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Regional impacts of Climate Change on Water Resources: the Jucar Basin, Spain

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Abstract: The Spanish Agency of Metereology (AEMET) released in 2008 a set of downscaled climate change scenarios over Spain that are the reference to be taken by other public bodies implicated in the development of adaptation strategies. In this paper AEMET scenarios are analysed for the control period (1960-1990), for the period 2010-2040, and their impact on water resources is assessed by means of a rainfall-runoff model. It is found that over the control period, where the simulated scenarios can be compared against historical records, these scenarios honour temperature records. However, there are significant differences for rainfall. AEMET scenarios yield average precipitations that are lower (by 20%) than historical records. This fact underlines both the need of improving the calibration of General Circulation Models and the downscaling procedures for regional studies. For the period 2010-2040 the different scenarios show a great dispersion in the anomalies, mainly in precipitation amounts and its spatial variability, with an average precipitation anomaly of - 4% and a temperature anomaly of +1.02 ºC. Thus, the impact on water resources shows a great degree of dispersion, ranging from -13.45 to 18.1% with a mean value of -2.13%. These results revel the potential impacts of climate change on water resources for the next decades, with estimations to be accounted by water agencies, and the need to improve the current models calibration and downscaling methodologies to reduce the uncertainty of impact predictions.

***Keywords**:* Climate Change, General Circulation Model, Impact on water resources, Downscaling, Júcar River Basin

1. INTRODUCTION

Both the Intergovernmental Panel on Climate Change (IPCC) and the European Union agree in predicting that, within the geographical scope of the Jucar Basin (JB), climate change will cause severe reductions in water resources due to increasing temperatures and a decrease in rainfall during the XXI century. Thus, reduction of runoff scheduled for the decade 2090-2099 with respect to the period 1980-1999 is -30% ("Climate Change and Water", IPCC Technical Paper VI. IPCC, June 2008). The increase in temperature in this area, compared to the period 1960-1990, would be +3.5 °C for the period 2070-2100, and precipitation will decrease by 25% over the same period (PRUDENCE, IPCC SRES A2).

In view of these predictions, water resources agencies need estimations of CC impacts (Tanaka et al. 2006) for the short and medium term (20/30 years), and not only for the end of the XXI century. Thus, it is essential to have reliable CC scenarios for a period like 2010-2040, and the assessment, using reliable hydrological model, of their impact on water resources. Only climate change scenarios available for these years are processed by means of a hydrological model to assess impact on water resources (Chirivella 2011).

This paper discusses the regionalized climate scenarios for the Spanish territory now in effect. These were presented by the Spanish Agency of Meteorology (AEMET), in March 2008, pursuant to the National Plan for Adaptation to Climate Change (PNACC) prepared by the Spanish Office for Climate Change (OECC). These AEMET scenarios are obtained from general circulation models of the third report of the IPCC (TAR, 2001), based on emissions scenarios A2, B2 (Nakicenovic et al. 2001) and IS92a, and downscaled by statistical and dynamic procedures. Those obtained with dynamic techniques are part of the PRUDENCE project and only provide results for the last third of the XXI century. Only a few scenarios obtained with different statistical techniques (a total of eleven) provide simulations for the period of interest, 2010-2040, as shown in Table 1.

The most significant features of this scenarios for the JB area are that all of them show an increment of temperatures (T_{max} more than T_{min}), and a decrease of precipitation, mainly in spring. The study to be carried out with these scenarios is twofold. Firstly, to compare, over the control period (1960-90), AEMET scenarios against historical records. Secondly, given that there are no impact studies with these scenarios, analyzing their impact on water resources, both surface and groundwater, using the rainfall-runoff model PATRICAL (Pérez-Martín, M.A. 2005), for the period 2010-2040.

Statistical downscaling techniques are based on quantitative relationships between atmospheric variables (predictors) and local variables (predictands), usually maximum and minimum temperature and precipitation. Rests on the assumption that the relationships established between predictors and predictands are invariant to climate change, which is questionable.

Water policy must take into account these scenarios of climate change on their water balances. Furthermore, these predictions make inevitably improve the regulation of water resources, relying on the joint use of surface and groundwater resources.

Table 1. AEMET CC scenarios that provide information for the period 2010-2040.

Downscaling method	Scenarios	General model	Nº Scenarios
SDSM – INM	A2, B2	HadCM3	2
Analogues FIC	A2, B2	CGCM2, ECHAM4	4
Analogues INM	A2, B2	CGCM2, ECHAM4	4
Analogues INM	Is92a	HadCM2	1
TOTAL			**11**

2. THE JÚCAR BASIN. CASE STUDY

The Júcar Basin (JB) extends over 43,000 km^2 and is located in eastern Spain. Water planning and management depends on the Spanish government through the Júcar River Basin Authority (Confederación Hidrográfica del Júcar). The JB is made up by three main rivers named as Júcar, Turia and Mijares, and by other minor watersheds, all of them discharging to the Mediterranean Sea.

The climate in the Júcar basin has a high temporal and spatial variability, with an average annual rainfall of 500 mm, varying between 320 mm $year^{-1}$ in the driest years, and almost 800 mm in the wettest years. The average annual rainfall in turn has important spatial differences. In the most southern areas the average annual rainfall is as low as 300 mm, while in other areas it reaches values above 800 mm.

In order to assess the impact of CC on water resources, seven control points have been selected over the basin hydrographical network. The water flows at these control points can provide a good quantification of water availability in the basin. The goal is to compare water runoffs at these points, for the different scenarios, against historical records. Three of these points correspond to the river mouths of the three main rivers Júcar, Turia and Mijares. The other four points belong to the mid-upper basin at the locations of the main reservoirs in the water resources system. Figure 1 shows the location of the seven control points where the water balance will be also monitored for the different scenarios analyses.

<u>Upper basin checkpoints:</u>

CONTRERAS (J)

ALARCÓN (J)

BENAGÉBER (T)

ARENÓS (M)

<u>River mouth checkpoints :</u>

JÚCAR

TURIA

MIJARES

Figure 1. Control Points for the assessment of impacts on water resources.

3. METHODOLOGY

3.1 Climate Change Scenarios

The eleven selected scenarios described above are given by the values of daily precipitation (P) and maximum and minimum temperature (T_{max} and T_{min}) at a limited number of locations where these variables have been downscaled. Depending on the methodology, the set of data points is differently distributed (fig. 2). Scenarios corresponding to Analogue-FIC and SDSM methodologies provide these variables at weather station locations. The Analogue-INM method provides the variables at a regular grid of 50 x 50 km. (figure 2)

Each scenario provides the value of the daily rainfall and maximum and minimum temperature for every day of the 30 year period from 2010 to 2040, and for every day in the 30 year control period 1960-1990. Since the applied rainfall-runoff model works on a monthly basis, CC scenarios have been pre-processed assigning to each point the local mean maximum and minimum temperature as well as the monthly-accumulated value of precipitation. Subsequently, the average values of these variables were obtained for every month considering the control period 1960-1990, and the next three future decades 2011-2020, 2021-2030 and 2031-2040.

By comparing the above averaged climatic variables over the control period 1960-1990 against historical records, a quantitative estimation of the reliability of the different scenarios for the JB will be obtained. Besides, the term “anomaly” is defined as the difference between future climate and past climate, as represented by the simulated series provided in every CC scenario. This “anomaly” is added to recent historical climate records, or current climate, to obtain future climate series (Mizanur et al. 2007). The anomaly term, which is computed for both temperature and precipitation, and for every CC scenario, constitutes an estimation of the average change of the main climate variables. However, it does not provide any indication of other changes as extreme weather conditions as floods or droughts.

Figure 2. Location of data points (Precipitation variable) for SDSM_INM method (left figure) and data points (Temperature and Precipitation variables) for Analogue-INM method (right figure)

Once the anomalies are obtained, the next step is the application of the rainfall-runoff model to obtain model outflows at control points. The series of temperatures and precipitation for this model are obtained from the historical records 1940-2007 modified using the computed "anomaly". Thus, there are as many input series for the model as CC scenarios times the anomalies for the next three decades (a total of 33 series). This approach assumes that the calibration of the rainfall-runoff model obtained for the historical series is valid for the modified series.

3.2 Rainfall-runoff modelling

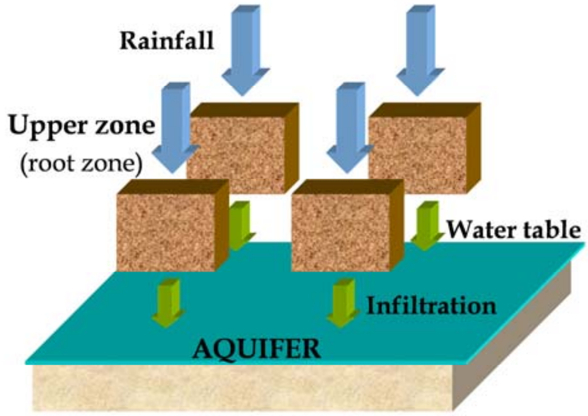

Figure 3. Schematic representation of the two conceptual layers. Upper layer for infiltration, evapotranspiration and water runoff; lower layer representing the aquifer storage and groundwater flow (Pérez 2005).

The rainfall-runoff model used is known as PATRICAL (Pérez 2005). This is a distributed model that reproduces the processes of runoff, evapotranspiration, infiltration, surface flow and groundwater flow (fig. 3) at the basin scale and includes capabilities to also simulate water quality (which is beyond the scope of this paper). PATRICAL derives from the model SIMPA - Integrated System to Model the Rainfall-Runoff Process (Estrela et al. 1996) (Ruiz 1999), and from the experience of its application to every basin in Spain during the preparation of the "White Paper on Water in Spain" (Estrela et al. 1999). The existence of previous calibration and applications of PATRICAL at the JB has made this model the most suitable one to simulate rainfall-runoff in this basin. PATRICAL has retained the Temez model (Témez 1977) as a featured derived from the successful experience with model SIMPA.

4. RESULTS AND DISCUSSION

4.1 Climate change scenarios verification

In order to verify the reliability of CC scenarios, the series of precipitation and temperature from selected scenarios are compared against historical records for the control period, 1960-1990. There are significant differences in precipitation when performing this comparison as shown in table 2. Every analyzed scenario provides precipitation values lower than historical records. The difference is within a range that goes from -7.53 % to -28.42 %, having an average value of -20.41%. Thus, while the annual average value recorded for this period in the JB is 509 mm/yr, the average of the six scenarios in the control period is 405 mm/yr. These differences are especially significant in the months of September, October and November. Moreover, due to the hydro-climatic features of this basin, these months have the greatest influence on water resources availability.

The simulated values of mean temperature (average maximum and minimum temperature) are much closer to those recorded than it happens with precipitation (table 2).

Table 2. Differences of precipitation and temperature in the control period between AEMET scenarios and historical records.

Percentage variation			Absolute variation (mm/yr)		
min	max	med	min	max	med
-28.88%	-7.53%	-21.59%	-146.96	-38.30	-109.85

Percentage variation			Absolute variation (º C)		
min	max	med	min	max	med
-10.84%	13.28%	-2.09%	-1.54	1.88	-0.30

4.2 Hydro-climatic anomalies in the period 2010-40

For each of the eleven scenarios examined, and for the period 2010-2040, we have obtained the difference of the monthly average temperature and the monthly accumulated rainfall with the average values of the control period 1960-1990 (tables 3).

In the case of rainfall, the anomaly is characterized by high dispersion (values between -15.32 % and 7.16%), with a low average (-4.03%). The temperature anomaly is characterized by less dispersion, but a higher average value of +1.52 °C (10.72%).

4.3 Climate Change impact on surface water resources

The above anomalies have been used to modify the 1940-2007 historic series in order to obtain new series that simulate future climate. A total of 33 series are obtained corresponding to the eleven climate change scenarios and with the anomalies obtained for the decades 2010-20, 2020-30 and 2030-40. These series are used as inputs for the rainfall - runoff model that yields the series of available water resources at the control points.

Table 3. Precipitation anomalies (as percentage of reference annual rainfall), Temperature anomalies (ºC) and total impacts on surface water resources at the mouth of the Mijares, Turia and Júcar rivers (as a percentage of average discharges) for the 2010-40 period, and for each of the eleven scenarios AEMET analyzed, over the period 1960 – 1990.

Anomalies and impact of WR of every AEMET scenario over period 1960 - 1990					
AEMET scenarios			**Precipitation anomalies (%)**	**Temperature anomalies (ºC)**	**Impact on WR (%)**
Statistical Downscaling Method	Global Model	Emissions Scenario	**2010 - 2040**	**2010 - 2040**	**2010 - 2040**
Analogues - FIC	CGCM2	A2	3.38%	1.38	11.10%
Analogues - FIC	CGCM2	B2	-10.29%	1.58	-10.84%
Analogues - FIC	ECHAM4	A2	-3.49%	1.70	-5.39%
Analogues - FIC	ECHAM4	B2	-7.79%	1.82	-10.61%
Analogues - INM	CGCM2	A2	-2.38%	1.55	3.45%
Analogues - INM	CGCM2	B2	-15.32%	1.59	-13.37%
Analogues - INM	ECHAM4	A2	-6.39%	1.55	-9.96%
Analogues - INM	ECHAM4	B2	-8.90%	1.87	-12.83%
Analogues - INM	HadCM2	Is92a	7.16%	1.10	18.11%
SDSM	HadCM3	A2	-2.86%	1.14	4.38%
SDSM	HadCM3	B2	2.58%	1.39	2.47%
Maximum value			7.16%	1.87	18.11%
Minimum value			-15.32%	1.10	-13.37%
Average			**-4.03%**	**1.52**	**-2.13%**

Table 3 shows the impact on the sets of checkpoints located at the lower basins (total water resources measured as total discharges of Mijares, Turia and Júcar rivers to the Mediterranean Sea) and upper basin, relative to the average for the period 1960 – 1990. It is also remarkable the fact that being the average impact on WR very low, -2.1 % at the lower basin (lower than values obtained in previous studies on the JB (Quereda et al. 2009), the dispersion among different scenarios is very wide, ranging from -13.4 % to 18.1 %. Note also that ECHAM4 is the GCM used to generate four of the considered scenarios and that results for these scenarios are quite consistent compared to the dispersion found with other GCM. This might be an argument to attribute more robustness to ECHAM4 results in this study area.

Regarding the anomalies, the temperature anomaly is always positive and precipitation P anomaly is, in general, negative, with a high dispersion. Nonetheless there is a general trend between this anomaly and the impact on WR. An important change in precipitation has a clear effect on WR, which follows the increment or reduction of precipitation. However, small P anomalies can produce an opposite effect in WR. This happens in two scenarios: Analogues-INM-CGCM2-A2 and SDSM-HadCM3-A2. This is due to the sensibility of the model to the change in the spatial and temporal distribution of precipitation, which plays an important role in evapotranspiration.

5. CONCLUSIONS

The regionalized climate change scenarios released by AEMET in 2008 as a reference to analyse future climate change impacts over peninsular Spain do reproduce well historical records of temperature in the geographical area covered by this paper, the Júcar Basin. However, they underestimate the precipitation (with an average value 20% lower than observations in 1960-90). This fact underlines both the need of improving the calibration of General Circulation Models and the downscaling procedures for regional studies.

The precipitation anomaly, obtained from AEMET scenarios to generated future precipitation series, presents a great dispersion. There are values between –15.3 % and 7.2 %, with an average of -4%. The temperature anomaly shows less dispersion with values between 1.1 º C and 1.9 º C, and an average of 1.5 ºC. Climate scenarios based on emission scenario B2 provide slightly higher increases in temperature than A2.

ECHAM4 is the model used to generate four of the considered scenarios whose results are quite consistent compared to the dispersion found with the other models. This might support the robustness of the ECHAM4 model to be used in this study area.

A detail analysis of the relation between the precipitation anomaly and the impact on water resources shows that the latter is highly sensitive to the distribution of the precipitation anomalies, both spatial (mainly upper basin areas) and temporal (mainly autumn and winter).

Another important observation is that, being B2 a scenario with lower GHG concentrations in the atmosphere, AEMET scenarios do not show temperature and precipitation trends as previously expected. In fact, emissions scenario B2 yields greater reduction of precipitation and greater increments of temperature, leading to greater impacts on water resources over 2010-2040. The limitations and appropriateness of current GCM and downscaling techniques over the Spanish Mediterranean coast should be carefully analysed. In this region there is a strong influence of Mediterranean coastal convective phenomena, and a lower influence of larger-scale atmospheric circulations that are well reproduced by general models.

Given the differences between the simulated values of precipitation and temperature variables in the control period, there is a need to generate new regionalized climate scenarios in the area that are based on different approaches, included dynamic downscaling. In addition, new scenarios should be also based on the results of general models from the fourth report of IPCC (2007), which are expected to be more reliable and accurate than those used in the regionalized scenarios released by AEMET in 2008 (based on the third report of the IPCC 2001).

Finally, we consider that the robustness shown by the model ECHAM4 in the study area is an important reason to use this model, and its upcoming versions, to base the generation of new regionalized scenarios. Besides, new CC scenarios should be also based on A1B emissions scenario. This is currently regarded as the one with the best fit to the current general economic development, and it has been used in recent European projects (PRUDENCE and ENSEMBLES).

Water policy must take into account these scenarios of climate change on their water balances. Furthermore, these predictions make inevitably improve the regulation of water resources, relying on the joint use of surface and groundwater resources.

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