Possible influence of large-scale climate indices on the variability of maximum streamflow in rivers of Peninsular Spain

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1. Introduction

It is well recognized the strong influence of large-scale climatic patterns in the variability of many components in the hydrological cycle (Markovic, et al. 2009). Previous studies in the Iberian Peninsula indentified the influence of atmospherics circulations in time series of precipitation (Muñoz, et al. 2004; Gallego, et al. 2005; Gonzalez-Hidalgo, et al. 2009; Rodriguez-Puebla et al. 2010), streamflow (Trigo, et al. 2004; Moreno, et al. 2006; Morán, et al 2010) and piezometric heights (Luque-Espinar, et al. 2008). However, the influence in the maximum streamflow has not been addressed.

In the present work we addressed the question, How is the influence of large scale climate patterns in the maximum streamflow in the Peninsular Spain?, we evaluate this linkage between this variables by mean of Granger causality test, discrete spectral analysis and continuous spectral analysis.

2. Objectives

In general, the principal objectives of this work are:

- Evaluate changes in a climatic variables have an impact on changes in the maximum hydrological variables in the study area.
- Identified the reproduction of climatic cycles in the maximum monthly time series in a discrete approach.
- Explore changes in variance and linkage in phases between the variables in short and long-term.

3. Study Area and Information

Spain is situated in a complex meteorological area, between mid latitudes and the north sub-tropics, between two important mass water (Atlantic Ocean and Mediterranean Sea), as well as very rugged orography, represented one of the most extreme cases of variability natural indicator within Europe.

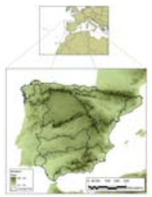


Figure 1. Study area with main hydrological divisions and principal mountains system

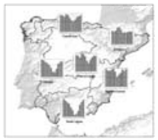


Figure 2. Patterns of wet days in some regions within the zone of study (base period 1960-1990)

The analysis is based on two types of information : Maximum streamflow time series and macroclimatic indices. We use 80 maximum monthly streamflow time series, distributed along the study area with at least 40 years (Fig.3).

Figure 3. Hydrological stations

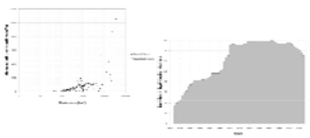


Figure 4. Left panel: Mean maximum monthly flow vs area, right: time series of number of gauge stations in a given year

We selected five teleconnection patterns NAO (North Atlantic Oscillation), AO (Artic Oscillation), MO (Mediterranean Oscillation), WeMO (Western Mediterranean Oscillation) and Multivariate ENSO Index.

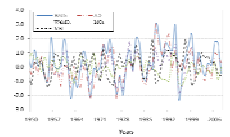


Figure 5. Evolution of the winter climatic indices in the last years

Macroclimatic indices	Dipoles	Information sites
NAO	Iceland and Gibraltar	http://www.cru.uea.ac.uk/
WeMO	Cadiz and Padua	http://www.ub.edu/gc/English/wemo.htm
MO	Gibraltar and Israel	http://www.cru.uea.ac.uk/
AO	Polar zone and Latitude 37°-45°	http://www.cpc.noaa.gov
MEI	Pacific Ocean	http://www.cpc.noaa.gov

Table 1. Teleconnection patterns

4. Methods

Granger Causality Test

This test is useful for evaluate when changes in a variable *X* will have an impact on changes other variable Y and provide valuable information about the power of the variable *X* in the future values *Y* (Granger, 1969). Let *X* and Y time series. We assume the null hypothesis H_0 that *X* does not cause *Y* (H_0: $\beta_1 = \beta_2 = \ldots = \beta_i$). To evaluate the null hypothesis, one first finds the proper lagged values of Y to include in a univariate autoregression of Y:

$$Y_t = \alpha_0 + \alpha_1 Y_{t-1} + \alpha_2 Y_{t-2} + \cdots + \alpha_i Y_{t-i} + \varepsilon_t \quad (1)$$

Here Y_{t-i} is retained in the regression if and only if it has a significant t-statistic; m is the greatest lag length for which the lagged dependent variable is significant. Next, the autoregression is augmented by including lagged values of *X*:

$$Y_t = \alpha_0 + \alpha_1 Y_{t-1} + \alpha_2 Y_{t-2} + \cdots + \alpha_i Y_{t-i} + \beta_0 + \beta_1 X_{t-1} + \beta_2 X_{t-2} + \cdots + \beta_i X_{t-i} + \varepsilon_t \quad (2)$$

We obtain RSS (full model) from Ec.2 and RSS(restricted model) from Ec.1. According to *F*-test evaluate the explanatory power.

$$F\left[\{(N-k)/q\} \cdot \{(RSS_{restricted} - RSS_{full})/RSS_{full}\}\right] \quad (3)$$

N: number of observations; *k*: number of parameters from full model; q: number of parameters from restricted model The null hypothesis is rejected if *F*-value > critical value from the F-distribution, then we can say *X* causes Y.

Spectral Analysis

The first approach in the analysis of the linkage between climatic oscillation and hydrological cycles we used classic spectral analysis. There are many methods for estimate the spectral density, we decided to use the Blackman-Tukey method, where this is calculate from the covariance function (Chatfiel, 1991):

$$S(\omega) = \frac{1}{\pi}\left\{w(0)C(0) + \sum_{k=1}^{m} w(k)C(k)\cos(\omega k)\right\} \quad (4)$$

Where $s(\omega)$ is the estimated spectral density for frequency ω, C(k) in the function of covariance for k-ésimo value and w(k) weighting function, know a "lag-window", wich is used to give less weight to the covariance estimates as the lag increases. The lag window used was the Tukey window:

$$w(k) = \frac{1}{2}\left\{1 + \cos\left(\frac{\pi k}{m}\right)\right\} \qquad 0 \le k \le m \quad (5)$$

m is the maximum number of lags for the covariance function used in the spectral estimation, the maximum number of lags are n-1, where n is the number of data. We identified the principal cycles for different confidence levesl 99%, 95%, >95% and no detected by mean of the method propose by Luque, et al (2008).

Continuous Wavelet

Continuous approach in the linkage of climatic and hydrology variables we used Wavelet analysis and two useful tool for this analysis cross wavelet transform and wavelet coherence transform. The continuous wavelet transform (Torrence and Compo, 1998) allow decompose a time series in the time-frequency domain, y we will indentified the principal oscillations and how this change in time. We selected for this work the Morlet wavelet:

$$\psi_0(\eta) = \pi^{-1/4} e^{i\omega_0 \eta} e^{-\eta^2/2} \quad (6)$$

Where ω_0 is the dimensionless frequency and η dimensionless time. The cross wavelet transform (XWT) defined :

$$W^{xy}(s,t) = W^{x}(s,t) W^{y*}(s,t) \quad (7)$$

this allow identified when the time series oscillated in a common frequency in time, besides detect the intermittent coupling. Another tool is how coherent is the cross wavelet transform, who is the wavelet coherence transform (WCT). Which is a measure of the intensity covariance between the timer series. According with Torrence and Webster (1999) is defined:

$$R_n^2(s) = \frac{\left|S\left(s^{-1} W_n^{XY}(s)\right)\right|^2}{S\left(s^{-1}\left|W_n^{X}(s)\right|^2\right) \cdot S\left(s^{-1}\left|W_n^{Y}(s)\right|^2\right)} \quad (8)$$

5. Results

The results obtained with Granger causality test, allow to indentified the important impact of the macroclimatic indices in the behavior of the maximum streamflow. It is clear the influence of the NAO and AO indices in the time series of the Atlantic basins and principally for 90 and 95%, the MO index show important impact in time series of the Atlantic and the Ebro confederation for 90 and 95%. The MO index show significance result in timer series from the façade Mediterranean principally in basins from Jucar and in the lower of Ebro.

Figure 6. Maps of statistically significance for Granger causality test between monthly maximum streamflow and monthly circulation patterns

Discrete Spectral Approach

After that, we used the classical spectral analysis for explored the connection between climatic cycles and oscillations in the maximum hydrologics. We identified the principal oscillation modes in the macroclimatic series for confidences levels of 90 and 95% (Table 2). Figure 7 show power spectrum of monthly time series with bands of confidence levels.

Climatic indexes	Periods (years)						
NAO (monthly)	0.5	1	2.3 - 2.7	5-5.7	8	12.3	24
NAO (winter)	2.3 - 2.7	3	5.0 - 6.0	8.2	15		
AO (monthly)	0.5	1	2.5 - 2.7	5.4 - 6	8	12	
AO (winter)	2.4	5.6	8	9.3	18.5		
WeMO (monthly)	0.5	1	2	3.3	5	7.5	16
WeMO (winter)	2.2 - 2.5	3.6	6.5	15	22		
MO (monthly)	0.5	1	2.8	5.8			
MO (winter)	2.5	4.5	6				
MEI (monthly)	2.4 - 2.8	3.7	5.3	6.5	8.3	14.5	

Table 2. Principal cycles observed in the teleconnection patterns

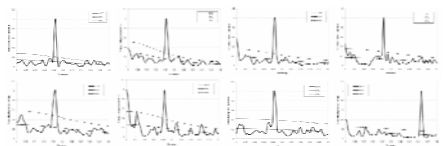


Figure 7. Maximum monthly streamflow power spectrums

In order to observe the spatial distribution of principal cycles in the study area, we elaborated maps according different confidences levels, we consider semi-annual, annual e interannual cycles (2.3-2.8 years, 5-6 years y 8-12 years).Table 3 show the results of significant time series in percentage for different confidence levels (90%, 95%, <95% and no detectable). Figure 8 show maps of statically significance cycles.

It is clear the importance of annual cycle in all the stations. The semi-annual is evident in 69% time series principally in the Cantabrian and Pyrenees basins. The quasibienal cycle (2.3-3 years) it is an important cycle in the region, in time series from the Atlantic and Mediterranean which has been linked with the modes of oscillation of NAO and NAO, and WeMO in the Mediterranean facade. The 5-6 years cycle is statically significant in time series of the Duero, Tajo and Jucar principally, which will be asociated with the cylcles identified in the NAO, AO and WeMO. By other hand, is less evident the 8-12 years cycle, which has been observed in 39% time series, to be more stronger in Duero, Tajo, Jucar and lower Ebro. Exist an important overlapping in the influence of macroclimatic indices.

Cycles	Level of significance (%)				
	>99	99 - 95	<95	Detected	No detected
Semi-annual	45	20	4	69	31
Annual	94	6	0	100	0
2.3 - 2.8 years	28	34	16	77	23
3.2 - 4 years	4	31	16	51	49
5 - 6 years	3	19	18	39	61
8 - 12 years	3	15	20	38	63

Table 3. Percentages of appearance of the confidence levels of the cycles

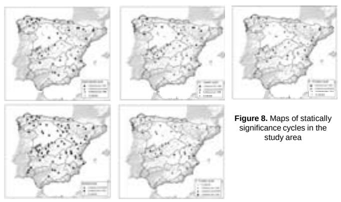
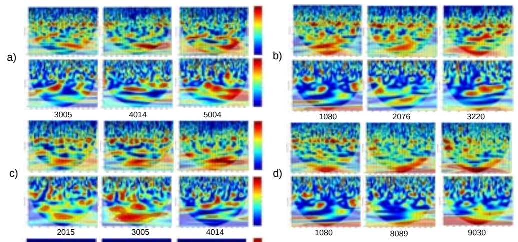
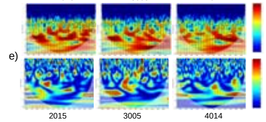


Figure 8. Maps of statically significance cycles in the study area

Continuous Spectral Approach

- Short – term

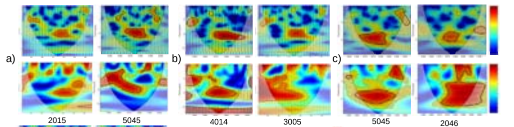


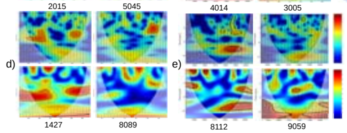


Important influence of the NAO, AO and MO evolution in timer series in short-term of the Atlantic façade in spectral bands of 2-4 years (1960-1975, 1985-1995), 5-6 years (1995-2005) and 8-12 years (1980-2005). WeMO in time series of the Cantabrian and Mediterranean zones in spectral bands of 2-3 years (1950-1965;1985-1990) and 5-8 years (1950-1970). Possible influence of MEI depends of the intensity events and exist an alternative in phase.

Figure 9. Cross-wavelet transforms and squared coherence, between monthly maximum streamflow and macroclimatic indices (a)NAO; b)AO; c)MO, d)WeMO and e)MEI. The thick black contour designates the 95% confidence level against red noise and the cone of influence, where the effects become important. The relative phase relationship is shown as arrows (where in phase pointing right and anti-phase left)

- Long - term





It is clear the influence of macroclimatic phenomena in the evolution in long-term of the maximum streamflow in spectral bands of 2-4 and 6-8 (NAO, AO and MO) in the Atlantic basins. Influence of WeMO in the Cantabrian and Mediterranean façade in 2-3, 5-6 and 10-12 years.

Figure 10. Cross-wavelet transforms and squared coherence, between annual maximum streamflow and winter macroclimatic indices (a)NAO; b)AO; c)MO, d)WeMO and e)MEI. The thick black contour designates the 95% confidence level against red noise and the cone of influence, where the effects become important. The relative phase relationship is shown as arrows (where in phase pointing right and anti-phase left)

6. Conclusions

The results allow to evidence the important influence of the climatic patterns in the evolution of the maximum streamflow, as well as the spatial variation of this influence in the study area. Its clear that influence is limited by the principal mountain system. The granger test show the significant impact of the climatic variables in the hydrological variables. The spectral analysis show the linkage between the variables in different cycles and the continuous analysis evidence intermittent association along the time. Exist overlapping areas in the influence of this phenomena and it is important to considerate the connection between the atmospheric and ocean configuration. In general, the results provide valuable information about the climatic indices for improve forecasting and use in non-stationary framework.

Acknowledgments

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