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Connection between autumn Sea Surface Temperature and winter precipitation in the Iberian Peninsula

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ABSTRACT

The oceanic influence on winter precipitation in the Iberian Peninsula has been evidenced in numerous scientific papers. Large-scale forecasting models generally use variables such as Sea Surface Temperature (SST), soil moisture and ice cover, but they are not very accurate yet. Using observational data, this paper analyzes the influence of North Atlantic and Mediterranean SST on winter precipitation in the Iberian Peninsula between October 1951 and September 2011. First, trends of both data sets have been calculated to study their behavior during the past six decades, showing an overall increase of SST and a substantial decrease in winter precipitation in the Iberian Peninsula, except in eastern and south-eastern regions. Then, connection patterns between autumn Sea Surface Temperature Anomalies and winter precipitation have been studied to identify ocean regions that may be used as potential predictors of winter precipitation. After applying a Principal Component Analysis to cluster the information provided by the 1431 measuring points of a SST grid with a small number of variables, the Principal Components extracted were introduced into a Multiple Linear Regression algorithm in order to obtain an estimation of winter precipitation in each river basin. The validation process has shown that the algorithm explains nearly 50% of inter-annual variability of winter precipitation in the basins of the Iberian Peninsula with a strongly oceanic influence; this percentage is somewhat lower in the Mediterranean regions.

1. Introduction

In the past decades, a general decrease of winter precipitation has been observed in the Iberian Peninsula, except in the Mediterranean region (Rodrigo and Trigo, 2007; López-Bustins et al., 2008). The decline is particularly pronounced in March (del Río et al., 2005). This fact leads to a decrease of the water resources available.

Winter precipitation is very important in the Iberian Peninsula because the filling of reservoirs depends heavily on the precipitation registered in this period. Many economic activities that depend directly on water resources could optimize their management if they had a medium-large scale estimation of expected precipitation. Several studies (IPCC., 2007; del Río et al., 2011) predict declines in winter precipitation in the Iberian Peninsula over the next few decades. This fact makes that precipitation forecasting with several months in advance be even more necessary, with the aim of minimizing losses in economic sectors directly linked to climate variability. Among others, the Sea Surface Temperature (SST), can act as a potential large-scale predictor of winter weather in Europe (Folland et al., 2012).

The Atlantic Meridional Overturning Circulation (AMOC) leads warm and saline waters from the Tropical Atlantic to North Atlantic high latitudes where they cool and sink, forming deep and cold currents that return southwards (Ortega et al., 2012). This causes heat transport northward. Some evidence indicates that when the thermohaline circulation is strong, the North Atlantic is warm, and vice versa. Trouet et al. (2012) point out that an intensification of the AMOC leads to Sea Level Pressure (SLP) anomalies that induce a positive phase of the North Atlantic Oscillation (NAO), and conversely a weakening of the AMOC that induces a negative phase of the NAO.

The anomalies of Atlantic Ocean SST are characterized by opposite signs in each hemisphere during a particular season (Hodson et al., 2010). This interhemispheric dipole pattern shows multi-decadal variations in the AMOC, revealing itself as a potential predictor of Atlantic Multidecadal Oscillation (Knight, 2009) which is of great importance as it causes significant impacts on the American, African and Eurasian climates.

Various thermodynamic processes, such as evaporation, global warming, and precipitation, depend on thermal coupling between the ocean and the atmosphere. Negative feedback that occurs in the heat

Abbreviations: AMOC, Atlantic Meridional Overturning Circulation; ERSST, Extended Reconstructed Sea Surface Temperature; KMO, Kaiser–Meyer–Olkin; MSE, Mean Square Error; MLR, Multiple Linear Regression; NAO, North Atlantic Oscillation; PA, Precipitation Anomalies; PCA, Principal Component Analysis; PCs, Principal Components; RV, Reduction of Variance; SLP, Sea Level Pressure; SST, Sea Surface Temperature; SSTA, Sea Surface Temperature Anomalies.

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flux between ocean and atmosphere involves the existing Sea Surface Temperature Anomalies (SSTA) energy exchange to the atmosphere at mid-latitudes (Frankignoul and Kestenare, 2002).

SSTA influence climate by affecting the flow of sensible and latent heat exchange between the ocean and the atmosphere. The magnitude of sensible and latent heat fluxes depends on the geographic extension and location of areas with negative or positive SSTA. SSTA higher than 2 °C in the North Atlantic have been found to cause changes in atmospheric circulation. For example, the position of the SST maximum gradient affects the formation and trajectory of cyclonic waves in the North Atlantic (Phillips and Thorpe, 2006). This is because SST partially determines the horizontal temperature gradient in the atmosphere. Persistent SSTA cause changes in general atmospheric circulation controlling the NAO Index, which in turn is linked with winter precipitation in the Iberian Peninsula (Antunes et al., 2010). Due to the high thermal inertia of large water reservoirs like the Atlantic Ocean, it becomes viable to use SST as a predictor of weather conditions over the coming months (Rodwell et al., 1999).

The main previous studies on the relationship between SST and Precipitation Anomalies (PA) in Iberia can be summarized as follows: the relationship between SST in the Atlantic and Iberian rainfall was studied first (Zorita et al, 1992; Rodríguez-Fonseca and de Castro, 2002). Then, Gámiz-Fortis et al. (2008 and 2010) studied the predictability of Iberian river flows; by studying SST, certain goals have been completed, such as the forecasting of droughts in Portugal (Santos et al., 2014), East-Atlantic pattern predictions (Iglesias et al., 2014), and precipitations in north-western Iberia through the SST in the Pacific and in the Atlantic (Lorenzo et al., 2010, 2011). Nevertheless, we noticed the lack of an application of climate variability of the Atlantic SST to the peninsular hydrology on a regional scale and, in particular, to facilitate water management (for human consumption, irrigation, electricity production) in each watershed.

In this article, the main aims are:

1. To analyze the trends of Iberian Peninsula precipitation in winter, and autumn SST in order to study the current climate status.
2. To assess the relationship existing between autumn SSTA and winter precipitation in the different river basins of the Iberian Peninsula. We will thus identify the Atlantic Ocean regions that are potential predictors of winter precipitation.
3. To develop and validate a winter precipitation algorithm based on a Multiple Linear Regression (MLR), using as predictor the Principal Components (PCs) obtained after applying a Principal Component Analysis (PCA) on autumn SSTA. This algorithm can be useful in the management of water resources in the Iberian Peninsula, an issue of the highest importance due to the scarcity of water and the high interannual variability in precipitation.

This article is organized as follows: Section 2 defines the study area; Section 3 explains the database and the methodology used. Section 4 details the different results obtained in this article, together with the discussion. Finally, a summary of the conclusions is offered in Section 5.

2. Regional setting

The Iberian Peninsula is located in south-western Europe, communicating with France through Pyrenees. The rest of the Iberian Peninsula perimeter is coastline, so it has a clear oceanic influence. It has two marked slopes. The northern and western rivers flow into the Atlantic Ocean, while eastern peninsular rivers flow into the Mediterranean Sea.

Winter precipitation regimes in the Iberian Peninsula are characterized by the position occupied by the Azores High and the Icelandic Low, which determine the trajectory of storms crossing Europe. This precipitation depends mainly on perturbations derived from the polar front jet moving eastward from the Atlantic Ocean (Trigo and DaCamara, 2000; García-Herrera et al., 2005). This Atlantic character is compatible with a Mediterranean component in the eastern regions, responsible for cyclogenetic processes associated with the Mediterranean Sea, causing heavy precipitation episodes in this area, especially in autumn, and also in winter (de Luis et al., 2010).

3. Materials and methods

3.1. Data sets

In this paper, monthly precipitation data (in mm) between October 1951 and September 2011 have been used, which comprises a database of 60 full hydrological years. These data come from 50 weather stations belonging to the meteorological observatory network of the Spanish Meteorological Agency and 11 weather stations belonging to the network of Portugal's Institute of Meteorology. These observatories were selected on the basis of the completeness of their data series. Only observatories with fewer than 2% of missing values in the whole period under study were chosen. Missing values were replaced by the value for precipitation for the same month at the nearest station, with compensation for the difference between monthly averages at these two observatories. The homogeneity of the data series for each station was evaluated using the non-parametric Kruskal–Wallis test (Essenwanger, 1986). A further quality control was applied to ensure the homogeneity of each basin: each of the different stations in each basin should have a minimum correlation of 85% with the remaining stations in this basin. The results obtained were satisfactory for 60 stations and 11 basins (Fig. 1), confirming the homogeneity of the data sets. The Almeria station was removed because the correlation with the remainder stations from this basin was under 85%, because of its extreme dryness. The Ebro basin has been divided into two zones because some stations showed a correlation with the mean of the basin lower than 85%. Nevertheless, with the division in medium and upper Ebro basin, the correlations rose above 85% in both zones separately.

The resolution of precipitation algorithm is linked with the results (Sharma and Huang, 2012), so a homogeneous network of 60 weather stations in the Iberian Peninsula is enough for this study. Winter precipitation has been considered as the sum of monthly precipitation in January, February and March due to its better adaptation to hydrological year.

Regarding monthly SST data, the database compiled by Smith et al. (2008) has been used, more precisely the latest version of the Extended Reconstructed Sea Surface Temperature (ERSST) analysis, v3b. This analysis takes data from the International Comprehensive Ocean–atmosphere Data Set (ICOADS) release 2.4. The database is completed at the end of each month with the Global Telecommunications System (GTS) ship and buoy data available for that month. ERSST v3b is equal to v3 described in Smith et al. (2008), except that no satellite data are used because they cause residual biases. This database covers the period from 1880 to the present, but the data are more reliable from the 1940s. For this paper, SST data between October 1951 and September 2011 have been used. The SST database consists of a 2° latitude × 2° longitude grid, in which we have selected the points defined between 0°–80° N and 96° W–10° E. Finally, a grid consisting of 1431 points with known SST has been obtained which extends over the North Atlantic and the Mediterranean region close to the Iberian Peninsula. In this paper, autumn SST refers to the average of the SST registered during October, November and December.

3.2. Sea Surface Temperature anomalies

SSTA data have been used to achieve comparable SST measures both in cold and warm North Atlantic regions and in different seasons. The value of SSTA (in °C) is the difference between a given monthly SST at a particular point and the SST average at that point during that same month over a reference period, which in this case is from October 1951 to September 2011. First, the mean monthly values for each 1431 measuring point of the SST have been calculated. Then, the mean