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DYNAMICAL-STATISTICAL DOWNSCALING OF PRECIPITATION IN PENINSULAR SPAIN AND BALEARIC ISLANDS DURING THE 21ST CENTURY

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Abstract

Simultaneously to the global warming, it has been observed a redistribution of the rainfall and other atmospheric variables (e.g. pressure, wind, cloudiness), with even higher spatial variability than temperature. For precipitation in the Mediterranean, observations indicate a loss in this resource that is estimated between 5-20% during 1901-2005. However, the robust detection of precipitation trends is always problematic owing to their high spatial and temporal variability. Atmosphere-Ocean General Circulation Models (AOGCMs) constitute the primary tool used by scientists to render future climate projections, at typical resolution of 100 - 300 Km. Regional Climate Models (RCMs) operating at higher horizontal resolution (20 - 40 Km) are being nested within AOGCM for specific regions of the world to better estimate climate change impacts at adequate spatial and temporal resolution. Armengual et al. [2010] were pioneers in the application of a novel study of the climate change in Platja de Palma, Spain (SPdP), based on the evolution of the meteorological variables in this geographical environment. In the present work, we apply the same statistical downscaling approach used by them to study posible changes in precipitation signal in Peninsular Spain and Balearic Islands along the 21st century. We show in this work just a breef collection of the products, centered in the ensemble mean of calibrated data and seasonal analysis, but we can see how precipitation regimes seems to change until the end of this century: a persistently decrease of annual mean precipitation until 2090, tending of increase in precipitation in South of Spain during the summer, and decrease in other regions and other seasons. We propose to apply this same procedure to Temperature Predictions in a similar gridpoints database, what can give us important information in fields of social, economical and enviromental impacts of climate changes in Spain.

1 Introduction

The expression Global Changes is used by a large range of scientists to define the set of environmental changes affected by the human activity, specially the changes in the processes that determine the functions of the Earth System (Duarte et al.; Fishlin et al. [2007]). The fact that these changes are occurring in a time step about just a few decades and the fact that the main driver of these changes is only one species of animal, Homo Sapiens, motivated the use of the word Anthropocen to refer to the actual geological state of the Earth (Crutzen and Stoermer [2000]; Duarte et al.). Changes in climate needs a special attention in this context, because they represent a trigger for many other changes.

Observations show that the global mean surface temperature has increased notably during the 20th century. In fact, the second half of the twentieth century has been very probably the warmest period at least for the last 1300 years in the northern hemisphere (Fishlin et al. [2007]). According to the CRU/Hadley Centre data (Brohan et al. [2006]), 11 of the 12 warmest years of the instrumental record have been observed during the 1995-2006 period. The rate of global surface warming for 1979-2005 is estimated at 2.68^o C per century. Furthermore, the estimated trends at regional scale for this interval show high spatial variability and, for the Mediterranean area as a whole, IPCC settles this trend between 2.5 and 3.5^o C per century.

Simultaneously to the global warming, it has been observed a redistribution of the rainfall and other atmospheric variables (e.g. pressure, wind, cloudiness), with even higher spatial variability than temperature. For precipitation in the Mediterranean, observations indicate a loss in this resource that is estimated between 5-20% during 1901-2005. This decrease appears to be smaller than 3% towards the end of the period (1979-2005; IPCC, 2007). However, the robust detection of precipitation trends is always problematic owing to their high spatial and temporal variability (?).

Atmosphere-Ocean General Circulation Models (AOGCMs) constitute the primary tool used by scientists to render future climate projections, at typical resolution of 100 - 300 Km. The AOGCM simulations are currently performed under a wide range of scenarios for greenhouse gas emissions and aerosols. These scenarios describe plausible evolutions for these emissions depending on socioeconomic conditions and world development guidelines.

Albeit climate change is a problem of global causes and consequences, its impacts become apparent locally. Climate change effects at regional and local scales, such as an increase in the frequency and/or intensity of extreme events, require quantitative estimations of their impacts at adequate spatial and temporal resolution. For this purpose, Regional Climate Models (RCMs) operating at higher horizontal resolution (20 - 40 Km) are being nested within AOGCM for specific regions of the world.

The study of climate change from instrumental records aggregated in databases of regional range (e.g. Peninsular Spain and Balearic Islands) can mask the local features.

Being aware of this problem, Homar et al. [2010] carried out a study of the recent trends for rainfall and temperature in the Balearic Islands by working with complete daily time series for the 1951-2006 interval. Their results show a loss in annual rainfall amounts at a rate of 16.6 mm per decade with 87% of statistical significance. Autumns and winters (the most wet seasons) are the main responsible for this deficit. It is also observed an increasing contribution of the extreme daily precipitation (weak or very intense) and a decreasing contribution of the intermediate amounts to the total accumulations.

Armengual et al. [2010] carried out a study of the climate change in Platja de Palma, Spain (SPdP), based on the evolution of the meteorological variables in this geographical environment. They were pioneers in the application of a novel statistical downscaling approach to correctly handle daily RCMs outputs. To this aim, observed and simulated daily series of minimum and maximum temperatures, precipitation, relative humidity, cloud cover and wind speed were analyzed. Available data came from the last generation RCMs simulations run within the ENSEMBLES project under the SRES A1B scenario. Once RCMs daily series have been statistically downscaled to SPdP, they have analyzed the projected climate change signal. Results have been discussed in terms of the changes in the annual and seasonal mean regimes, as well as in terms of the changes in the frequency of the extreme events.

In the present work, we propose to apply the same statistical downscaling approach used by Armengual et al. [2010] to study posible changes in precipitation signal in Peninsular Spain and Balearic Islands along the 21st century. To do this, we use the same RCMs outputs at regional scales used by them, and a database of observed precipitation in Spain at regional scale (resolution of 20 Km), organized by ESTCENA project.

We organize this report as follows: in the second section we talk about the data and the statistical downscaling approach used; in the third section we talk about the validation of the method in our application to all Spain regions; in the fourth section we discuss the main results; and in fifth section we talk about future projects.

2 Database and Methodology

Observations of Precipitation were obtained from a new publicly available high-resolution daily precipitation gridded dataset developed for peninsular Spain and the Balearic islands, using 2756 quality-controlled stations (this dataset is referred to as Spain02). The grid has a regular 0.2^o (aprox. 20km) horizontal resolution and spans the period from 1961 to 2003 (Herrera et al. [in press]). In total, we used information about the 1445 land points represented by this dataset.

Regarding the future projections, we have used the regional simulations database available from the ENSEMBLES European project. Daily climate data from 12 different RCMs run from 1961 to 2090 for the SRES A1B scenario have been considered (Armengual et al. [2010]).

To properly manage the RCMs data at such local scale, we have applied the same statistical downscaling method presented in Armengual et al. [2010] for each RCM output. It consists of calculating the changes in the cumulative distribution functions (CDFs) of daily values between two 20-year past simulated periods (control: 1961-1980; verification: 1981–2000), and successive 20-year simulated time-slices from 2011 until 2090. We have not used the years between 2001 and 2010 in order to maintain the span of 20-years until the last date of our database.

These variations are corrected and then transferred to the observed CDFs for the same control period, thus obtaining new calibrated CDFs which convey the climate signal for the subsequent time intervals.

Recalling that our control period is 1961-1980 and the future period any subsequent 20-year interval, the statistical downscaling method can be written as the following relationship between the ith ranked values of p_i, o_i, sp_i and sf_i of calibrated (i.e. projected), observed, present simulated (control) and future simulated CDFs, respectively:

$$p_i = o_i + g\overline{\Delta} + f\Delta'_i \tag{1}$$

where

$$\Delta_i = sf_i - sp_i \tag{2}$$

$$\overline{\Delta} = \frac{\sum_{i=1}^{N}(\Delta_i)}{N} = \frac{\sum_{i=1}^{N}(sf_i - sp_i)}{N} = \overline{sf} - \overline{sp} \tag{3}$$

$$\Delta'_i = \Delta_i - \overline{\Delta} \tag{4}$$

and

$$g = \frac{(\sum_{i=1}^{N} o_i)/N}{(\sum_{i=1}^{N} sp_i)/N} = \frac{\overline{o}}{\overline{sp}} \tag{5}$$

$$f = \frac{\sigma_o}{\sigma_{sp}} = \frac{R_o}{R_{sp}} \tag{6}$$

As surrogates of the population variability, R_o and R_sp are the parametric differences between P90 and P10 percentiles of precipitation in the observed and raw control simulated data, respectively.

Δ_i is the difference between the future and control raw ith ranked values; thus it can be expressed as the sum of the mean regime shift ($\overline{\Delta}$), plus the corresponding deviation Δ'_i from this shift (Eqs. 4). In expression (1), omission of g and f parameters (i.e. $g = f = 1$) would be the special case of an uncalibrated method in which the "simulated climate change signal" Δ_i is simply added without any adjustment to the present local climate. Therefore, $g\overline{\Delta}$ is a term that modulates the variation in the mean state, and $f\Delta'_i$ a term that calibrates the change in variability. The use of g and f parameters serves to reconcile the RCM with the observed climate. A parameter value greater(smaller) than 1 would act inflating(deflating) an otherwise too low(high) contribution to the change of the corresponding climate attribute (i.e. mean regime or spread) (Armengual et al. [2010]).

The ratio of non-rainy days between observed and projected series is conserved from the rate obtained between the control and future simulated raw data. Thus, it is intended to respect the internal dynamical evolution of the modeled climate when dealing with the drying or moistening of the rainfall regimes (Armengual et al. [2010]).

This method provides daily projected series of precipitation for all the 1445 grid points of our database and is applied on the 12 considered RCMs and 20-years periods spanning over the years 1981–2000 and 2011–2090.

3 Validation of the statistical downscaling approach

We have evaluated the performance of the multimodel mean by comparing the raw and calibrated data percentiles against the observed ones. Figure 1 shows the cumulative distribution functions for the 20-year validation period (1981-2000) in four particular points of the database, representing different pluviometric regimes: Extremadura, Santiago de Compostela, Almería and Palma. Santiago de Compostela and Almería represent the opposite pluviometric regimes: wet and dry regimes, respectively. In this figure, the red line shows the CDF of precipitation in each point for all the 20-years period given by the RCM models without calibrate; black one shows the same for the data obtained after calibration; and the blue one shows the observed precipitation in each point in the same validaton period. For each one of the four regions the CDFs shows that the statistical method gives a data maxcloser to observed precipitation.

Analogously, Figure 2 shows the boxplot of the distribution of precipitation in the validation period (1981-2000) for all 1445 gridpoints, considering the 3 data: RCM models data; calibrated data; and observed data. One more time we can see that calibrated data boxplot is more similar to observed boxplot than the uncalibrated one, both in average values and in 75% and 25% quartiles.

Figure 3 shows the map of Spain, with all the gridpoints, each one with a color that indicates: Absolute (a) and Relative (c) Difference (in mm) of Annual Mean Observed Precipitation and Uncalibrated RCM models, during validation period; Absolute (b) and Relative (d) Difference (in mm) of Annual Mean Observed Precipitation and Calibrated RCM models, during validation period. In both cases, in absolute differences and in relative differences, the Calibrated models are more similar to the observation data than Uncalibrated one. In this figure we can also note that the differences between Calibrated and Observed data are higher in the dry region of SE of Spain, and is lower in the wet region of NW of Spain.

These evidences, beyond the results of Armengual et al. [2010] to SPdP station justify the use of the calibrated data in the analysis of climate changes signals in precipitation of Spain, as we will show in next section.

4 Results and Discussions

The first step to start the analysis of the calibrated predictions was to calculate the ensemble among the 12 RCMs models used. Each model has different characteristics that may allow it to better predict some regions than others, so to use an ensemble is a good option to consider all the advantage and disadvantages of all models and do not need to use all of them separately. Figure 4 shows the Ensemble mean of the 12 models for all 1445 gridpoints for the validation period.

Figure 5 shows the Standard Deviation for the same validation period among all the 12 models. It shows that there are more deviations among the models in regions SW, N and NW of Peninsular Spain and North of Mallorca, at Balearic Islands. Because the Standard Deviation is an absolute value, we show in Figure 6 the Relative to present Standard Deviation in each region (we consider as present the validation period 1981–2000). Deviation values of precipitation are higher for grid points from South of Spain can be explained because this region is characterized by a higher pluviometric variability (identified by the standard deviation) of because of the uncertainty of the RCMs, that have different advantages and disadvantages for that region.

Figure 7 shows the boxplot of the Distribution of Precipitation in the 1445 gridpoints for the validation period (1981–2000) and for the four 20-year predicted periods: 2011–2030; 2031–2050; 2051–2070; 2071–2090. The plots shows a clear decrease in the average and in the range of precipitation in each projected 20-year related to present (validation period). It shows the decrease of the mean precipitation and of both, 75% and 25% quantile. Also outliers precipitation values decrease with time.

Figure 8 shows the precipitation predictions for the 4 predicted 20-year sets (2011–2030 (a); 2031–2050 (b); 2051–2070 (c); 2071–2090 (d)) and in Figure 9 there is the difference of this future precipitation with respect to present precipitation. We can see that the higher proportional decrease of precipitation is in NW region (Galicia) and in the South/SW regions. Until the end of XXI century those regions may lose about 25% of the precipitation recorded in 1981–2000 validation period. Other regions appears to lose less than 10% or even gain about 10 to 20% of precipitation related to present days, the last one are located in mountain regions in North and in Northern Mallorca.

Figure 10 shows the Standard Deviation for the same four predicted 20-year sets, and we can see that the variability of the ensemble results is higher in mediterranean and in the SW regions of the Peninsula.

Figure 11 shows the distribution of precipitation in all gridpoints, for 4 seasons (winter (a); spring(b); summer (c); autum (d)) during present days (1981–2000) and for the four 20-year predicted date. It is clear the decrease in the mean precipitation values for summer and spring seasons, as it is for the range of precipitation in those seasons (see the 75% and 25% quantiles represented in the boxplot). Although it is not so clear a decrease in the mean precipitation values of winter and autum, we verify a small decrease in winter mean precipitation after 2031–2050, and in the range of precipitation of the autum after the same period.

Figure 12 shows the mean precipitation in Spain during the 4 seasons (winter (a); spring(b); summer (c); autum (d)) and we can compare it with the absolute values of precipitation during the 4 predicted period: 2011–2030 (Figure 13); 2031–2050 (Figure 15); 2051–2070 (Figure 17); 2071–2090 (Figure 19). Figures 14, 16, 18 and 20 shows the same.

For the winter and the autum, we note an increase about 30% of precipitation in relation to present, during the first predicted period (2011–2030) in NE region, and a decrease about 20% in Balearic Islands and in the NW region of the Peninsula, in the wetest spanish region of Galicia. In subsequent periods the decrease in precipitation in Galicia is intensified, as the same time that starts to decrease the precipitation in South regions about 20%.

For the spring, we note a decrease about 20-40% in precipitation in all regions of Spain during the first predicted period (2011–2030), with more emphasis in central region. In next predicted periods this decrease is sustained, and at the last period (2071–2090) almost all the coutry has a decrease about 40% during spring.

For the summer, at a first time we note a higher decrease of precipitation in NW region (Galicia), about 40% related to present days. At the same time, there is an increase of precipitation in South regions, about 20-40%. Other regions in the center of the Peninsula and in Mediterranean areas shows a decrease about 20% in precipitation. During next 3 periods the patterns of increase in South region and decrease of precipitation in the other ones continues, but with much more intensity in these last changes than in the first.

5 Conclusions and Perspectives

The first thing we can conclude from this work is that the statistical method of calibration of RCMs predictions is robust to work with multiple locations, the CDF and boxplot analysis show that this method makes the calibrated models more similar to observed data than uncalibrated ones. The Standard Deviation analysis showed that the RCM models seems to treat differently the dryer regions, as the South of Spain.

Considering this, and using the ensemble mean of the 12 RCMs, we could see that precipitation regimes seems to have important changes until the end of this century. Annual mean precipitation tends to decrease persistently until 2090. South of Spain tends to have more precipitation during the summer than it has in present days, and all other regions tend do have decrease of precipitation in different intensities and in different seasons. While NW Peninsular region tends to have a higher decrease in its precipitation during winter and autum, the Center of Peninsular region tends to have a decrease about 40% in its precipitation during spring season.

We show in this work just a breef collection of the products, centered in the ensemble mean of calibrated data and seasonal analysis, but we have a daily calibrated series that can bring us many other results in future. For example, we could explain the temporal variability of the models, just by using shorter scales of time in these analysis. Also, we could study extreme events of precipitation or dry season.

The very next step of this work is to improve analysis of the differences between predictions and observed data, to have quantitative results about the trends already visualized in the graphics we showed here. At the same time, we can start running this same statistical downscaling procedure with Temperature Predictions in a similar gridpoints database. Both, precipitation and temperature, can give us important information in fields of social, economical and enviromental impacts of climate changes in Spain.

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Figures and captions

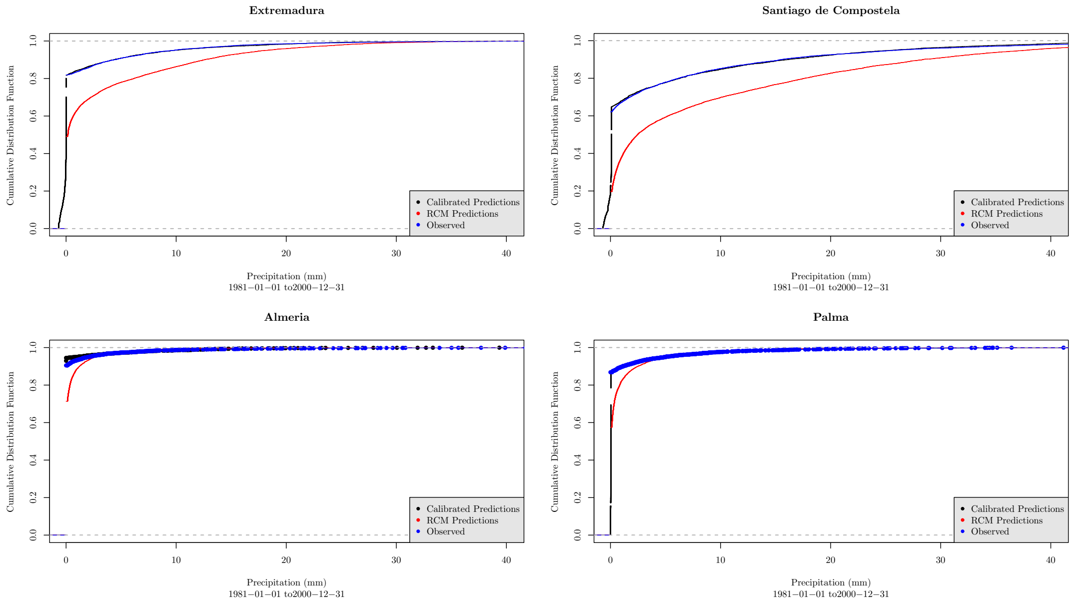

Figure 1: CDFs of a Calibrated RCM (black), the same but Uncalibrated RCMs (red) and Observed data (blue) for the period of validation (1981–2000).

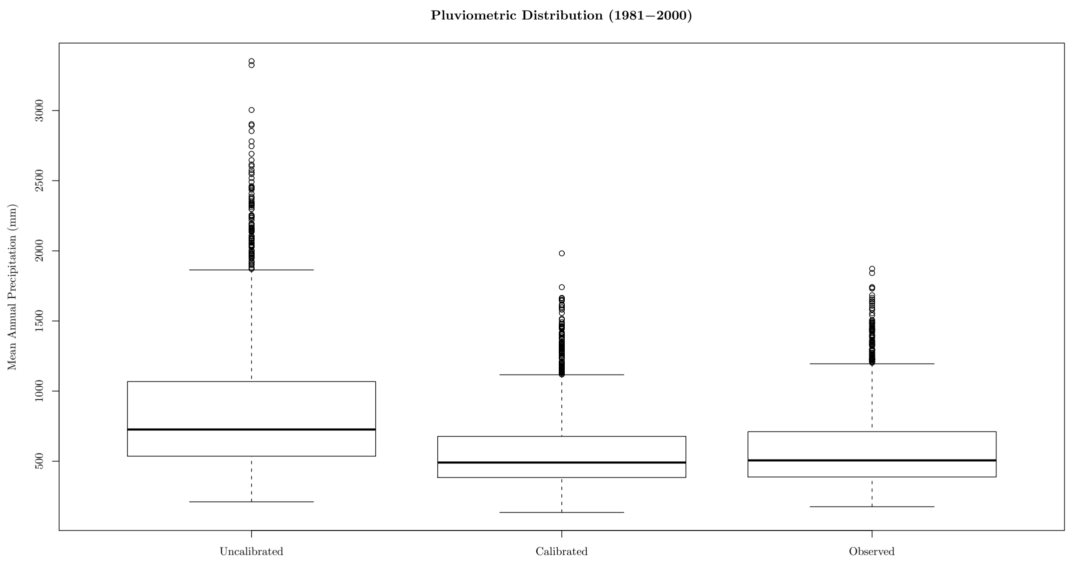

Figure 2: Distribution of Ensemble Mean precipitation (represented in a boxplot) in all 1445 gridpoints during the validation period (1981–2000) for Uncalibrated, Calibrated and Observed data.

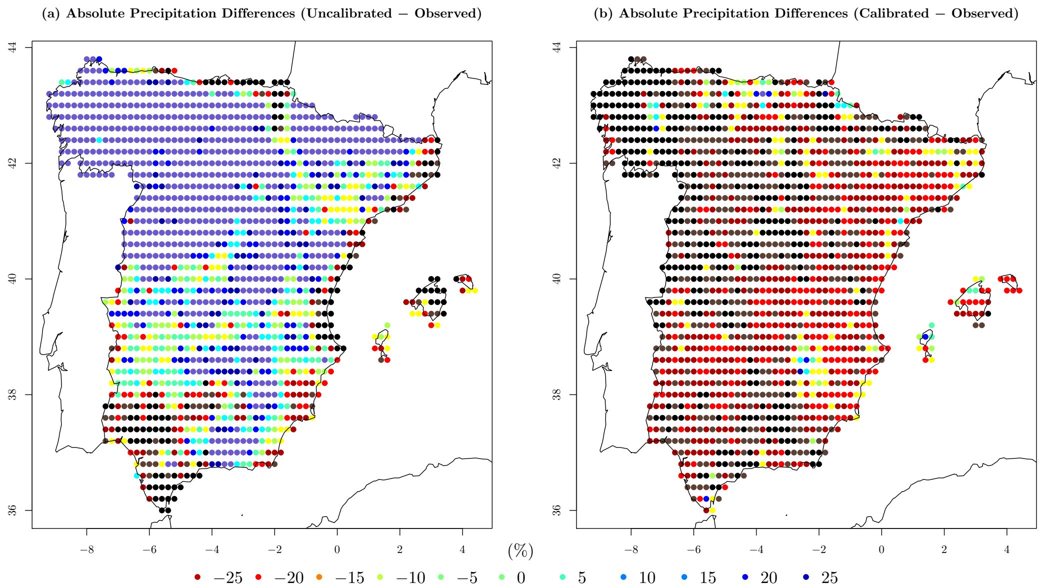

Figure 3: Absolute Differences between: (a) Uncalibrated Ensemble Mean of precipitation and the Annual Mean Observation data; and (b) Calibrated Ensemble Mean of precipitation and the Annual Mean Observation data.

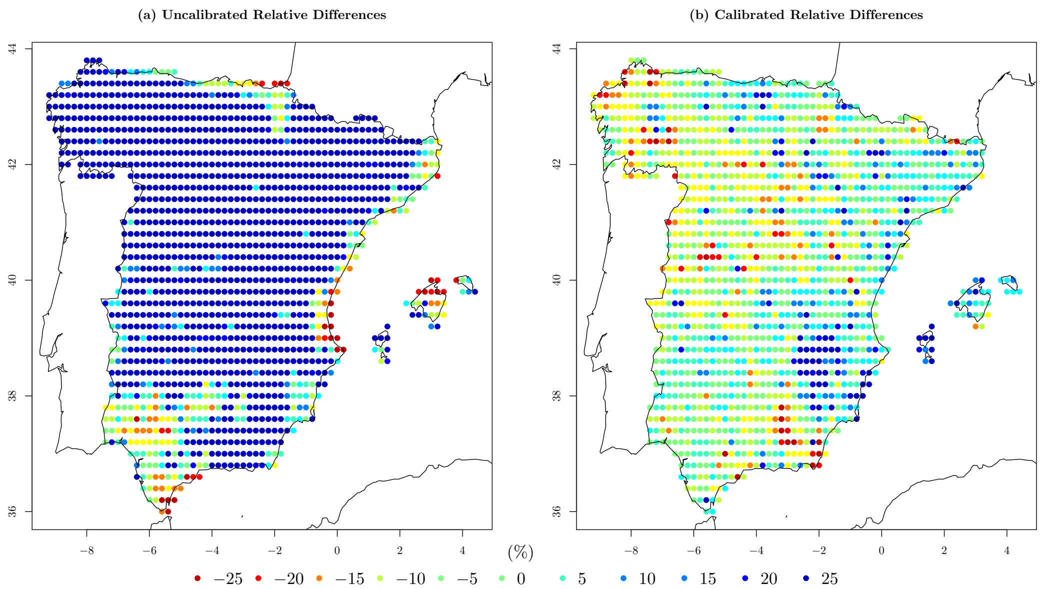

Figure 4: Relative to Present Differences with respect to: (a) Uncalibrated Ensemble Mean of precipitation; and (b) Calibrated Ensemble Mean of precipitation.

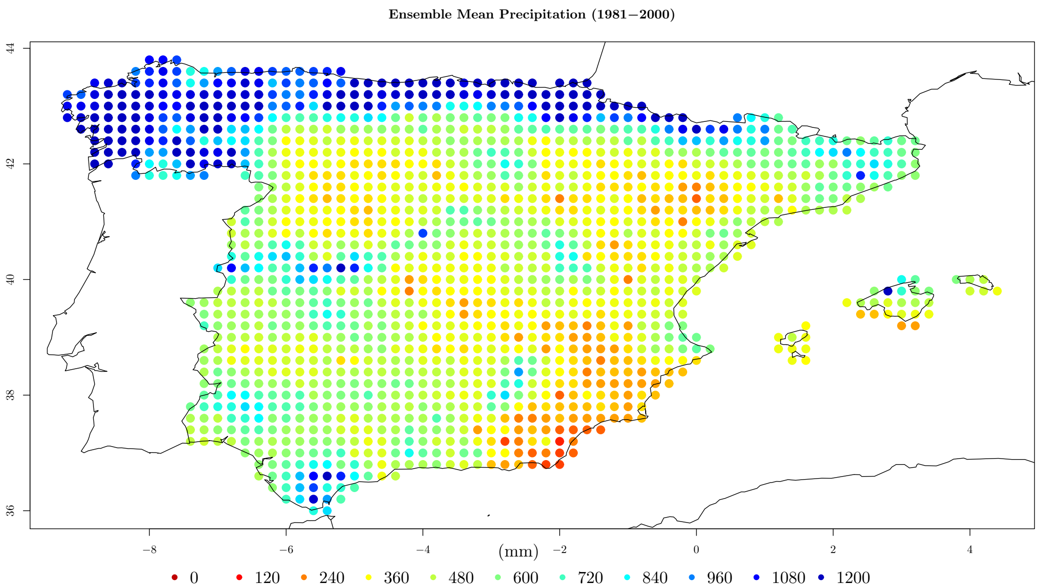

Figure 5: Ensemble Mean of annual precipitation of the 12 RCM models for all 1445 gridpoints for the validation period.

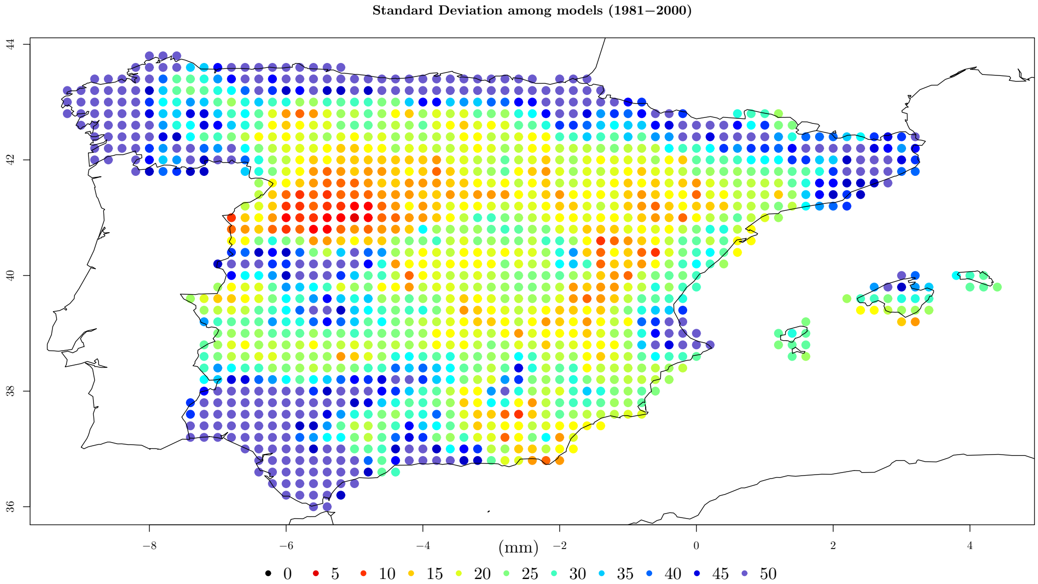

Figure 6: Standard Deviation among the the 12 RCM models for all 1445 gridpoints for the validation period.

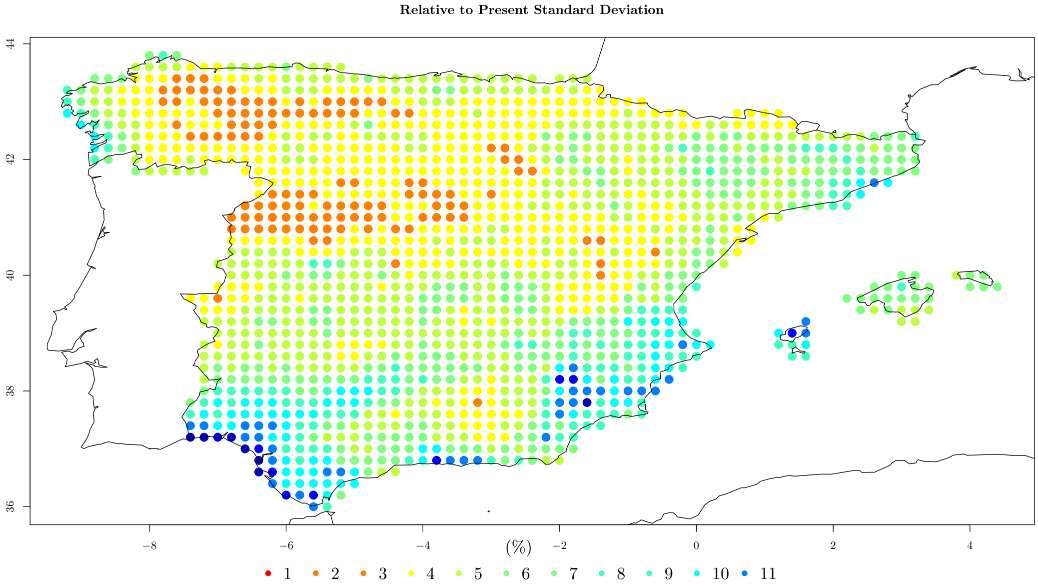

Figure 7: Relative to Present Standard Deviation among the 12 RCM models for all 1445 gridpoints for the validation period.

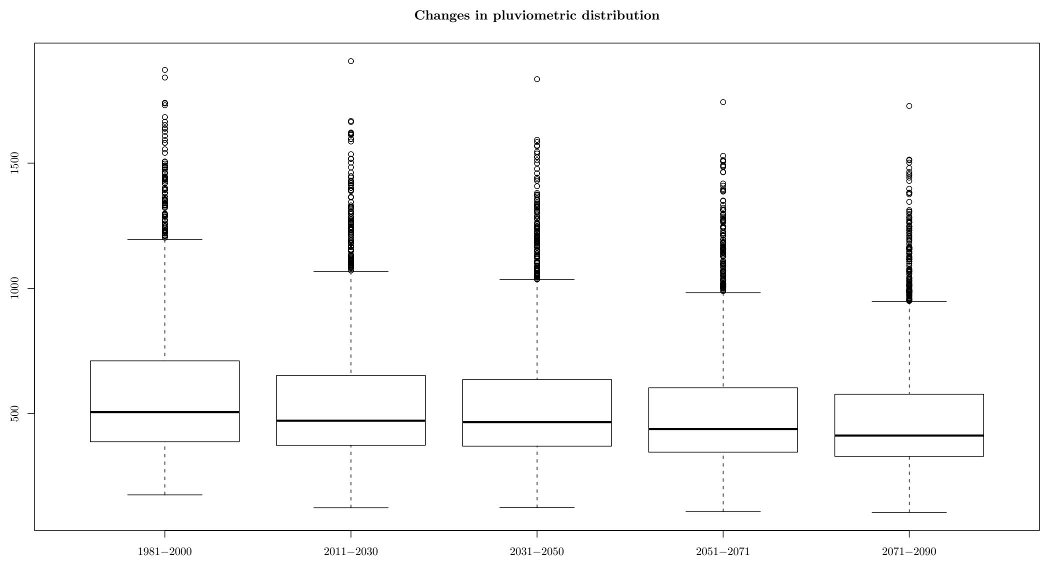

Figure 8: Boxplot of the Distribution of precipitation in the 1445 gridpoints for the validation period (1981–2000) and for the four 20-year predicted periods: 2011–2030; 2031–2050; 2051–2070; 2071–2090.

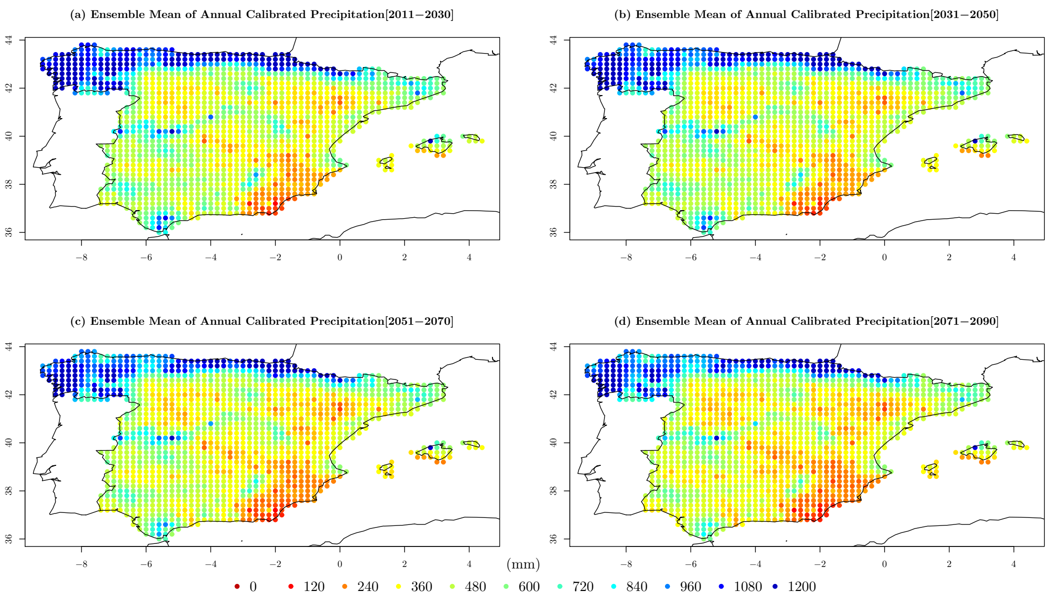

Figure 9: Ensemble Mean of annual precipitation for the 4 predicted 20-year periods (2011–2030 (a); 2031–2050 (b); 2051–2070 (c); 2071–2090 (d)).

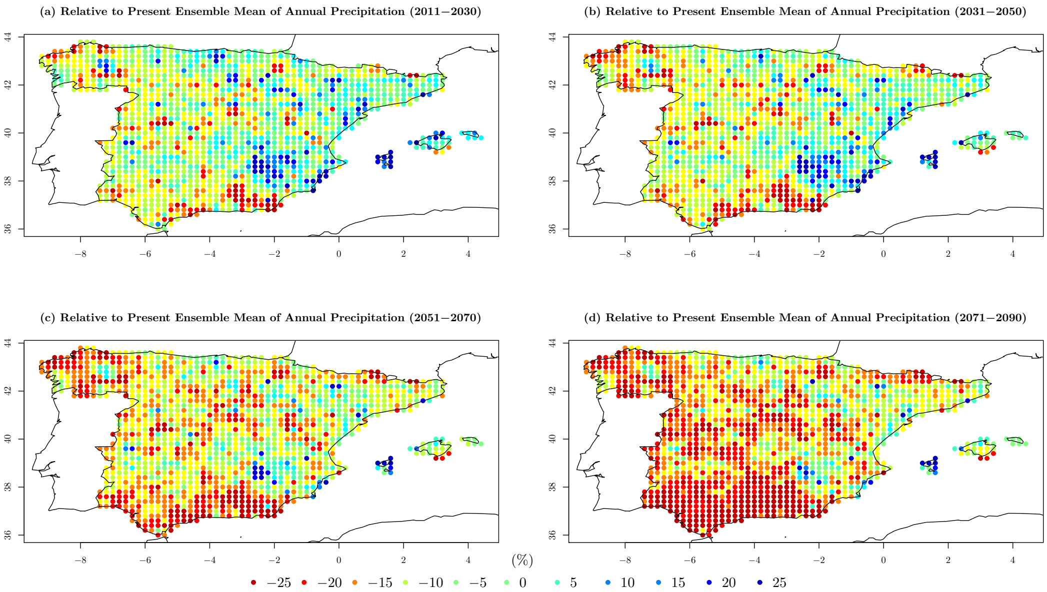

Figure 10: Relative to Present Ensemble Mean of annual precipitation for the 4 predicted 20-year periods (2011–2030 (a); 2031–2050 (b); 2051–2070 (c); 2071–2090 (d)).

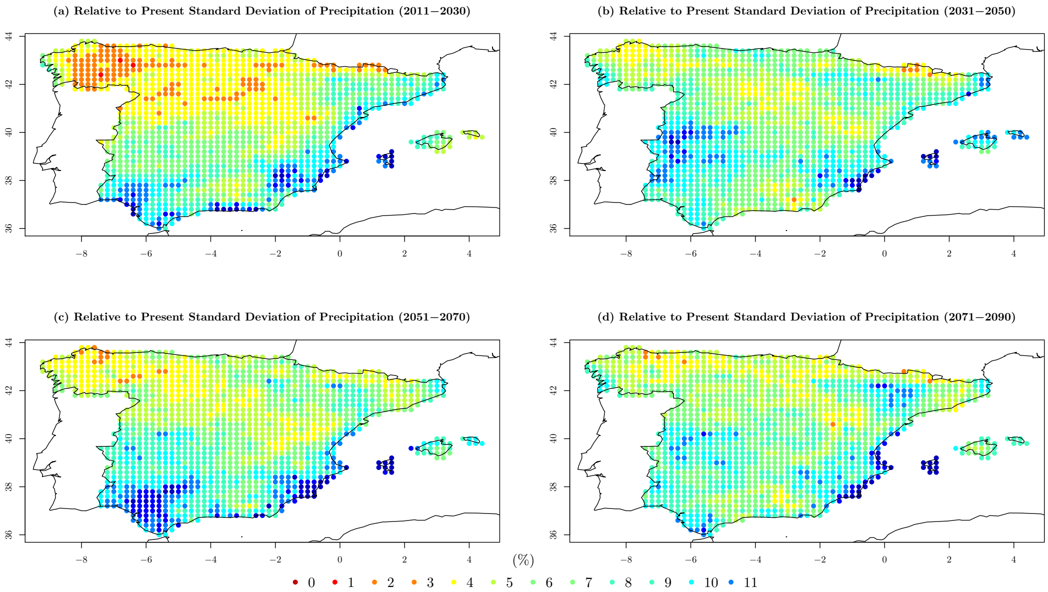

Figure 11: Relative to Present Standard Deviation of precipitation among the 12 RCMs for the 4 predicted 20-year periods (2011–2030 (a); 2031–2050 (b); 2051–2070 (c); 2071–2090 (d)).

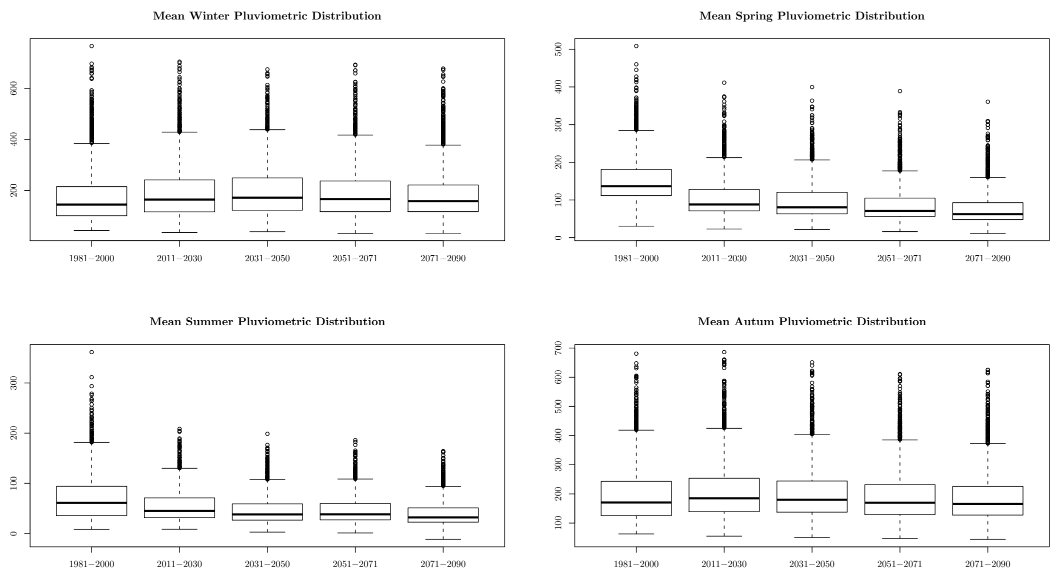

Figure 12: Distribution of Ensemble Mean of annual precipitation in all gridpoints, for 4 seasons (winter (a); spring(b); summer (c); autum (d)) during present days (1981–2000) and for the four 20-year predicted date.

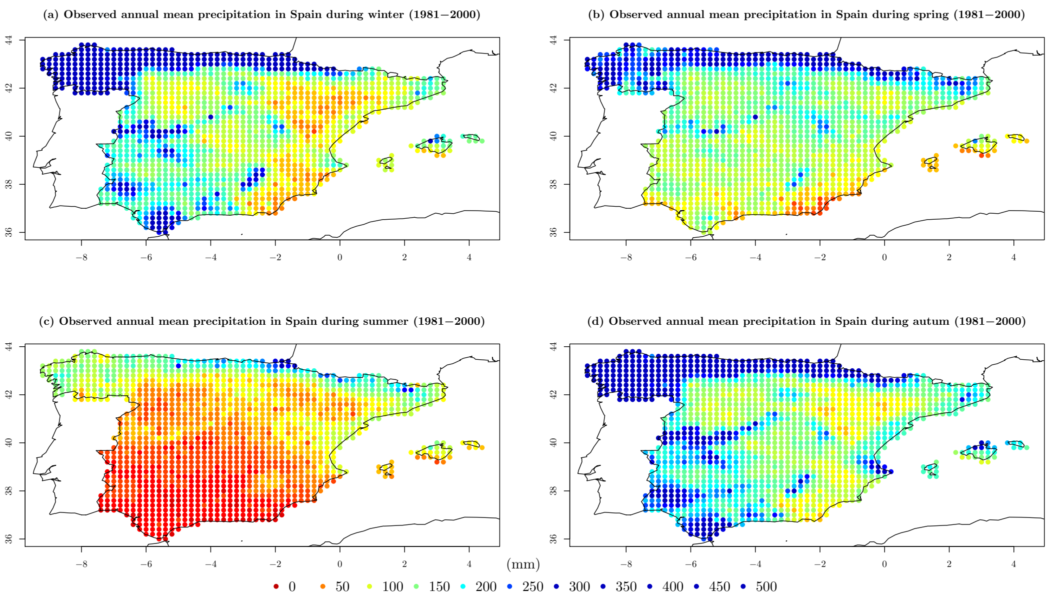

Figure 13: Observed annual mean precipitation in Spain during the 4 seasons of the validating period (winter (a); spring(b); summer (c); autum (d)).

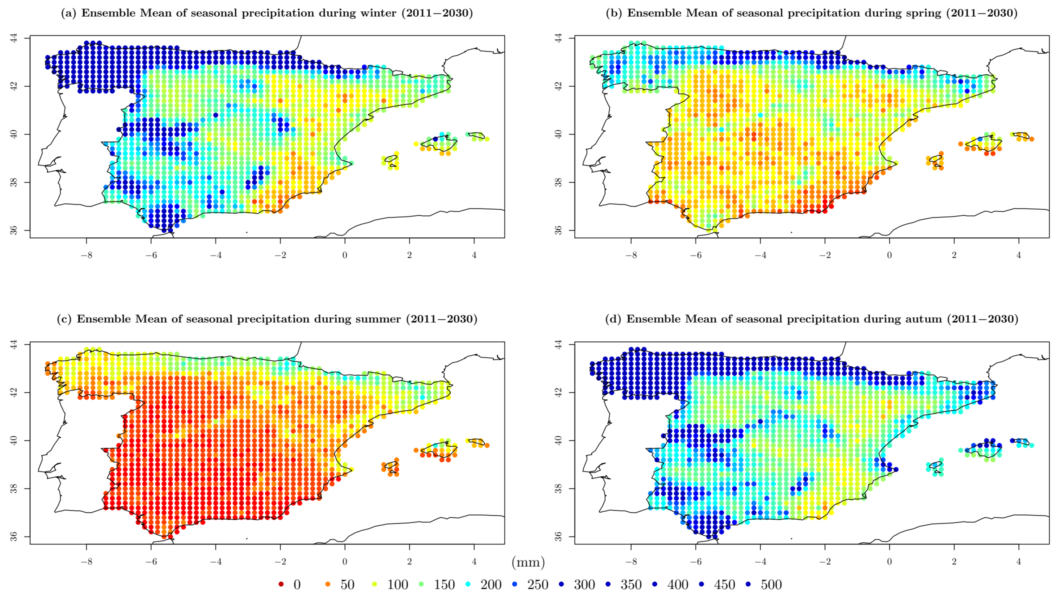

Figure 14: Absolute values of Ensemble Mean of annual precipitation during the 4 seasons for the predicted period of 2011–2030

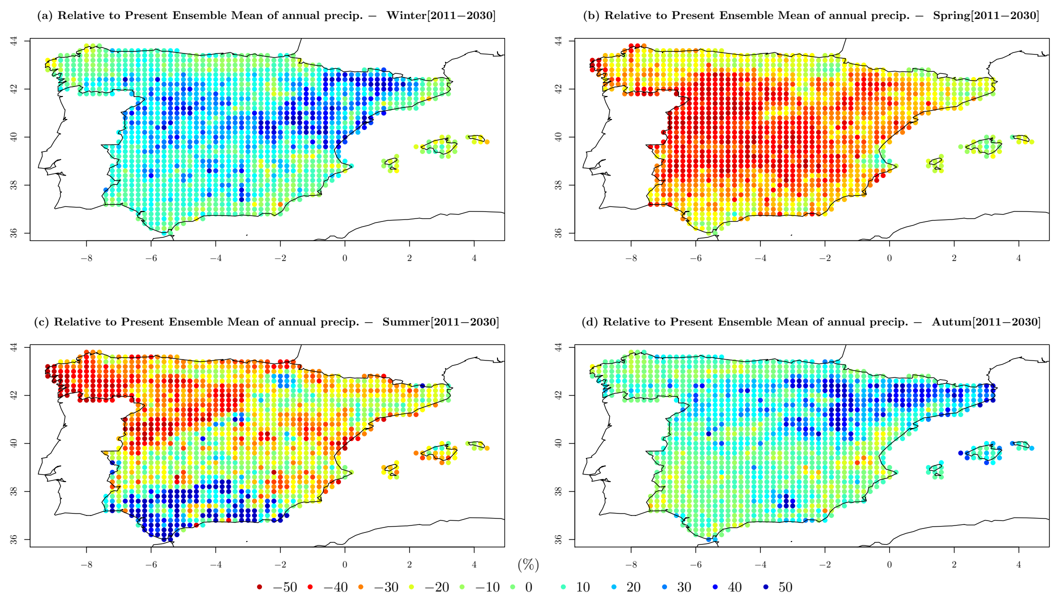

Figure 15: Relative to Present Ensemble Mean of annual precipitation during the 4 seasons for the predicted period of 2011–2030.

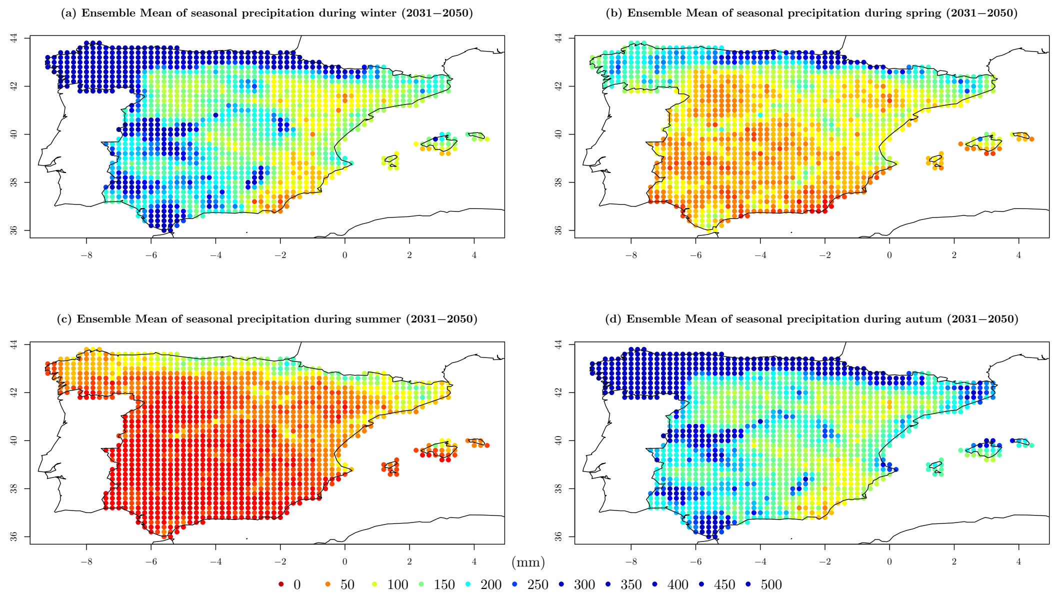

Figure 16: Ensemble Mean of seasonal precipitation during the 4 seasons for the predicted period of 2031–2050

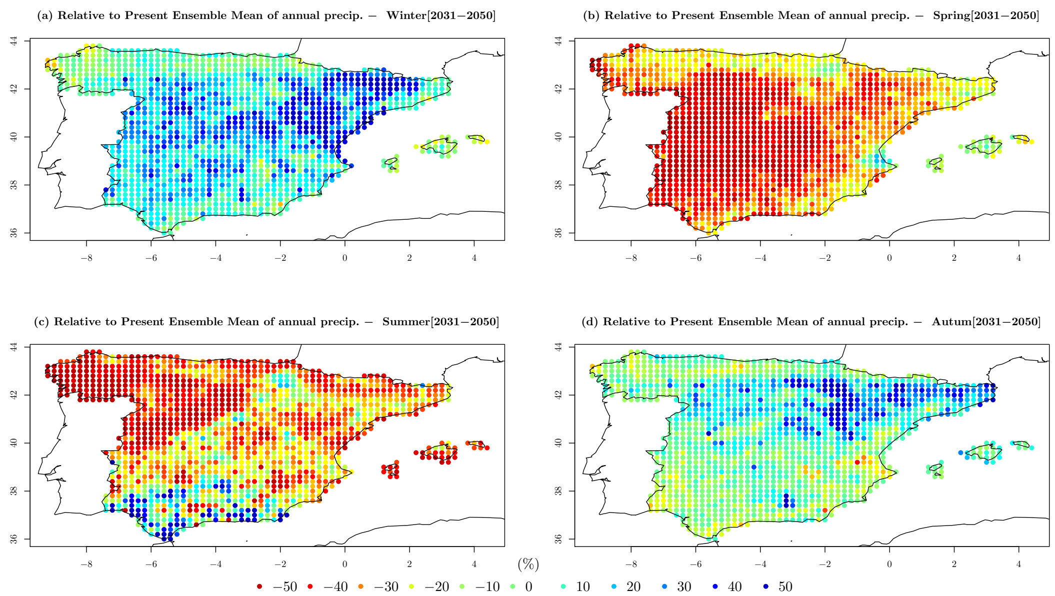

Figure 17: Relative to Present Ensemble Mean of annual precipitation during the 4 seasons for the predicted period of 2031–2050.

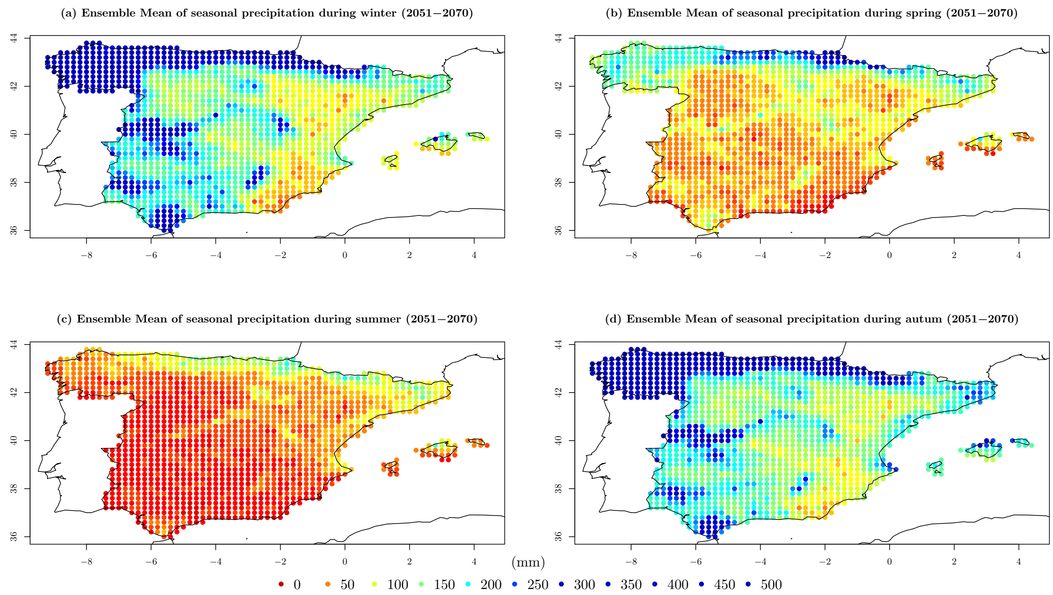

Figure 18: Ensemble Mean of seasonal precipitation during the 4 seasons for the predicted period of 2051–2070

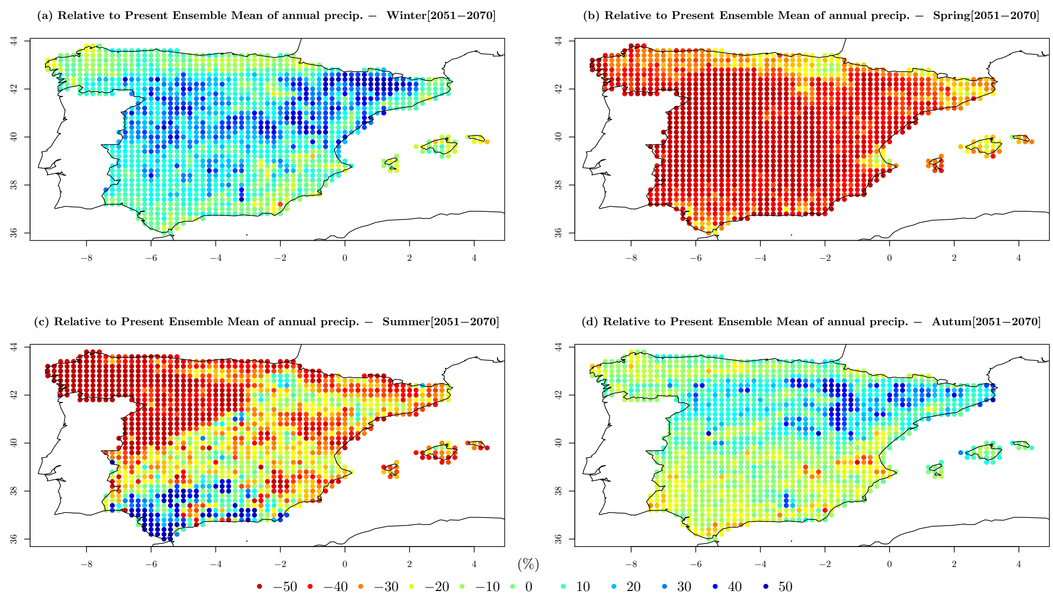

Figure 19: Relative to Present Ensemble Mean of annual precipitation during the 4 seasons for the predicted period of 2051–2070.

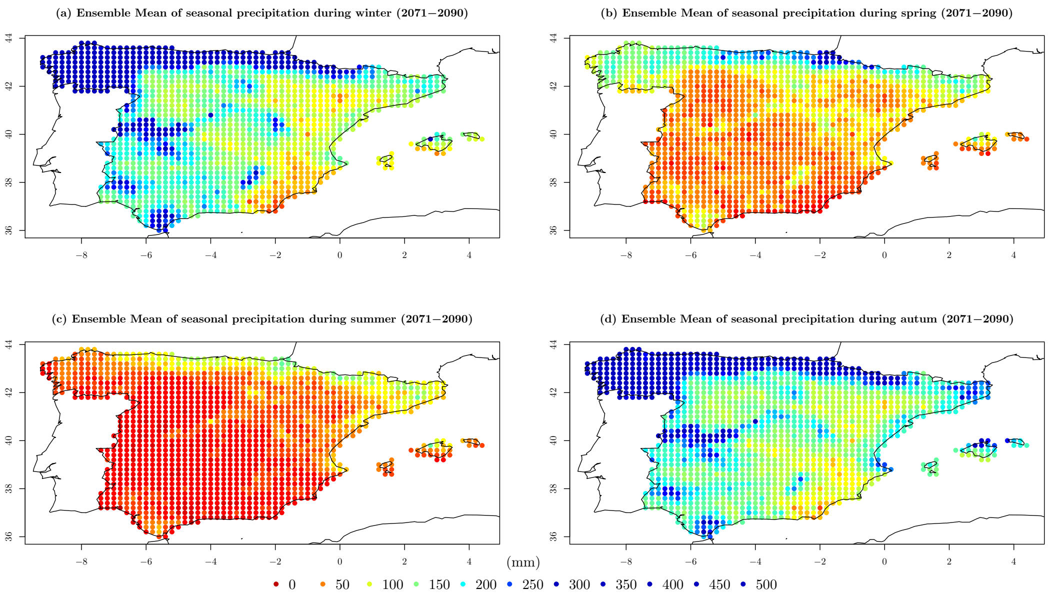

Figure 20: Ensemble Mean of seasonal precipitation during the 4 seasons for the predicted period of 2071–2090

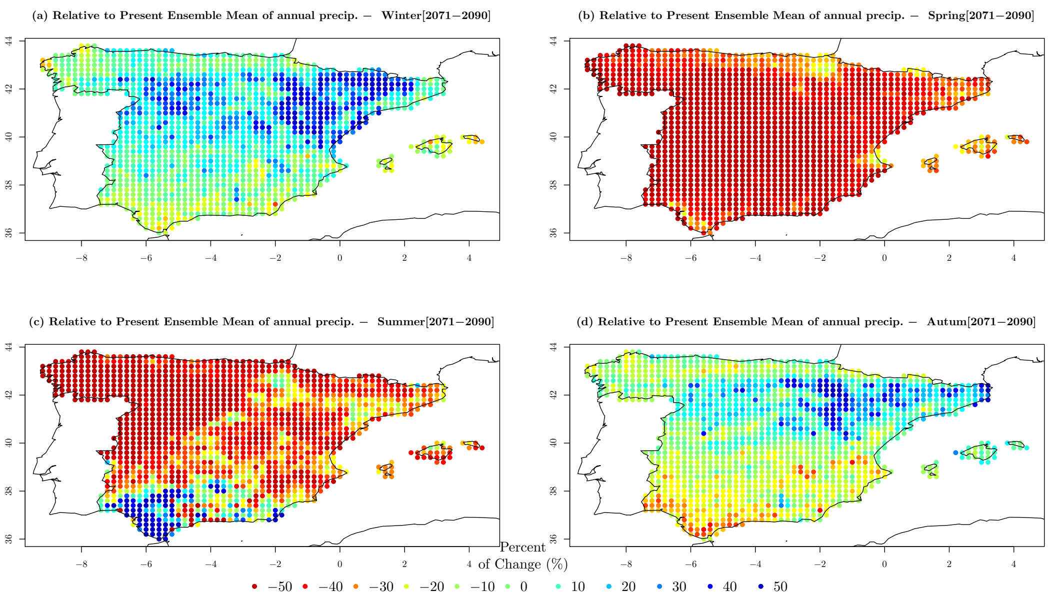

Figure 21: Relative to Present Ensemble Mean of annual precipitation during the 4 seasons for the predicted period of 2071–2090.

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