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Dynamical versus statistical downscaling for the generation of regional climate change scenarios at a Western Mediterranean river basin: The Jucar basin.

Short title: Dynamical vs statistical downscaling to generate climate change scenarios

Chirivella, Vicente; Capilla, José E.; Pérez-Martín, Miguel A.

Research Institute of Water and Environmental Engineering; Universitat Politècnica de València, Camino de Vera, s/n, 46980 Valencia, Spain

ABSTRACT

Current climate change predictions for Western Mediterranean show significant increase of temperature, and decrease of precipitations, with great variability depending on General Circulation Models (GCM) and downscaling approaches. This paper analyses how dynamic downscaling improves climate change scenarios statistically based. The study area is the Jucar River Basin (JB), with results from ECHAM5 GCM, and a close time frame 2010-40 appropriated for decision-making. The dynamic downscaling is performed with the Regional Model (RCM) RegCM3. It is applied to a coarse grid over the Iberian Peninsula, and then to a finer grid over the JB. The RCM is customized to reproduce Western Mediterranean climatic conditions using the convective precipitation scheme of Grell; the non-convective scheme is customized changing the default RH_{min} and C_{ptt} parameters to reproduce precipitations originated by larger-scale atmospheric circulations.

The RCM results, compared to current official Spanish AEMET scenarios – statistically based - reproduce much better historical data (used to verify scenarios generation). They foresee a 21.0 % precipitation decrease for 2010-40, compared to previous ECHAM4 predictions with statistical downscaling (–6.64 %). Most significant reductions in February, September and October. Average estimated temperature increase is 0.75 °C, with high increments in July (+3.05 °C) and August (+1.89 °C).

Keywords: *Climate Change, Downscaling, Júcar River Basin, Western Mediterranean, non-convective precipitation, convective precipitation*

INTRODUCTION

Current climate change predictions over the Mediterranean region foresee a pronounced decrease in precipitation, especially in the warm season, except for the northern Mediterranean areas in winter. The scenarios generated by the

Global Circulation Models (GCM) are generally consistent (Giorgi & Lionello 2008), although at the regional level, where predictions are obtained by downscaling methods, there are changes mainly induced by orographic conditions and other local characteristics than cannot be captured by the coarse grids used by GCM. Anyway, the intensity and robustness of the climate change signals produced by a range of global and regional climate models suggest that the Mediterranean might be an especially vulnerable region to climate change (CC).

At the most western extreme of the Mediterranean a set of CC is made available by the Spanish Agency of Meteorology (AEMET 2008). These CC, pursuant to the National Plan for Adaptation to Climate Change (PNACC), MIMAM (2006), are based on GCM results from the third report of the IPCC (2001), based on emissions scenarios A2, B2 and IS92a, and obtained by statistical and dynamic downscaling. The scenarios obtained with dynamic downscaling methodologies are part of the Prediction of Regional scenarios and Uncertainties for Defining EuropeaN Climate change risks and Effects, EU 5th Framework (PRUDENCE) project (Hesselbjerg & Bøssing 2005) and only provide results for the last third of the 21st century. In this project, local boundary conditions for Regional Circulation Models (RCM) are taken from the general circulation model (GCM) HadCM3 (Rodríguez et al. 2007) and ECHAM4, which are considered the circulation models that best reproduce European climate conditions. ECHAM4 is a recent release of the ECHAM model series (Roeckner *et al.* 1996).

The scope of future climate change scenarios of the research presented in this paper is the period 2010-40. This is a timeframe easier to understand for policy makers, and much closer than most predictions which are addressing the end of the century. Decision-makers in charge of water resources planning need to count on reliable estimates of climate change impacts (Tanaka *et al.* 2006) for a reasonable time term. Thus, most projections, generally obtained for the end of this century, are not really useful for planning. It is unrealistic considering the possibility of making decisions that might strongly affect many socio-economical aspects, based on model predictions 80 years ahead.

There are eleven AEMET scenarios for this period, and all of them have been generated by statistical downscaling. A more detail description is presented by Chirivella (2011). Every scenario includes the historical period 1960-90, referred to as control period, where historical records are available and can be compared to simulated scenarios, as will be recall below. Statistical downscaling techniques are based on quantitative relationships between atmospheric variables (predictors) and local surface variables (predictands) (Wigley 2004). This approach is based on the assumption that the relationships established among predictors and predictands remain invariant in the future, even under the climate change scenario. This is clearly questionable and future research will certainly address the validity of this assumption. The statistical methods that have been used to generate the AEMET scenarios include two approaches. The first, the Statistical Downscaling Method (Wilby 2002), based on regression models among temperature and precipitation at weather stations, and every predictand (precipitation, maximum temperature and minimum temperature). The second, the Analogues Method, based on calibrating relationships among predictors and predictands but considering only observed data belonging to days, time periods, or events in which the patterns of atmospheric circulation show a certain degree of similarity. Thus, large-scale situations simulated by the GCM are used to find similar situations within the historical records database. The set of similar observed situations leads to a calibrated relationship that is used for the downscaling process.

Schmidli *et al.* (2007) compare results of different statistical downscaling models and RCM in the European Alps. They find that statistical methods strongly underestimate the magnitude of the year-to-year variations and that the RCM are more capable of reproducing spatial variability over complex terrains. More recently, Jann & Kavvas (2013), compared statistical downscaling results with a RCM, for northern California, finding clearly better results with the RCM and concluding that it is questionable whether the statistical method applied is suitable for the assessment of the impact of future CC at regional scales as the future climate will evolve in time and space as a nonlinear system with land–atmosphere feedbacks. The Western Mediterranean, and more specifically, the Spanish Mediterranean, can be subjected to different climatic influences with important changes from the coast to inland areas. Thus, for the Region of Valencia, according to Millan *et al.* (2005), the precipitation components include Atlantic fronts, convective–orographic storms, and easterly advections over the Mediterranean Sea, all of them defining the trends and changes of the temporal and spatial variability of precipitation. It is questionable that current statistical methods can properly reproduce the local combination of these components together with the influence of short-distance orographic variability in this area. These circumstances call for more physically based approaches for downscaling. In this paper the Jucar River Basin District (JB) is used as a representative example of the conditions described above. The JB is a well-studied area with a history of data collection and model applications that makes it suitable for the goals of this paper (Ferrer *et al.* 2012).

Chirivella *et al.* (2014) show that in the JB the selected AEMET scenarios reproduce reasonably well historical records of temperature (with average differences between -1.53ºC and +1.88 ºC, with a total average of - 0.05ºC). However, they underestimate the precipitation (with an average value 20% lower than observations in the control period: 1960-90), and have a great dispersion (with deviations ranging from -28.42% to -7.53%). Moreover, the spatial and temporal dispersion of precipitation distributions, in every scenario, is also noticeable within the control period. As shown by Chirivella *et al.* (2012, 2014), it remains within the range of precipitation anomalies - difference between future and past climate, as represented by the simulated series provided in every climate change scenario (see Mizanur *et al.* 2007 and Rodriguez *et al.* 2007) - and this can have a direct impact on the future availability of water resources in the basin. These authors also show that scenarios based on ECHAM4 results, four out of the eleven scenarios, are the most consistent among them, compared to the dispersion found when using other GCM. ECHAM4 also reproduces better than the other models the precipitation in the upper basin, even when examining more recent records (Ferrer Polo 2009). These facts support, although subjected to future scientific evidence, the robustness of ECHAM4 model to be used in this study area. It is also important to know that according to Chirivella *et al.* (2014) climate change scenarios based on ECHAM4 predict a decrease of available water resources of 10% within the period 2010-2014. However, these scenarios do not reproduce well enough the spatial distribution of temperature and precipitation during the control period.

Given the differences between the simulated values of precipitation and temperature variables with historical records in the control period, there is a need to look for more accurate and appropriate methods to generate new regionalized scenarios in the area, and dynamic downscaling is considered a potential alternative. In addition, new scenarios can be based on the results of GCM 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). The robustness shown by the model ECHAM4 in the study area is an important reason to use this model, and its newer versions, to base the generation of new regionalized scenarios.

Based on the above considerations, the research described in this paper explores – for the first time - the application of dynamical downscaling methods to generate short term (2010-40) scenarios and compares them to current available scenarios based on statistical methods. We used as starting point ECHAM5 GCM results (Roeckner 2003) described in the fourth report of IPCC (2007), and the emissions scenario A1B (Nakicenovic & Swart 2000). The Regional Climate model (RCM) used is RegCM3, version 3.1 (Elguindi *et al.* 2007). This model is the third generation of the Regional Climate Model originally developed at the National Center for Atmospheric Research during the late 1980s and early 1990s. The model is currently supported by the Abdus Salam International Centre for Theoretical Physics (ICTP), Trieste, Italy. This model application requires both a progressive downscaling of ECHAM5 results, and the customization of the RCM. The first is done firstly by applying RegCM3 to a coarse grid over the Iberian Peninsula. Then, a finer grid, nested in the previous one, supports the application to the JB area. At the same time, in order to reproduce the specific climatic characteristics, RegCM3 parameters are customized using the period 1990-2000 as control period. Thus, both convective precipitation and non-convective precipitation schemes are analysed in order to better fit historical records. We show comparisons of how the dynamical approach improves the reproduction of control periods with respect to previous statistical scenarios, and the change in temperature and precipitation predictions.

THE JÚCAR RIVER BASIN DISTRICT

The Júcar River Basin District (JB) located in eastern Spain, extends over 43,000 km^2 and 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. Most of its territory belongs to the Region of Valencia (Fig. 1) with some areas in the neighbouring regions of Aragon, Catalonia and Castilla-La Mancha. Thus, water planning and management depends on the Spanish government through the Jucar River Basin Authority (*Confederación Hidrográfica del Júcar*).

The climate in the JB has a high temporal and spatial variability, with an average annual rainfall of 500 mm, varying between 320 mm/year for the driest years to 800 mm/year in the wettest years. The average annual rainfall in turn has important spatial differences; in southern areas the average annual rainfall stands at values lower than 300 mm, while in other areas it reaches values above 800 mm. Within the geographical scope of the JB, we can distinguish several hydroclimatic areas (Pajares 2002) shown in Fig. 1.

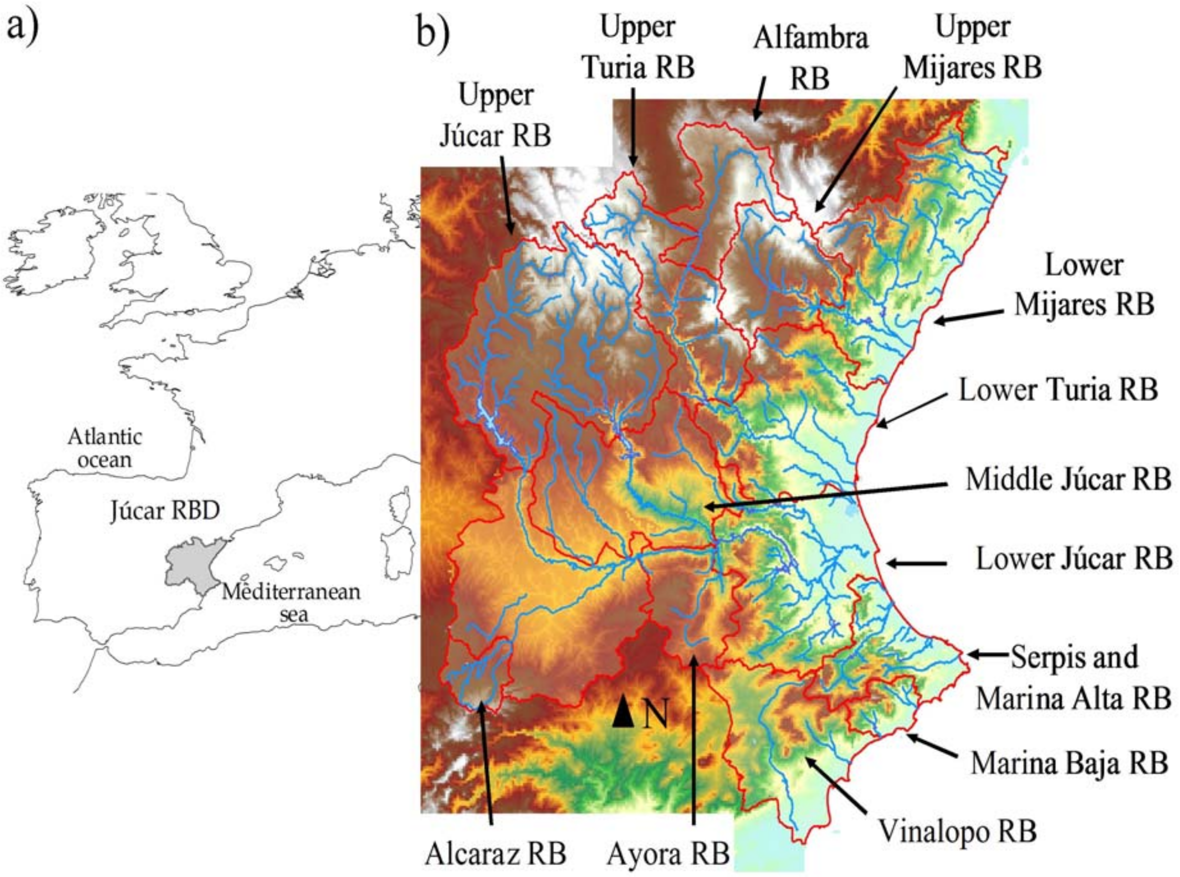

Fig. 1 Júcar River Basin: (a) geographical location, and (b) the three main rivers Júcar, Turia and Mijares, and hydroclimatic zones.

METHODOLOGY

The steps followed in this research include: the customization and application of RegCM3 over the Iberian Peninsula (IP) and the JB areas, the comparison of dynamically obtained results with statistically based previous results with the respective control periods, and the comparison of predictions for future CC. As explained above we start from the ECHAM5 GCM results, which are processed to be dynamically downscaled with the RCM RegCM3. This model has been extensively used in several studies (e.g., Kieu *et al.* 2006; Zanis *et al.* 2009; Mizanur *et al.* 2007). The model is made up by three modules: Pre-processing, Process, and Post-Process. Pre-processing includes, in turn, two steps: Terrain and ICBC. Terrain defines the domain and mesh size (10 km is the minimum value available), and interpolates the land use and geometric dimensions in each point of the grid (2 minutes is the maximum resolution data). ICBC integrates climate data from GCM models and incorporates them into the grid. These data are the initial and boundary conditions during simulation. The Process module solves the equations of the dynamic model at the spatial mesh defined. Finally, Post-Processing obtains monthly and annual averages of climate variables.

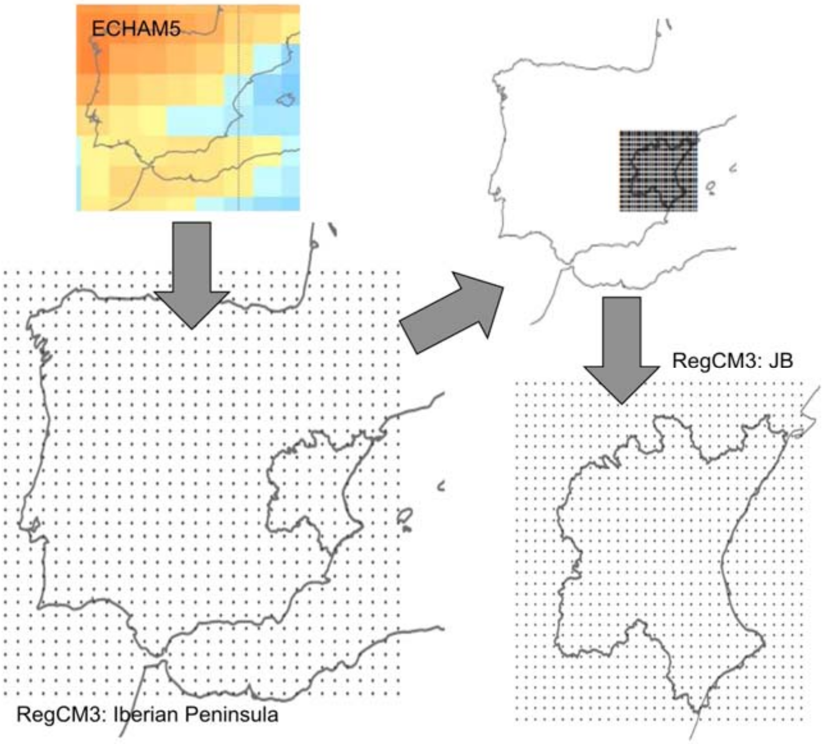

Fig. 2 Dynamic downscaling from ECHAM5 GCM. On the left, the first step: application to the Iberian Peninsula with a regular coarse grid of 30 x 30 km. On the right, the second step: application to the JB area, using a finer grid of 10 x 10 km nested in the coarse grid.

The downscaling process has been developed in two steps illustrated on Fig. 2. Note that the resolution of the model over the JB area goes from roughly four cells, in ECHAM5, to 35 x 34 cells in the RegCM3 nested grid. The customization of RegCM3 for the JB area has included the adjustment of the convective and non-convective precipitation schemes. This is a process usually necessary to adapt the model capabilities to the climatic characteristics of the area under study, see for instance Davis et al. (2009). Thus, four different simulations have been performed for every grid in order to analyse the results of the four convective precipitation schemes available in the RCM: Kuo scheme (Anthes 1977) (referred to as simulation KS in this paper), Grell scheme AS74 (Arakawa & Schubert 1974) (simulation GSA), Grell scheme BC80 (Fritsch & Chappell 1980) (simulation GSB), and Emanuel scheme (Emanuel & Zivkovic-Rothman 1999) (simulation ES). Comparing these four simulations with the historical records in the control period 1990-2000, we have chosen the one that best reproduces the average temperature variables (mean maximum and minimum temperature) and the cumulative monthly rainfall. This comparison has been made for the whole JB, and for each hydro climatic area shown on Fig. 1. Once selected the convective precipitation scheme, the non-convective precipitation scheme has been adjusted to improve the reproduction of winter precipitation historical records.

CUSTOMIZATION OF THE REGIONAL CLIMATE MODEL AND RESULTS

Convective precipitation scheme

Table 1 and Fig. 3 show both the average of monthly precipitation (P) and temperature (T) in the JB for the period 1990 - 2000, and both historical and simulated P and T values for the nested grid obtained with each convective precipitation scheme.

The four schemes correctly reproduce the temperature records, with small differences between them, and a similar behaviour in March where simulated temperature values are always slightly below the historical record. The simulations obtained with the Grell convective precipitation schemes (simulations GSA and GSB) are better than those with the Emmanuel (ES) and Kuo Scheme (KS) in reproducing the historical records of precipitation, both in absolute values (462 mm/year in Grell Scheme AS74; 482 mm/year in Grell Scheme BC80; compared with 452 mm/year historical records), and in the sum of the squared monthly differences. Also, the simulated values with Grell schemes are closer to the historical records in autumn and winter, which is important given its influence on water resources availability (Chirivella 2011; Chirivella *et al.* 2014). Note the high value of the simulated precipitation for the month of February which is more than two times the historical record. Simulation GSA provides the lowest value (62 mm compared to 32 mm).

	Historical records P	RegCM3 P (mm) Simulated values				Historical records T	RegCM3 T (ºC) Simulated values			
		GSB	GSA	ES	KS		GSB	GSA	ES	KS
October	66,12	71,75	77,75	107,20	90,56	14,56	15,74	14,92	15,81	15,39
November	34,54	43,71	49,51	48,37	86,86	10,24	10,40	10,22	10,68	10,03
December	51,47	22,73	30,89	19,81	32,61	7,42	8,22	7,92	8,44	7,74
O-N-D	152,14	138,20	158,14	175,38	210,03	10,74	11,46	11,02	11,64	11,06
January	40,11	40,02	41,37	45,41	46,48	6,44	6,96	6,80	7,22	6,58
February	32,32	70,26	61,64	78,20	73,84	7,88	7,28	7,53	7,60	7,23
March	31,28	29,51	38,24	46,79	41,16	10,55	8,55	8,52	8,56	8,25
J-F-M	103,71	139,80	141,25	170,41	161,47	8,29	7,60	7,62	7,79	7,35
April	39,11	34,09	34,90	64,78	39,44	12,04	12,57	12,15	12,40	11,87
May	44,84	29,63	29,00	62,74	42,97	15,92	15,53	15,56	15,32	15,32
June	29,65	20,50	16,45	43,49	13,36	20,12	21,12	20,32	20,75	20,98
A-M-J	113,60	84,21	80,35	171,01	95,77	16,03	16,40	16,01	16,16	16,06
July	13,05	24,81	22,77	54,55	10,69	23,48	23,73	22,83	23,16	23,38
August	21,55	23,04	24,55	41,13	16,93	23,94	23,48	22,46	23,18	23,62
September	47,98	52,00	54,69	83,09	55,40	19,50	19,75	19,72	19,95	19,93
J-A-S	82,57	99,85	102,01	178,77	83,01	22,31	22,32	21,67	22,10	22,31
TOTAL	**452,02**	**462,06**	**481,75**	**695,57**	**550,29**	**14,34**	**14,45**	**14,08**	**14,42**	**14,19**
Σ dif^{2}		**2.881,89**	**2.284,20**	**9.764,99**	**5.902,54**		**8,43**	**7,56**	**2,30**	**8,01**

Table 1 Precipitation (mm) and Temperature (ºC) for the control period (1990-2000): Historical records and simulated values with the four convective precipitation schemes. The lowest row shows the sum of squared monthly differences between the historical records and each of the simulations.

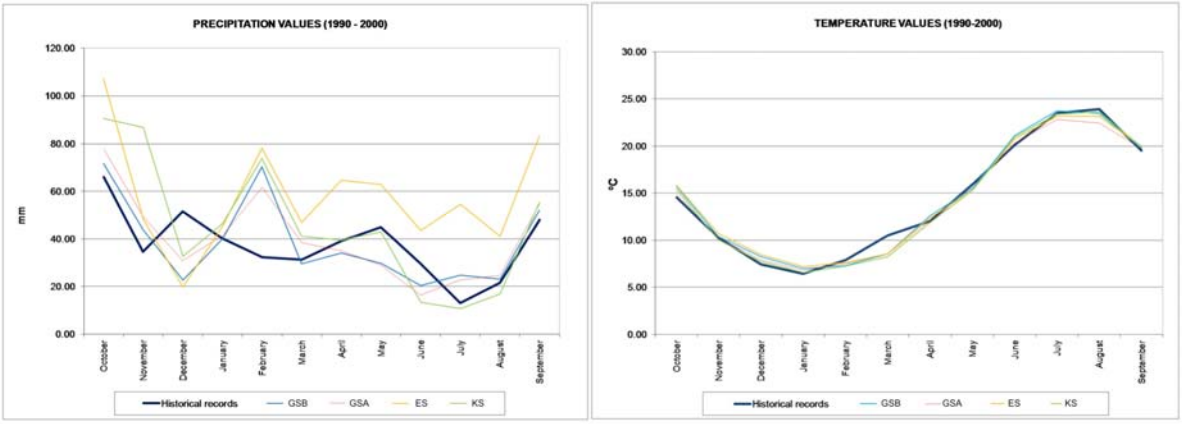

Fig. 3 Average monthly Precipitation (mm) and Temperature (ºC) in the JB for the control period 1990-2000. Observed data and simulated values for the four convective precipitation schemes.

The best performance of the simulations with Grell schemes can be observed (Table 2) also in most of hydro climatic areas of JB. Simulation GSA is the closest to the particularly high rainfall recorded in the area of the Marina Alta and Serpis.

	Historical records	RegCM3 Simulated values			
		GSB	GSA	ES	KS
Bajo Júcar	513,88	528,13	530,09	611,11	729,54
Alfambra	392,92	419,33	469,44	737,10	400,28
Alto Turia	448,33	478,79	525,25	786,66	548,44
Bajo Turia y Palancia	435,12	491,47	500,44	685,75	689,01
Marina Baja	442,91	264,78	267,92	441,67	266,25
Alto Mijares	479,53	557,38	589,05	954,20	537,83
Vinalopó Alacantí	295,23	260,05	255,75	359,62	241,37
Bajo Mijares	518,42	476,24	483,90	791,77	441,47
Marina Alta y Serpis	661,55	396,34	417,05	531,58	472,40
Sierra Alcaraz	473,67	384,50	398,65	567,31	342,38
Ayora Almansa	395,52	456,57	465,43	531,08	524,34
Alto Júcar	530,72	584,55	647,13	795,09	706,67
Medio Júcar	383,69	440,94	446,77	562,92	638,52
Σ (sim - histo)^2		134.002,29	149.495,76	755.428,47	329.982,40

Table 2 Annual precipitation (mm) in different areas of the JB for the control period (1990 - 2000): Historical records and simulated values for the four convective precipitation schemes. The sum of squared differences between annual observed data and simulated values is given in the lowest row.

Another important result that confirms the appropriateness of the RCM application for the downscaling process is that the agreement of simulated values with historical records improves from the coarse grid to the fine grid. As an illustration, Fig. 4 and Table 3 show this improvement for the simulation GSA (Grell scheme AS74).

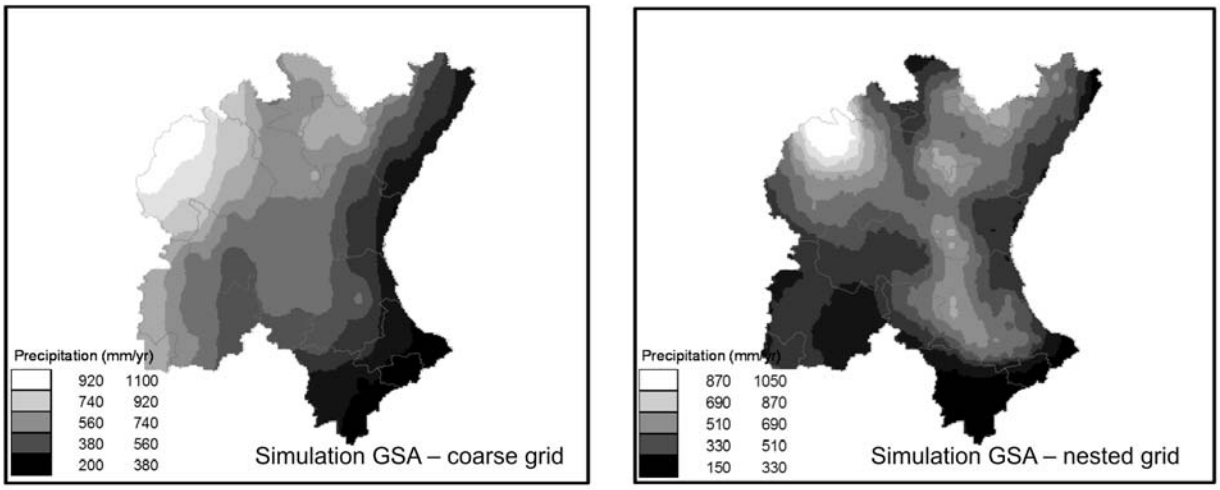

Fig. 4 Simulated annual precipitation in the period 1990-2000 (mm/yr) with Grell scheme AS74. On the left coarse grid; on the right the fine grid.

	Historical records (i)	Simulated values (ii)		$\sum (ii - i)^2$	
		GSA (coarse grid)	GSA (fine grid)	GSA (coarse grid)	GSA (fine grid)
Upper basin					
Alfambra	392,92	638,64	469,44	10.211,98	4.610,07
Alto Turia	448,33	631,35	525,25	8.879,97	3.665,42
Alto Mijares	479,53	628,87	589,05	8.071,43	5.235,45
Sierra Alcaraz	473,67	661,30	398,65	7.992,55	3.004,44
Alto Júcar	530,72	801,79	647,13	14.868,20	6.026,23
Middle basin					
Vinalopó Alacantí	295,23	343,11	255,75	1.904,70	1.214,00
Ayora Almansa	395,52	518,53	465,43	5.013,36	2.990,16
Medio Júcar	383,69	557,18	446,77	7.125,28	3.001,48
Lower basin					
Bajo Júcar	513,88	474,58	530,09	3.944,40	4.019,22
Bajo Turia y Palancia	435,12	484,48	500,44	4.668,71	4.316,73
Marina Baja	442,91	252,25	267,92	4.427,82	3.883,15
Bajo Mijares	518,42	445,33	483,90	4.616,90	3.457,83
Marina Alta y Serpis	661,55	306,17	417,05	13.735,26	7.672,01

Table 3 Differences of precipitation (mm) in the control period (1990–2000) between simulated values for the coarse grid and the fine grid and historical records, in each hydroclimatic zone of the JB. The sum of squared differences is obtained on a monthly basis.

Non-convective precipitation simulation

A general problem found is that simulated scenarios yield excessive precipitation in February. The influence of larger-scale, non-convective, atmospheric circulations in the JB area (Atlantic fronts in this case study) is generally low (e.g., Millán & Estrela 2008; Estrela *et al.* 2002; López & Martin 2001). According to our results, it seems that the non-convective precipitation scheme used in RegCM3 is not able to properly reproduce this little influence with the standard RegCM3 modelling parameters. Non-convective precipitation is modelled by the SUBEX module (Pal *et al.* 2000) and it allows the customization of several parameters to honour local climatic conditions. SUBEX – that refers to the subgrid explicit moisture scheme - was developed to treat non-convective cloud and precipitation processes replacing an older simple explicit moisture scheme. It calculates the autoconversion of cloud water to rainwater, accretion, evaporation, and cloud fraction at each grid point.

A careful sensitivity analysis of the influence of the different parameters on winter season precipitation was carried out. In order to do that a reduced control period of five months, Nov-91 through Apr-92, was chosen to run RegCM3 with multiple sets of SUBEX parameters. The model was run for the whole IP using the coarse grid (Fig. 2) and the Grell AS74 convective scheme already chosen. The study has been focused on four parameters described by Elguindi *et al.* (2007): RH_{min} which is the relative humidity threshold at which clouds begin to form, C_{ppt} which can be considered as the inverse of the characteristic time for which cloud droplets are converted to raindrops, C_{evap} which is a factor that relates the percentage of precipitation that evaporates before reaching the earth's surface, and C_{aac} which is the accretion rate coefficient that correlates the amount of precipitation originated in a cell when the precipitation of the upper cells falls on it. The analysis has been quite simple because of the difficulty to run multiple times RegCM3 for an automatic search of a set of parameters yielding an optimum approach of historical records. A range of variability was defined for every parameter and the analysis of results for different subsets of modified parameters produced the best and reasonable improvement in fitting historical records. Two parameters were found to improve the reproduction of historical records: RH_{min} and C_{ppt}. Thus, RH_{min} has been increased from the default value, 0.8, given in RegCM3, to 0.9, and C_{ppt} decreased from the default value of 0.00025 s^{-1} to 0.0001 s^{-1}. Note that the precipitation increases when RH_{min} decreases and also when C_{ppt} increases. Finally, the results obtained with the coarse grid were verified for the fine grid in the JB domain and for more extended time periods. The fine grid even yields better simulated values in winter than the coarse grid. Thus, the simulated values for February-92 go down to 50.77 mm/month (compared to 68.40 mm) and the total precipitation in the period of Jan92 - Mar92, goes down to 109.44 mm (compared to 157.17 mm). These results are slightly better than those obtained for the coarse grid used in the sensitivity analysis.

DISCUSSION

The comparison between simulated and historical records of precipitation in the control periods shows a clear improvement for the dynamic downscaling approach obtained with the customization of RegCM3 for the JB. Fig. 5 shows the difference between the control period 1960-90 against the average of the eleven AEMET (2008) scenarios, and between the control period 1990-2000 and the RCM results. The simulated average precipitation in the control period of AEMET scenarios is 21% lower than the observed data, while that obtained with the new scenario is 6% higher. The latter values are shown in Table 4. In addition, the monthly distribution of precipitation obtained with RegCM3 fits better historical records than in the AEMET scenarios (Fig. 5).

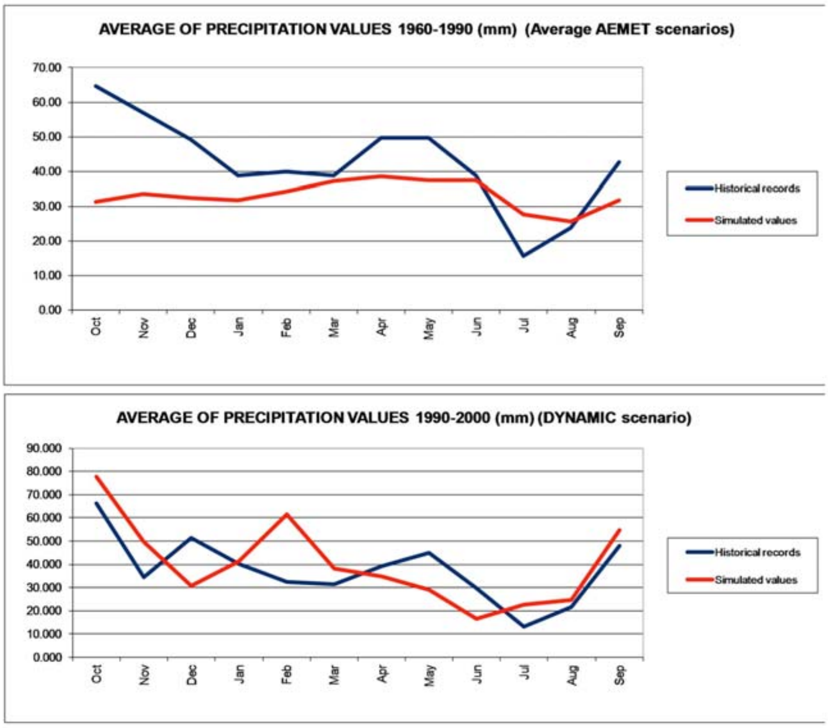

Fig. 5 Comparison between simulated and historical records of average monthly precipitation for the control periods. Upper graph for the average of AEMET scenarios, and lower graph for RCM results.

Table 4 shows the detail differences between monthly historic averages of T and P for the control period and the difference with RegCM3 simulated values (ΔT* and ΔP*). As indicated above these are much closer to the control period than happens with statistical climatic scenarios from AEMET (2008). In the same Table, the climatic anomalies of T and P, ΔT and ΔP, are presented calculated for the decades 2010-20, 2020-30, and 2030-40, as well as for the whole period 2010-40. There is a clear trend of increase in T and decrease of P, with variations along the three simulated decades. For the whole territory of the JB, RegCM3 foresees a 21.0 % decrease in precipitation for the period 2010-40, i.e. 95.23 mm/year. This is considerably greater than the average anomaly predicted by the average of statistically based AEMET scenarios, -4.03 %, and – 6.64 % predicted by the average of scenarios based on ECHAM4 (Chirivella et al. 2014). The most significant reductions are produced in the months of February, September and October. The increase in average temperatures is estimated as 0.75 °C, from a simulated value of 14.08 ºC in the decade 1990-00, to an average of 14.83 ºC for 2010-40. Note that this increment is strongly concentrated in the summer months: in July (+3.05 °C) and in August (+1.89 °C).

It is important to understand the influence that the temporal and spatial distribution of anomalies will have on the availability of water resources (Bates *et al.* 2008). The impact on water resources depends also on seasonal and spatial variations of T and P. According to the results of the RCM, the greatest reductions of P, in percentage terms, are expected in coastal areas, being less pronounced in inland areas; this change is more pronounced in autumn and winter thus foreseeing a greater impact on water resources. Regarding T, the increase in absolute value (not in percentage) is similar at upper, mid and lower basin areas. As already indicated above, its increment is mainly concentrated in the summer months, reducing its adverse effect on water resources availability, but posing a serious threat regarding potential future heat waves.

	1990-00: Observed data		1990-00: RegCM3		2010-20		2020-30		2030-40		**2010 - 40**	
	T	P	ΔT*	ΔP*	ΔT	ΔP	ΔT	ΔP	ΔT	ΔP	ΔT	ΔP
October	15,03	66,12	-0,11	11,63	-0,65	-29,75	0,33	-40,93	0,30	-21,98	**-0,01**	**-30,89**
November	10,06	34,54	0,16	14,97	-0,11	-8,51	0,12	-21,12	0,65	-12,06	**0,22**	**-13,90**
December	7,15	51,47	0,77	-20,58	-0,68	22,58	-0,10	0,78	0,12	3,55	**-0,22**	**8,97**
O-N-D	10,75	152,14	0,27	6,01	-0,48	-15,68	0,12	-61,27	0,36	-30,49	**0,00**	**-35,81**
January	6,50	40,11	0,31	1,26	-0,09	-3,87	0,47	-0,89	-0,16	-3,41	**0,07**	**-2,72**
February	7,63	32,32	-0,09	29,32	0,40	-33,31	-0,56	-26,85	1,50	-30,50	**0,45**	**-30,22**
March	10,34	31,28	-1,82	6,96	0,76	-10,75	0,26	-10,42	0,34	15,30	**0,45**	**-1,96**
J-F-M	8,16	103,71	-0,54	37,54	0,36	-47,93	0,06	-38,16	0,56	-18,61	**0,32**	**-34,90**
April	12,20	39,11	-0,05	-4,21	1,22	0,29	-0,20	-10,12	0,51	-7,75	**0,51**	**-5,86**
May	15,97	44,84	-0,41	-15,84	0,77	7,02	1,35	-16,11	0,68	-2,28	**0,93**	**-3,79**
June	20,62	29,65	-0,29	-13,20	0,93	6,08	0,83	5,16	1,83	18,98	**1,20**	**10,07**
A-M-J	16,26	113,60	-0,25	-33,25	0,97	13,39	0,66	-21,07	1,01	8,95	**0,88**	**0,42**
July	23,72	13,05	-0,89	9,72	2,05	-6,28	2,24	-6,78	4,86	-2,75	**3,05**	**-5,27**
August	23,81	21,55	-1,35	3,00	1,33	-2,94	1,65	4,73	2,68	-0,02	**1,89**	**0,59**
September	19,59	47,98	0,14	6,71	0,27	-26,72	-1,07	-11,72	2,21	-22,33	**0,47**	**-20,26**
J-A-S	22,37	82,57	-0,70	19,44	1,22	-35,94	0,94	-13,77	3,25	-25,10	**1,80**	**-24,94**
TOTAL	**14,38**	**452,02**	**-0,30**	**29,74**	**0,52**	**-86,16**	**0,44**	**-134,27**	**1,29**	**-65,25**	**0,75**	**-95,23**

Table 4. Differences of simulated T and P with the control period, ΔT* and ΔP*, and anomalies of T and P, ΔT and ΔP, for the decades 2010-2020, 2020-2030 and 2030-2040, and for 2010-40, referred to the control period 1990-2000.

Another interesting result seen when comparing with statistically-based AEMET predictions, is that the RegCM3 anomaly precipitation variation during the three decades (-86.16 mm; -134.27 mm; -65.25 mm) is much higher than that obtained by the AEMET scenarios (-5.46 mm; -12.73 mm; -19.55 mm). The same results as observed with respect to spatial variability (Chirivella *et al.* 2014). This confirms the results obtained by Schmidli *et al.* (2007) when comparing downscaling methodologies in a different regional environment.

The RCM projections shown in this paper show trends similar to those generated in the ENSEMBLES project (Van der Linden & Mitchell 2009), although in this project there are different downscaling approaches, applied to different regional studies, and for the end of 21st century. In ENSEMBLES, some scenarios predict P anomalies close to -20 % and a T anomaly of 1 ºC in some parts of Spain. These results are also based on the fourth report (AR4) of IPCC, and A1B emissions scenario, although are referred to a longer time term.

CONCLUSIONS

This paper presents the results of a dynamical downscaling approach compared to other obtained by statistical methodologies. The geographical area where the study is done is a western Mediterranean basin, the Júcar river Basin (JB), where there is a combined influenced, over short distances, of precipitations of different origin (convective and non-convective precipitations), next to a strong impact of local orography variability. The time frame is the period 2010-40 for which no previous dynamic scenarios have been generated and only statistical ones are available.

The regional climate model used, RegCM3, has been applied using a coarse grid of 30 x 30 km over the Iberian Peninsula, and then a nested grid of 10 x 10 km over the JB area. The starting input data come from the ECHAM5 GCM model (fourth report of IPCC). Thus, the resolution over the JB goes roughly from 4 cells (ECHAM5) to 35x34 cells (RegCM3 with fine grid). The RCM has been successfully customized to reproduce the local convective and non-convective precipitations local conditions. The most suitable convective scheme has been found to be the Grell Scheme AS74 (Arakawa and Schubert, 1974). The non-convective scheme has been adapted by changing some of the default RegCM3 parameters (RH_{min} and C_{ppt}) in order to diminish the influence of Atlantic fronts in the RCM results over the JB. Compared to the current official AEMET (2008) scenarios over Spain, the dynamical downscaling approach reproduces much better historical data used for the verification of RegCM3 – the control period 1990-00.

The results of RegCM3 foresee a 21.0 % decrease in precipitation in the JB for the period 2010-40, i.e. 95.23 mm/year. This is considerably greater than previous predictions. In fact, the average of AEMET scenarios, based on ECHAM4, is –6.64 % (Chirivella et al. 2014). The most significant reductions are produced in the months of February, September and October. Regarding temperature, the average increased is estimated as 0.75 °C, with very significant increments in July (+3.05 °C) and in August (+1.89 °C).

In view of this results, we conclude that statistical downscaling approaches can fail in the reproduction of local, but important, climatic characteristics that require a dynamic downscaling approach as the research presented in this paper. Western Mediterranean, and more specifically, the Jucar river basin, is a good example of this situation. Besides, the RegCM3 model has been customized for its application in the area for further regionalizations of climate change scenarios.

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