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INFLUENCE OF LOW-FREQUENCY VARIABILITY PATTERNS WEMO AND NAO ON STREAMFLOW OF THE RIVERS IN CATALONIA (1951-2000)

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I. INTRODUCTION

Rainfall in the north-eastern corner of the Iberian Peninsula is linked during cold periods to internal cyclogenesis in the Western Mediterranean basin, showing weak correlation with the North Atlantic Oscillation (NAO). Thus, new proposed low frequency variability pattern in Mediterranean, called Western Mediterranean Oscillation (WeMO; Martín Vide, 2002; Martín Vide, et al., 2006) allows a better understanding of monthly rainfall anomalies in the western coast of the Mediterranean Sea. Therefore, precipitation in Catalonia is actually better explained by NAO index, in the Ebro basin, and the WeMO index, in the inner part of Catalonia (Catalonian Internal Basins, CIB) due to their orientation to Mediterranean flows (figure 1).

In 2004 the Spanish Government approved the AGUA plan to manage water resources. Despite this program was mainly focused on changing water policies in Spain, decreasing the social and economical dependence on surface water resources, the prolonged drought occurred in Catalonia in 2008 highlighted how water resources are still really linked to streamflows of majors rivers. Therefore, this paper aims to find correlations between monthly rivers discharges and two indexes (NAO and WeMO) which explain rainfall in Catalonia during the cold months of the year. Obtaining statistical significance correlations during the second half of the 20th century enables to progress in the mid-long term prediction of discharges, improving management of water resources in Catalonia.

II. STUDY AREA

This paper analyzes those major Catalan rivers that flow onto the Mediterranean Sea (figure 1). In this sense, this paper focuses on rivers of CIB (Llobregat, Ter, Fluvià, Tordera, Congost, Anoia, Francolí and Foix) and those belonging to Ebro Basin (Noguera Pallaresa,

Noguera Ribagorçana and Segre). Some analyses deal only with Pyrenean Rivers, because of the large importance of their discharges regarding water consumption in Catalonia.

III. DATA AND METHODOLGY

This study is centred on the period between 1951 and 2000. The paper deals with those river stations with series longer than 40 years and with an 80% of the total data (SMC, 2000). Data from eleven streamflow gauging stations have been used, most of them corresponding to main rivers in Catalonia. All these stations are located near sources, minimizing human alteration to streamflows. Furthermore, data has been validated with Thom's test. The Pearson's correlation coefficient has been the main method used on a monthly basis, working at the 95% confidence level. NAO index and WeMO index values have been extracted from the data base of the Climate Research Unit (University of East Anglia) and the Group of Climatology (University of Barcelona).

IV. RUNOFF

Discharges are related to more permanent factors, such as lithology or topography, and others more changeable such as land uses, intensity of precipitation or antecedent humidity. Analyzing intra-anual variability, Serrano Muela et al., (2008) show how in Mediterranean environments under certain conditions of vegetation and high drainage capacity, streamflow is highly explained by water table and antecedent humidity, suggesting that runoff is not necessarily only related to precipitation, either amount or intensity.

V. RESULTS

Table 1 shows the seasonal rank discharges of all the rivers analysed in the second half of the twentieth century, highlighting the third position of autumn in rivers with Mediterranean regimes, despite the season is the rainiest one in most of these basins. Thus, low level of discharges in July and August in the Pyrenean Rivers (Figure 2), with a high precipitation in summer, confirms the importance of antecedent moisture on runoff generation. Therefore, winter is ranked in first or second position in seasonal rank discharges in those rivers that have little snow influence.

Analysing monthly discharges and the correlations with the two low-frequency variability patterns, runoff cannot be associated with the evolution of both indexes during warm periods, from April to September, although April shows a slightly negative relationship, which is significant in some basins, due to its closeness to winter dynamic. Incidence of patterns on the monthly runoff shows a negative relationship in most of the rivers, where significant statistical correlations are clearly visible during autumn and winter. As in the precipitation WeMOi has a stronger incidence in CIB (López Bustins, 2007; table 2) with high values of Pearson's correlation coefficients like in river Ter in October (r = -0.41), December (r = -0.44) and January (r = -0.47), or in river Tordera in October (r = -0.48), December (r = -0.39) January (r = -0.42) and February (r = -0.31).

Table 3 shows the relationship of the NAO index with monthly discharges for the second half of the twentieth century. These values highlight how NAO index has a higher relationship with western rivers during more months, those belonging to Ebro Basin, as the Noguera Ribagorzana with values like (r = -0.50) in October, (r = -0.36) in January and (r = -0.39) in February. Anyway, the NAO pattern shows also a remarkable incidence with the rest of the rivers in January and February, such as river Tordera (r = - *0.49)*. Instead, Noguera Pallaresa shows a weak influence with both patterns, due to northern situation of its catchment, responding better to positive phases of NAO.

In order to understand whether there is any kind of relationship between patterns and spring discharges in the Pyrenean Rivers, I have calculated the Pearson's correlation coefficient between the winter index, average from December to February, and monthly runoff from March to July. Table 5 shows WeMOi average related with rivers of CIB during spring. River Ter has significant correlations during April and May (-0.30), and there is a weakening of the influence level in summer. In Table 5 correlations with winter average of NAOi are shown, with high correlations on western rivers, Noguera Ribagorçana (r = -0.17 to r = -0.41). To confirm the correlation between patterns and the snowmelt streamflow, I have analyzed in detail evolution of Noguera Ribagorçana (Figure 3), with significant correlation at the 99% confidence level (*p-value* = 0.0018). The evolution show how winter rainfall affects discharges strongly during thaw, even when the coldest season reaches the lowest annual rainfall in the Pyrennes. Thus, spring and summer discharges unlikely reach high values if the NAO index has a positive average during the winter.

VI. CONCLUSSIONS

Winter plays an important role in the monthly annual discharges in the second half of the twentieth century, becoming a determining factor in Pyrenean Rivers to generate peak streamflows in spring. In addition there is an asynchrony between precipitation (or snow) and discharges, explained by the lithology and by the importance of antecedent soil moisture in the generation of runoff, in Mediterranean areas where evapotranspiration is very high during the warm semester of the year.

This paper is a first approach on the level of correlation between discharges of Catalan rivers with NAO and WeMO indexes on a monthly resolution. Firstly it should be noted that streamflows in cold half of the year are linked to the evolution of low frequency variability patterns. Thus, the correlations obtained reaffirm in hydrology the regionalization existent on the rainfall in Catalonia between the incidence of the NAO, with higher correlations to the western sector, and WeMO with a stronger and longer influence in eastern sectors. These correlations are high for several months at a 95% level of confidence, and spatially important, because they affect all rivers during winter, with the exception of Noguera Pallaresa due to its northern exposition.

The fact that the significant correlations correspond to main periods in the generation of the annual streamflow, make it a useful tool to improve in the forecast of medium and long-term discharges, which could allow to advance in the rationalization of consumption of water surface resources.