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North Atlantic Oscillation as a cause of the Hydrological Changes in the Mediterranean (Júcar River, Spain)

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Abstract:

Significant changes in the Júcar River Basin District's hydrology in the Mediterranean side of Spain, have been observed during last decades. A statistical change-point in the year 1980 was detected in the basins' hydrological series in the main upper river, Júcar and Túria basins.

In the study scope are, the North Atlantic Oscillation (NAO) is linked with the winter precipitations in the Upper Basins, which are here responsible for the major part of streamflow. So changes in the rainfall has an important effect in the natural river flows. The statistical analysis detected a change at NAO's seasonal pattern, what means a considerable reduction of winter rainfalls in the Upper River basins located in the inland zone which is simultaneously the water collection and reservoirs area (a -40% of water resources availability since 1980).

Hydro-meteorological data and a Water Balance Model, Patrical, have been used to assess these water resources' reduction. Results points out to the change in the Basin's precipitation pattern in the inland areas (upper basins), associated to Atlantic weather patterns, as the main cause, while it has not been detected in the coastal areas.

All these changes implies water stress for water resources planning, management and allocation, where more than 5.2 million people and irrigation of 390,000 hectares are served, joint to the time variability, an important territorial imbalance exists between resources and demands. Thus, in the main upper basins, with the biggest streamflow's reductions, locate the largest reservoirs in terms of water resources collection and reserves.

1 INTRODUCTION

The mean annual streamflow and the hydrological regime, which determines the water resources availability, have suffered in recent decades from major changes in many areas of the world, for example in Asia (Shengzhi-Huang et al. 2016, Tao et al., 2011; Zhang et al., 2011.), and inside Europe, significantly relevant in the Mediterranean regions (García-Ruiz et al., 2011), such are the cases of Italy (Senatore et al., 2011) and Spain (Morán-Tejeda et al. 2011), where changes on the hydrological regimes have an immediate effect on water resources availability and increase the probability of water scarcity problems. River regimes characterize the monthly distribution of streamflow and reflect the climatic and physiographic characteristics of a basin (Morán-Tejeda et al., 2011).

Water resources management and planning require methods of water resources' forecasting which have traditionally accepted the hypothesis of maintenance of hydrologic parameters, for instance mean values and variance. However, the stationary hypothesis of the hydrological regime cannot be taken for granted (Milly et al., 2008).

A large number of methods (Bayazit, 2015; Xiong et al., 2015) have been employed to analyze the non-stationarity in univariate hydrological series: analyzing trends (Kendall, 1975; Chiew and McMahon, 1993; Moraes et al., 1998; Yue et al., 2002), detecting change-points in time series (Reeves et al., 2007; Perreault et al., 1999; Rasmussen , 2001; Wong et al., 2006; Xie et al., 2014), hydrological extremes (El Adlouni et al., 2007; Villarini et al., 2009; Villarini and Serinaldi, 2012), extreme low-flows (Du et al., 2015), and frequency analysis (Strupczewski and Kaczmarek, 2001; Strupczewski et al., 2001a,b). Within this paper the three methods described by Reeves et al. (2007) to detect undocumented changes in climate data series have been applied. These methods are: 1) standard normal homogeneity (SNH) test, 2) a variant of the SNH test and 3) Wilcoxon's nonparametric test.

Two climate teleconnections are used to explain the hydrological conditions in the Mediterranean region, the North Atlantic Oscillation (NAO) and the WeMO (Western Mediterranean Oscillation). The NAO Index (NAOI, Hurrell and Deser, 2009) is determined as the difference of normalized pressures at sea level between measured values in Azores 38ºN and Iceland 65ºN. This index can be annual, monthly or daily, and the winter NAOI determines the major or minor amount of rain in winter in many Spanish regions, but not in the Mediterranean coastal areas. The NAO phenomenon appears in two variants, the positive one NAO+ and the negative NAO-. The NAO+ is the variant where high pressures are located in Azores area while low pressures dominate at lower Iceland area, and consequently a mass of humid air reaches England. And in the contrary case, when low and high pressures are not well defined and the NAO front has a curved trajectory, NAO^-, these jet streams affect Spain.

The WeMO is a regional teleconnection pattern as an alternative to the NAO to explain the pluviometry behavior of the peninsular east, next to the Mediterranean coast. The WeMO, obtains its greater correlations in those zones where the influence of the NAO is practically null.

In the Mediterranean area of the Iberian Peninsula as in the study case, the Júcar River Basin District (Júcar RBD), water resources availability have especially decreased in last decades. This RBD supplies water for urban use (5.2 million people) and irrigation systems (390,000 hectares of agricultural land) and in this paper are presented the considerable reduction of water incomes in its largest rivers since the 1980s (CHJ, 2005), trying to confirm this fact through a technical based discussion. These reductions have important implications for the water resources availability and future water management. The Spanish government issued a Ministerial-Order, *ARM/2656/2008 Order of 10 September on water planning*" in order to analyze the viability of water systems in the coming years. The Order recommends using all the available hydrological data and specifically indicates that "water balances should be assessed using water resources series for the periods 1940-2005 and 1980-2005, to show the major differences between the results for each period".

The changes observed in the Júcar RBD flows could have been due to different causes, including climate pattern, land use changes or anthropogenic effects (Morán-Tejeda et al., 2012) suggest, in the Duero River Basin, that further increases in forest area will enhance hydrological decline and highlight the importance of integrating land-cover information in water availability assessments in a region where water is a strategic resource. Sridhar and Nayak (2010) indicated that impact assessment studies should be carried out to distinguish between natural and human-induced changes.

Once clarified the causes of the water resources decline in the Júcar RBD, it is necessary to develop a more reliable planning and management. For this purpose, the water flows obtained from the gauging stations along the RBD have been previously naturalized, which means assessing the water flow in natural conditions that would exist without the human activity influence. This previous step is essential in order to feed a simulation model, the Patrical distributed Water Balance Model (WBM) (Pérez-Martín et al., 2014), which let reproduce the natural hydrology and finally identify and quantify the causes of the changes observed in the Júcar RBD. The time period used for hydrological data series tackles from 1940 to 2014, as this period is the most updated and reliable data series. The analysis of the changes on the hydrological regime, combined with the results from a water simulation model, can be used to characterize recent changes in weather patterns. Nowadays there is uncertainty about future weather patterns in this region, which is influenced by the global climatic regime of the Atlantic Ocean and the regional conditions associated with the Mediterranean Sea (López-Bustins et al., 2008).

The importance of detecting and validating these changes on the hydrological regime, lies not only in the need of monitoring the hydrological patterns, but also in the fact of evidencing changes on climate and water resources availability, and maybe stressed by human action. There are evidences of observed changes in many climate variables, including hydrological extremes, attributed to anthropogenic climate change (Hegerl and Zwiers, 2011; Bindoff et al., 2013; Trenberth et al., 2015; Stott et al., 2016; National Academies of Sciences, Engineering, and Medicine, 2016). Many studies detect significant hydrological changes in observed datasets (Merz et al., 2012).

Dealing with this paper-organization, Section 2 describes the study case, and the methodology used to detect change points on hydrology. Section 3 deals with results and discussion, describing the observed changes on the streamflow and the model’s performance of observed streamflow by the Patrical WBM. Section 4 analyses through the hydrological model the causes of the hydrological changes observed, analyzing them and focusing on changes in land uses and changes in climate patterns. Section 5 links the changes on climate patterns with changes on NAOI describing the influence of different factors on the hydrological regimes, the observed facts and the results distinguishing between the upper and the lower river basin, Section 6 describes the importance of the results and its implications for the water resources management within the Júcar RBD (the implications of these changes for water resources availability and water policy in the river basin), and finally Section 7 deals with the conclusions of the study.

2 STUDY CASE AND METHODOLOGY

2.1 Study Case: Júcar River Basin District

The Júcar RBD with a surface of 42,735 km^2 located in the eastern side of Spain is formed by a number of watersheds that flow into the Mediterranean Sea (Fig. 1a). The Júcar, Túria and Mijares are its three largest rivers. Groundwater is especially important in the basin, as over 70% of the river flows come from groundwater discharges, a more detailed description is included in (Ferrer et al., 2012).

The areas near the coast below approximately 600 m.a.s.l. are much more influenced by the effects of the Mediterranean Sea (Fig. 1b), according to precipitation variation coefficient of the Júcar RBD (Pajares, 2002), which reaches higher values in these areas (Fig 1c). The greater precipitation variability in the coastal areas is due to the presence of convective storms from the Mediterranean Sea, which are much heavier than those produced by Atlantic weather fronts. The inland and the coastal areas are different homogeneous climatic regions defined by CEDEX (2009), based on basin topography, altitude, rainfall and the value of the highest precipitation quartiles.

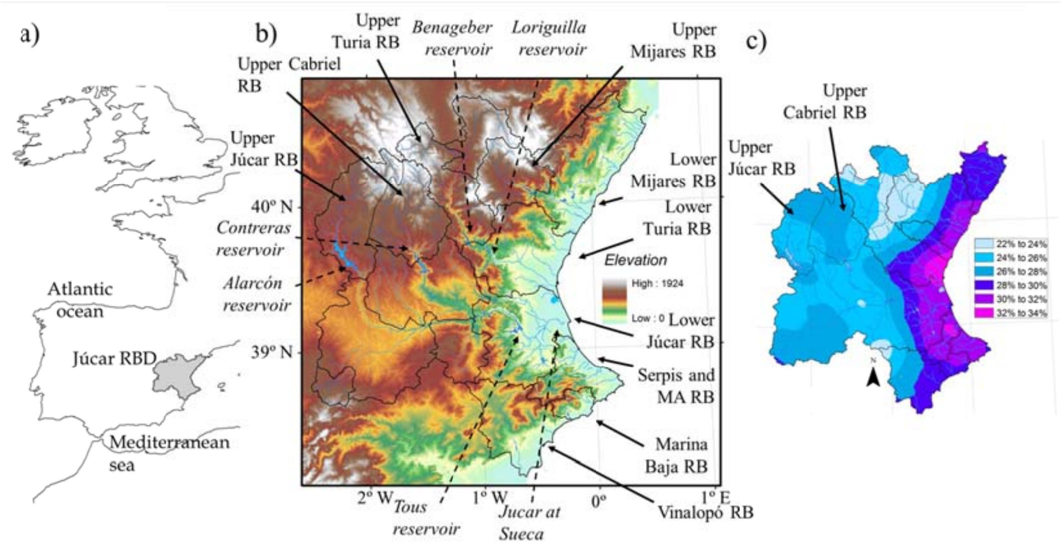

Fig. *1. a) Júcar RBD location, b) Digital Elevation Model and hydroclimate regions, and c) Variation Coefficient of the Precipitation (%) in the Júcar RBD.*

These are the two most strategic areas for water resources management in the whole Júcar RBD, as rivers runoff can be stored in its three largest reservoirs located in the inland areas, while in the coastal areas are located the major water demands. These main reservoirs are: Alarcón reservoir (1,112 hm^3) in the Upper Júcar River Basin (RB), Contreras reservoir (444 hm^3) in the Upper Cabriel RB and Benagéber reservoir (221 hm^3) in the Upper Túria RB, providing water to the largest cities in the district (approximately 2 million people) and also to a large agricultural area (between 100,000-150,000 ha).

Climate data come from the weather stations of the Spanish Meteorological Agency (AEMET, 976 rain gauges and 456 thermometers) and at the Automatic Hydrological Information System of the Júcar RBD (SAIH, 167 rain gauges and 20 thermometers), from October-1940 to September-2016.

Mean annual precipitation (average value 500 mm/year) varies widely throughout the Júcar RBD. In most southern regions, the driest mean annual precipitation is under 300 mm/year, while in other areas it reaches values above 800 mm/year for wettest registers. The monthly precipitation distribution in the Júcar RBD has a strong seasonal influence, with lower precipitation in the summer months. Mean temperature varies from less than 10 ºC in inland to 20 °C in the center and south coastal area. Average daily temperatures ranges also presents a wide range of variability with a low value near 6 °C in January to a maximum of 24 ºC in July and August.

Hydrologic data sets used are naturalized river flows obtained through observed flows at gauging stations and reservoirs along the Júcar RBD at monthly scale (from October-1940 to September-2016), as the WBM is fed by naturalized flows to reproduce the natural hydrology. Thus, reservoir regulation is compensated, adding to the river-flow the water stored in the reservoirs and subtracted when the reservoirs are releasing; water withdrawals are added to observed flows, while water-uses-returns along the river (urban supply and irrigation catchments, irrigation returns, etc.) are subtracted. These observed data come from the Júcar River Basin Authority's (RBA) flows-gauging and monitoring network that provides time flows series for research, control and hydrological planning purposes.

2.2 Methodology: Statistical Methods

The three methods described by Reeves et al. (2007) to detect undocumented changes in climate data series have been applied: 1) standard normal homogeneity

(SNH) test, 2) a variant of the SNH test and 3) Wilcoxon's nonparametric test. The SNH test was first applied to climate data by (Alexandersson, 1986). The variant of the SNH proposed by Reeves et al. (2007) solves the inaccuracy that variance can be different before and after of the change point.

The SNH and its variant procedure are also a likelihood ratio test when the model errors are IID (independent and identically distributed) and Gaussian. Normality of errors is a debatable assumption for many climatologically series. To reject "false change-point" on the basis of one or two outliers, especially near the record boundaries (first record t=1 or t=n last record), it is desirable a more robust procedure (Reeves et al., 2007), applying the nonparametric SNH procedures, which are based on apply to the relative data ranks rather than to the observed values. The Wilcoxon's nonparametric test is also applied in this work, which is based on the Wilcoxon rank-sum statistics, equivalent to the Mann–Whitney statistics used by Pettit (1979).

When a change-point is detected in data series the t-student test (Livingston, 2003) is applied - and its variant Welch–Satterthwaite t-test when the assumption that both samples have the same variance is rejected (Welch, 1938; Satterthwaite, 1946) - to determine if the change in mean streamflow is significant and also the confidence interval (Miao and Chiou, 2008). Both tests were applied to previously normalized data.

A statistical analysis was performed using this naturalized and normalized river flows, with very similar results in both tests, so the variance does not change. When variance is equal, the 95% confidence interval (95% CI) has similar values with both t-student and Welch–Satterthwaite formulas (Miao and Chiou, 2008). The three methods of statistic test and confidence interval are included in Table 1.

Method	**Statistic Test**	***p < 0.05***
SNH (Alexandersson 1986)	Tc	8.81
Variant SNH (Reeves et al., 2007)	Tc^2	9.94
Wilcoxon's nonparametric test (Petit, 1979)	Wc	8.38
t-student test and Welch–Satterthwaite test	t	2.29

Table 1. The 95% critical values for three simple change-point models and t-student test.

3 RESULTS & DISCUSSION

3.1 Observed Changes on Streamflow

Júcar and Túria RBs are the largest within the Júcar RBD, 65% of the RBD's total area (Table 2). The analysis is developed in several scope areas moving downstream. The results evidence that the headwaters of Júcar, Cabriel and Túria rivers have the largest reductions and present a significant change-point on the hydrological incomes (flows) in the same year, 1979/80, for the three methods applied (*p* < 0.05). Table 2 shows the statistical analysis' results, firstly for the Júcar and Cabriel rivers upper basin till the reservoir locations of Alarcón and Contreras and the total values for the sum of both; secondly, the results of the Túria river till the Benagéber reservoir point and finally, downstream for the whole Júcar RB till the Sueca monitoring point:

RB Scope / Monitoring Point (MP)	**Júcar upper basin. / MP: Alarcón reservoir**	**Cabriel upper basin./MP: Contreras reservoir**	**Júcar+ Cabriel upper basin**	**Túria upper basin./MP: Benagéber reservoir**	**All Júcar RB /MP: Sueca**
Area (km^2)	2,952	3,356	6,308	4,326	21,579
Mean 1940-2014 (hm^3/year)	399.0	339.6	738.6	265.7	1,515.0
Tc (8.81, p < 0.05)	16.6 (yes)	15.6 (yes)	16.8 (yes)	26.2 (yes)	23.9 (yes)
Tc2 (9.94, p < 0.05)	21.6 (yes)	19.9 (yes)	22.0 (yes)	42.0 (yes)	36.4 (yes)
Wc (8.38, p < 0.05)	16.8 (yes)	16.6 (yes	18.5 (yes)	28.7 (yes	26.3 (yes)
Significant change (yes/no)					
Year of change point			1979/1980		
Mean before 1980 (hm^3/year)	483.0	413.2	896.1	321.0	1,748.7
Mean after 1980 (hm^3/year)	283.1	238.2	521.4	189.3	1,192.7
	-41.4%	-42.3%	-41.8	-41.0%	-31.8%

RB Scope / Monitoring Point (MP)	**Júcar upper basin. / MP: Alarcón reservoir**	**Cabriel upper basin./MP: Contreras reservoir**	**Júcar+ Cabriel upper basin**	**Túria upper basin./MP: Benagéber reservoir**	**All Júcar RB /MP: Sueca**
% of change					
Student's t statistic **(2.29, $p < 0.05$)**	4.92	4.76	5.00	6.90	6.33
Significant change (yes/no)			Yes		
95% CI Upper basin (hm^3/year)	576.1	497.5	1,068.2	364.8	1,950.2
95% CI Lower basin (hm^3/year)	389.8	328.8	724.0	277.2	1,192.7

Table 2. Statistical analysis of annual mean-river-flows changes of the three largest Júcar RBs since 1980.

The hydrological time series tackles from 1940 till 2014, and represent the 95% of confidence interval. These results compare the difference between the annual mean river flows for two time periods, from 1940 till 1980, and from 1980 till 2014, being the hydrological year 1980 considered as the change-point. The comparison points out a considerable reduction on mean annual river flows reaching a percentage of 42.3% and strongly marked in the upper basins area, so this reduction going downstream decreases till 31.8% considering all the Júcar RB. This fact evinces that the hydrological change (reduction) appears prevailingly at the upper basins (Upper and Middle Júcar RBs and Upper Túria RB) and not in the lower basins closer to the coast (Fig. 2).

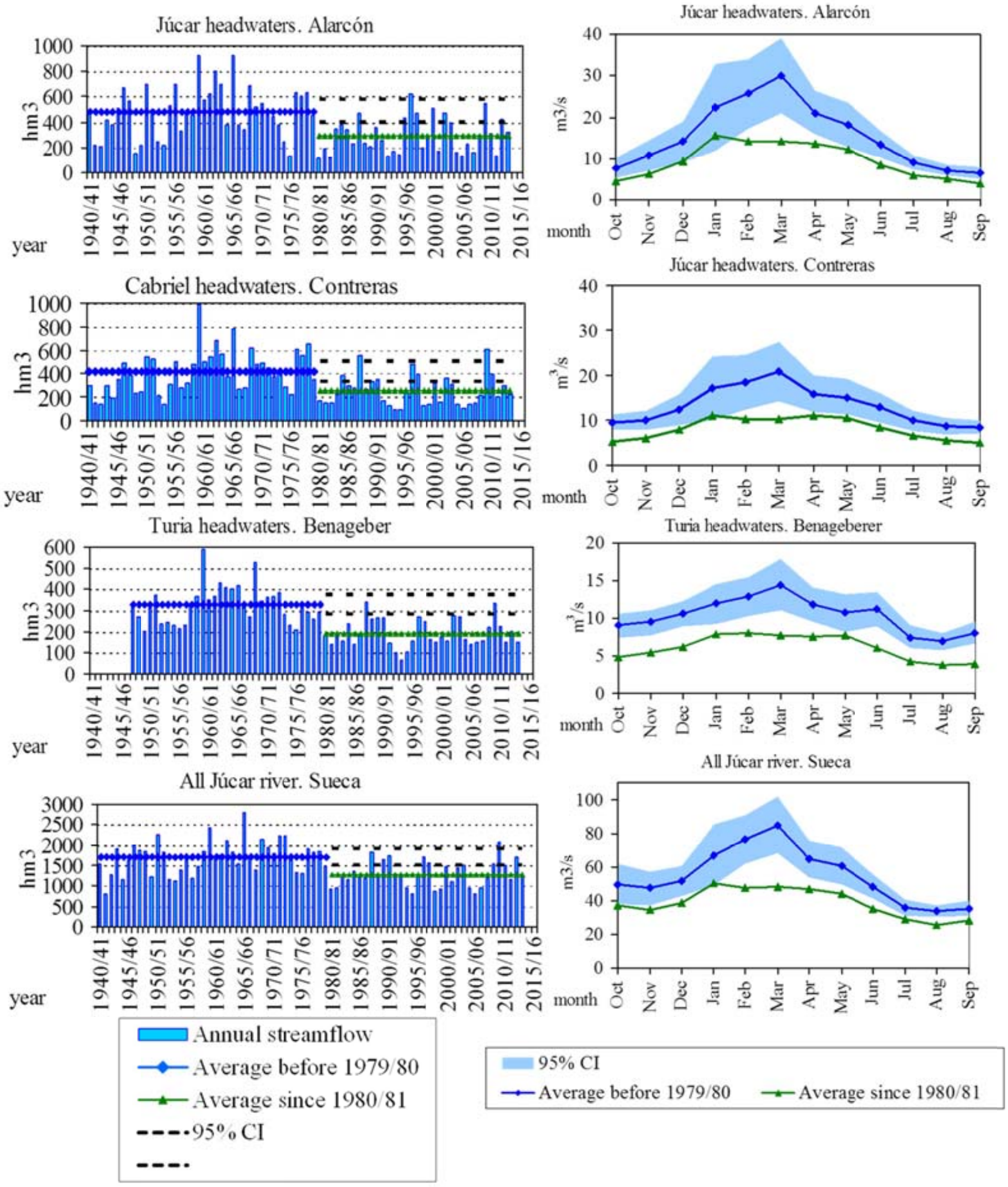

Fig. 2. Annual streamflow for Júcar (Alarcón reservoir inflows, Contreras reservoir inflows and streamflow at Sueca), and Túria (Benagéber reservoir inflows), average for the period 1940-1980, confidence intervals (95%) and average since 1980.

These main reductions in the inland area, which affect to the total resources of both rivers, occurred in autumn and winter, take place in February and March, which is consistent with the reduction observed in the Duero River Basin in Spain (Morán-Tejeda et al. 2011) and other areas of Spain (Lorenzo-Lacruz et al., 2012).

The Upper Júcar basin, formed by the inflows to the Alarcón reservoir in the Júcar River and the inflows to the Contreras reservoir in its main tributary, the Cabriel River, have a clear seasonal hydrological regime, with lower flows during summer and higher flows in January, February and March, due to winter precipitation and snow melt. These streams have a significant change in their mean flow regime, mainly due to the reduction in the winter flows, which exceed 50% in February and March.

The Upper Túria RB hydrologic regime is more uniform than the Júcar case, due to the higher amount of water obtained from the aquifer. The river flows of this upper basin have significant reductions in all months, associated with a general reduction in the water reserves of these aquifers. This reduction on groundwater reserves is mainly consequence of natural causes, since the groundwater exploitation by the local population in this basin is very low or null (CHJ, 2005). The hydrological regime of this basin has been notably affected by the disappearance in recent years of the normal flow increase in March associated with snow melt in the upper watersheds (Estrela et al., 2014).

The relative 95% CI is narrower in the upper than in the lower basins, since the hydrological regime in the vicinity of the coast is affected by heavy rainfall episodes due to the influence of convective storms from the Mediterranean Sea. The lower basins, nearest to the coast, have had no significant changes in their hydrological regime.

3.2 Hydrological Modeling

Patrical Water Balance Model (WBM) is used to simulate the hydrological cycle for the whole Júcar RBD and determine monthly precipitation and temperature patterns by means of the inverse distance squared weighting (IDW) interpolation method. Details and justification of the procedures employed are described in Pérez-Martín et al. (2014). The Patrical model is a monthly distributed WBM that simulates the main variables of the hydrological cycle from October 1940 until September 2016 and calculates river flows at all points in the river basin. This model has been used as the basic tool for water planning in the Júcar RBD. Thus, the model is accurately calibrated to reproduce the physical and hydrological conditions in the RB (Pérez-Martín et al., 2014). It is currently the most validated hydrological model in the Júcar RBD (Chirivella et al., 2015).

Patrical model obtains monthly flows assessed along the RB network, which are compared with the observed flows data (Fig. 3) in order to evaluate and adjust the model performance.

Figure 3 compares the adjustments between simulated and observed hydrological series for the four main management points within the Júcar RBD, which correspond to the areas where most of the water resources are collected. These management points are: water incomes (before reservoir or upstream) to Arenós reservoir in Mijares River, water incomes to Benagéber reservoir in Túria River, and water incomes to Alarcón and Contreras reservoirs in Júcar and Cabriel Rivers respectively – upper basins from Júcar River -.

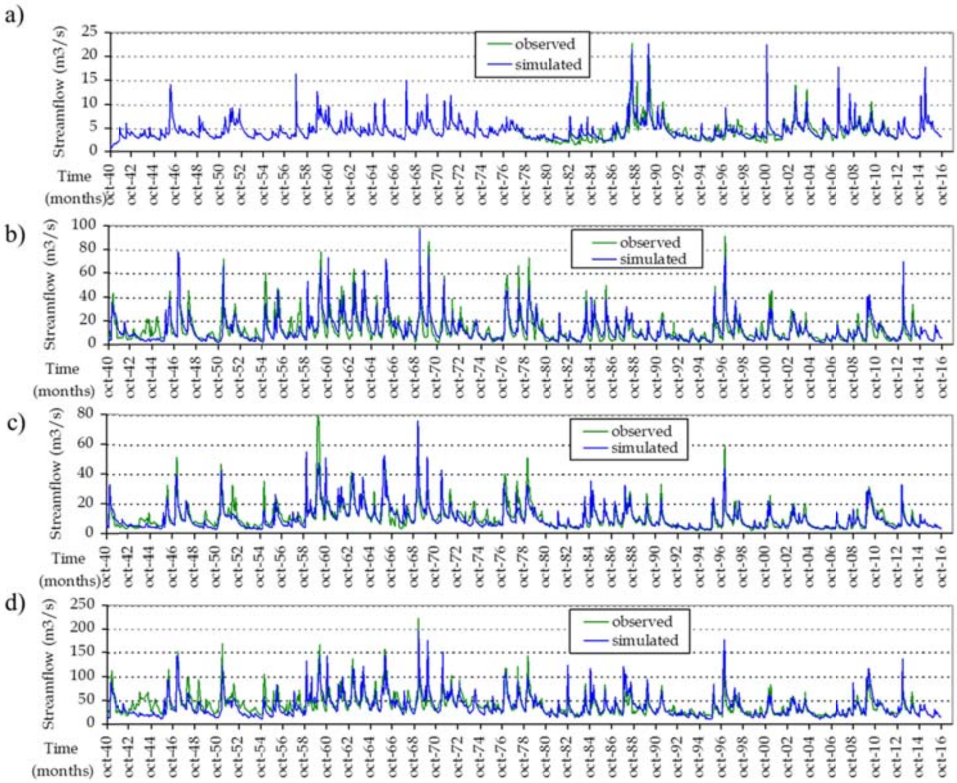

Fig. 3. Natural observed and simulated streamflow at: a) Arenós Reservoir (Rel. Bias 2% NSE=0.66), b) Alarcón Reservoir (Rel.Bias 9% NSE=0.67), c) Contreras Reservoir (Rel. Bias 1% NSE=0.74) and d) Tous Reservoir Rel. Bias 6% NSE=0.42)

In order to check the Model's performance 17 monitoring points have been used (Fig. 4), through observed flows values in natural conditions for different sub-basins along the Júcar RBD and the time period from 1980 till 2016.

The assessment criteria used in the Model's checking process, is statistical error based, as follows: relative bias (*Rel.Bias*) –difference between average simulated inflow (*ASI*) and average observed inflow (*AOI*) - and Nash and Sutcliffe's (1970) Efficiency coefficient *NSE*. The *NSE values range is* [−∞, 1.0] and its optimal value is 1. Values between 0.0 and 1.0 are considered as acceptable levels of performance and values <0.0 indicates unacceptable performance (Moriasi et al. 2007).

With these two indicators, the performance is considered as satisfactory when (*NSE>0.5* and *relative bias*≤ ±0.25), good performance (*NSE>0.65* and *relative bias*≤ ±0.15) or very good performance (*NSE>0.75* and *relative bias*≤ ±0.10; Moriasi et al. 2007).

The obtained results show a Relative.Bias lower than 10% on all the monitoring points, what can be considered as a very good performance regarding mean value. The Nash Coefficient values (NSE) comprise from 0.6 to 0.7 in the upper Júcar RB, 0.42 in the intermediate point of Tous reservoir, and 0.07 in the final stretch of the Júcar River. Regarding the Mijares River scope, the adjustments are good, with values above 0.65. Finally, the performance for the Túria River is not good, according to the values of Nash coefficient.

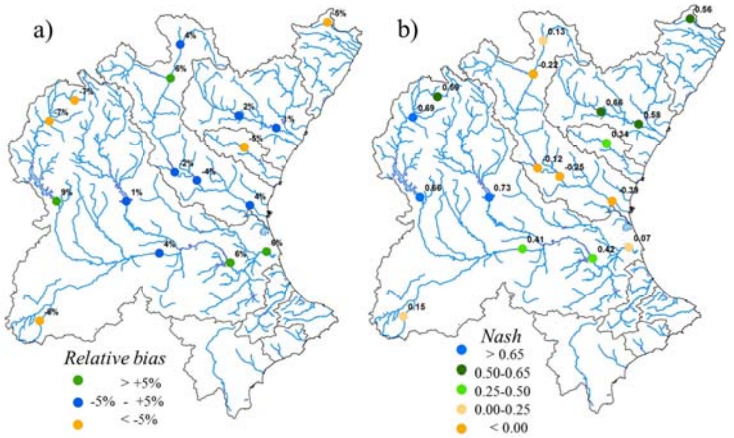

Fig. 4.Model performance a) Relative.bias and b) Nash coefficient for the period 1980-2016.

4 MODELLING HYDROLOGICAL CHANGES

4.1 Hydrological changes forced by land use changes

A preliminary analysis of the impact of land use changes on water resources was carried out using the Patrical WBM (Valero, 2007), where water surplus is generated in each cell of the RB according to land use and the terrain slope (Pérez-Martín et al., 2014) using land use data from the European Corine Land Cover satellite images maps (CLC1990) and (CLC2000).

The comparison of land use in the Júcar RBD (Table 3) between both maps (Valero, 2007) shows an increase of artificial surfaces area, due to the expansion of urban and industrial areas at the expense of a reduction on agricultural land surfaces. There is also a slight increase in forest and natural areas associated with a drop in agricultural activity in some rural areas.

Land use Júcar RBD	CLC 1990		CLC 2000		Change CLC 2000-1990 (km^2)	Relative Change (%)
	(km^2)	(%)	(km^2)	(%)		
Artificial surface	778.6	1.8	1,188.0	2.8	409.4	56.2
Agricultural areas	20,487.4	47.6	19,888.9	46,2	-598.5	-2.9
Irrigated areas	*4,198.8*		*4,547.5*		*348.7*	*8.3*
Non-irrigated areas	*16,288.6*		*15,341.4*		*-947.2*	*-5.8*
Forest and natural lands	21,442.2	49.9	21,636.7	50,3	194.4	0.9
Water bodies and wetlands	289.5	0.7	299.1	0.7	9.6	3.3

Land use Upper Júcar	CLC 1990		CLC 2000		Change CLC 2000-1990	Relative Change (%)
	(km^2)	(%)	(km^2)	(%)		
Artificial surface	7.5	0.28	12.7	0.48	5.2	69.3
Agricultural areas	1181.2	44.28	1159	43.45	-22.2	-1.9
Forest and natural lands	1445.1	54.17	1422.1	53.31	-23.0	-1.6
Water bodies and wetlands	33.6	1.26	73.8	2.77	40.3	120.3

Table 3. Land use in the Upper Júcar RB, taken from CLC 1990 and CLC 2000.

The impact of land use changes on natural water resources between 1990 and 2000 was assessed by the model (Pérez-Martín et al., 2014). In the three major rivers of the Júcar RBD the flow results showed a small change: +1.1% in the Mijares, +2.7% in the Túria and +1.4% in the Júcar Rivers, due to the growth of artificial surfaces in urban and industrial areas, which reduces the capacity of soil to retain water.

The specific analysis of one of the areas with the largest reduction on streamflow (33%), the Upper Júcar RB up to Alarcón reservoir, showed no significant change in land use between 1990 and 2000 (Valero, 2007). Land here is mostly covered by forest, natural areas (54%) and agriculture (44%) - (Table 3). There was a slight increase in artificial surfaces (below 1% of total area) and also a slight increase in surface water, due to larger water reserves in the Alarcón reservoir with respect to 1990. The model results indicated that these changes in land use caused a slight drop (around 1.9%) in the natural streamflow to the Alarcón reservoir, concluding that the impact on water resources due to land use changes in the Júcar RBD is not significant.

4.2 Hydrological changes forced by meteorological changes

The mean precipitation has decreased significantly since 1980 in the Júcar River Basin (Map in Fig. 5), principally in the inland area more influenced by Atlantic fronts; with a decrease between 10% and 20%, about 13% for Júcar and 9% for Túria RBs respectively. The annual precipitation reduction from 1980 on, in the Upper Júcar, is significant in comparison with annual precipitations values of previous period (1940-1980), being current annual precipitation 542 mm/year, being significance range (Student's 95% CI) of 549 -704 mm/year. Current annual precipitation in the Upper Túria is 477 mm/year, while the significance range goes from 462 to 582 mm/year.

In the coastal areas, more influenced by the Mediterranean Sea, the relative changes in precipitation were quite small, being result of the natural oscillations of climatic cycles and the wider confidence interval, due to the torrential nature of precipitations produced from the Mediterranean Sea between August and December. Average monthly precipitation in recent years is inside the range of the reference period (95% CI) and Upper Mijares and Lower RBs did not showed any significant changes even appearing an increase in annual precipitation in the Marina Alta (MA) area and Lower Júcar RBs.

The great reduction in water resources detected in the Upper Júcar and Túria RBs in February, March and April are directly related to the reduction in precipitations taking place from January till March in these areas (Fig. 5).

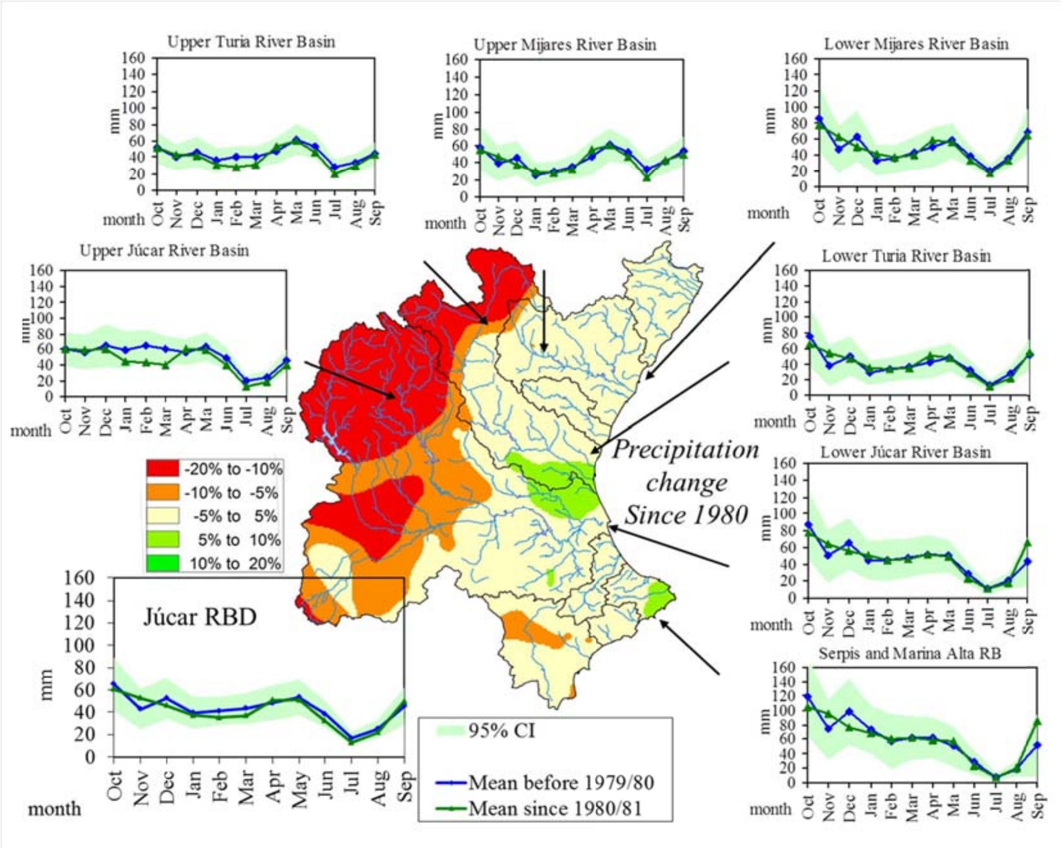

Fig. 5. Central map: Distributed changes in the observed mean precipitation since 1980 (1980-2010) refer to the previous period (1940-1980) in the Júcar RBD. Monthly figures: Precipitation pattern before 1980 and the Student's 95% CI and precipitation pattern since 1980 in different areas.

The observed reductions in the Upper RBs were faithfully reproduced by the model, as expected from the observation of the rainfall difference map in Figure

5. The model parameters related to the RB characteristics were not modified during the simulation, just forcing the model by precipitation and temperature changes, confirming them as the cause of the streamflow reduction.

Figure 6 shows, two hydrological regimes which were assessed from simulated monthly streamflow in the different areas of the RB, historical (1940-1980) and recent regime (1980-2016), with the Student's 95% CI, being compared to the hydrological regime observed in these periods.

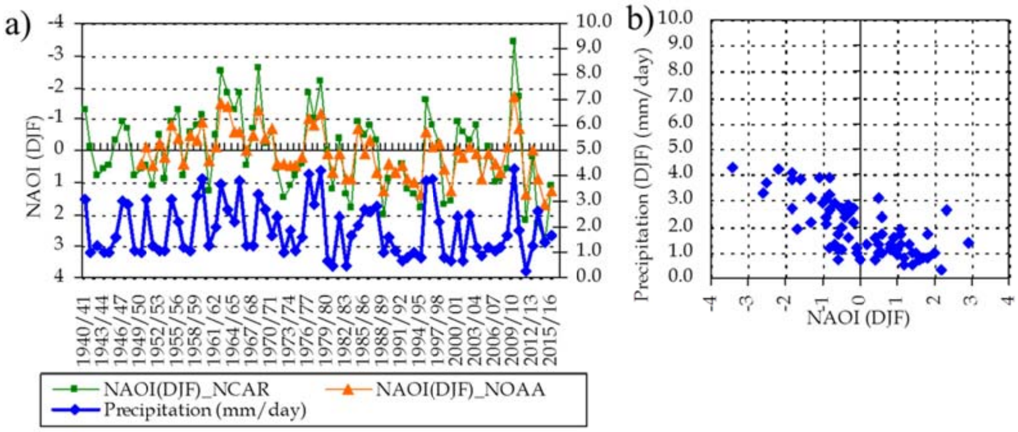

Fig. 6. Simulated change (in percentage) in annual runoff since 1980 referred to the previous period (1940/1980). Simulated and observed hydrological regime before (Student's 95% CI) and since 1980 in different subbasins of the Júcar RBD.

The major change in the hydrological regime since 1980 (1980-2016) referred to the previous period take place in the Upper Júcar and Túria RBs (Fig. 6). The reduction in the Upper Júcar RB is more significant from January to March reaching over 20 m^3/s, which is more than 50% of the mean flow in these months. In the Upper Túria RB the most significant reduction occurs in March (7 m^3/s), which means a reduction of 47% referred to the mean streamflow in the previous period in March.

The Upper Mijares RB hydrological regime is quite uniform, since the flows have mainly aquifers origin and because Mijares River is relatively short and its upper basin is closer to the coast, being the only one of the three rivers that experienced no significant changes in its hydrological regime.

5 INFLUENCE OF THE NORTH ATLANTIC OSCILLATION (NAOI) CHANGES

Within this epigraph an analysis of the monthly NAOI values (JFM) is held and presented in Figure 7. On one hand, Figure 7 a) shows the annual pattern for the monthly NAOI values, assessed for two different time periods: 1940-1980, and 1980-2016. Winter NAOI (January-March) presents significant changes (95 CI). This indicator changes in the upper Júcar RB from negative values to positive values and consequently decreases winter rainfall. The normalized NAO Index presents negative values for the 1940-1980 period when NAOI start a positive phase (Pinto and Raible, 2012)

On the other hand, Figure 7 b), represents the monthly NAOI JFM values for the whole time-series. The tendency line of the monthly NAOI values for the whole-time-series, shows that positive NAOI values appear in a more persistent way, which means lower precipitations.

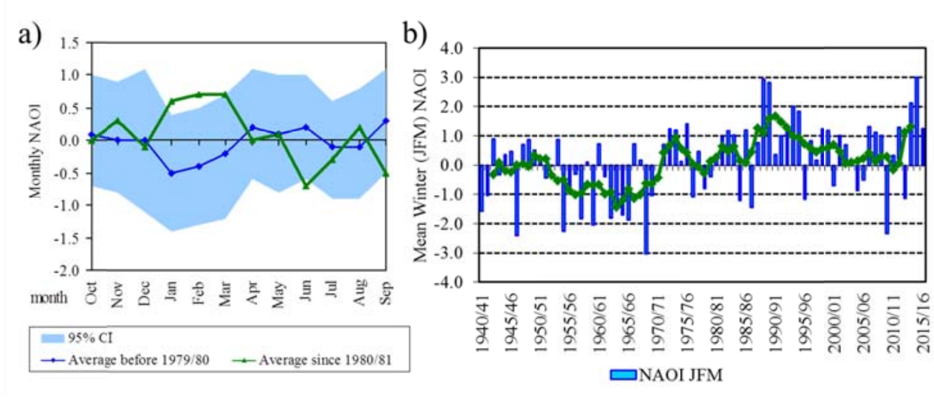

Fig. 7. a) Average NAOI monthly-values within a year, for two time periods data: before and after 1980/81; b) Average winter NAOI (JFM) annual-values (Time-period: 1940-2016).

The coastal pattern, located in the lower RBs and the upper Mijares basin, is due to the regional regime associated with the Mediterranean Sea. There is no correlation between NAOI and precipitation in the coastal area (r=-0.07). However, coastal winter precipitation (DJFM) and the Western Mediterranean Oscillation Index (WeMOi, Martin-Vide and Lopez-Bustins, 2006) are well correlated (r=-0.61).

Winter NAO Index (NAOI, Hurrell and Deser, 2009) have high inverse correlation (Pearson r= -0.73 and -0.71 respectively) with winter precipitation (DJF) (around 30% of the annual precipitations), so high precipitations are produced when negative NAOI is detected (Fig. 7a). Two versions of this winter index (DJF) are used, version with data provided by NCAR (Hurrel et al., 2016) and version with data provided by NOAA The high correlation is preserver until March, the precipitation from December to April has very high correlation with its corresponding NAOI index (DJFMA) (r=-0.68 and r=-0.65), this precipitation corresponds around 50% of the total annual precipitation in this area and is the main responsible for the runoff generation in the year. In general terms, a linear regression shows, that when NAOI in winter is below -2.0, daily precipitation is above 3.5 mm/day; and for NAOI above 2.0, daily precipitation this year is below 0.5 mm/day, although being aware of the existence of cases with higher rainfall.

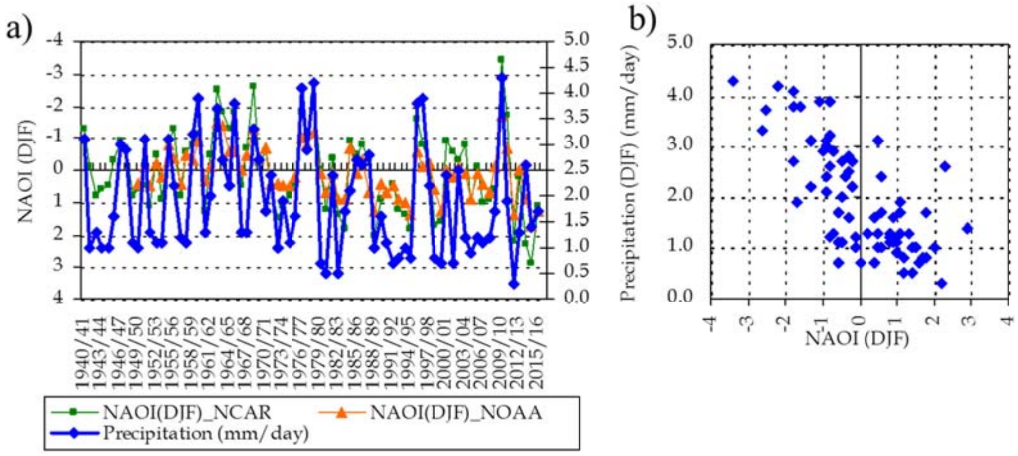

Fig. 8. NAOI (DJF) index (data from NCAR and NOAA) and winter (DJF) daily precipitation (mm/day) in the Upper Júcar from 1940 to 2016.

6 CONSEQUENCES IN THE RIVER BASIN MANAGEMENT

The observed streamflow's reductions have important implications for water resources management, supply of water demands and the environment.

The natural resources in the joint Upper Júcar and Túria RBs fell from 1,605 hm^3/year in the previous period (1940-1980) to 1,194 hm^3/year since 1980 (1980-2016), which means a reduction of around 26%.

The Consumption-to-availability (CTA) index, defined as the total water withdrawals-to-availability ratio, or the water exploitation index (WEI), defined as the total water withdrawals-to-availability ratio within a RB, are used to measure water stress being under severe stress if $CTA > 0.3$ or if $WEI > 0.4$ (EEA, 2003). Current water use in the Júcar and Túria RBs is described in Table 4 (CHJ, 2015). Total withdrawals are 2,284.8 hm^3/year and consumption is 1,235.0 hm^3/year. The current WEI and CTA values for the regulated resources indicate that both RBs, Júcar (1.6 and 1.0) and Túria (3.2 and 1.4), are currently under severe water stress. Going downstream and considering non-regulated water resources coming from the final river stretches in the water balance, reach values of $CTA=0.7$ for Júcar RB and $CTA=0.8$ for Júcar RB.

As conclusion in the Júcar RBD, consumption exceeds regulated availability and evidences that long-term sustainability of the river basins is at risk, as shows the following table in the MPs located in the Loriguilla and Tous reservoirs:

	Túria (Loriguilla)	Júcar (Tous)	**Total Túria and Júcar**
Area (km^2)	4,928	17,871	**22,799**
a) Mean 1940/41-1979/80 (hm^3/year)	276.7	1,329.2	**1,605.9**
b) Mean 1980/41-2015/16 (hm^3/year)	205.8	988.4	**1,194.2**
Change (b-a)/a (%)	-25.6%	-25.6%	**-25.6%**
2) Total withdrawals (hm^3/year)	**655.7**	**1,629.1**	2,284.8
Domestic withdrawals (hm^3/year)	145.6	139.8	**285.4**
Agricultural withdrawals (hm^3/year)	459.3	1,414.6	**1,873.9**
Industrial and others withdrawals (hm^3/year)	50.8	74.7	**125.5**
1) Net total consumption (hm^3/year)	**281.9**	**953.1**	1,235.0
Domestic consumption (hm^3/year) (20%)	29.1	28.0	**57.1**
Agricultural consumption (hm^3/year)	198.9	844.2	**1,043.1**
Industrial and others consumption (hm^3/year)	50.8	74.7	**125.5**
WEI 1940/41-1979/80 (2/a)	2.4	1.2	**1.4**
WEI 1980/41-2015/16 (2/b)	3.2	1.6	**1.9**
CTA 1940/41-1979/80 (1/a)	1.0	0.7	**0.8**
CTA 1980/41-2015/16 (1/b)	1.4	1.0	**1.0**
Including non-regulated resources			
Area (km^2)	6,384	21,573	**27,957**
b) Mean 1980/41-2015/16 (hm^3/year)	347.4	1,311.4	**1,666.8**
WEI 1980/41-2015/16 (2/b)	1.9	1.2	**1.4**
CTA 1980/41-2015/16 (1/b)	0.8	0.7	**0.7**

Table 4. Water availability for different periods and the relative change. CTA and WEI in the Júcar and Túria river basins considering long-term water availability and availability in the last two decades.

7 CONCLUSIONS

The observed hydrological regime in the main upper basins of the Júcar RBD in the Mediterranean Spanish region has changed since 1980 (1980-2016) referred to previous period (1940-1980). A significant reduction in annual streamflow has occurred in the upper basins, -41% in Júcar River, -42% in Cabriel River and -41% in Túria River, due to considerable reductions of precipitations in winter, and consequently of streamflow, what suppose a symptom of water stress and unsustainability, joint to the fact of being the biggest RBs (Júcar RB with 22,359 km^2 – 49.83% - and Túria RB with 7,532 Km^2 – 16.79% -) in the whole RBD and where the major amount of water resources are collected in reservoirs and managed by the RBA. Minor changes have been observed in the hydrological regime in the coastal areas where the current regime remains similar to the previous period. This phenomenon of more significant reduction on the average streamflow in the upper basins, take also place in other RBDs within Spain such as Segura or Tajo RBD (CHJ 2015)

The Patrical WBM is used to perform these hydrological changes resulting a significant reduction in the annual streamflow in the Upper Júcar RB of 32%, higher in February (-40%) and March (-49%), where significant reductions on precipitation are observed. The model performance confirmed thus these significant changes in precipitation and streamflow.

The climate in the Júcar RBD's upper basins is influenced by global atmospheric circulation from the Atlantic Ocean and the regional effect of the Mediterranean Sea. The effects of the Atlantic can be clearly observed in the inland area of the

Upper RBs while the pattern in coastal areas is associated with the regional influence of the Mediterranean Sea combined with Atlantic fronts.

In the inland areas, Upper Júcar RB, precipitation has fallen down by 13.4%, with a significant change on the February-March mean, with a reduction of 33%.

Winter rainfall (DJF) in the inland areas is highly inverse correlated to the winter NAOI, so when the NAOI is positive, precipitations are lower. The NAOI's analysis shows a real change in comparison with the period previous to 1980, which has produced a drastic modification in the rainfall pattern in the Júcar upper-basins and other upper-basins within Spain such as Guadiana River or Segura River. Zooming the hydro-climatic behavior within the Júcar RBD scope, winter NAOI presents an acceptable correlation with precipitations in the upper Júcar basin, while in the lower Júcar basins, closer to the coast, this correlation between NAOI and precipitations doesn't exist. This fact is explained through the Mediterranean Oscillations index (MOi), and more specifically the WeMO.

Changes in land use in the upper basin of the major rivers have not significantly influenced the water resources' reduction, while changes observed in the hydrological regime resulted to be the real changes-engine and streamflow's reduction within the upper-basins of the Júcar RBD.

The upper basins are strategic points in the Júcar RBD since in these areas are most of the water resources are collected and stored in reservoirs. This analysis is highly relevant in relation to studies on climate change, as it provides information on the trends in climate patterns in the Iberian Peninsula and the Mediterranean region and their impact on water resources.

The changes observed in the hydrological regime imply a -25.6% of reduction in water availability in the two major rivers of the Júcar RBD, Júcar (-25.6%) and Túria (-25.6%), which should be taken into account in the River Basin Management Plan while assessing the long-term feasibility of its water resources allocation, since the water stress indicators have strongly increased (CTA and WEI).

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9 REFERENCES

Alexandersson, H., 1986: A homogeneity test applied to precipitation data. J. Climatol., 6, 661–675.

Bayazit M. 2015. Nonstationarity of Hydrological Records and Recent Trends in Trend Analysis: A State-of-the-art Review. Environ. Process. (2015) 2:527–542 DOI 10.1007/s40710-015-0081-7

Bindoff, N. L., Stott, P. A., Allen, M. R., Gillett, N., Gutzler, D., Hansingo, K., Hegerl, G., Hu, Y., Jain, S., Overland, J., Perlwitz, J., Sebbari, R. and Zhang, X., 2013, 'Detection and attribution of climate change: From global to regional', in: Mokhov, I. I., Stocker, T. F., Qin, D., et al. (eds), Climate change 2013: The physical science basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge; New York,pp. 867–952.

CEDEX, 2009. Mapa de caudales máximos. Centro de Estudios y Experimentaciones CEDEX, Ministerio de Medio Ambiente y Medio Rural y Marino. Spain.

Chiew, F. H. S., and T. A. McMahon (1993), Detection of trend or change in annual flow of Australian rivers, Int. J. Climatol., 13, 643–653, doi:10.1002/joc.3370130605.

CLC1990. Corine Land Cover 1990. Directorate-General for Environment. European Environment Agency (EEA).

CLC2000. Corine Land Cover 2000. Directorate-General for Environment. European Environment Agency (EEA). Published 1 January 2002.

Chirivella V, Capilla JE, Pérez MA. 2015. Modelling Regional Impacts of Climate Change on Water Resources: the Júcar Basin, Spain. Hydrological Sciences Journal. doi: 10.1080/02626667.2013.866711

CHJ 2005. Provisional Art. 5 Report Pursuant to the Water Framework Directive. Júcar River Basin Authority (Confederación Hidrográfica del Júcar), Ministry of Environment, Spain.

CHJ 2015. Júcar RB Management Plan 2015_2021. Júcar RBA (Demarcación hidrográfica del Júcar). Confederación Hidrográfica del Júcar, Ministry of Environment, Spain.

Du, T., L. Xiong, C.-Y. Xu, C. J. Gippel, S. Guo, and P. Liu (2015), Return period and risk analysis of nonstationary low-flow series under climate change, J. Hydrol., 527, 234–250, doi: 10.1016/j.jhydrol.2015.04.041.

EEA (European Environment Agency), 2003. Indicator Factsheet WQ01c. Available online, URL: http://www.eea.europa.eu/data-and-maps/indicators/water-exploitation-index

El Adlouni, S., T. B. M. J. Ouarda, X. Zhang, R. Roy, and B. Bobee (2007). Generalized maximum likelihood estimators for the nonstationary generalized extreme value model, Water Resour. Res., 43, W03410, doi: 10.1029/2005WR004545.

Estrela, T., Pérez-Martín, M.A., Vargas, E. 2012, Impacts of Climate Change on Water Resources in Spain. Hydrological Sciences Journal. Volume 57, Issue 6, 2012, pages 1154-1167. http://dx.doi.org/10.1080/02626667.2012.702213.

Ferrer J., Pérez-Martín, M.A., Jiménez, S., Estrela, T., Andreu, J. (2012), GIS based models for water quantity and quality assessment in the Júcar River Basin, Spain, including climate change effects. Science of the Total Environment. DOI.

García-Ruiz, J.M., López-Moreno J.I., Vicente-Serrano S.M., Lasanta–Martínez T. Beguería S., 2011. Mediterranean water resources in a global change scenario. Review Earth-Science Reviews 105 (2011) 121–139

Hegerl, G. and Zwiers, F., 2011, 'Use of models in detection and attribution of climate change', Wiley Interdisciplinary Reviews: Climate Change 2(4), 570–591(doi: 10.1002/wcc.121).

Hurrell, J. W., and C. Deser, 2009: North Atlantic climate variability: The role of the North Atlantic Oscillation. J. Mar. Syst., 78, No. 1, 28-41

Kendall, M. G., 1975, Rank Correlation Measures, Charles Griffin, London, U. K.

Livingston E. H, 2003. Who Was Student and Why Do We Care So Much about His t-Test? Journal of Surgical Research 118, 58–65 (2004). doi:10.1016/j.jss.2004.02.003

López-Bustins J.A., Martín-Vide J., Sánchez-Lorenzo A., 2008. Iberia winter rainfall trends based upon changes in teleconnection and circulation patterns. Global and Planetary Change 63 (2008) 171–176.

Lorenzo-Lacruz, J., S.M. Vicente-Serrano, J.I. López-Moreno, E. Morán-Tejeda, J. Zabalza, 2012. Recent trends in Iberian streamflows (1945–2005). Journal of Hydrology 414–415 (2012) 463–475.

Martín-Vide, J. and Lopez Bustins, J.A., 2006. The Western Mediterranean Oscillation and Rainfall in the Iberian Peninsula. A: International Journal of Climatology, 26 (11): 1455-1475.

Merz, B., Vorogushyn, S., Uhlemann, S., Delgado, J. and Hundecha, Y., 2012, 'HESS Opinions 'More efforts and scientific rigour are needed to attribute trends in flood time series", Hydrology and Earth System Sciences 16(5),1 379–1 387 (doi: 10.5194/hess-16-1379-2012).

Miao W., P. Chiou, 2008. Confidence intervals for the difference between two means. Computational Statistics & Data Analysis 52 (2008) 2238 – 2248. doi:10.1016/j.csda.2007.07.017

Milly, PC, Betancourt J, Falkenmark M, Hirsch RM, Kundzewicz ZW, Lettenmaier DP, 2008. Stationary is dead: Whither water management? Journal Science. Volume 318. Pagination 573-574.

Morán-Tejeda, E. López-Moreno J.I., Ceballos-Barbancho A., Vicente-Serrano S.M. 2011. River regimes and recent hydrological changes in the Duero basin (Spain). Journal of Hydrology 404 (2011) 241-258.

Morán-Tejeda, E. Ceballos-Barbancho A. Llorente-Pinto J.M. López-Moreno J.I. 2012. Land-cover changes and recent hydrological evolution in the Duero Basin (Spain). Reg Environ Change (2012) 12:17–33. DOI 10.1007/s10113-011-0236-7

Moraes, J. M., H. Q. Pellegrino, M. V. Ballester, L. A. Martinelli, R. Victoria, and A. V. Krusche (1998), Trends in hydrological parameters of southern Brazilian watershed and its relation to human induced changes, Water Resour. Manage. 12, 295–311, doi:10.1023/A:1008048212420.

Moriasi DN, Arnold JG, Van Liew MW, Bingner RL, Harmel RD, Veith TL (2007) Model evaluation guidelines for systematic quantification of accuracy in watershed simulations. Transactions of the American Society of Agricultural and Biological Engineers. 50(3):885−900, doi:10.13031/2013.23153

National Academies of Sciences, Engineering, and Medicine, 2016, Attribution of Extreme Weather Events in the Context of Climate Change, National Academies Press, Washington, D.C. doi: 10.17226/21852

Pajares-Candela, Antonio. 2002. Modelación cuasidistribuida de los recursos hídricos y establecimiento de zonas hidroclimáticamente afines en el ámbito de la Confederación Hidrográfica del Júcar. Escuela de Caminos Canales y Puertos, Universidad Politécnica de Valencia.

Pérez-Martín MA, Estrela T, Andreu J and Ferrer J. 2014. Modeling Water Resources and River-Aquifer Interaction in the Júcar River Basin, Spain. Water Resource Management (2014) 28:4337–4358 DOI 10.1007/s11269-014-0755-3

Perreault, L., M. Hache, M. Slivitsky, and B. Bobee (1999), Detection of changes in precipitation and runoff over eastern Canada and US using a Bayesian approach, Stochastic Environ. Res. Risk Assess. 13, 201–216, doi: 10.1007/s004770050039.

Pettit, A. N. (1979), A non-parametric approach to the change-point problem, Appl. Stat., 28, 126–135.

Pinto JG and Raible CC 2012. Past and recent changes in the North Atlantic oscillation. WIREs Clim Change 2012, 3:79–90. doi: 10.1002/wcc.150

Rasmussen, P. (2001), Bayesian estimation of change points using the general linear model, Water Resour. Res., 37, 2723–2731, doi: 10.1029/2001WR000311.

Reeves J., Chen J., Wang X.L., Lund R., Lu Q., 2007. A Review and Comparison of Changepoint Detection Techniques for Climate Data. Journal of Applied Meteorology and Climatology Volume 46.

Satterthwaite, F.E., 1946. An approximate distribution of estimates of variance components. Biometrics Bull. 2, 110–114.

Senatore A., et al., 2011: Regional climate change projections and hydrological impact analysis for a Mediterranean basin in Southern Italy. Alfonso Senatore, Giuseppe Mendicino, Gerhard Smiatekb, Harald Kunstmann. a Dipartimento di Difesa del Suolo, Università della Calabria, P.te P. Bucci 41b, 87036 Rende (CS), Italy. b Institute for Meteorology and Climate Research (IMK-IFU), Karlsruhe Institute of Technology, Kreuzeckbahnstrasse 19, 82467 Garmisch-Partenkirchen, Germany. Journal of Hydrology. Volume 399, Issues 1–2, 8 March 2011, Pages 70–92.

Shengzhi Huang, Dengfeng Liu, Qiang Huang & Yutong Chen 2016. Contributions of climate variability and human activities to the variation of runoff in the Wei River Basin, China. ISSN: 0262-6667 (Print) 2150-3435 (Online) Journal.

Stott, P. A., Stone, D. A. and Allen, M. R., 2004, 'Human contribution to the European heatwave of 2003', Nature 432, 610–614.

Stott, P. A., Christidis, N., Otto, F. E. L., Sun, Y., Vanderlinden, J.-P., van Oldenborgh, G. J., Vautard, R., von Storch, H., Walton, P., Yiou, P. and Zwiers, F. W., 2016, 'Attribution of extreme weather and climate□related *events', Wiley Interdisciplinary Reviews: Climate Change 7(1), 23–41 (doi: 10.1002/wcc.380).*

Strupczewski, W. G., and Z. Kaczmarek (2001), Non-stationary approach to at-site flood frequency modeling II. Weighted least squares estimation, J. Hydrol., 248, 143–151, doi: 10.1016/S0022-1694(01)00398-5.

Strupczewski, W. G., V. P. Singh, and W. Feluch (2001a), Non-stationary approach to at-site flood frequency modeling I. Maximum likelihood estimation, J. Hydrol., 248, 123–142, doi:10.1016/S0022-1694(01)00397-3.

Strupczewski, W. G., V. P. Singh, and H. T. Mitosek (2001b), Nonstationary approach to at-site flood frequency modeling III. Flood analysis of Polish rivers, J. Hydrol., 248, 152–167, doi:10.1016/S0022-1694(01)00399-7.

Sridhar V. and Nayak A., 2010. Implications of climate-driven variability and trends for the hydrologic assessment of the Reynolds Creek Experimental Watershed, Idaho. Journal of Hydrology 385 (2010) 183–202.

Tao H., Gemmer M., Bai Y., Su B., Mao W., 2011. Trends of streamflow in the Tarim River Basin during the past 50 years: Human impact or climate change?. Journal of Hydrology 400 (2011) 1–9.

Tarasinska, J., 2005. Confidence intervals for the power of Student's t-test. Statistics & Probability Letters 73 (2005) 125–130.

Trenberth, K. E., Fasullo, J. T. and Shepherd, T. G., 2015, 'Attribution of climate extreme events', Nature Climate Change 5(8), 725–730 (doi: 10.1038/ nclimate2657).

Valero Villarroya, María. 2007. Evaluación de los efectos del cambio en los usos del suelo mediante el uso de un modelo de simulación del ciclo hidrológico aplicado en la cuenca del Júcar. Ejercicio final de carrera. Escuela de Caminos Canales y Puertos, Universidad Politécnica de Valencia.

Villarini, G., F. Serinaldi, J. A. Smith, and W. F. Krajewski (2009), On the stationarity of annual flood peaks in the Continental United States during the 20th Century, Water Resour. Res., 45, W08417, doi: 10.1029/2008WR007645.

Villarini, G., J. A. Smith, and F. Napolitano (2010), Nonstationary modeling of a long record of rainfall and temperature over Rome, Adv. Water Resour., 33, 1256–1267, doi:10.1016/j.advwatres.2010.03.013.

Welch, B.L., 1938. The significance of the difference between two means when the population variances are unequal. Biometrika 29, 350–362.

Wong, H., B. Q. Hu, W. C. Ip, and J. Xia (2006), Change-point analysis of hydrological time series using grey relational method, J. Hydrol., 324, 323–338, doi:10.1016/j.jhydrol.2005.10.007.

Xie, H., D. Li, and L. Xiong (2014), Exploring the ability of the Pettit method for detecting change point by Monte Carlo simulation, Stochastic Environ. Res. Risk Assess, 28(7), 1643–1655, doi:10.1007/s00477-013-0814-y.

Xiong, L., C. Jiang, C.-Y. Xu, K.-x. Yu, and S. Guo (2015), A framework of change-point detection for multivariate hydrological series, Water Resour. Res., 51, doi:10.1002/2015WR017677.

Yue, S., P. Pilon, and G. Cavadias (2002), Power of the Mann–Kendall and Sperman's rho tests for detecting monotonic trends in hydrological series, J. Hydrol., 259, 254–271, doi: 10.1016/S0022-1694(01)00594-7.

Zhang Q., Singh V.P., Sun P., Chen X., Zhang Z., Li J., 2011. Precipitation and streamflow changes in China: Changing patterns, causes and implications. Journal of Hydrology 410 (2011) 204–216.