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Robust inferences on climate change patterns of precipitation extremes in the Iberian Peninsula

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ABSTRACT

This work presents a methodology to make statistical significant and robust inferences on climate change from an ensemble of model simulations. This methodology is used to assess climate change projections of the Iberian daily-total precipitation for a near-future (2021–2050) and a distant-future (2069–2098) climates, relatively to a reference past climate (1961–1990).

Climate changes of precipitation spatial patterns are estimated for annual and seasonal values of: (i) total amount of precipitation (PRCTOT), (ii) maximum number of consecutive dry days (CDD), (iii) maximum of total amount of 5-consecutive wet days (Rx5day), and (iv) percentage of total precipitation occurred in days with precipitation above the 95*th* percentile of the reference climate (R95T). Daily-total data were obtained from the multi-model ensemble of fifteen Regional Climate Model simulations provided by the European project ENSEMBLES. These regional models were driven by boundary conditions imposed by Global Climate Models that ran under the 20C3M conditions from 1961 to 2000, and under the A1B scenario, from 2001 to 2100, defined by the Special Report on Emission Scenarios of the Intergovernmental Panel on Climate Change.

Non-parametric statistical methods are used for significant climate change detection: linear trends for the entire period (1961–2098) estimated by the Theil-Sen method with a statistical significance given by the Mann-Kendall test, and climate-median differences between the two future climates and the past climate with a statistical significance given by the Mann-Whitney test. Significant inferences of climate change spatial patterns are made after these non-parametric statistics of the multi-model ensemble median, while the associated uncertainties are quantified by the spread of these statistics across the multi-model ensemble. Significant and robust climate change inferences of the spatial patterns are then obtained by building the climate change patterns using only the grid points where a significant climate change is found with a predefined low uncertainty.

Results highlight the importance of taking into account the spread across an ensemble of climate simulations when making inferences on climate change from the ensemble-mean or ensemble-median. This is specially true for climate projections of extreme indices such CDD and R95T. For PRCTOT, a decrease in annual precipitation over the entire peninsula is projected, specially in the north and northwest where it can decrease down to 400 mm by the middle of the 21st century. This decrease is expected to occur throughout the year except in winter. Annual CDD is projected to increase till the middle of the 21st century overall the peninsula, reaching more than three weeks in the southwest. This increase is projected to occur in summer and spring. For Rx5day, a decrease is projected to occur during spring and autumn in the major part of the peninsula, and during summer in northern Iberia. Finally, R95T is projected to decrease around 20% in northern Iberia in summer, and around 15% in the south-southwest in autumn.

1. Introduction

Precipitation is one of the principal climatic variables (Peixoto and Oort, 1992) and its variability has an essential role in water

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resources and management which in turn controls agriculture, river flow and hydroelectricity production, tourism, and other important economic activities for social development. Precipitation in the Iberian Peninsula (Portugal and Spain mainlands) exhibits high spatial and temporal variability because of the Iberian complex orography, latitudinal location (between tropical and mid-latitudes), longitudinal location (between the Atlantic ocean and the Mediterranean Sea), and diverse weather regimes (Esteban-Parra et al., 1998; Rodriguez-Puebla et al., 1998; Goodess and Palutikof, 1998; Serrano et al., 1999a; Trigo and DaCamara, 2000; Goodess and Jones, 2002; Santos et al., 2005; Cortesi et al., 2014). Iberian annual total precipitation presents a large south-east–northwest positive gradient ranging, approximately, from 200 mm in the southeastern Spanish regions (eastern Andalucía, Murcia, south of Comunidad Valenciana, and southern Castilla-La Mancha) (Romero et al., 1998; Herrera et al., 2010; Couto et al., 2011) to 2000 mm in the northwestern regions (Portuguese Minho and Spanish Galicia) (Herrera et al., 2010; Belo-Pereira et al., 2011; Couto et al., 2011). Most of the annual precipitation occurs from September to May (Esteban-Parra et al., 1998; Herrera et al., 2010; Belo-Pereira et al., 2011) due to baroclinic synoptic-scale perturbations generated near the polar jet stream and moving eastward from the Atlantic Ocean (Ulbrich et al., 1999), although mesoscale convective systems are also responsible for precipitation over the eastern half of the peninsula (Romero et al., 1998). Summer rainfall depends especially on local factors and is mainly caused by convective storms associated with ground heating, high moisture content, and upper instability (Serrano et al., 1999a). Western and central regions are characterized by maximum rainfall records in winter, whereas in the east the absolute maximum occurs in autumn followed by a relative maximum in spring (Rodriguez-Puebla et al., 1998; Romero et al., 1998; Trigo and Palutikof, 2001; Herrera et al., 2010; Belo-Pereira et al., 2011).

Iberian precipitation also presents large interannual variability (Rodriguez-Puebla et al., 1998; Muñoz Díaz and Rodrigo, 2004b) which is linked to the variability of the atmospheric circulation associated to the North Atlantic Oscillation (NAO) (Ulbrich et al., 1999; Rodríguez-Puebla et al., 2001; Muñoz Díaz and Rodrigo, 2004a) and weather types or regimes (Trigo and DaCamara, 2000; Santos et al., 2005; Cortesi et al., 2013). Iberian precipitation has been shown to be correlated with sea surface temperatures (SSTs) in the tropical Pacific ocean associated with El Niño-Southern Oscillation (ENSO) (Rodó et al., 1997; Rocha, 1999; Mariotti et al., 2002; Vicente-Serrano, 2005; Shaman and Tziperman, 2010) whose major temporal variability lies on the interannual scale (Neelin et al., 1998). Conducting a composite analysis of European winter precipitation anomalies, Pozo-Vázquez et al. (2005) found a significant response to La Niña events in the Iberian Peninsula. Dependencies on Atlantic SSTs were also found by Fernández-González et al. (2014). Iberian precipitation is also forced indirectly by global SSTs through the NAO and the North Atlantic-European (NAE) weather regimes: it has been found a significance response of the NAO to ENSO (Melo-Gonçalves et al., 2005; Zhang et al., 2015) and to Atlantic SST anomalies (Czaja and Frankignoul, 2002; Peng et al., 2003; Frankignoul and Kestenare, 2005), and also a significance response of the NAE weather regimes to ENSO (Moron and Plaut, 2003) and to Indo-Pacific SSTs (Sanchez-Gomez et al., 2008).

Significant negative trends of annual precipitation sums have been observed over the Iberian Peninsula (Rodrigo and Trigo, 2007; de Luis et al., 2010), Portugal (de Lima et al., 2013, 2015), Spain (Río et al., 2011), northeastern Iberia (López-Moreno et al., 2010), and Andalusia in southern Iberia (Hidalgo-Muñoz et al., 2011). Lopez-Bustins et al. (2008) reported significant negative trends of winter rainfall over most of 51 meteorological stations scattered across the Iberian Peninsula, and a significant negative trend of the average of all stations, for the last 40 years of the 20th century. These authors also found significant negative correlations between the winter NAO index, which presents a positive trend in this period (Hurrell, 1995), with winter rainfall over almost the entire Iberian area. Note that a strong positive phase of the NAO (high positive NAO index value) is associated with a northeastward shift of the Atlantic storm track which causes decreases in storminess and precipitation over the Iberian Peninsula (Ulbrich et al., 1999). Consistent with this, Goodess and Jones (2002) showed that the observed trends in the frequency of the circulation weather types (Jones et al., 1993) over Iberia (Goodess and Palutikof, 1998) are related to the observed positive trend of the NAO index, and responsible by the decreasing rainfall over Iberia: the frequencies of the low (high) rainfall types Anticyclonic and Hybrid Anticyclonic (Cyclonic and Hybrid Cyclonic), positively (negatively) correlated with the NAO index, have been increasing (decreasing). Spring precipitation sums also present a negative trend in the last three decades overall the peninsula (Serrano et al., 1999b) because of the intense decline of precipitation observed in March (Zhang et al., 1997; Corte-Real et al., 1998; Trigo and DaCamara, 2000) caused by the reduction of occurrence of rainy weather regimes (Corte-Real et al., 1998; Trigo and DaCamara, 2000) and by large-scale circulation changes associated to the NAO (Zhang et al., 1997; Corte-Real et al., 1998; Paredes et al., 2006). In autumn, regions with significant positive trends of precipitation were found in Portugal (de Lima et al., 2013) and Spain (de Luis et al., 2010; Gonzalez-Hidalgo et al., 2010; Río et al., 2011). For summer, de Luis et al. (2010) found significant negative trends in southern areas of Spain, where precipitation is exclusively convective in this season. Monthly analysis revealed that these negative trends are mainly due to the decrease observed in June (de Luis et al., 2010; Mosmann et al., 2004). For Portugal, de Lima et al. (2013) found positive and negative trends but none of these were found to be significant.

In the last decade, several studies on observed precipitation extremes were published for the Iberian Peninsula using different datasets, time-ranges, definition of extremes, data treatments, and statistical methods (García et al., 2007; Rodrigo and Trigo, 2007; Rodrigo, 2010; López-Moreno et al., 2010; Gallego et al., 2011; Hidalgo-Muñoz et al., 2011; de Lima et al., 2013, 2015). For the second half of the 20th century, Rodrigo (2010) found, four all seasons of the year, significant positive trends in the probability of daily rainfall lesser than the long-term 5th percentile, mainly in the north and south of the Iberian Peninsula, and significant negative trends in the probability of daily rainfall greater than the long-term 95th percentile in the north and south of the peninsula. Accordingly, Rodrigo and Trigo (2007) reported negative trends of the 95th percentile of daily rainfall for the northern and southern Iberia in winter, and southern Iberia in summer. For the same period, García et al. (2007) found negative trends of seasonal maxima of daily rainfall for the west and southwest of the Iberian Peninsula in winter and spring. For the 1954–2006 period, Gallego et al. (2011) detected significant negative trends of heavy precipitation over almost the entire area of the Iberian Peninsula in winter and over western Iberia in spring. For autumn, they found significant positive trends over the west and centre of the peninsula. These authors also estimated the observed trends for the consecutive dry days: positive (negative) trends over most of Iberia in spring (autumn), and positive (negative) trends in the southeastern (northwestern) half part of the peninsula.

Studies about climate change projections have been made analysing General Climate Model (GCM) simulations, and summarized by the Intergovernmental Panel on Climate Change (IPCC) Assessment Reports, namely the Fifth and last report (IPCC, 2013). It