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Abstract: During the last decades, extreme precipitation events have been the target of numerous studies all over the world, particularly to evaluate their eventual changes under the possible range of climate change scenarios with consequences on human society. As such, there is a growing need for a more detailed knowledge of precipitation climate change. To address this, the study performed here presents a spatial and temporal analysis based in the trends of extreme precipitation indices, over the Iberian Peninsula (IP) and from 1986 to 2005. This is considered as reference period by the Intergovernmental Panel on Climate Change (IPCC) to evaluate recent climate change. Simulations were performed using the Weather Research and Forecast (WRF) model, which was forced by the MPI-ESM-LR, because it is considered to be one of the best overall global climate models in simulating the European climate. To evaluate the MPI results, WRF was also forced by the ERA-Interim reanalysis, for the same region and period analysed. With a horizontal resolution of 9 km, both of daily precipitation simulations were used to calculate the extreme precipitation indices recommended by Expert Team for Climate Change Detection Monitoring and Indices (ETCCDMI). Then, annual and seasonal trends of the indices were computed together with their statistical significance. The main results indicate an increase of Consecutive Dry Days (CDD), mainly in the south of the Iberian Peninsula, for both simulations, and no statistically significant trends of Consecutive Wet Day (CWD). The annual spatial trend of R75p (number of days when the precipitation is above the 75th percentile) reveals a negative trend (more intense in MPI-driven simulation), mainly in the northeast of the Iberian Peninsula. The R95TOT, which is the precipitation fraction due to R95p, indicate an increase in the ERA-driven simulation and decrease in the MPI-driven simulation, in the annual analysis.

Highlights

- Daily precipitation simulations forced by MPI-ESM-LR and ERA-Interim
- Recent climate change analysis (from 1986 to 2005) over the Iberian Peninsula
- Low statistically significant trends in consecutive wet day
- Increase of consecutive dry days, mainly in the south
- Decrease of number of days when the precipitation is above the 75th percentile

Recent climate change trends of extreme precipitation in the Iberian Peninsula

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Abstract

During the last decades, extreme precipitation events have been the target of numerous studies all over the world, particularly to evaluate their eventual changes under the possible range of climate change scenarios with consequences on human society. As such, there is a growing need for a more detailed knowledge of precipitation climate change. To address this, the study performed here presents a spatial and temporal analysis based in the trends of extreme precipitation indices, over the Iberian Peninsula (IP) and from 1986 to 2005. This is considered as reference period by the Intergovernmental Panel on Climate Change (IPCC) to evaluate recent climate change. Simulations were performed using the Weather Research and Forecast (WRF) model, which was forced by the MPI-ESM-LR, because it is considered to be one of the best overall global climate models in simulating the European climate. To evaluate the MPI results, WRF was also forced by the ERA-Interim reanalysis, for the same region and period analysed. With a horizontal resolution of 9 km, both of daily precipitation simulations were used to calculate the extreme precipitation indices recommended by Expert Team for Climate Change Detection Monitoring and Indices (ETCCDMI). Then, annual and seasonal trends of the indices were computed together with their statistical significance. The main results indicate an increase of Consecutive Dry Days (CDD), mainly in the south of the Iberian Peninsula, for both simulations, and no statistically significant trends of Consecutive Wet Day (CWD). The annual spatial trend of R75p (number of days when the precipitation is above the 75th percentile) reveals a negative trend (more intense in MPI-driven simulation), mainly in the northeast of the Iberian Peninsula. The R95TOT, which is the precipitation fraction due to R95p, indicate an increase in the ERA-driven simulation and decrease in the MPI-driven simulation, in the annual analysis.

Keywords: Recent climate change, Extreme precipitation events, Iberian Peninsula, MPI, ERA-Interim

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Introduction

Trends in extreme weather and climate events have been receiving increasing attention because they are likely to affect human society and natural environment (Kogan, 1995; Karl and Easterling, 1999; Easterling, 2000; Kundzewicz et al., 2014) more profoundly than the changes in the mean climate (Katz and Brown, 1992; Groisman et al., 1999). Since 1950, a significant portion of the global land area has been increasingly affected by a significant change in climatic extremes (Frich et al., 2002; IPCC, 2012) with a decrease of precipitation in subtropical areas and an intensification of extremes (Trenberth, 2011). Although some regions have experienced a trend towards more intense and longer droughts, particularly southern Europe and West Africa; in other regions, such as central North America and north-western Australia, droughts have become less frequent, less intense, or shorter. The clear signs of change are very robust, although, large areas are still not represented, especially South America (Frich et al., 2002).

Precipitation is highly variable, in space and time, in the Iberian Peninsula (IP) (Fernández-Mills, 1995; Rodríguez-Puebla et al., 1998; Esteban-Parra et al., 1998) due to the wide geographic diversity and its diverse atmospheric circulation patterns. The North Atlantic Oscillation (NAO) is

one of the most important mechanisms associated for this variability (Rodríguez-Puebla et al., 1998, Trigo et al., 2002), especially in the winter, when this pattern is more active (Hurrell et al., 2003, Vicente-Serrano et al., 2011). As such, the extreme precipitation events in the IP are usually associated with low pressure systems with Atlantic origin (Haylock and Goodess, 2004), although some extreme events in summer or autumn can be related to Mediterranean low pressure systems (Ramos et al., 2015). During the winter, in the IP, a large number of precipitation events travel predominantly along the North Atlantic, or through the Azores-Mediterranean axis. These are associated with low-pressure systems which do not cross directly over the IP (Trigo, 2006). However, it should be noted that most well developed extratropical cyclones often reach up to 2000 km in diameter, and that the frontal precipitation associated with extratropical cyclone travel cyclone precipitation represents the main source of the total precipitation (Hawcroft et al., 2012).

The analysis of the extreme precipitation depends on the available dataset and the goal of the study. Depending on that, different methods can be adopted. In recent years, a large amount of the scientific literature on the analysis of climate extremes has been based on the use of "extreme indices", which can either be based on the probability of occurrence of given quantities or on threshold exceedances (Seneviratne et al., 2012), such as the number, percentage, or fraction of days, generally defined for given time frames (days, month, season, annual) with respect to a reference time period. One of the advantages of using the predefined extreme indices recommended by the *Expert Team on Climate Change Detection and Indices* (http://cccma.seos.uvic.ca/etccdi) is that it allows a comparison between modelling and observational studies, and across regions.

Understanding the spatial and temporal variability of these precipitation extreme indices and their association with atmospheric processes could help to project the frequency and severity of extremes. These indices have been widely used to analyse extreme precipitation, at local, regional and global scales, and to undertake trend analyses on daily precipitation indices worldwide e. g., over Central and South America (Aguilar et al., 2005), Europe (Moberg and Jones, 2005; Hidalgo-Muñoz et al., 2011; Casanueva et al., 2014), IP (Lana et al., 2004 and 2006; Casas et al., 2007; Rodrigo and Trigo, 2007; Vicente-Serrano et al., 2007; López-Moreno et al., 2010), the Mediterranean region (Norrant and Douguédroit, 2006), Italy (Brunetti et al., 2000), Portugal (Costa and Soares, 2008; Lima et al., 2014) and Spain (Turco and Llasat, 2011).

Extreme precipitation indices have been computed for the IP using data from observatories, e. g., Rodrigo and Trigo (2007); López-Moreno et al. (2010); Acero et al. (2012); Lima et al. (2014). In generally, the trends of the extreme precipitation indices for the Iberian Peninsula indicate a decrease on the daily intensity of rainfall, no significant changes in the number of wet days and an increase of dry day, especially in the south of the IP. Most authors concluded that the changes in precipitation and derived extreme indices were associated with climate dynamics to interpret the opposite trend found over different European regions. The trend of the indices was linked with the data source and most studies use observations data set. The main disadvantage using observations was the grid, which was not regular.

Recently, the knowledge of climate variability and climate change has increased, due to the new generation of state-of-the-art Global Climate Models (GCMs), which provide simulations for the 20th century and projections for the 21st century, for a regular grid. For instance, the Coupled Model Intercomparison Project Phase 5 (CMIP5) (Taylor et al., 2012) includes more comprehensive global climate models, with a new set of emission scenarios called Representative Concentration Pathways (RCPs) (Moss et al., 2010) and with a spatial resolution that helps to address different scientific questions. However, even though they

provide useful information, the low resolution of GCMs is not enough to evaluate the climate changes at a regional or local scale. Nonetheless, GCMs can be dynamically downscaled in order to obtain Regional Climate Models (RCM), whose main purpose is to produce climate information at regional resolutions. The higher spatial resolution of the RCMs allows a more detailed representation of topography, vegetation cover, land-sea contrasts and the implementation of a more detailed small-scale physical process.

According to Brands et al. (2013), the Max Planck Institute Earth System Model at base resolution (MPI-ESM-LR) is one of the best models at simulating the climate in Europe, for the temperature. Therefore, the MPI-ESM-LR was used in this study to force the regional model – the Weather Research and Forecasting (WRF) model (Skamarock, 2008). This weather model was designed for research and operational applications at the mesoscale. Therefore, extreme precipitation events were studied, in order to evaluate their eventual changes and with a more detailed knowledge of precipitation climate change.

In short, the aim of this study is analyse the evolution of extreme precipitation events over the IP, between 1986 and 2005. For that, two simulations were used (MPI-driven and ERA-driven simulations) to computed annual and seasonal extreme precipitation indices. The structure of the paper is as follows: the data and methods used to run the model and analyze its output are described in Section 2; the results obtained for the trends in multi-day rainfall are presented and discussed in Section 3; and finally the conclusions of this study are exposed in Section 4.

Data

Daily simulations of accumulated precipitation were performed using the Weather Research and Forecast (WRF) model. The initial and boundary conditions were applied by using the MPI-ESM-LR (with the r1i1p1 initialization), with a horizontal resolution of 200 km x 200 km and a time step of six hours. To validate these results, a second simulation with the WRF forced by the ERA-Interim reanalysis (ERA) was performed. It is one of the most recent reanalysis available from the European Centre for Medium-Range Weather Forecasts (ECMWF), with a horizontal resolution of 0.75° x 0.75° and a time sampling interval of six hours. The study was focused on the -recent past climate of the 20 years between 1986 and 2005, which is considered the reference period by the Intergovernmental Panel on Climate Change (IPCC) to evaluate recent climate change. The spatial domain covers the IP, delimited by latitude and longitude of range 33.2219°N - 45.3575°N and 11.8057°W - 5.4642°E, respectively, and the model's output was obtained with a horizontal resolution of 9 km x 9 km (rotated grid). This area is characterized by the high land-ocean contrast, with the influence of the Atlantic Ocean and the Mediterranean Sea, which, combined with the topography, are responsible for the climate in the study area (Lima et al., 2014). According to the classification of Martín-Vide and Olcina (2001), the climate types over the IP are Oceanic and Mediterranean.

The spatial variability of IP rainfall is such that some regions receive precipitation of more than 3,000 mm/year, while others, in the southeast for example; receive less than 200 mm on average (Acero et al., 2012), with the predominance of convective precipitation (Tullot, 2000). Although rainfall is generated by different physical processes at different times of year (Llasat and Puigcerver 1997), the intensification of rainfall during the rainy seasons is due to frontal systems coming in from the Atlantic Ocean (Trigo and DaCamara 2000; Santos et al., 2005) which cause persistent rainfall.

Methods

To study the extremes precipitation events during the recent years, an annual and seasonal (Winter – December, January, February; Spring – March, April, May; Summer – June, July, August and Autumn – September, October, November) analysis of the trends of the extreme precipitation indices was performed.

Sixteen indices based on the daily precipitation and recommended by the joint CCI/WCRP-CLIVAR/JCOMM *Expert Team for Climate Change Detection Monitoring and Indices* (ETCCDMI) (Peterson et al., 2001) were calculated (Table 1), for the entire grid of the simulations (MPI-driven and ERA-driven simulations). For each point of the grid, the indices were computed for each year and each season of the 20 years.

The indices are divided in the following classes: Absolute, Threshold, Duration, Percentilebased and other indices (Alexander et al., 2006 Sillmann et al., 2013b). Absolutes indices include the Rx1day and Rx5day which describe the greatest daily accumulated precipitation sum for 1 and 5 day intervals. Frich et al. (2002) used the Rx5day index to evaluate the flooding potential, because consecutive wet days contribute to flood conditions. The threshold indices contain the R10mm (Heavy precipitation days) and the R20mm (Very heavy precipitation days) which count the number of days with accumulated precipitation above 10 and 20 mm, respectively. The CWD (Consecutive wet days) and CDD (Consecutive dry days) indices were include in the duration indices. The CWD represent the greatest number of consecutive days with accumulated precipitation higher than 1 mm, in opposite to CDD which count the number of consecutive days with precipitation lower or equal to 1 mm. The percentile-based indices includes R95p and R99p, which describe the numbers of days with precipitation higher than the 95th, 99th percentile calculated for the wet days (based on the reference period). Other indices were all calculated as R75pTOT, R95pTOT and R99pTOT, which correspond to the quotient of precipitation amount on R75p, R95p and R99p and total amount, respectively. The SDII index (simple daily intensity) describes the mean precipitation amount per wet day, while the PRCTOT (total wet-day precipitation) is nothing more than the total annual precipitation on wet days (precipitation above 1 mm). The latter two indices do not fall in any of the categories defined and are not directly associated with extreme precipitation, but are linked to mean values instead. In this study, the R75p indicate the moderate were also calculated, for the same method of R95p or R99p, as well as the Prec90p, representing the 90th percentile of rainday amount.

Annual and seasonal trends were performed using the Theil-Sen regression (Theil, 1950; Sen, 1968). This is a non parametric test, so that any particular distribution was assumed and it is less influenced by outliers. Sen's slope estimates the magnitude of the variable-time relationship by means of a nonlinear procedure.

To evaluate the statistical significance of the extreme precipitation trends, the Mann-Kendal test (Kendall, 1975; Mann, 1945) was applied to all computed trends (MPI-driven and ERA-driven simulations), at a 95% significance level. The Z Kendall's coefficient gives us the significance of the trend, calculated as the median of the set of slopes joining pairs of points. The trends of each index were plotted and over these spatial distribution trends, the significant test was marked with dots representing the grid point where the trend is significantly different from zero at a 95% significance level.

Results

The results of the annual and seasonal trend, for the extreme precipitation indices, are presented in three sections. In order to understand the precipitation distribution over the IP, the mean of the daily precipitation amount was calculated, in the first section. The second section focuses on duration indices' trends of CWD index (Greatest number of consecutive days RR above 1 mm) and CDD index (Greatest number of consecutive days RR below 1 mm). The last section reports the results for the R75p index (Precipitation on moderate days) and the R95pTOT (Precipitation fraction due to R95p) indices. In sections 2 and 3, for the annual analysis, all days of the year were used and the seasonal analysis was produced for winter; spring; summer and autumn.

1.1. Mean precipitation amount

The mean of the daily precipitation was computed for the 1986-2005 period and the results using the MPI-driven and ERA-driven simulations are displayed in Figure 2 (left and right, respectively). The highest annual mean is located in the north (northeast, centre and northwest) of the IP for both simulations; on the other hand the lowest means occurred in the southeast of Spain and north of Africa (Mediterranean coast), in agreement with previously studies using observations, e.g., Rodrigo and Trigo (2007); López-Moreno et al. (2010). Comparing the results for both simulations, the means using the MPI-driven were higher than the means using the ERA-driven simulation. Whereas the maxima of the annual average range from around 10 to 11 mm/day for the MPI-driven simulation, for the ERA-driven simulation they vary from around 7 to 8 mm/day. In particular, these maxima correspond to the north coast of Portugal, north of Spain and Pyrenees. The geography of the study area influences the spatial variability of the climate but also the seasonal variation from the coastal areas to the IP's centre. This seasonal variability can be observed in the results of Figure 2 (bottom). The highest mean precipitation was obtained for the winter, reaching maxima of over 14 mm/day for the MPIdriven simulation, and 10 mm/day for the ERA-driven simulation. Similar patterns can be noted during the spring and autumn, for both simulations, with maxima around 10 mm/day and 8 mm/day, for the MPI-driven and ERA-driven simulations, respectively. As expected, the summer represents the lowest means. However the mean precipitation for the MPI-driven simulation is slightly higher, compared with the ERA-driven, especially in the north of Spain, the Pyrenees and south of France.

Although the annual and seasonal spatial patterns of the MPI-driven simulation generally agree well with the patterns of ERA-driven simulation, the first produces a slight wet bias in the precipitation, compared with the reanalysis. The main differences occur for the north of Portugal and northwest of Spain, for all seasons, and over the centre-south of the IP, especially in winter and spring. Understanding the spatial and seasonal means of the precipitation amount for the study period obtained for the 1986-2005 period by the MPI-driven and ERA-driven simulations and their differences, the trend of the extreme precipitation indices were computed.

1.2. CWD and CDD indices

According to the IPCC (2013), the contrast in precipitation between wet and dry regions and between wet and dry seasons will increase, although there may be regional exceptions. In this section is analysed how much the greatest number of consecutive days with a precipitation amount above and below 1 mm changes, through the trends of the CWD (Figure 3) and CDD (Figure 4) indices, respectively. Figures 3-4 show the annual (top) and seasonal (bottom) trends, for the MPI-driven simulation (left) and the ERA-driven simulation (right). The annual trend of the CWD index reveals a decrease of wet days, with maxima around -0.4 days/year. Nonetheless, the number of the significant trends is low over the entire IP, with some exceptions. Comparing the annual trends for both simulations, highest differences are observed in the northwest of the IP (centre and north of Portugal and northwest of Spain). Whereas the MPI-driven simulation results exhibit positive significant trends (of about 0.3-0.4 days/year), a negative trend (not statistically significant) was found for the ERA-driven simulation.

Similar patterns were obtained for some regions in the Rx1day and Rx5day indices (not show), excepted in this region for annual and seasonal trends. Thus, the greatest consecutive number of wet days probably can be higher than 5 days. In addition, the annual CWD trends are mainly associated with the winter trend (as can be seen in Figure 3), when the probability of the occurrence of wet days is higher. In terms of mean precipitation (Figure 2) the precipitation of

the MPI-driven simulation was higher than the ERA-driven simulations. And, this can be influence the CWD trends and the differences between the two annual trends.

For the ERA-driven seasonal trends, the CWD increased in the northwest of the IP (around 0.2 days/year), for spring and autumn, and decreased in the winter. A large statistically significant region was only identified in the summer of the ERA-driven simulation, in the south of the IP. Regarding to the seasonal trends of the MPI-driven simulation, negative trends predominate over the PI, except during winter.

Trends do not reveal pronounced changes and only show few regions with a statistically significant trend. Similar tendencies towards less extended consecutive wet days have been reported by, e. g., Alexander et al., (2006), Rodrigo and Trigo (2007), Lima et al., (2014).

Regarding to the CDD index, the maximum number of dry days during the analysis period, has a statistically significant increase in the south of the IP, in north-eastern Spain and the north of Africa (with higher magnitude in the ERA-driven simulation trends) and a decrease (although not statistically significant) in the centre of the IP.

The maxima annual trends in the south of the IP have a peak of approximately 2 days/year and 3 days/year, for the MPI-driven and ERA-driven simulation, respectively. These values are especially influenced by the summer and autumn, as we can see on the seasonal analysis, in the south of the IP and north Africa. In north-eastern Spain, most of the precipitation falls in autumn and spring (García-Ruiz et al., 2001) and their annual trend increase (in agreement with López-Moreno et al., 2010) can be particularly associated with these seasons.

Aside from the annual trend magnitude difference between the simulations, the pattern can be considered similar, with exception of northeast of the IP and the northern coast of Portugal, with opposite statistically significant trends with the MPI-driven simulation (positive trend) and ERA-driven simulation (negative trend). The main differences in the MPI-driven and ERA-driven simulations occur in this region, and maybe cause by an overestimated of the precipitation as is clear in the Figure 2. The more significant patterns differences occur in the winter and spring, with opposite statistically significant trend signs varying between Portugal, the southeast and the northeast of the IP. Haylock and Goodess (2004), in a winter trend analysis in the 1958-2000 period, have seen a small decrease of CDD in the northwest of the IP while the rest of the peninsula has seen large increases.

1.3. R75p and R95TOT indices

Figure 5 shows the trends of the R75p, i.e., the trend of the number of days when the precipitation amount is higher than the 75th percentile, for the MPI-driven (left) and ERA-driven (right) simulations. In general, annual trends do not yield a clear spatial pattern, but the main changes indicate a decrease in the northeast of the IP, for both annual spatial trends, with statistically significant maxima, around -0.7 days/year. Comparing the annual trends, the main difference occurred in the northwest and north of the IP and in the north of Africa, revealing a decrease in the number of days higher than the 75th percentile for the MPI-driven simulation, and an increase, for the ERA-driven trend. Seasonally and for the MPI-driven simulation, a decrease of R75p predominates in spring, summer and autumn, contrary to the increase in winter and in the northeast of the IP, in the spring. For the ERA-driven, seasonal trends are mainly negative in winter and summer and positive in spring and autumn. Statistically, the significant trends are more related with the decreases in all seasons, except for winter.

A similar trend is detected in the R10mm and R20mm (no show), number of days on which precipitation value falls above 10 and 20 mm, respectively. Thus, the 75th percentile can contain values of precipitation higher than 10 mm. Moreover, some regions of the annual, spring, summer and autumn trend of R95p can be compared with the Rx1day and Rx5day (the greatest 1 and 5 day sum – not show) and consequently, the events of 1 and 5 days were included in the number of wet days above the 75th percentile. Note that these indices were influenced by the atmospheric circulations and the topography effect, especially noted in the Rx1day and Rx5day.

The annual and seasonal trends of the R95p index are showed in Figure 6, for the MPI-driven simulation (left) and ERA-driven simulation (right). This index only exhibit for the locals where the precipitation amount was above R95p. Annually, ERA-driven simulation produces more regions with increasing trends (maxima of around 0.01 %/year), which are statistically significant in some regions of the IP's centre. In the annual spatial trends of the MPI-driven simulation, negative predominate over the IP (maxima higher than -0.01 %/year), statistically significant in the northeast and south of the IP.

In the seasonal analysis, patterns in the trends for both simulations were not similar, as well as, the number of regions with R95pTOT trend. Negative trends predominate in winter, summer and autumn and positive trends in the spring, for the MPI-driven simulation. Considering the ERA-driven simulation trends, positive values predominate in the spring and autumn. Through the number of calculated trends, it is possible conclude that more precipitation days above P95p were occurred in the MPI-driven simulation comparing with the ERA-driven. The spatial pattern obtained for the R95TOT trend index was very similar with to the indices SDII, R75TOT, R90TOT and R99TOT. In the winter, the large-scale circulation is mainly driven by the position and intensity of the Icelandic low. Consequently, most of the IP is affected by westerly winds that carry moist air and produce rainfall events (Trigo and Dacamara, 2000), which is intensified with typical depressions. The rainfall is mostly due to meridional fluxes (Goodess and Jones, 2002) associated with the local topography, force an ascent of the air mass and, as a consequence, produce precipitation (Rodrigo and Trigo, 2007).

Conclusions

The precipitation in the IP is highly variable in space and time, and is especially influenced by the wide geographic diversity and climate dynamics of the region. The climate models take all these influences into account, in order to reproduce the precipitation as well as possible. In this work, the WRF model, forced by MPI and ERA-Interim, was used to simulate daily precipitation from 1986 to 2005 over the IP, with the goal of analysing precipitation recent climate change. The same analysis was applied to MPI-driven and ERA-driven simulations. Firstly, annual and seasonal extreme precipitation indices for each year between 1986 and 2005 were computed. Then, the annual and seasonal trends of these indices in the gridded fields were computed and tested for statistical significance. The analysed indices allow the assessment of many aspects of a changing global climate, including changes in intensity, frequency and duration of precipitation events. These indices represent events that occur several times per year or season, to give them more robust statistical properties than measurements of extremes precipitation.

To understand the variability over the IP produced by the two simulations, the daily mean precipitation was computed between 1986 and 2005. The results show higher values in the northern coast of the IP and lower values in the southeast of the IP and the north of Africa (Mediterranean coast). Aside from the similar pattern between the results given by the two simulations, significant differences in magnitude were observed. Generally, the results for MPI-diven simulation were higher compared with ERA-driven simulation. Consequently, this is reflected in the trends of the extreme precipitation indices.

In short, the heavy and very heavy precipitation days (R10mm and R20mm, respectively) decrease in winter and summer and increase in spring and autumn (for ERA-driven simulation). The trend of the highest precipitation amount in 5 and 1 days (Rx1day and Rx5day) periods are not very conclusive, with regions of positive and negative trends, although a statistic significance decrease was found in winter and summer. Negative trends predominate in the highest consecutive wet days (CWD) annual trend, except in spring and autumn. On the other hand, positive trends predominate in the highest consecutive dry days (CDD), especially in the

south of the IP. The results for the R75p are similar to the R10mm and R20mm indices. For the R95TOT index, more regions with increasing trends were found (annually and seasonally), which are statistically significant in some regions of the IP's centre in the annual, spring and autumn analysis. The R95TOT index reveals similar patterns for Simple daily intensity (SDII) and Prec90p, so the extreme precipitation events were found in regions with higher precipitation intensity in wet days, and the precipitation of these regions were included in the 90th percentile. In these indices, the influence of the topography is reflected, as it uses the absolute precipitation value in its computation

In general, mean precipitation were higher for the MPI-driven simulation compared to the ERAdriven simulation. Therefore, some differences were observed in the trends using the ERAdriven and MPI-driven simulations, particularly in: (1) winter and autumn for R10mm, R20mm, R75p, R90p, R95p indices; (2) annual, winter and autumn trends in the northern of IP for CWD; (3) winter and spring over the entire IP for CDD; (4) spring and autumn in the northeast of the IP for R90pTOT, R95pTOT, Rx1day, Rx5day indices. The northeast of the IP was the regions with better agreement between the two simulations.

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Figure 1 – Map of the Iberian Peninsula showing the topography and the WRF domain, with a rotated grid with a horizontal resolution of 9 km.



Figure 2 - Annual (top) and seasonal (bottom) mean (mm/day/year) of the daily precipitation among calculated for the 1986-2005 period over the Iberian Peninsula and for MPI (left) and ERA (right).



Figure 3 - Annual (top) and seasonal (bottom) trends (in days/year) of the Greatest consecutive wet days – CWD index calculated for the 1986-2005 period over the Iberian Peninsula for the MPI-driven (left) and ERA-driven simulations (right). Dots indicate significant trends (95%).



Figure 4 - Annual (top) and seasonal (bottom) trends (in days/year) of the Greatest consecutive dry days – CDD index calculated for the 1986-2005 period over the Iberian Peninsula for the MPI-driven (left) and ERA-driven simulations (right). Dots indicate significant trends (95%).



Figure 5 - Annual (top) and seasonal (bottom) trends (in days/year) of the Precipitation on moderate days – R75p index calculated for the 1986-2005 period over the Iberian Peninsula for the MPI-driven (left) and ERA-driven simulations (right). Dots indicate significant trends (95%).



Figure 6 - Annual (top) and seasonal (bottom) trends (in %/year) of the Precipitation fraction due to R95p – R95pTOT index calculated for the 1986-2005 period over the Iberian Peninsula for the MPI-driven (left) and ERA-driven simulations (right). Dots indicate significant trends (95%).

Index	Description	Formula
RX1day (mm)	Highest precipitation amount in one-day period	Maximum precipitation on 1-day intervals
RX5day (mm)	Highest precipitation amount in 5 consecutive days	Maximum precipitation sums on 5-day intervals
R10mm (days)	Heavy precipitation days	Number of days with RR ≥10 mm
R20mm (days)	Very heavy precipitation days	Number of days with RR ≥20 mm
CDD (days)	Consecutive dry days	Maximum length of dry spell (RR <1 mm)
CWD (days)	Consecutive wet days	Maximum length of wet spell (RR ≥1 mm)
R75p (days)	Precipitation on moderate days	Number of days when RR> 75ptile calculated for wet days (on basis of 1986-2005)
R90p (days)	Precipitation on wet days	Number of days when RR> 90ptile calculated for wet days (on basis of 1986-2005)
R95p (days)	Precipitation on very wet days	Number of days when RR> 95ptile calculated for wet days (on basis of 1986-2005)
R99p (days)	Precipitation on extremely wet days	Number of days when RR> 99ptile calculated for wet days (on basis of 1986-2005)
R90pTOT (%)	Precipitation fraction due to R90p	Precipitation fraction due to R90p
R95pTOT (%)	Precipitation fraction due to R95p	Precipitation fraction due to R95p
R99pTOT (%)	Precipitation fraction due to R99p	Precipitation fraction due to R99p
Prec90p (mm/day)	90th percentile of rainday amounts	Precipitation 90 calculated for wet days
SDII (mm/day)	Simple daily intensity index	Total precipitation divided by number of wet days (≥1 mm)
PRCTOT	Total wet-day precipitation	Total precipitation from days ≥1 mm

Table 1 – Extreme precipitation indices calculated in this study.