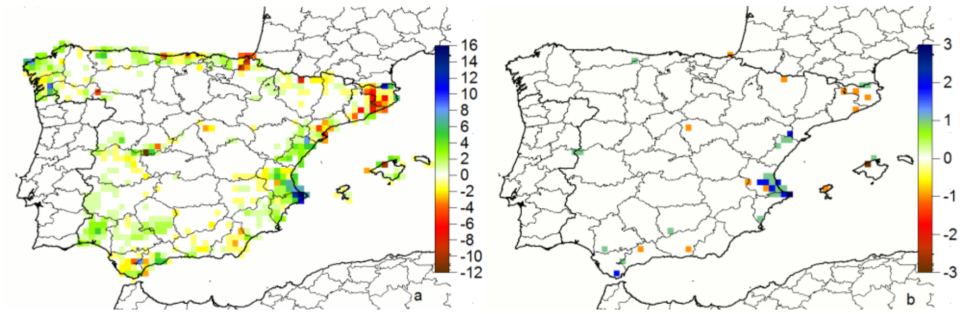


Figure 23: Change between the number the days during the study period that has rained more than (a) 100mm and (b) 200mm.

Figure 23 shows that these results show different trends of change in different regions. Recall that for these changes significance has not been calculated because they are a difference between two absolute values.

For events of more than 100mm (Figure 23 (a)), a large increase is found throughout the Valencian coast, especially in the Sierra de Aitana. This distribution is repeated for events of more than 200mm (Figure 23 (b)). In Catalonia a decrease of the two types of events can be seen. For the rest of the region under study an intermediate situation occurs, although in Galicia and western Andalusia positive changes prevail.

Seasonal maps of these variables do not provide much new information because changes take place in the same places and in the same sense as in Figure 23 (see the appendix).

The results of annual days with or without rain are complementary, so we have decided to display the map corresponding to the days when there has been rain only. The figure below corresponding to the seasons displays the most relevant information.

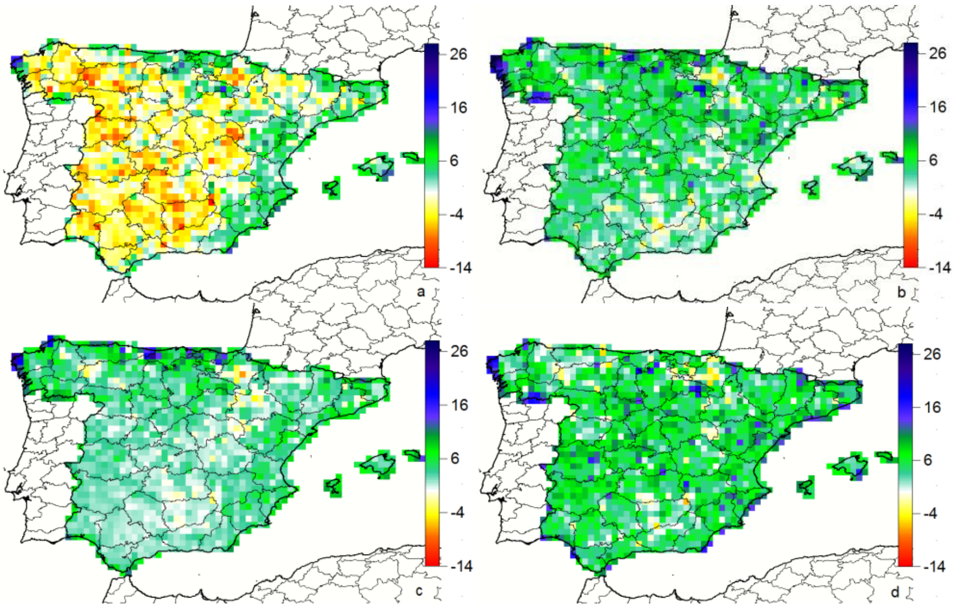


Figure 24: Change between the number of days per year of rain for winter(a), spring(b), summer(c) and autumn(d).

In winter there has been a general reduction of rainy days in the whole of the Peninsula except in Catalonia, Valencia, Murcia and the Balearic Islands, and in some other coastal points. In the remaining seasons, the change is positive: it has rained more during the second period in a fairly widespread way.

If we look at the result the duration of sequences of rainless days (Figure 26) and rainy days (Fig. 24). See significant changes in the same direction as Figure 24.

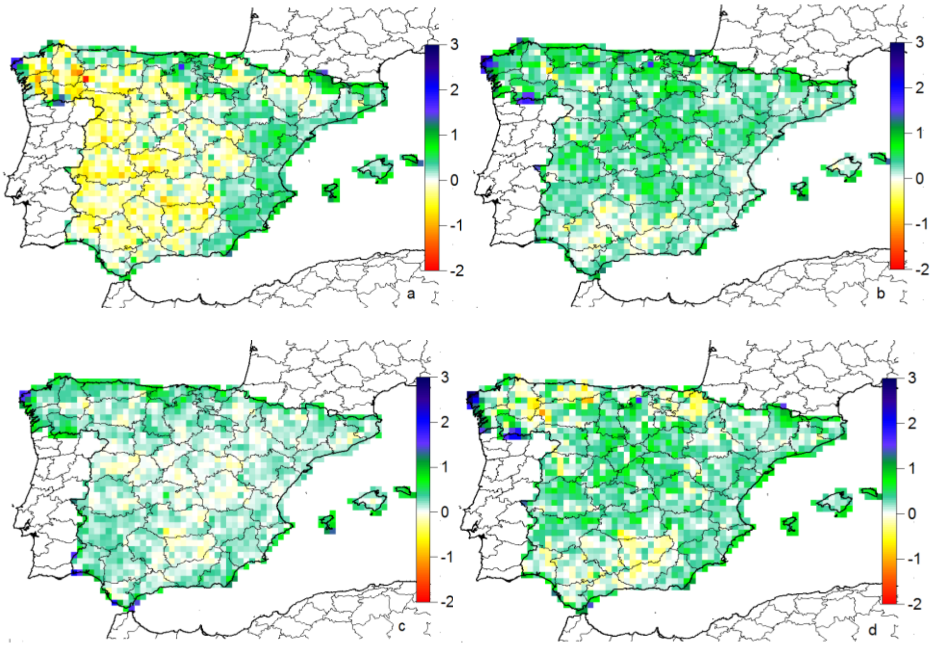

Figure 25: Change between the average length of wet episodes for winter(a), spring(b), summer(c) and autumn(d) , with a significance of 90%.

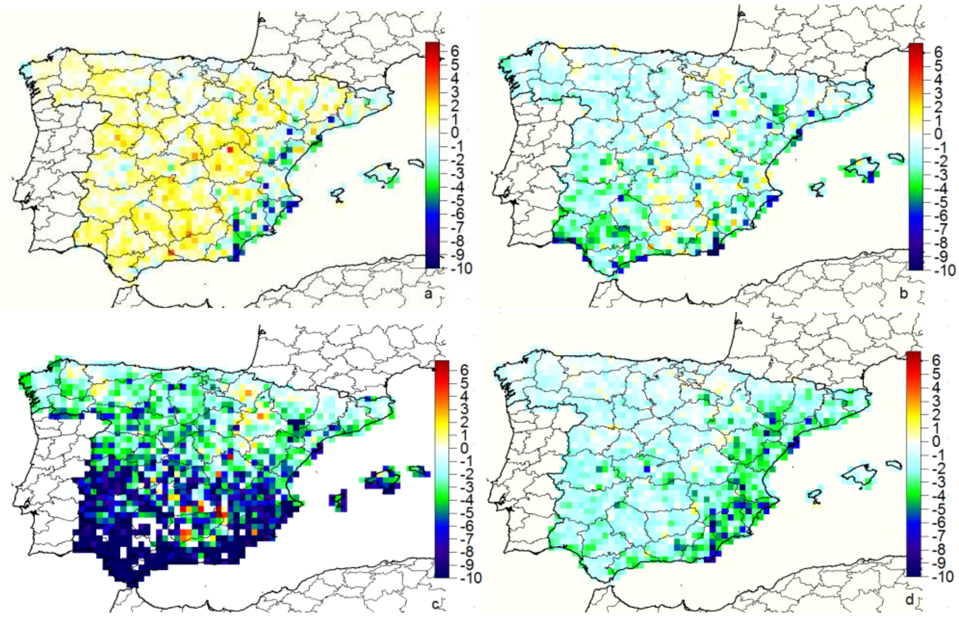

Figure 26: Change between the average length of dry episodes for winter(a), spring(b), summer(c) and autumn(d) , with a significance of 90%.

In winter there has been a widespread and significant reduction of consecutive rainy days, as well as an increase in the number of dry days, except in the east coast and the Balearics, where change is in the opposite direction. For the other seasons increased consecutive rainy days occur widely and a general decrease in the consecutive days without rain is observed. In summer, there is a very large area in the southern part of the territory with a statistically significant reduction in the duration of consecutive days without rain. There is a difference of up to 10 fewer days in the average of days without rain.

## 3.3. CALCULATION OF RETURN PERIODS.

The result of the calculation we have made in this section is the probability of occurrence of events over some different values. In order to make its interpretation easier, the spatial distribution of the inverse of these probabilities have been represented in maps of return periods. Cutoff values based on the representation of the climate and the possible impacts on society were chosen.

### 3.3.1. Maximum daily temperature.

The maximum daily temperature is a variable that directly affects both wildlife and people. Higher daily maximum temperatures can cause an increase in the mortality of plants and animals. These dangerous temperatures for the environment do not depend on an absolute value but they depend on the difference with the usual temperature of an area. To check these effects over the entire region under study, values of 30, 35, 40 and 45 ° C have been selected. Thus, we can study quite high temperatures both in the northern and southern regions.

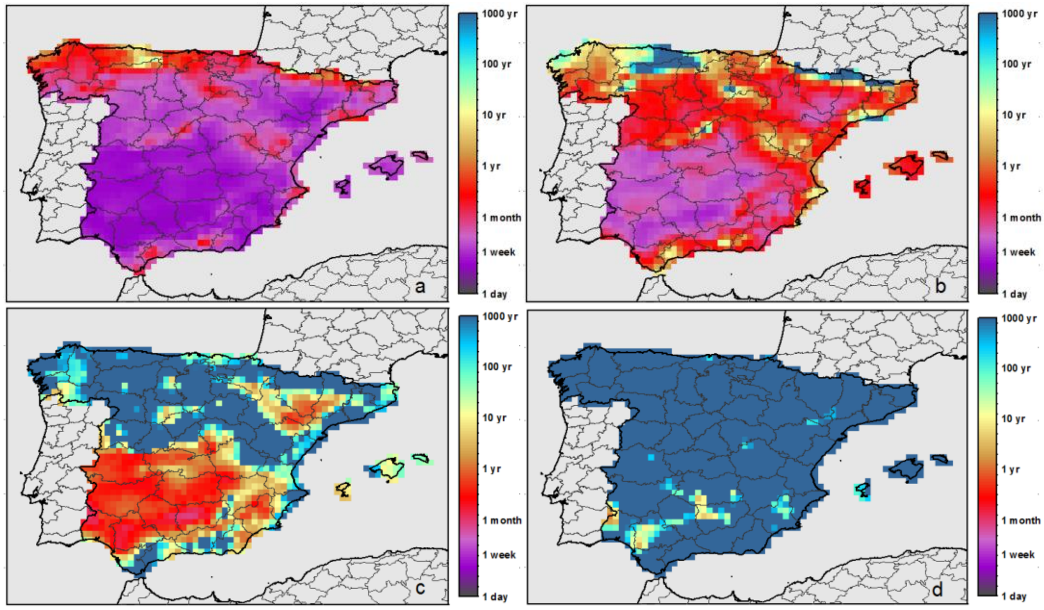


Figure 27: Return periods corresponding to a maximum daily temperature of 30(a), 35(b), 40(c) and 45(d) degrees Celsius.

The return values of 30 ° C in Figure 27 (a), let us see that it is a very common condition throughout the area under study except in Galicia, the Cantabrian coast, the Pyrenees and some points of high altitude. This happens a couple of times a year or until once every ten years in Asturias. The maximum values of 35 ° C in Figure 27 (b) are less frequent. In some isolated points of the Pyrenees and Cantabria they are either nonexistent or only occur in periods near of 1000 years. These values are more common in the inner region of the southern half of the Peninsula. The values of 40 ° C (c) and only occur regularly in the southern half of the peninsula and the Ebro Valley. In the Balearic Islands, the interior of Galicia and in some more regions these values are only reached once every 10 to 100 years. The map of return periods for values of 45 ° C in Figure 27 (d) shows a very extreme situation for the maximum temperature. We can see that these periods mainly appear between once every few years and a hundred years in the valley of the Guadalquivir with recurrence. The inland area of Murcia is also affected by these episodes every few decades. In Ibiza a few pixels appear in frequencies of less than once every 1000 years. This result might seem strange, but we can find it if we search the actual occurrence in these years of study. We cannot say too much about the isolated points because little information is available about what really happened there.

### 3.3.2. Minimum daily temperature.

The minimum temperature may not condition the life of the people living there as strongly as the maximum, but it clearly has an impact on vegetation and crops. Temperatures below 0 degrees imply a possible freezing of water as well as of the least adapted vegetables.

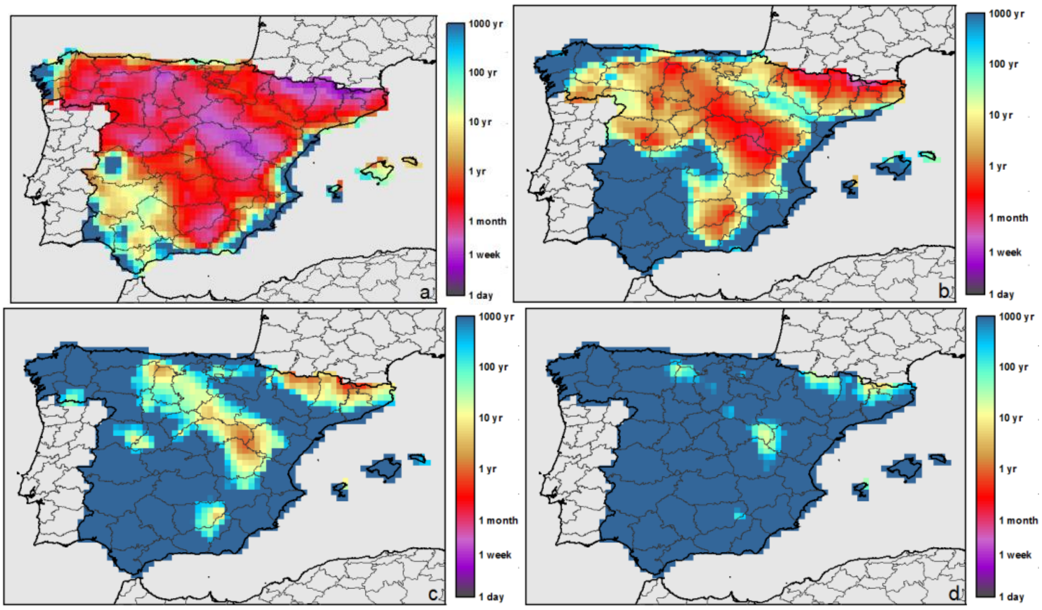


Figure 28: Return periods corresponding to a minimum daily temperature of -5(a), -10(b), -15(c) and -20(d) degrees Celsius.

The minimum temperatures below -5 ° C in Figure 28 (a) frequently occur in the region under study, especially in the places with more elevation of the Peninsula, which include the Pyrenees, Iberian, Central and Penibetic Systems and the Cantabrian Mountains. In areas of the Mediterranean coast and Galicia, recurrence of episodes of -5 ° C is greater than 1000 years. For values of -10 º C (b), areas with more recurrence include the entire central plateau, the Ebro Valley and the Pyrenees. Both in the Pyrenees and the Iberian system the return period of -10 ° C is lower than a year, so every year at least an event of this nature occurs. Recurrence periods of temperatures of -20 ° C in Figure 28 (c) are only found in the Pyrenees and the Iberian system, where they occur every few years. In areas close to Andorra such periods take place each year.

Some values are observed in Sierra Nevada and Sierra de Gredos, with a recurrence between 10 and 100 years. Other pixels that appear with values lower than 1000 years, as in Ibiza and Menorca, make no sense and are probably due to errors in the data base Spain02. For the graphic representation of -20 ° C in Figure 28 (d) very few values appear lower than 1000 years and it is a very extreme temperature. Note that its location coincides with the highest points of the main mountain ranges of the region under study.

### 3.3.3. Precipitation.

The return periods of intense rainfall events are a great tool for planning and managing infrastructure and public works. Intense rainfall events can cause major damage to infrastructure or crop fields. It is therefore important to know how the return periods of these events are distributed and what are the most vulnerable regions to major disasters of this type are.

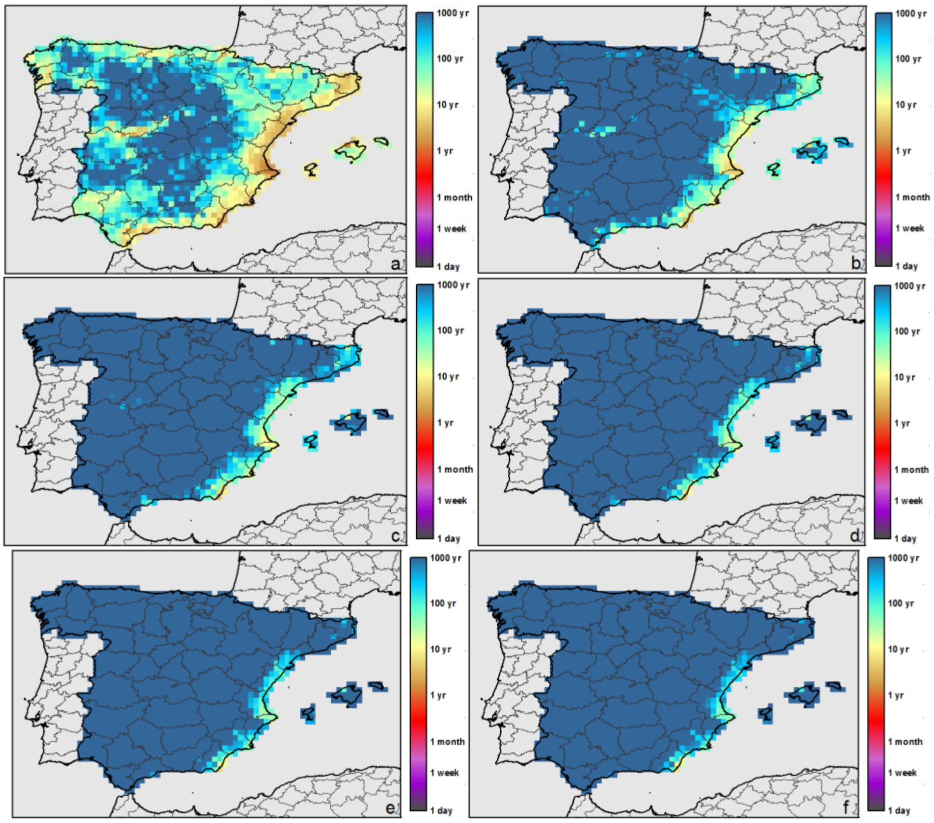


Figure 29: Return periods corresponding to a daily precipitation of 100(a), 200(b), 300(c), 400(d), 500(e) and 600(f) mm.

Events of 100mm rainfall in Figure 29 (a) are quite common in the study region. Occur throughout the region, except in the interior of the peninsula. The Mediterranean coast shows return periods lower than ten years for these events. Events of 200mm in Figure 29 (b) are found in regions where they are much less extensive and the shorter return periods appear on the coast of Valencia, where it is of ten years. For larger events, the distributions of the return periods are very similar. As daily precipitation increases, areas with periods shorter than 1000 years, are reduced and closer to the coast. We should also emphasize a point in the Sierra de Tramuntana which coincides with the major events of more than 200mm (Figure 10 (b)).

Keep in mind that to generate these return periods, using the Generalized Pareto Distributions, we used a threshold of 90%, this means that we only applied the method to the top 10% of values. That means that in the case of precipitation, in some places, this 10% can include many 0. In some places it can rain a lot less often than 10% of the days. In these places we can find some rare values, i.e. pixels with values which are different from those expected. In these places, although the database is correct, the model chosen to calculate the extreme values does not work properly. We can see this effect at Cape Gata, where return periods of 10 years were obtained for 400, 500 and 600 mm for daily precipitation. One way to fix this error is to choose a higher threshold, 95%, for example.

# 4. DISCUSSION.

## 4.1. CHARACTERIZATION.

The Spain02 database, used for making a thermo-pluviometric characterization of Peninsular Spain and Balearic, allows identify sufficiently detailed characteristics of the different climatic regions of the study region.

In broad terms, we can divide the Iberian Peninsula into 5 regions with different climates. The different climatic regions can be differentiated by the influence by of the sea, whether by the Mediterranean Sea or the Atlantic Ocean, and whether they are coastal or inland zones. Mountain areas behave differently from the rest. The Balearic Islands have some characteristics similar to those of the Mediterranean coast of the Peninsula, but with some important differences.

In both, the results of daily maximum as daily minimum temperature display a clear gradient north - south. The communities of Madrid, Castile and León, Aragon, Catalonia and the further north have a colder climate than the others. Both daily maximum and minimum temperatures are lower for these communities. An exception is the Ebro Valley, which presents similar temperatures to those of the southern part of the peninsula. The Balearic Islands also behave like the southern part.

The southern and eastern part of the Peninsula, along with the Balearic Islands, are the regions that are most influenced by the presence of the Mediterranean Sea. This presence implies both maximum and minimum temperatures above areas influenced by Atlantic. The coastal areas around the country have more stable temperatures throughout the year. Thus, temperatures are higher in winter and lower in summer. The Mediterranean coast is characterized by having the highest minimum daily temperatures throughout the year.

Regarding precipitation, this work has shown that there is a big difference between the mean daily precipitation and mean number of days with rain. For the daily average a marked north - south gradient appears again, where the northern part receives more rainfall. For the average daily precipitation of rainy days, this gradient disappears: the areas near the coast and in the mountain systems receive more precipitation on rainy days. The plateaus are the areas where fewer rain is measured on rainy days. In contrast, Murcia, Almeria and Alicante, along with some areas of the Ebro Valley, are the locations where less precipitation is recorded for the daily average.

The event with more than 100 and more than 200mm have been characterized in the coast and in some mountain systems. The product of the number of rainy days per year is quite similar to the result obtained in the average of daily precipitation. However, the days of rain and no rain we show that while rainy days followed an east-west gradient, the days without rain followed a north-south gradient. Thus, in areas such as the Mediterranean coast, consecutive days of rain are very scarce and long periods of rainless days hardly ever occur. In contrast, in Andalusia, where there are more days of rain, in summer undergoes periods of days without rainfall which are longer than across the region under study.

## 4.2. SEARCH FOR EVIDENCE OF CLIMATE CHANGE.

The study of the search for evidence of changes in the climate of the region has allowed us to detect significant changes in most of the products generated.

Both the maximum and minimum daily temperatures have experienced warming. The mean difference between these two periods studied showed that there has been a significant and widespread increase in the region for both variables. The mean daily temperatures are the products with more regions of significant change. If we focus on the seasons: winter and spring have experienced a more widespread geographically significant increase of daily maximum temperatures. For the minimum daily increase more general occurs in autumn.

An increase in the number of consecutive hot days, affecting large areas of the southern half of the peninsula, and a significant increase in the length of consecutive days over 30 ° C affecting the regions of Andalusia and Castilla la Mancha has also been detected. Regarding the coldest days, with a minimum of 0 ° C or lower, the total number of days per year has decreased widely throughout the region. And further studying the duration of consecutive days with these characteristics, we see that the most important changes also involve a significant reduction.

All these effects on temperature match what the IPCC (Stocket et al. 2013) has already proven to occur worldwide. Significant changes in precipitation have also been detected. Their behavior is not homogeneous in the study area, in contrast with what happens in temperature. For daily rainfall, the areas with significant changes are scattered, but still many points change for winter, autumn and the annual average. This is not the case in spring and summer. However, the direction of change is not homogeneous, the change involves a decrease in winter and an increase in autumn. The behavior of the average rainfall of rainy days per year is more homogeneous and involves a generalized reduction in virtually all significant points, which are many and are well distributed in the region.

An interesting result that has been identified is the number of days of rain per year. While in spring, summer and autumn widely rains more days, in winter it rains a much less frequently in the region (except the Mediterranean coast). The same result was obtained on the number of consecutive days with and without rain: whereas in other seasons it rains for more consecutive days and the days without rain are reduced, the opposite occurs in winter.

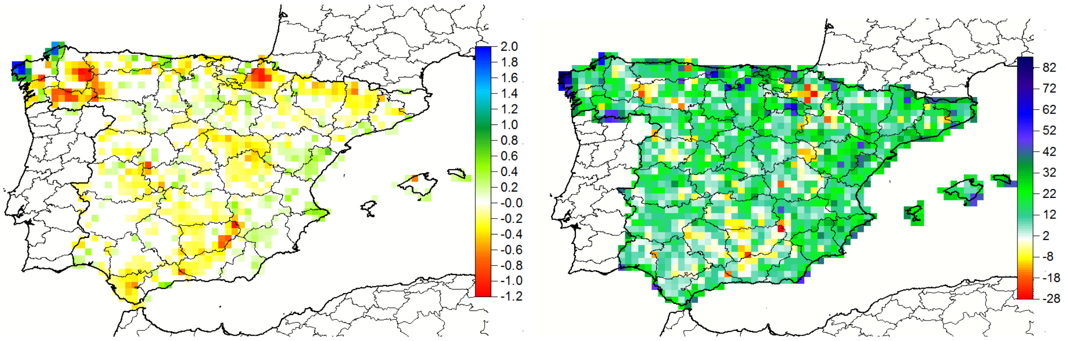


Figure 30: Change in the precipitation: (a) between the average daily precipitation, with a significance of 90%, (b) between the number of days per year of rain.

By taking into account the averages of these variables for the entire year (Figure 30) it is clear that it rains less but for more days a year in most of the areas studied.

## 4.3. CALCULATION OF RETURN PERIODS.

The calculation of return periods and their representations on maps allow us to clearly see the areas affected by the conditions that have been considered interesting. For the maximum daily temperature of 30 ° C it is observed to be very common. The higher temperatures mainly affect the south of the Peninsula and 45 ° C are only registered in areas of the Guadalquivir valley. For the minimum daily temperatures, however, the northern area is the most affected by lower minimums; specifically the high mountain areas have return periods of 10 years for temperatures of -20 ° C, which are very low.

The return maps for large precipitation events are perhaps the most interesting because they show areas with more precipitation and recurrence of these which have a high direct impact on society. The region most affected by torrential rains in the area under study is undoubtedly the Mediterranean coast, particularly Valencia with recurrence of hundreds of years up to values as catastrophic as 600mm of daily precipitation.

# 5. CONCLUSIONS.

The characterization has allowed us to see that the study region is divided into several sub-regions. Each with distinct characteristics of precipitation and temperature which may be affected differently by climate change.

Clearly, the results obtained here show that global warming is affecting the region covered by this study. A significant overall increase in daily maximum and minimum temperatures has been demonstrated. As regards precipitation, the results are not as clear-cut. A significant change was detected, but this varies in each region and for each season. In general we can say that it rains less and there is less daily rainfall, but it rains more often. Nevertheless, in places like the coast of Galicia and Valencia a larger average daily precipitation is found and it also rains more days per year, so we cannot give a general behavior of this variable as we could do with temperature.

The return period maps allow us to see the most vulnerable places to each type of event: whereas the northern part of the Peninsula and high mountain areas are vulnerable to the lowest daily minimum temperatures, the southern part of the Peninsula and especially the valley of the Guadalquivir are vulnerable to the highest maximum daily temperatures. The Mediterranean coast has proven to be the most susceptible to the heaviest daily precipitation.

These particularly vulnerable regions should adapt to each type of risk. Identifying risk areas is only the first step to good planning and land management. With climate change, these risk areas can change and shift. It is important therefore update these maps with the latest information possible. Hence, this result is interesting because with the Spain02 data, that comprises 47 very recent years, we are capable of displaying current return periods.

This study was intended to analyze how the climate in the region under study has experienced the effects of global change. The region under study has been quite sensitive to change. All regions with different climates that have been identified in the characterization have been affected by a change in thermo-pluviometric characteristics. This shows that for Peninsular Spain and the Balearic Islands, climate change is an issue of vital interest, which deserves further study. We should not only examine how this will affect the region, but also how it should adapt to the new situation.

## 6. REFERENCES.


AEMET, I. (2011). Iberian climate atlas. *Agencia Estatal de Meteorología (España) and Instituto de Meteorología (Portugal), Madrid, Spain*.

Coles, Stuart(2011). *An introduction to statistical modeling of extreme values*. Vol. 208. London: Springer.

Diffenbaugh, N. S., & Giorgi, F. (2012). Climate change hotspots in the CMIP5 global climate model ensemble. *Climatic change*, *114*(3-4), 813-822.

El Kenawy, A. M., López-Moreno, J. I., & Vicente Serrano, S. M. (2011). Recent trends in daily temperature extremes over northeastern Spain (1960–2006). *Natural Hazards and Earth System Sciences*, *11*(9), 2583-2603.

Ferro, C. A., & Segers, J. (2002). *Automatic declustering of extreme values via an estimator for the extremal index*. Eurandom.

Field, C. B. (Ed.). (2012). *Managing the risks of extreme events and disasters to advance climate change adaptation: Special report of the intergovernmental panel on climate change*. Cambridge University Press.

Herrera, S., Gutiérrez, J. M., Ancell, R., Pons, M. R., Frías, M. D., & Fernández, J. (2012). Development and analysis of a 50-year high-resolution daily gridded precipitation dataset over Spain (Spain02). *International Journal of Climatology*, *32*(1), 74-85.

Herrera S., Fita L., Fernández J.& Gutiérrez M.(2010). *Evaluation of the mean and extreme precipitation regimes from the ENSEMBLES RCM multi-model simulations over Spain.* Journal of Geophysical Research.

Romero, R., Guijarro, J. A., 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*(5), 541-560.

Sousa, P. M., Trigo, R. M., Aizpurua, P., Nieto, R., Gimeno, L., & Garcia-Herrera, R. (2011). Trends and extremes of drought indices throughout the 20th century in the Mediterranean. *Natural Hazards and Earth System Science*, *11*(1), 33-51.

Stocker, T. F., Qin, D., Plattner, G. K., Tignor, M., Allen, S. K., Boschung, J., ... & Vasconcellos de Menezes, V. (2013). *Climate Change 2013. The Physical Science Basis. Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change-Abstract for decision-makers*. Groupe d'experts intergouvernemental sur l'evolution du climat/Intergovernmental Panel on Climate Change-IPCC, C/O World Meteorological Organization, 7bis Avenue de la Paix, CP 2300 CH-1211 Geneva 2 (Switzerland).

Valencia, J. L., Tarquis, A. M., Saá-Requejo, A., & Gascó, J. M. (2012). Change of extreme rainfall indexes at Ebro River Basin. *Natural Hazards and Earth System Science*, *12*(7), 2127-2137.

# 7. APPENDIX.

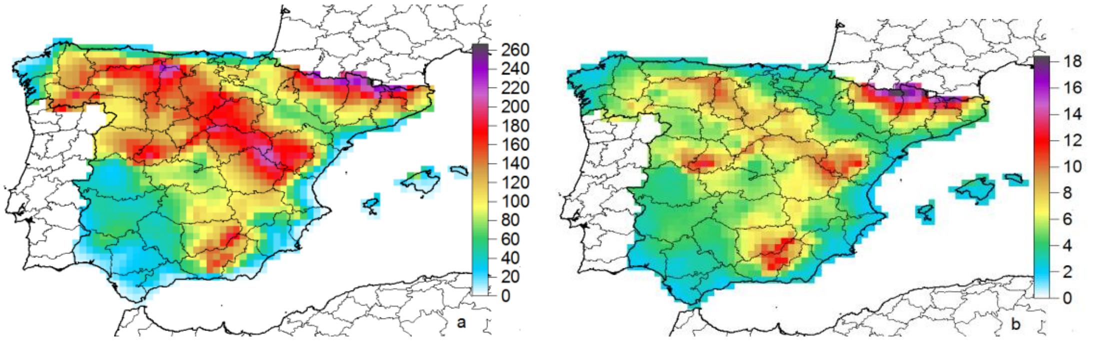


Figure 31: The days that the minimum temperature is not exceeded 3 degrees. (a) The average number of days per year. (b) The average length of consecutive days.

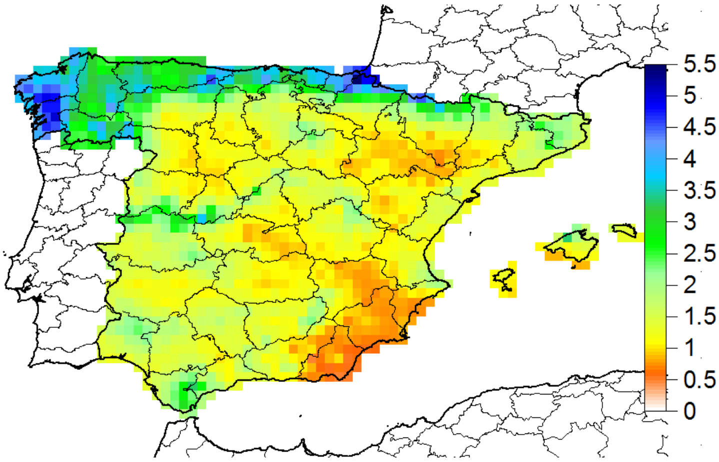


Figure 32: The average daily precipitation in mm.

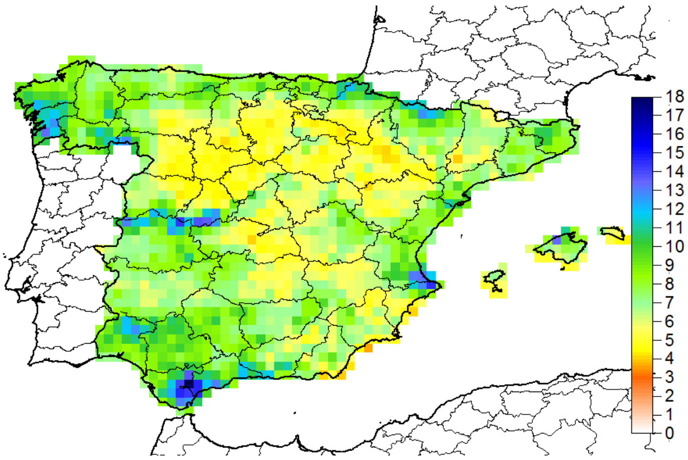


Figure 33: The average daily precipitation in mm of rainy days.

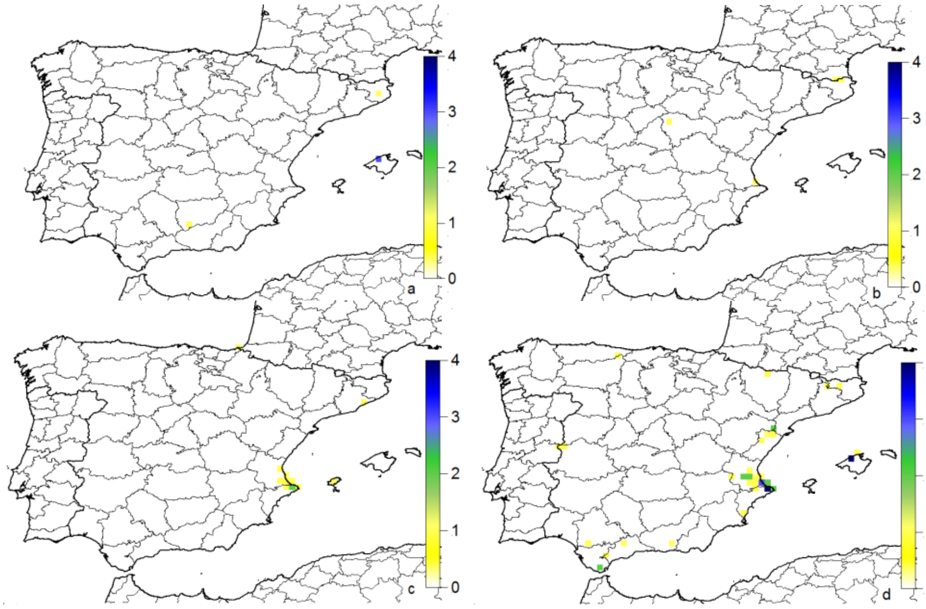


Figure 34: Number the days during the study period that rains more than200mm for winter(a), spring(b), summer(c) and autumn(d).

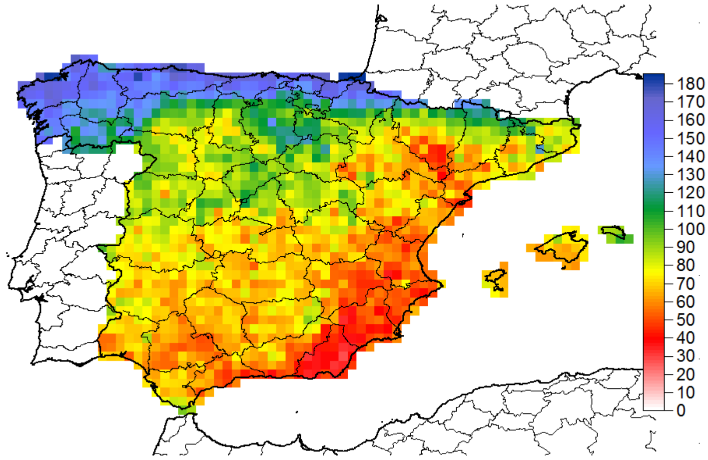

Figure 35: The number of days per year of rain.

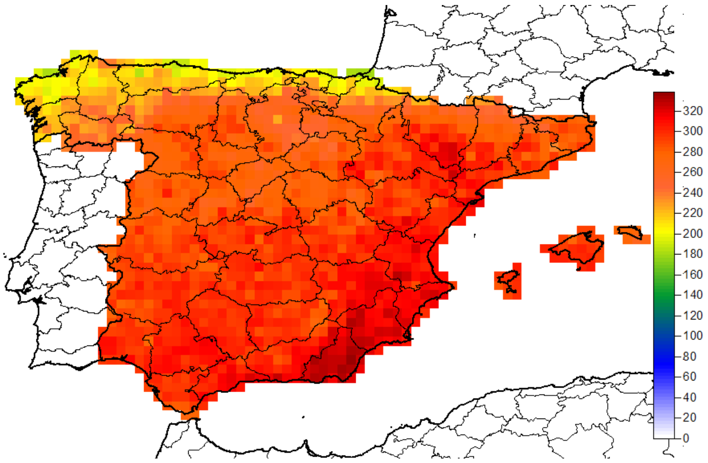

Figure 36: The number of days per year of without rain.

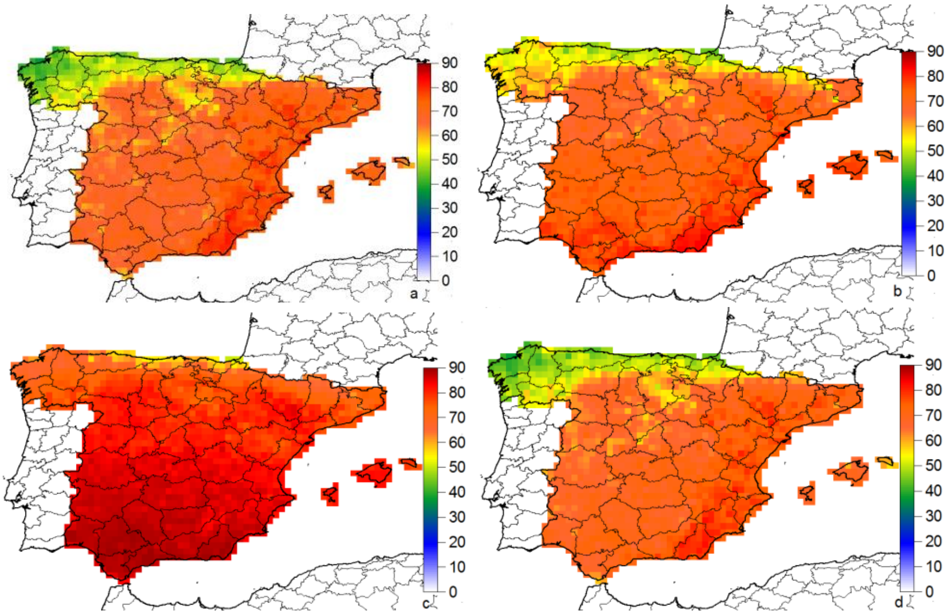

Figure 37: The number of days per year without rain for winter(a), spring(b), summer(c) and autumn(d).

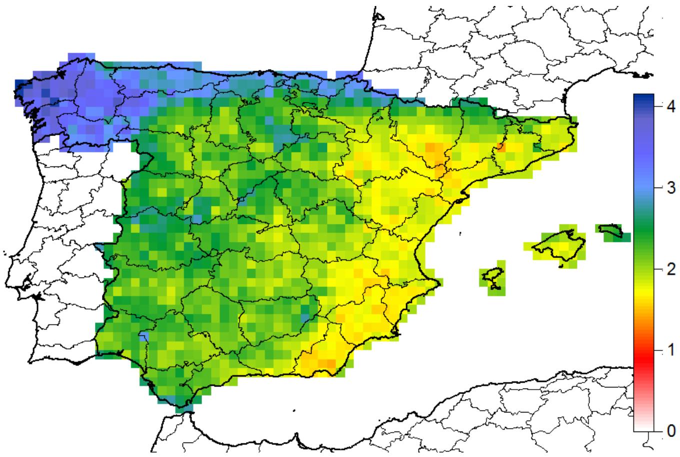

Figure 38: The average length of consecutive days of rain.

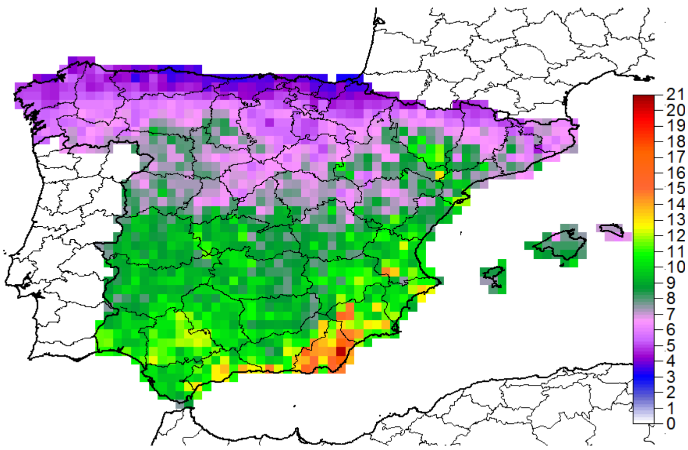

Figure 39: The average length of consecutive days without rain.

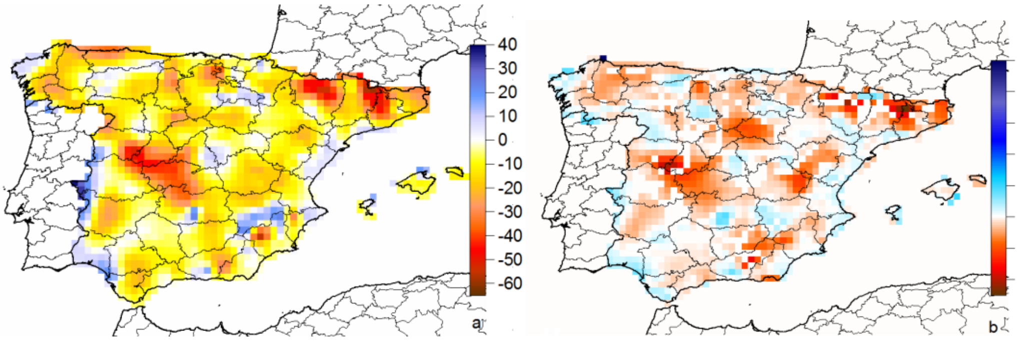


Figure 40: Change between the days that the minimum temperature is not exceeded 3 degrees. (a) The average number of days per year. (b) The average length of consecutive days, with a significance of 90%.

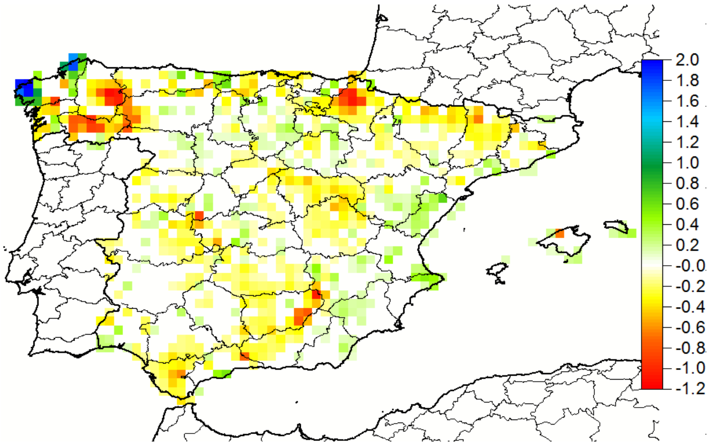


Figure 41: Change between the average daily precipitation(in mm), with a significance of 90%.

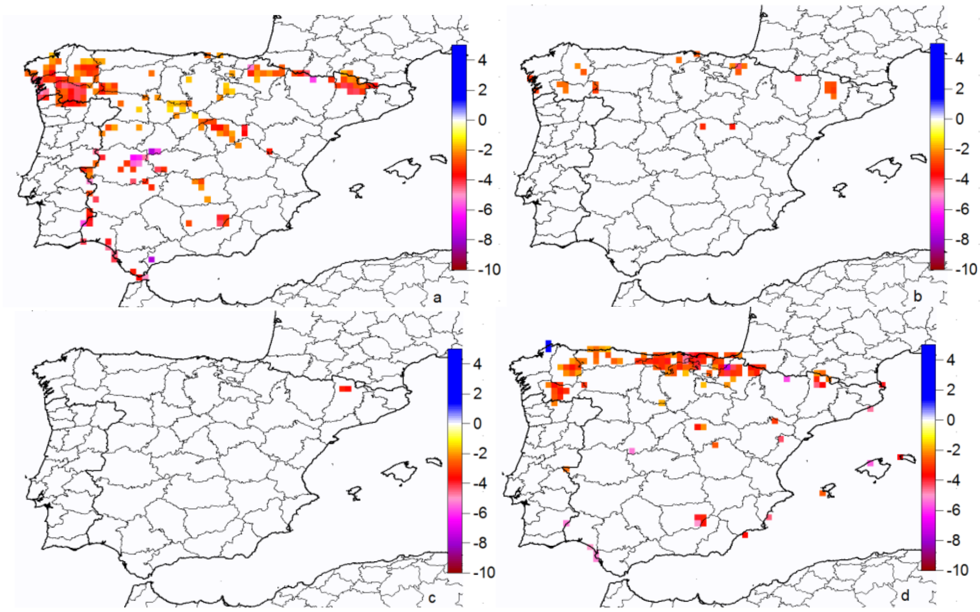


Figure 42: Change between the average daily precipitation(in mm) of rainy days for winter(a), spring(b), summer(c) and autumn(d), with a significance of 90%.

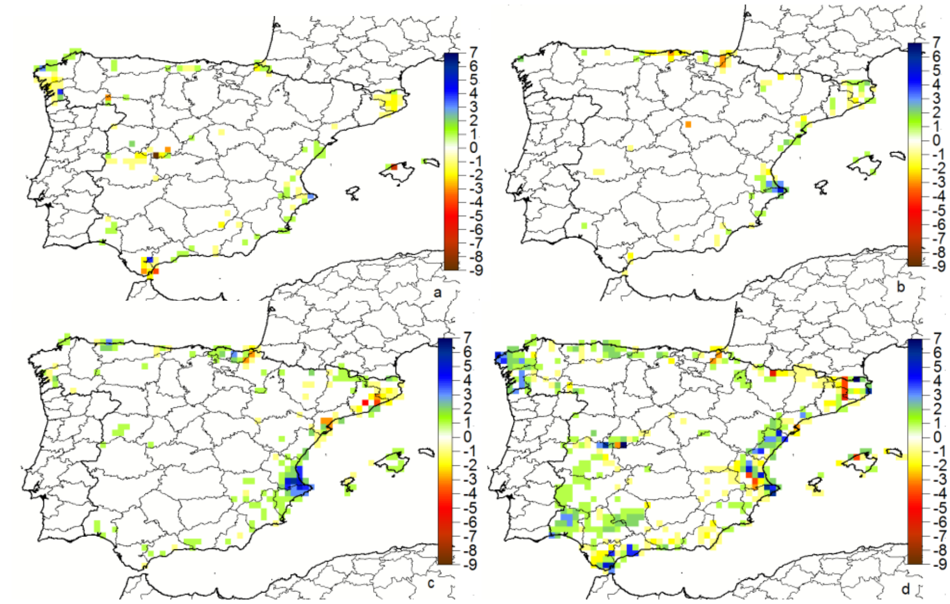


Figure 43: Change between the number the days during the study period that rains more than100mm for winter(a), spring(b), summer(c) and autumn(d).

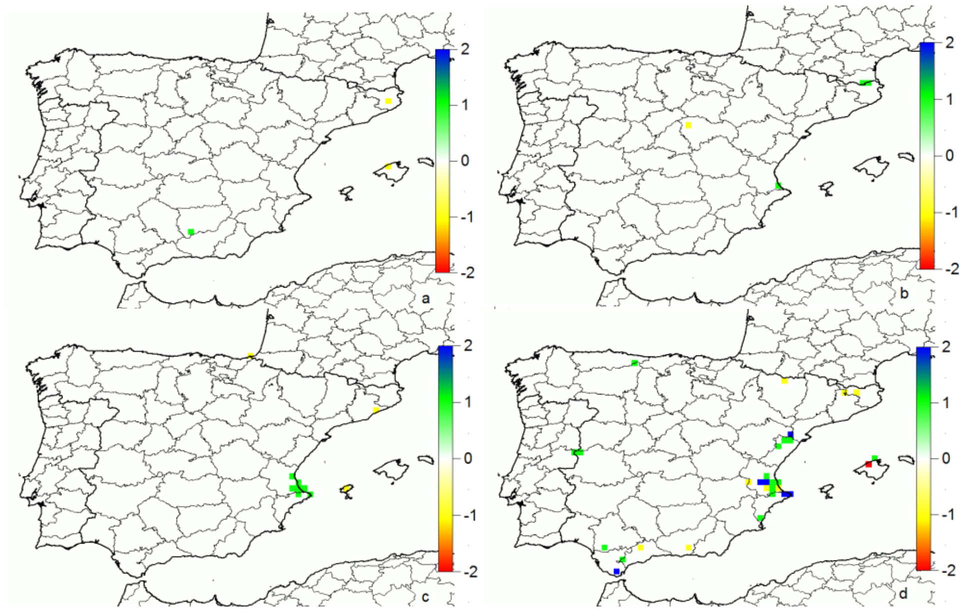


Figure 44: Change between the number the days during the study period that rains more than 200mm for winter(a), spring(b), summer(c) and autumn(d).

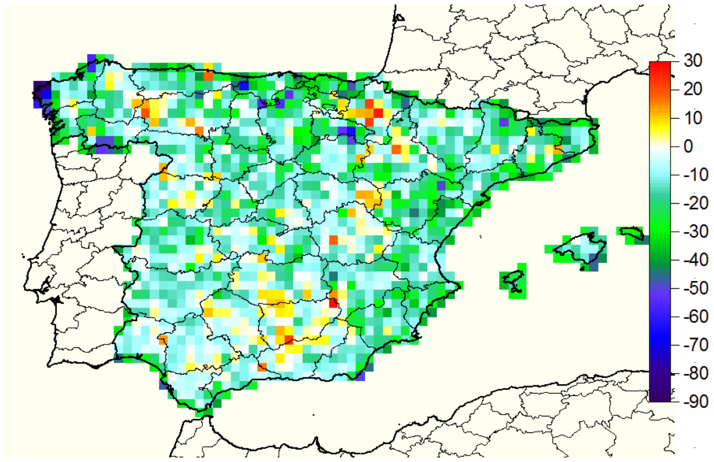


Figure 45: Change between the number of days per year of without rain.

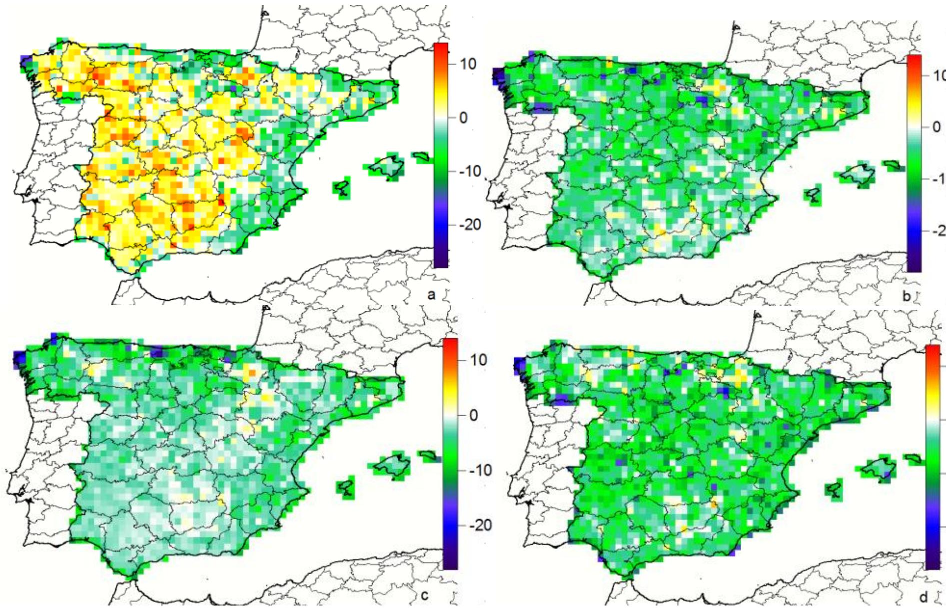


Figure 46: Change between the number of days per year without rain for winter(a), spring(b), summer(c) and autumn(d).

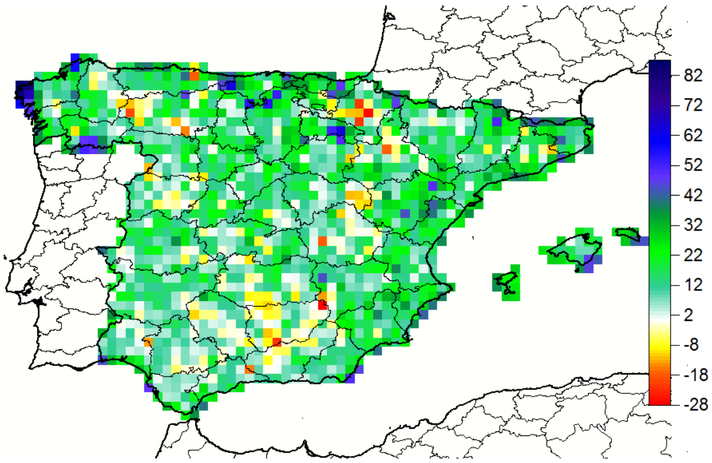


Figure 47: Change between the number of days per year of rain.

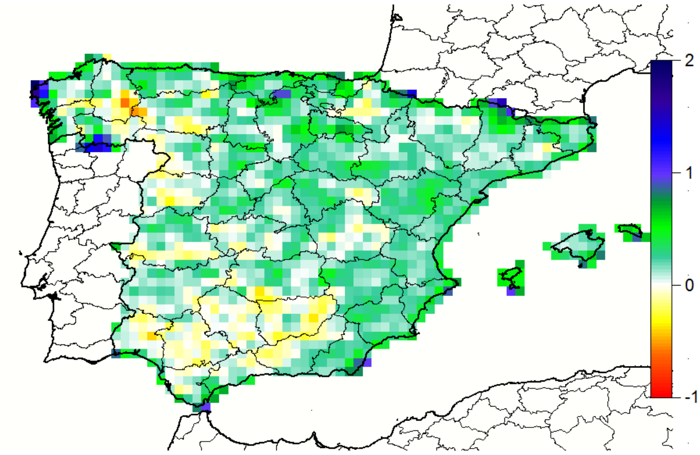

Figure 48: Change between the average length of consecutive days of rain, with a significance of 90%.

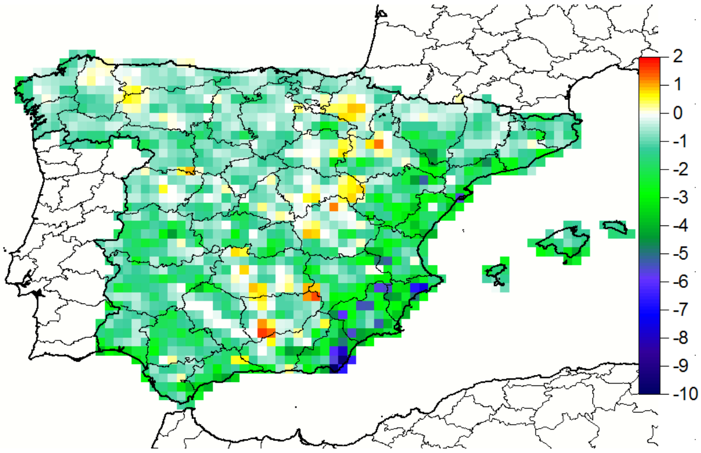

Figure 49: Change between the average length of consecutive days without rain, with a significance of 90%.