Article

Quantification of the expected changes in annual maximum daily precipitation quantiles under climate change in the Iberian Peninsula

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Abstract: Climate model projections can be used to assess the expected behaviour of extreme precipitations in the future due to climate change. In Europe, the EURO-CORDEX project provides precipitation projections in the future under various representative concentration pathways (RCP), through regionalised Global Climate Model (GCM) outputs by a set of Regional Climate Models (RCM). In this work, 12 combinations of GCM and RCM under two scenarios (RCP 4.5 and RCP 8.5) supplied by the EURO-CORDEX programme are analysed in the Iberian Peninsula. Precipitation quantiles for a set of probabilities of non-exceedance are estimated by using the Generalized Extreme Value (GEV) distribution and L-moments. Precipitation quantiles expected in the future are compared with the precipitation quantiles in the control period, for each climate model. An approach based on Monte Carlo simulations is developed, in order to assess the uncertainty from the climate model projections. Expected changes in the future are compared with the sampling uncertainty in the control period. Thus, statistical significant changes are identified. The higher the significance threshold, the fewer cells with significant changes are identified. Consequently, a set of maps are obtained for various thresholds, in order to assist the decision making process in subsequent climate change studies.

Keywords: Precipitation; Climate Change; EURO-CORDEX; Uncertainty; Iberian Peninsula;

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1. Introduction

Currently, there is a general concern about how climate will change in the future. The society and the ecosystems around it are vulnerable to any changes in the frequency and intensity of extreme events, such as heat waves, heavy precipitation, droughts, or wind storms, among others, as seen in recent years [1]. Possible changes in the climate will manifest locally via changes in regional weather patterns, amplifying the frequency or the magnitude of extreme events.

How the climate will behave in the future can be assessed through the use of Global Climate Model (GCM) outputs. GCMs are simplified representations of the Earth's climate system that allow us to know the possible evolution of climate in the future, as well as to study the effect of changes in a set of forcing variables, such as greenhouse emissions. To overcome the gross spatial resolution of GCM, Regional Climate Models (RCM), focus on some regions of the world, are used to simulate the climate behaviour at a higher spatial resolution.

Since the idea of dynamical downscaling, several RCMs have been developed, improved, and applied throughout the world to produce high-resolution climate information under potential future scenarios for a range of impacts studies [2]. The most recent RCMs, have a spatial resolution of 0.11°, that has been proved as appropiatelly enough to both represent the orography and capture the interaction of atmosphere flow and surface, making it ideal for regions with substantial orographic features [3, 4].

Given its high potential impact, further studies were devoted to assess the future behavior of extreme precipitations [1, 5-7]. However, most of them are conducted at an European scale, or focused on specific areas of interest. In the Iberian Península, few studies can be found [8, 9]. A general agreement about a decrease in average rainfalls [10] together with an increase in extreme events is found from previous studies. However, the results do not agree neither on the extent of the change nor the spatial distributions of such changes.

This paper offers a new approach to study the effect of climate change on extreme precipitations in the Iberian Peninsula in the future. In addition, it seeks to add conclusive results, statistically based, about the expected change in maximum daily precipitation. Future climate scenarios are based on the Fifth IPCC Assessment Report (AR5) on climate change that considers four Representative Concentration Pathways (RCP), depending on the total radiative forcing at 2100: 2.6, 4.5, 6.0 and 8.5. Findings of this study can be very useful for subsequent climate change studies, showing relevant results to decision makers.

2. Base data

Data used in this study is supplied by the CORDEX project, from the regionalization of GCMs, through a set of RCMs. Model realizations follow the guidelines of the AR5. The region of interest in this study is Europe (EURO-CORDEX; [11]), as it is the only region that includes the entire Iberian Peninsula.

Precipitation time series under climate change scenarios are available freely at any of the European datanodes. Outputs of the RCMs are supplied by cells with different spatial resolution and different RCPs. In this study, the finest spatial resolution (0.11° ~ 12.5 km) and daily time resolution is selected, both for the control (1951-2005 or 1971-2005, depending on the model) and future (2006-2100) periods. RCP 4.5 and RCP 8.5 emission scenarios are considered. 12 models from the EURO-CORDEX project have been selected.

The study area is the Iberian Peninsula and the Balearic Islands, in the South of Europe. Thus, the European mesh have been clipped to a 10 km radius from the coast (or in the case of northern Spain, from the border) of the studied area. This new area includes 4293 cells of the total mesh of Europe.

3. Methodology

3.1. Annual Maximum Series

Climate models supply daily precipitation series. Annual maximum series (AMS) of daily precipitations have been extracted, both in control and future periods. Three time intervals in the future period have been considered: 2011-2040, 2041-2070, and 2071-2095. Thus, two AMS of 30 years and one of 25 yearsfrom the future period, as well as one of 54 or 34 years (depending on the model) from the control period have been obtained.

Precipitation quantiles for a set of probabilities of non exceedance (termed as return periods in years) can be estimated by fitting a frequency distribution to the AMS. Seven return periods (2, 5, 10, 50, 100, 500 and 1000 years) were selected as representative probabilities for civil engineering design purposes as sewage systems, culverts or dams. Then, the precipitation depth for a given return period has been determined by the Generalized Extreme Value (GEV) distribution function fitted to the series through the L-moments method. The use of the three-parameter GEV function ensures to capture the behaviour of the right tail of the distribution adequately.

From both sets of precipitation quantiles, in the control and future periods, the relative differences (Δ) between them have been obtained, calculated for each model, cell, emission scenario and return period, following the equation 1. Consequently, possible systematic biases of the climate models can be overcome.

$$\Delta = \left(\frac{Q_{fut}(T) - Q_{con}(T)}{Q_{con}(T)}\right) \quad (1)$$

being $Q_{con}\,(T)$ and $Q_{fut}(T)$ the precipitation quantile for the T-year return period in the control and future periods, respectively.

After the process, a set of 12 relative differences, or deltas, for each climate model are obtained at each period and emission scenario. The 50 (median), 68 and 90 percentiles were selected to show the general change trend in maximum precipitations over the Iberian Peninsula. In order to present the results visually, a smoothing procedure was adopted, consisting of interpolating linearly the deltas from the initial grid to a new finner grid of 5 km.

3.2. Uncertainty Analysis

Quantile estimates from a distribution function for a given probability entail a range of variability, or uncertainty, around the calculated value. Uncertainty analyses try to quantify such range, which is useful to establish thresholds for which a possible change in the future can be included inside "natural" variability or not.

To obtain this range, a set of 1000 random series with values between 0 and 1, assimilated to probabilities, of three different lengths, two of 30 and one of 25 values, were generated for each cell and model. The lengths of the periods in the future were considered, as the uncertainty in the precipitation in the future is quantified. The probabilities were transformed into precipitation valuesby using the GEV function fitted to the control period. Consequently, a new set of 1000 GEV distribution functions were obtained, for each cell and model. The range of variability for each return period was quantified.

If the precipitation quantile in the future were outside the two-sided threshold, the change is considered significant. Therefore, such change can be considered due to climate change. In order to identify the significance of the change, a threshold needs to be selected. In addition, the number of models that confirm a significant change in the future needs to be determined. Thus, different combinations of both thresholds were considered to see how the change in precipitacion varies over the study area.

With the thresholds selected, the median of the changes defined by equation 1 for all models shows the possible change in the future in those cells where the change is significant, and the number of models is appropriate. The reason of chossing all the models is their equiprobability. Despite the fact that just some of them have a significant change, none of them can be removed because of their equal probability of occurrence.

4. Results

4.1. Future projections

Raw projections of annual maximum daily precipitations give a general view of what is the general trend expected in the future. The median (percentile 50) offers an average change over the models that explains the change that is expected to occur. Meanwhile, higher percentiles, specially the 90th percentile, show the areas where there may occur larger changes. As an example, in Figure 1, the change in the middle future period (2041-2070) for the 100-year return period precipitation is presented through the 50^{th} , 68^{th} and 90^{th} percentiles.

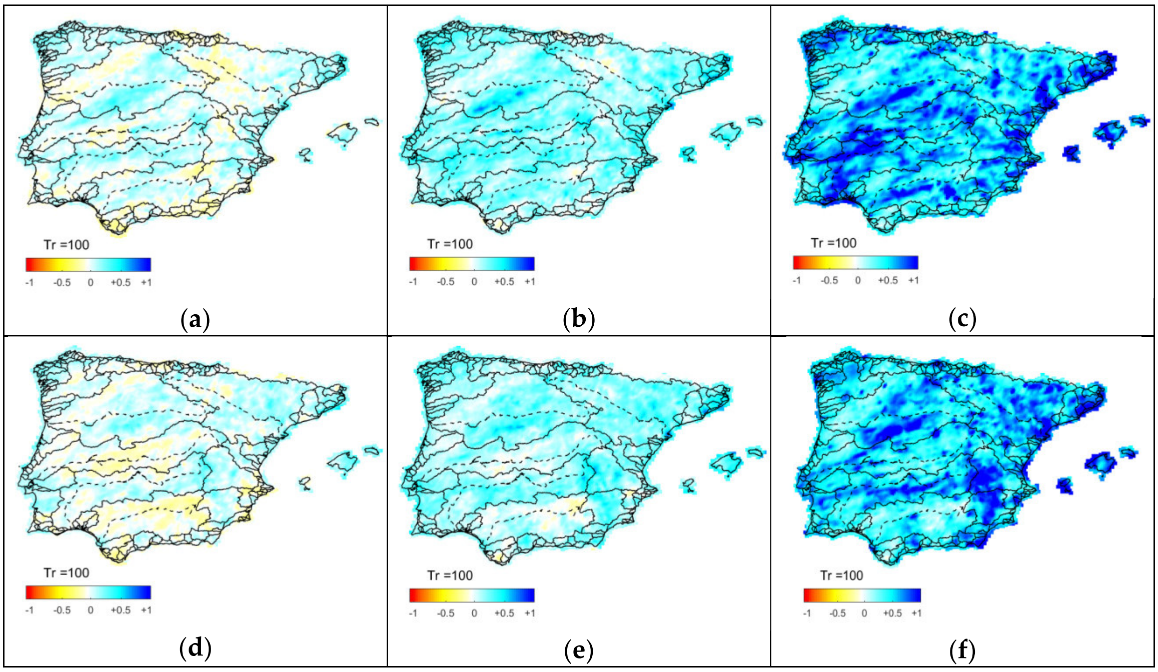

Figure 1. Relative changes in the 100-year return period maximum daily precipitation for percentiles of 50% (a-d), 68% (b-e) and 90% (c-f), for the future time interval 2041-2070, with the RCP 4.5 in the first row and RCP 8.5 in the second row. The bar in the lower left corner indicates the relative difference between control and future intervals.

4.2. Assessment of the uncertainty thresholds

Searching for the appropriate significance thresholds, both the two-sided significance threshold and the minimum number of models with change were analysed (Figure 2), plotting the average percentage of cells per model vs the significance threshold (draw in the figure as one-side limit). The 100-year return period precipitation in the future period 2041-2070 was selected. The results for other return periods and periods are also available. Both emission scenarios, RCP 4.5 in Figure 2.a and RCP 8.5 in Figure 2.b, were considered. For each graph, several distributions that represent the minimum number of models (N) with change can be seen.

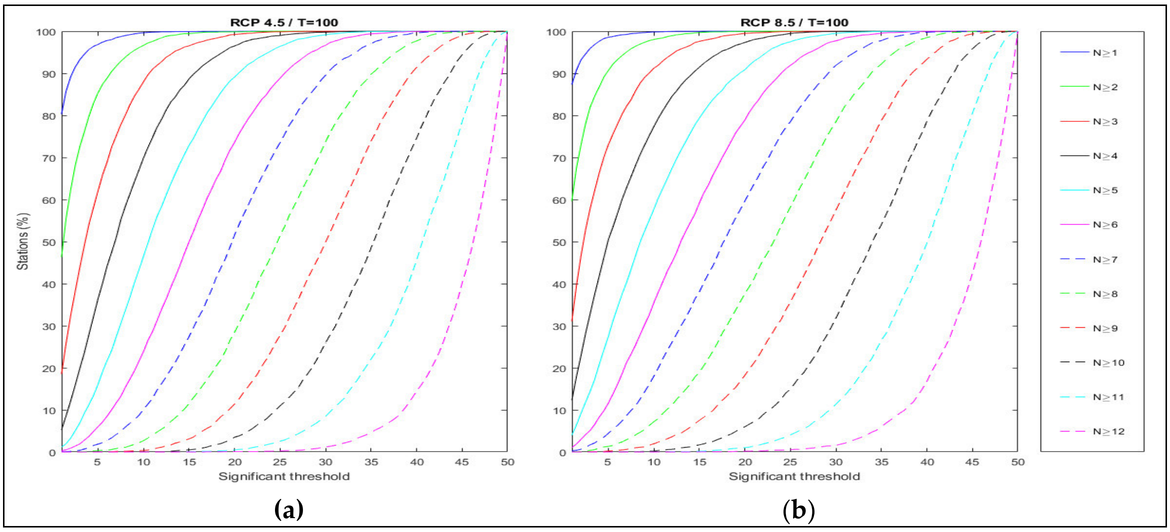

Figure 2. Distribution of the average percentage of cells per model vs threshold of significance for the 100-year return period precipitation in the future time interval 2041-2070 for RCP 4.5 (a) and RCP 8.5 (b). Each curve represent a minimum number of models with significant change (from N≥1 to N≥12). The significance threshold shown in the x-axis represents the one-side threshold. However, the output corresponds to the significance considering both sides.

4.3. Spatial distribution of significant changes

Spatial distribution of cells with significant change for various thresholds were outlined in Figure 3, in order to explore further about the selection of the significant thresholds. A minimum number of models with change equal to six (at least the half of the models) was selected, as showing all the thresholds is impractical. Following the previous analyses, the 100-year return period precipitation, in the future period 2041-2070 was selected. Three thresholds of interest were used(5, 10 and 20% two-sided significant thresholds). In order to present the results, the same smoothing procedure used in Section 4.1 was adopted.

As expected, the higher the threshold, the more amount of cells are significant. Furthermore, following results of Figure 2, RCP 8.5 have quite more significant cells than RCP 4.5, for all thresholds. In general, despite some zones, both scenarios present similar areas of change, reaching changes of about 50% in both directions. However, RCP 8.5 shows more areas with negative changes than RCP 4.5, specially in the middle areas of Tagus and Guadalquivir river basins. Finally, it is interesting to see how significant descreasing changes do not arise until the 20% threshold is seleceted in both emission scenarios.

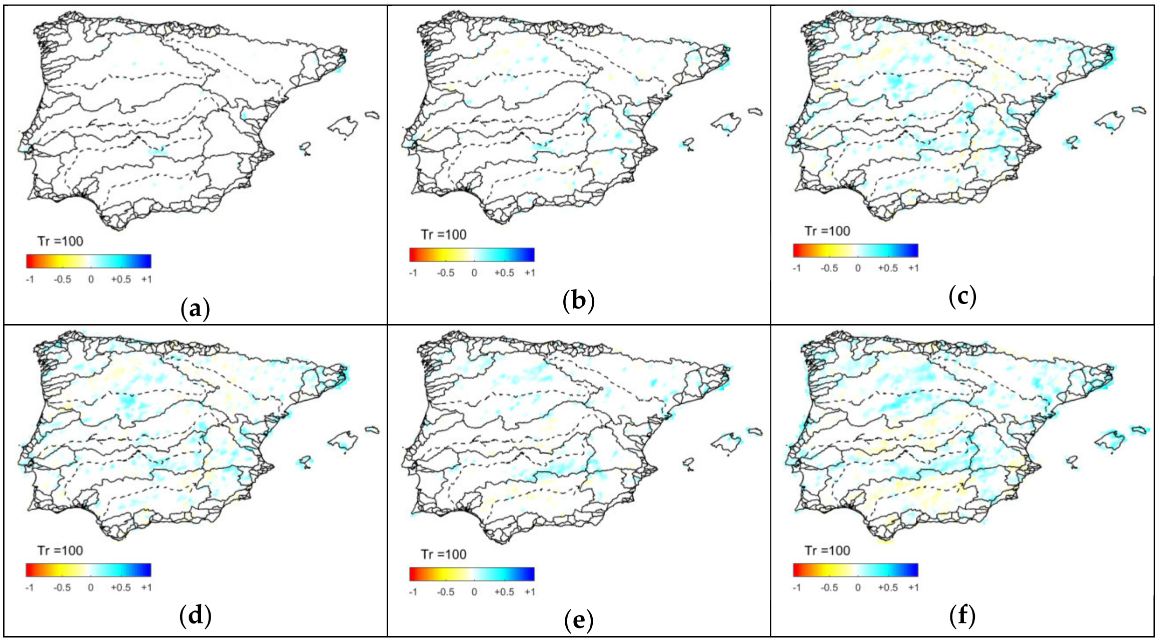

Figure 3. Spatial distribution of significant changes in the 100-year precipitation quantile with a significant two-sided threshold of 5% (a,d), 10% (b,e) and 20% (c, f), with a minimum number of six models with significant change in the future period 2041-2070, for RCP 4.5 in the first row and RCP 8.5 in the second row.

5. Discussion and Conclusions

5.1. Uncertainty thresholds

Results show the difficulty in selecting a threshold, both for significance values and minimum number of models. Both scenarios behave in a similar way, and the equidistancy between the distributions of the minimum number of models, make the election hard.

Regarding the minimum number of models (N), a general option may be to select at least the half of the total number of models (in this case N≥6). This was the decision taken in this study. A higher threshold, especially more than eight models, leads to a high significance threshold to obtain change values.

The choice of the significant threshold depends on the scientific rigor required. A threshold of 1% means there are no cells with change, so higher thresholds must be chosen. As Figure 3 shows, some areas can be identified with a threshold of 5%. However, most of the changes come from a single cell with change. This result shows a common problem of this type of studies, the 'island effect'. Individual cells without any other cell with change around it makes it difficult to trust that there is a change in that local area, since changes should occur across a larger region, and not locally. Consequently,caution should be exercise when obtaining conclusions about such cells.

5.2. Significant changes in models projections

A general assessment over all return periods could be confusing, as they show differing areas with change. Therefore, the 100-year precipitation quantile in the future period 2041-2070 is considered in the discussion. From Figure 3, some conclusions can be obtained. Areas with positive change in both scenarios are the upper part of Guadiana river basin, the central part of Duoro river basin and some specific areas of the Mediterranean coast. On the other hand, negative changes can be found in RCP 8.5 in the Tagus river basin and southest Spain. This last trend agrees with findings of [8]. Nevertheless, results of this paper show many more areas with positive change in that region.

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