SEASONAL STREAMFLOW FORECAST IN THE IBERIAN PENINSULA BASED ON LAGGED TELECONNECTION INDICES

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ABSTRACT

This work assesses the potential of teleconnection indices as predictors of seasonal streamflow in the Iberian Peninsula (IP). The database comprises 382 streamflow time series from gauging stations, covering the period from October 1975 to September 2008. Four forecasting scenarios were developed, considering the information provided by teleconnection indices from one year to the previous season to the seasonal streamflow to be predicted.

The results indicate reasonable good predictions for autumn streamflow in stations located in the Mediterranean Andalusian Basin (being the North Atlantic Oscillation and the Artic Oscillation of the previous winter the main predictors) and in some stations located in the Douro and Tejo Basins (using as predictors the related to the El Niño phenomenon in previous autumn and the Western Mediterranean Oscillation and the East Pacific – North Pacific pattern in spring of the previous year). As winter streamflow forecasting concerns, forecasting skill is poor when predictions are made with more than one season in advance, with the exception of some stations located in the Mediterranean sector. However, the accuracy of the forecasting improve significantly when the information provided by the Snow Advance Index in previous October is added. Regarding spring streamflow, reasonable forecasting skill is found in stations in northwest and centre of the IP with climatic information until two seasons in advance. In this case, the main predictors are El Niño1+2 of previous autumn and winter and the Indian Ocean Dipole in previous autumn.

Key words: Teleconnection indices, streamflow, Iberian Peninsula, forecasting.

RESUMEN

En este trabajo se ha evaluado la capacidad predictiva de los índices de teleconexión de estaciones previas sobre el caudal estacional de los ríos en la Península Ibérica. La base de datos de caudal la conforman 382 estaciones de aforo cubriendo el periodo desde octubre de 1975 hasta septiembre de 2008. Adicionalmente, se consideraron cuatro escenarios de predicción, en función de la información climática disponible con cuatro, tres, dos o una estaciones de adelanto.

Los resultados muestran que las mejores predicciones para el caudal de otoño se localizan en la cuenca mediterránea andaluza, a partir de la información climática del invierno previo (particularmente de la aportada por la Oscilación del Atlántico Norte y la Oscilación del Ártico), y en las cuencas del Duero y Tajo (siendo en este caso los principales predictores los índices relacionados con el fenómeno de El Niño en el otoño previo, así como la información dada por la Oscilación del Oeste del Mediterráneo y el índice Pacífico Este – Pacífico Norte de la primavera previa). En el caso del caudal de invierno, la predicción con adelanto de más de una estación resulta ser bastante pobre (excepto para algunas estaciones localizadas en el sector mediterráneo). Sin embargo, la información climática obtenida del otoño previo (especialmente la proporcionada por el índice que mide el avance de la nieve en Eurasia en octubre) aporta un incremento en la capacidad predictiva. En el caso del caudal de primavera, la capacidad predictiva encontrada es modesta y particularmente localizada en el cuadrante noroeste de la península, con información de dos estaciones previas (en especial del índice del Niño1+2 en otoño e invierno previos y del índice del dipolo del Océano Índico del otoño previo).

Palabras clave: Teleconexiones, caudal, Península Ibérica, Predicción.

1. INTRODUCCION

The increasing water demands from various sectors, such as hydropower industry, tourism, and agriculture together with the concerns of the effects of climate change on future water availability have become water resources management a challenging problem. This issue is particularly relevant on the Iberian Peninsula (IP), an area very demanding on water resources and usually under water stress situation.

The large-scale atmospheric circulation patterns are responsible for most of the seasonal to decadal variability in IP rivers. Hence, the identification of main climatic drivers of streamflow variability may provide valuable information for long-range seasonal streamflow forecasting. In particular, several authors have addressed the effects of teleconnection patterns over hydrological variables on the IP (Rodriguez-Puebla et al., 2001; Trigo et al., 2004; Pozo-Vázquez et al., 2005; de Castro et al., 2006; Martin-Vide and Lopez-Bustins, 2006; Lorenzo et al., 2010; Morán-Tejeda et al., 2011; Brands et al., 2012, 2013, among others). On this study, teleconnection indices are evaluated as potential predictors of lagged seasonal streamflow on the IP. In addition, a prediction scheme based on simple linear regression is developed to evaluate the forecasting skills of these teleconnection indices.

2. DATA

2.1 Teleconnection indices

The monthly time series of Artic Oscillation (AO), North Atlantic Oscillation (NAO), East Atlantic pattern (EA), Pacific/North American pattern (PNA), Western Pacific pattern (WP), East Pacific North Pacific pattern (EP-NP), Scandinavian pattern (SCAND), East Atlantic Western Russian pattern (EA-WR), Atlantic Multidecadal Oscillation (AMO), Pacific Decadal Oscillation (PDO), ENSO indices (specifically: El Niño-1+2, Niño-3, Niño-4, and Niño-3.4 and SOI), were obtained from the Climate Prediction Center (CPC) at the National Center of Environmental Predictions (NCEP; www.cpc.noaa.gov). The monthly time series of Indian Ocean Dipole (IOD) and El Niño Modoki (EMI) were obtained from the Japan Agency for Marine-Earth Science and Technology website (www.jamstec.go.jp/). The monthly time series of WeMO were downloaded from the website http://www.ub.edu/gc/English/wemo.htm. The monthly time series of NPGO were obtained from the website http://www.o3d.org/npgo/. The monthly time series of SAI were kindly provided by the Justin Jones in personal communication.

The seasonal teleconnection indices were defined as averages of three months periods: autumn (September to November, 'son'), winter (December to February, 'djf'), spring (March to May, 'mam') and summer (June to August, 'jja'). The only exception is the SAI, because this index is a measure of the increasing in snow cover over Eurasia during October, so it is only available in autumn season.

2.2 Streamflow database

Monthly streamflow time series were obtained from the following water agencies:

- Centro de Estudios Hidrográficos (CEDEX). *http://hercules.cedex.es/anuarioaforos/default.asp*
- Agència Catalana de l'Aigua. *http://aca-web.gencat.cat/aca/appmanager/aca/aca/*
- Agencia Andaluza del Agua. *http://www.agenciamedioambienteyagua.es/*
- Sistema Nacional de Informaçao de Recursos Hídricos (SNIRH) de Portugal. *http://snirh.pt/*

The compiled dataset comprises 808 gauge stations in Spain, 246 in Portugal, and 326 reservoir entrances in Spain, totalling 1380 data series. Only series with a common period of at least 30 years of record and less than 10% of missing values were considered. After a balance between the spatial density (to cover as much area as possible of the IP), length of series and number of missing values, only stations with less than 10% of missing values in the period from October 1975 to September 2008 (time period was defined in terms of hydrological years instead of natural years) were used. A total of 504 of the 1380 stations that comprise the original database overcame this criterion.

Seasonal time series were averaged from the monthly values, defining winter from January to May (JFM), spring season from April to June (AMJ), summer from July to September (JAS) and autumn from October to December (OND).

The homogeneity of the time series was also checked. The main cause of this possible no natural regime on IP Rivers is the high amount of dams located into the river network. According to Kundzewics and Robson (2004), the Pettitt test was selected (Pettit, 1979) to check the homogeneity of time series. An advantage of this test is that it is non-parametric, so it does not assume that the data fit any probability distribution. Note that it was applied to the 'extended' seasonal streamflow time series (using all available records, not only the selected period). Additionally, in order to evaluate if an abrupt change found from the Pettitt test could be related to a change in the natural regime as a consequence of dam regulation, the percentage of common area between the curves of the annual cycles calculated using data from before and after the change point was calculated. Only the stations where this percentage was found above 50% were considered as homogeneous (totalling 382 of the 504 evaluated). The missing values presented in these seasonal time series were filled using a linear regression. Lastly, the time series were standardized following an approach similar to the proposed by Vicente-Serrano et al. (2011).

3. METHODOLOGY

3.1 Identification of stable predictors

Identification of stable predictors was achieved through the analysis of the variability of the correlation between seasonal streamflow and teleconnection indices using a moving window of 15 years. Following the criterion of Ionita et al. (2008) and Gamiz-Fortis et al. (2010) the correlation was considered to be stable for those stations where seasonal streamflow and teleconnection indices were significantly correlated at 90% level for more than 80% of the 15-year windows covering the period 1975–2008 and, furthermore, that the sign of the correlation did not change with time.

3.2 Forecasting scheme

A linear model based on stepwise multiple linear regression was developed for seasonal streamflow forecasting at each gauging station, using as predictors the stable and significantly correlated seasonal teleconnection indices. Seasonal streamflow in autumn, winter and spring were used as predictands. Summer was not considered because of it is the season with lowest streamflow regime and the smallest variability. Four forecasting scenarios were contemplated for each seasonal streamflow forecasting. The number of the scenario indicates the number of seasons in advance with which the prediction is made. For example, in case of autumn streamflow forecast, the predictors used in each scenario were: in the first scenario (referred as '4S' hereafter), the seasonal teleconnection indices of the previous autumn; in the following scenario (3S), the teleconnection indices from one year up to three seasons before (i.e. the seasonal teleconnection indices of the previous autumn and winter); in the next scenario (2S), the teleconnection indices for one year up to two seasons before (i.e. the seasonal teleconnection indices of the previous autumn, winter and spring); in the last scenario (1S), the teleconnection indices from one year up to the previous season (i.e. the teleconnection indices of the previous autumn, winter, spring and summer).

To evaluate the forecasting skill, the following verification measures were used: the Pearson correlation coefficient (named as 'RHO' hereafter), the Root Mean Square Error Skill Score (RMSESS) and the Gerrity Skill Score (GSS). The RHO provides a measure of the linear relation between the 'observed' and 'forecasted' series. The RMSESS is a measure of the forecasting error, which is referred to the climatological mean. Hence, positive (negative) values of RMSESS indicate better (worse) forecasting skill than climatology. The GSS identify the accuracy in forecasting streamflows that are in the same category that observations. The GSS is a weighted sum of elements in the contingency table of possible combinations of the forecast and observed categories, where the weights favour forecast closer to the observed categories. To the calculation of GSS, three categories were considered: below normal, normal and above normal, determined by the 33rd and 66th terciles. The GSS takes values between minus infinite and 1, where values greater than zero indicate that the forecast model is more skilful than climatology. More details of these verification scores can be found in Jolliffe and Stephenson (2003). Because of the limited length of records, the 'leave one out' procedure was followed to define the calibration and validation subsets. Then, the model was fitted to the calibration ($N-1$) data and tested on the withdraw year. This process was repeated for all years. Hence, the forecasted time series with the same length as the original were created, with calibration and validation subsets being independent in each realization.

4. RESULTS

The stability analysis of correlations between seasonal streamflow and teleconnection indices is shown in Figure 1. This figure indicates the number of gauging stations that present significant and stable (and also strongly stable) correlations with teleconnection indices at different lags. The maps with the location of the stations with stable correlation are not shown, but briefly commented.

Autumn streamflow presents significant correlation with ENSO indices of previous autumn (mainly for stations located in Douro and Tejo Basins, but also some stations located in the upper Jucar and Guadalquivir Basin), but in most cases they are not stable. This feature (many significant but not stable correlations) is also found in correlations between autumn streamflow and WeMO in previous spring and SCAND and SOI in previous summer. Although there are not so much stations stably correlated with SAI of previous autumn and NAO and AO of previous winter, they are grouped in the Mediterranean Andalusian Basin. Moreover, the EP-NP of the previous spring (for stations situated north-western quadrant of the IP), the WeMO of the previous spring (for Miño-Sil and headwaters of Ebro and Tejo Basins) and the EA of the previous summer (for stations in Miño-Sil, Tejo and Guadalquivir Basins) are also important predictors.

Winter streamflow presents significant but not stable correlations with WP and SCAND in previous winter and summer, respectively (in particular in Douro, Tejo and Guadalquivir Basins). Also, the EP-NP of previous spring presents stable correlations in stations located in the northern part of IP. The SCAND of previous autumn is stably correlated with stations in Miño-Sil, Douro, upper Ebro and Tejo Basins. However, the most remarkable results are found for the SAI of previous October, which presents stable correlations with stations in most of the IP, but the Cantabrian and Mediterranean slopes.

In case of spring streamflow, it is stably correlated with some indices of previous summer, such as the EP-NP (with stations in the Mediterranean slope), the PNA (with stations in the Miño-Sil, Douro and headwaters of Tejo Basins), the SCAND (which correlates stably with stations in the Guadalquivir River), the AO (specially with stations in the Miño-Sil, Douro, Tejo and headwaters of Ebro Basins), and the indices related with the ENSO phenomenon, in particular El Niño1+2 (with stations in the northwestern corner of the IP). Also, the NGPO and IOD in previous autumn present significant and stable correlations with some stations (located in downstream of Guadalquivir and Ebro Rivers in case of the NPGO, and in the Miño-Sil Basin for the IOD). Finally, winter NAO and SCAND present stable correlations with stations located in Tejo and Guadalquivir Basins in case of NAO and with stations in Douro, Tejo and Guadalquivir Basins in case of SCAND.

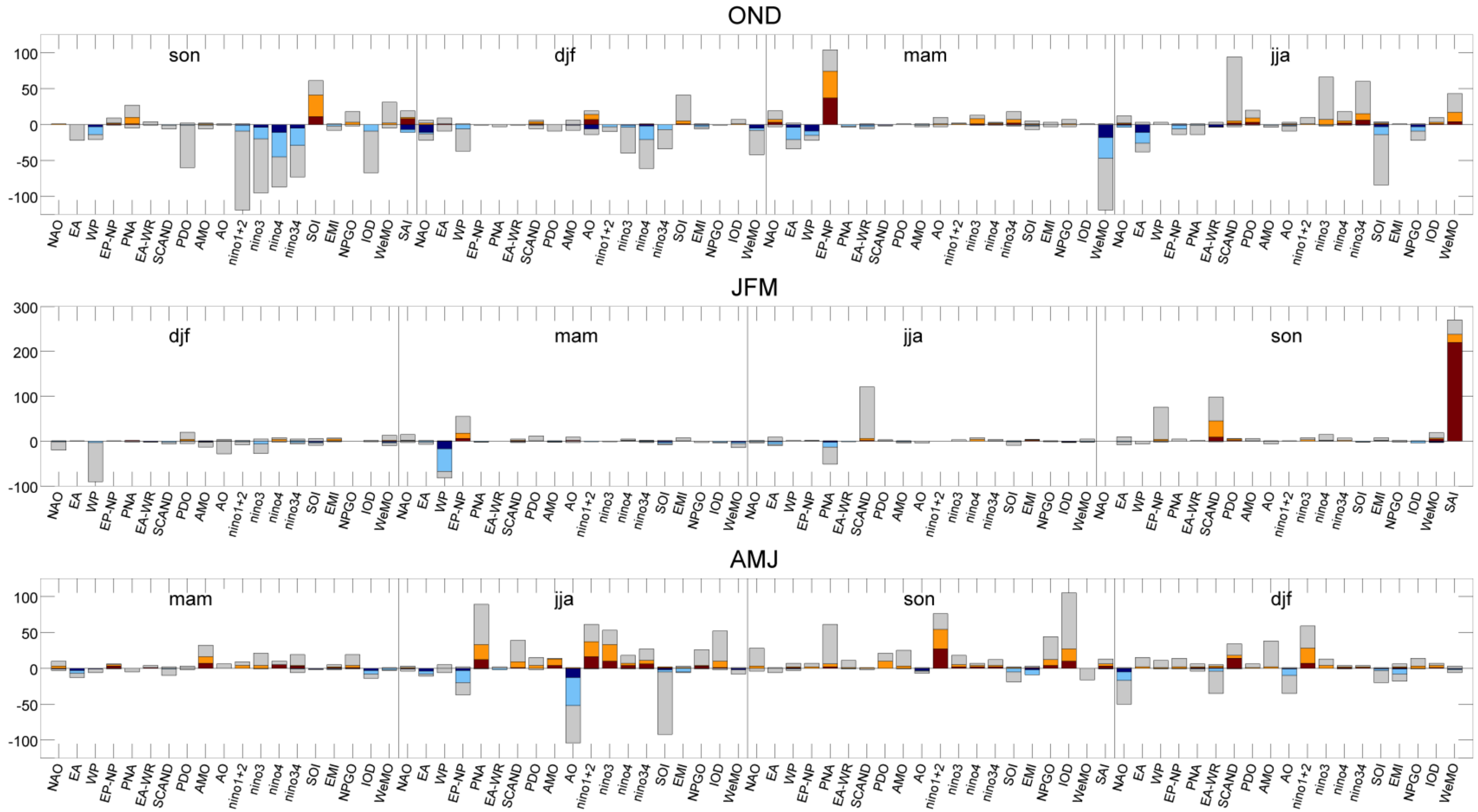

Fig. 1: Number of stations that present a significant (at 95% confidence level) (grey bars), stable (light blue and orange bars) and strongly stable (dark blue and dark red bars) correlation between teleconnection indices of four previous seasons (son –autumn, djf –winter-, mam –spring- and jja–summer-) to the correspondent seasonal streamflow (autumn –OND- in upper panel, winter –JFM- in middle panel and spring –AMJ- in lower panel). Negative numbers mean sum of stations with negative correlations.

Figure 2 summarizes the result for the three verification scores: RHO (Fig. 2a), RMSESS (Fig. 2b) and GSS (Fig. 2c) for the four forecasting scenarios considered. For autumn streamflow forecast, reasonable good forecasting skills are found in the Mediterranean Andalusian Basin (scenario 3S), with RHO, RMSESS and GSS reaching values around 0.6, 15% and 0.4, respectively. Also Douro, upper Ebro and Miño-Sil basins present some forecasting skills, increasing as lead-time forecasting diminishes. There forecasting skill for winter streamflow when considering scenarios 4S, 3S and 2S is limited. However, the scenario 1S shows good forecasting results for most of stations, particularly in centre and western of IP, indicated by values of RHO around 0.6, RMSESS between 10-30% and GSS above 0.4. Regarding spring streamlflow, forecasting skills are modest (with RHO, RMSESS and GSS values usually below 0.5, 15% and 0.3 respectively). In this case, teleconnection indices in previous summer (see scenario 3S) seem to have some forecasting skill, especially in Miño-Sil, upper Tejo and Guadalquivir Basins. Additionally, information of teleconnection indices of previous winter (scenario 1S) adds some improvements to the predictions.

5. SUMMARY AND CONCLUSIONS

This study presents valuable information about the potential forecasting skill of main teleconnection indices leading seasonal streamflow in the IP. The main conclusions are summarized in the following paragraphs.

Moderate predictions of autumn streamflow in the Mediterranean Andalusian Basin can be made more than two seasons in advance. Particularly, the NAO of previous winter appears as the most stable and highly correlated (0.64 in average) predictor. In case of Douro and Tejo Basins, the teleconnection indices used as predictors are mainly the related to the ENSO phenomenon in previous autumn, and the WeMO and EP-NP of the previous spring. The influence of the ENSO phenomenon on autumn precipitation in the Mediterranean area has been addressed (Mariotti et al., 2002; Rodó et al., 1997). In addition, these results indicated that despite WeMO index has been usually associated with extreme precipitation events over the Mediterranean façade of the IP (Martin-Vide et al., 2006; Hidalgo-Muñoz et al., 2011), there is a significant correlation between autumn streamflow and spring WeMO in the Tejo Basin.

The results obtained in forecasting winter streamflow indicate that predictions can be obtained with the information provided by SAI index in previous October. This result was expected, since SAI has been found a good predictor of following winter AO (Cohen et al., 2011) and NAO (which is a regional manifestation of AO) that are the main climatic drivers of precipitation during winter in the IP. Also, this finding is in the line of the results obtained for Brands et al. (2012, 2013), which found SAI a good predictor of wintertime climate conditions of the IP.

The poorest forecasting results are found in spring streamflow. Only some stations in North-West of IP (in Miño-Sil and Douro Basins) and in the central area of the IP (in Tejo and Guadalquivir Basins) present some forecasting skill. In this case El Niño-1+2 of previous autumn and winter was found the main predictor. The relation between spring precipitation in Europe and ENSO has been underlined before (Rodó et al., 1997;

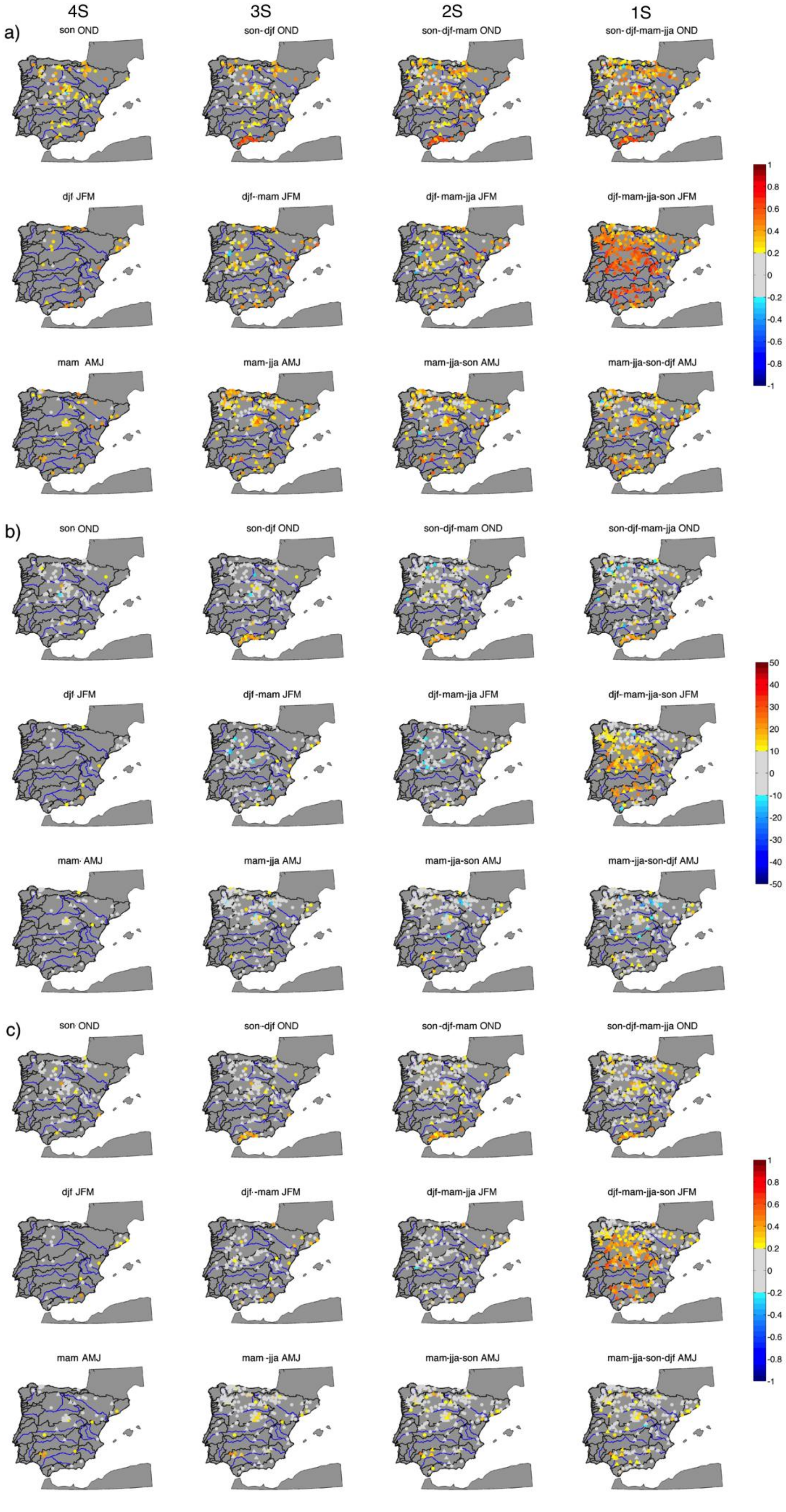

Fig. 2: Results for the verification scores a) RHO, b) RMSESS and c) GSS. In columns the four prediction scenarios considered (named at the top of the column) are presented. In rows each seasonal streamflow to be forecasted (OND, JFM and AMJ) are presented.

Lloyd-Hudges and Saunders, 2002; Mariotti et al., 2002). In particular, Lorenzo et al. (2010) found that, although the negative phase of ENSO almost always announces dry springs in northwestern of the IP, the positive phase of ENSO does not anticipate the appearance of wet springs. Also, SCAND and NAO indices in previous winter were found stable predictors in stations located in central areas of IP. Bearing in mind that winter NAO and SCAND are related to winter precipitation in the IP, this result could be explained by streamflow persistence or a lagged response (through snowmelt in spring).

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