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Modelling the spring Douro river flow using SST

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1. INTRODUCTION

The availability of water is mostly influenced by climate conditions that vary on seasonal, interannual, and decadal time scales. On seasonal timescales, anomalous atmospheric conditions are often linked with seasonal variations in the rivers streamflow, via variations in precipitation and temperature (Dettinger and Diaz, 2000; Cullen et al., 2002; Trigo et al., 2004). Usually, the skill of these long-range forecasts is associated with the introduction of predictors that represent the slow varying components of the climate system such as sea ice, snow cover, soil moisture, SSTs and major atmospheric circulation patterns such as the NAO in Europe or the PNA in North America (Wedgebrow et al., 2002).

Similar to other Mediterranean regions, winter- and spring-time Iberian river flows account for the majority of runoff, these being followed by a relatively long and dry summer period (Daveau, 1988; INAG, 2001). Because the NAO impact in Iberian Peninsula precipitation is particularly strong in winter, most studies have been focused to predict the Douro river flow in this season (Trigo et al., 2004; Gámiz-Fortis et al., 2008a, 2008b).

This paper presents a modelling scheme for spring Douro streamflow anomalies based in the combination of two methodologies: the identification of stable teleconnections between oceanic SST anomalies and river flow and secondly the use of ARMA models to predict quasi-oscillatory modes of the flow.

2. DATA

Douro is the second international largest river in Iberian Peninsula (after Tejo), and presents the most extensive basin within the Iberian Peninsula (Figure 1). The monthly time series of Douro discharge, used in this paper, were recorded at Pocinho (37.18ºN, 7.55ºW), which is situated in the lower part of the Douro catchment area. Data were kindly provided by the Portuguese National Electrical Supply Company (REN) and is restricted to the period 1956-2006. From the original monthly values we have computed the monthly standardized anomalies in relation to the period 1961-1990. Monthly anomalies over the months May and June were averaged to generate the spring flow anomaly time series. Global winter (DJF) SST taken from the HadISSTv1.1 data set (Rayner et al., 2003) derived from the Hadley Centre for Climate Prediction and Research (UK Meteorological Office) was used as predictor variable. Additionally sea level pressure (SLP) data from the NCEP/NCAR Reanalysis has been also used to illustrate some information.

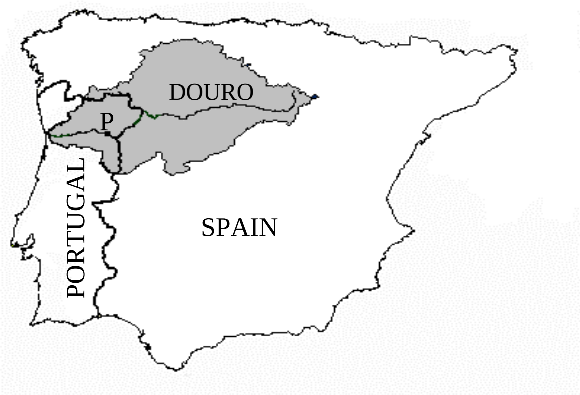

Figure 1. Location of the international Douro river basin (grey) in Iberian Peninsula and the catchments boundaries. Small black dot shows the location of river flow gauge at Pocinho (P) used in this study.

3. METHODOLOGY

Following the approach adopted by Ionita et al. (2008) we identify sectors of oceanic SST anomalies that can be used as predictors for Douro's river flow. We have evaluated the point linear correlation between the spring streamflow anomalies and the global SST anomalies from the previous winter. Regions showing significant correlations are identified as potential predictors, and those that can be classified as stable predictors are chosen. This is achieved through the analysis of the variability of the correlation between spring Douro flow anomalies and previous winter SST anomalies from potential predictor regions using a moving window of 15 years. The correlation is considered to be stable for those regions where spring streamflow and winter SST anomalies are significantly correlated at 90% level (r = 0.44) for more than 80% of the

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15-year windows covering the period 1956-2006 and, furthermore, that the sign of the correlation does not change with time. Regions verifying this criterion are considered as predictor in a multiple linear regression model to predict the spring Douro river flow anomalies. Additionally, in order to detect some other kind of influence from the ocean, we study the residual time series, which is generated like the subtraction of spring Douro river flow time series minus the modelling computed using the SST field. Singular spectral Analysis (Vautard et al., 1992) is applied to this remainder in order to detect quasi-oscillatory modes that could be associated with other parts of the ocean. Finally an ARMA model is fitted to the residual time series filtered by SSA and the improvement obtained by the combination of SST-alone model and ARMA model is evaluated. For model evaluation we employ the percentage improvement in the root-mean-square error over a climatological forecast ($RMSE_{cl}$) and over persistence ($RMSE_{per}$). Climatology is taken as the standardized long-term average prior to each year being forecasted, while persistence is taken as winter (JFM) Douro streamflow standardized anomalies.

4. RESULTS

The spatial correlation maps between spring flow and the previous winter SST and SLP are shown in Figure 2.

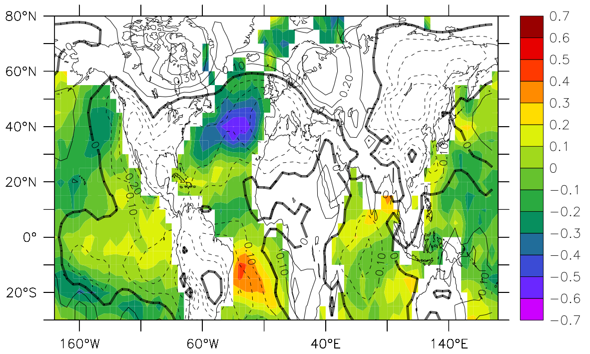

Figure 2. Correlations maps between the spring Douro streamflow anomalies and previous winter SST anomalies (colours), and previous winter SLP anomalies (contours). Values greater than 0.3 are significant at 95% confidence level.

For winter SST two regions with significant values are found, one in the south-western of Atlantic Ocean, and another one placed in the central of the North Atlantic. Based on this correlation maps we define the SST1 and SST2 indices by averaging the normalized SST anomalies for the regions showing maximum correlation values: SST1 = (45ºW-25ºW; 15ºS-10ºS) and SST2 = (45ºW-25ºW; 38ºN-42ºN). For winter SLP, the correlation map shows a centre of significant negative values over the Iberian Peninsula, to the east of the SST2 centre. The correlation between this SLP anomaly centre and the winter NAO index is 0.87. Figure 3 shows the correlation between the spring streamflow anomalies and the SST1 and SST2 indices in a moving window of 15 years. Stable correlations according to the criterion explained in the methodology are found for both indices, positive for the SST1 and negative for the SST2.

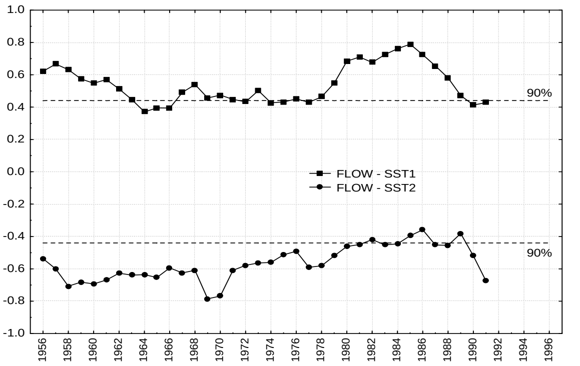

Figure 3. Running correlations (15-year windows) between spring flow and SST1 and SST2 indices. The correlation is plotted at the beginning of each 15-year window.

Using these indices as predictors for the spring Douro river flow we develop a model based on linear regression. The optimal model for explaining spring streamflow can be written as:

$$SST\_model = -0.65 * SST2 + 0.38 * SST1 - 0.48$$

Figure 4 shows the spring Douro streamflow time series and the modelling using SST1 and SST2 as explanatory variable of this model, which area almost independent of each other (r = -0.11).

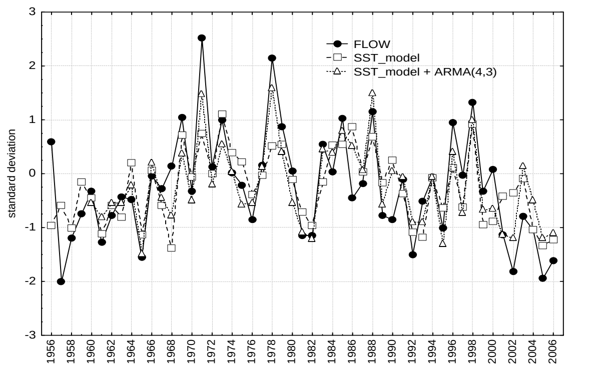

Figure 4. Observed (circle) and modelled spring flow anomalies during the period 1956-2006 based on winter SST anomalies from the stable regions (square) and the combined modelling [SST_model + ARMA (4,0,3)] (triangle).

Results show a considerable skill of the SST_model (see Table 1). Particularly the coefficient of multiple determination R^2 is 0.50, with MSE = 0.52, MAE = 0.57 and the correlation coefficient between the raw series and the model is 0.74. Additionally, the skill against climatology (persistence) is 38% (60%).

An additional study is carried out over the residual time series (residual = flow – SST_model) in order to improve the modelling of the spring Douro river flow variability. Singular spectral analysis applied over the residual show three significant quasi-oscillatory modes with periods around 2.4, 5 and 3 years. The SSA filter computed like the sum of the reconstructed components of these oscillatory modes (which will be called SSA_residual_filter here in after) explains the 60% of the total variance of the residual time series.

	SST_model	SST_model + ARMA(4,0,3)
MSE	0.52	0.23
MAE	0.57	0.39
Corr. Coef.	0.70*	0.87*
MSE_{cli}	0.84	0.84
MSE_{per}	1.27	1.27
$RSME_{cli\_}$(%)	38	73
$RSME_{per}$ (%)	60	81
%Ph. accord.	80	82

Table 1. Statistical results of the modelling carried out with the SST regression model, which uses the SST1 and SST2 indices as predictor variables, and the combined [SST_model + ARMA (4,0,3)] modelling. Values with "*" are statistically significant at the 95% confidence level

As we expected the correlation map between the SSA_residual_filter and the previous winter SST field does not show significant values. However, significant correlation values are found between the individual quasi-oscillatory mode with period around 3 years and the previous winter SST in the region of El Niño3, and the quasi-oscillatory mode with period around 5 years and the previous spring SST in the region of El Niño3.4, (see Figure 5). An additional SSA study to the winter SST in the El Niño3 region shows two significant oscillatory modes with periods around 5.3 and 3.4 years explaining a high fraction of the total variance of the series (41.2%). However, no significant correlation values are found between the 2.4 years oscillatory mode and previous seasonal SST. This result is suggesting that other influences, besides the SST, must be considered.

Using the sample Autocorrelation Function (ACF) and Partial Autocorrelation Function (PACF) (not shown) we find that while the raw and residual data behave like a white noise process, the SSA_residual_filter series shows a strong autocorrelation pattern. This makes the SSA_residual_filter more predictable compared to unfiltered one. Based on these analyses, we used the Akaike Information Criterion (AIC) to select an ARMA(4,0,3) model for the Douro. Finally the combined variance explained by the combined SST_model and ARMA model is 76% for the raw Douro river flow.

Figure 4 also shows the combined [SST_model + ARMA (4,0,3)] modelling. The correlation coefficient between the raw series and the new model is 0.87 (Table 1).We can see a clear improvement related with the SS_ model, particularly evident in the years 1965, 1971, 1974, 1976, 1977, 1978, 1981, 1982, 1983, 1985, 1989, 1991, 1996 and 2001.

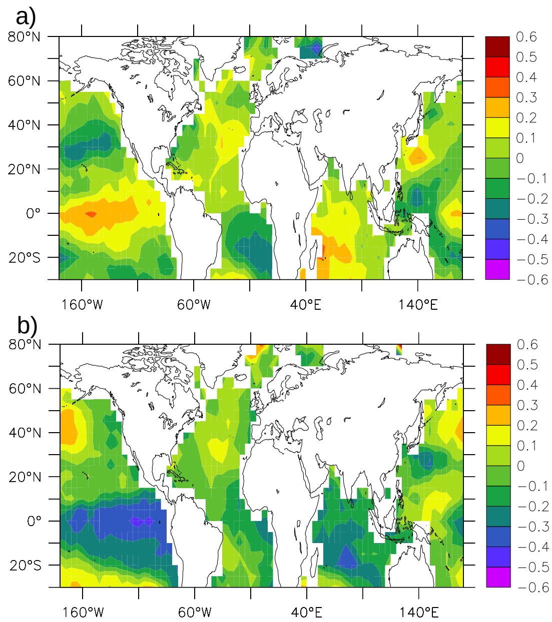

Figure 5. Correlations maps between a) the quasi-oscillatory mode with period around 5 years of the SSA_residual_filter and previous spring SST anomalies and b) the quasi-oscillatory mode with period around 3 years of the SSA_residual_filter and previous winter SST anomalies. Values greater than 0.3 are significant at 95% confidence level.

5. CONCLUSIONS

The predictability of the spring Douro flow anomalies using as predictor the sea surface temperatures has been studied. Two key regions where spring Douro flow anomalies and winter SST anomalies are stable correlated over the completed period are found in the Atlantic Ocean. One is sited in the central North Atlantic Ocean, and the other one is in the south-western part of the Atlantic, close to the South American coast. The corresponding indices computed averaging the SST anomalies in these regions are used as explanatory variables in a multiple linear regression model. We find that a significant portion of the variance (R^2 = 0.50) of the spring Douro river flow anomalies can be modelled based on the Atlantic SST from the previous winter. The modelling of Douro flow anomalies based on our statistical scheme is better than the modelling based on climatology and persistence, with most of the contribution coming from the middle latitudes in the North Atlantic Ocean. Additionally, the residual time series shows some quasi-oscillatory modes with periods around 2.4, 5 and 3 years. These latter appear to be associated with the SST from the ENSO region. Correlation coefficient between the 3 years oscillation and the previous winter SST anomalies in the region of El Niño3 is -0.40, while is 0.3 between the 5 years oscillation and the previous spring SST anomalies in the region of El Niño3.4. However, the 2.4 years oscillatory mode does not present significant correlations with seasonal SST. This result is suggesting that other influences different to the SST must be considered. The ARMA modelling applied to the filtered residual is able to provide the interannual linearly predictable signal contained in the history of the time series which is not related to the Atlantic SST. It could be argued that the ARMA model provides part of the low frequency (interannual) useful information for the modelling (R^2=0.17) that may result from the low frequency relationship between the Pacific SST and the precipitation/streamflow.

In summary, our analysis shows that previous winter SST anomalies from several Atlantic regions provide a significant source of predictability for spring Douro flow variability. Also, these regions contribute with the greatest part of explained variance. Because the SST from these regions is readily available this represents a source of predictability that can be exploited at present. Such a forecast could be useful to water managers in the Douro river basin. Additionally, the region of El Niño in Pacific Ocean seems to have some kind of association with the spring river flow, showing common oscillatory modes with period around 3 and 5 years. However the mechanisms responsible of this association are unclear and must be studied in detail.

6. ACKNOWLEDGMENTS

The Spanish Ministry of Science and Innovation, with additional support from the European Community Funds (FEDER), project CGL2007-61151/CLI, and the Regional Government of Andalusia, project P06-RNM-01622, have financed this study.

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