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Weather regimes—Moroccan precipitation link in a regional climate change simulation

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ABSTRACT

The local future climate conditions in Morocco under the SRES scenario A1B are studied by using two 30-year time-slice simulations performed by the variable resolution configuration of the global circulation model ARPEGE-Climate. The spatial resolution ranges between 50 and 60 km over the whole country. Firstly, the link between local precipitation and weather regimes in the North Atlantic basin is investigated in terms of mean precipitation and the frequencies of occurrence for wet and intense precipitation days. Then a statistical downscaling approach that uses large-scale fields to construct local scenarios of future climate change is validated in the case of Moroccan winter precipitation. The outputs of experiments carried out from an ensemble of regional climate models are used to assess the uncertainties associated to future climate change. These dynamical downscaling outputs have been also used to test the robustness of the results related to the statistical downscaling technique. Our results concerning the future climate conditions over Morocco show not solely a decrease in mean precipitation but also a change in the precipitation distribution and in extreme events.

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1. Introduction

Based on global general circulation (GCM) coarse-resolution models, the Fourth Assessment Report (AR4) of the Intergovernmental Panel on Climate Change (IPCC) projects a warming and negative trends of precipitation for subtropical Africa (IPCC, 2007). In particular, total winter precipitation in Morocco, is likely to decrease of about 20% by the end of the 21st century. Water resources in Morocco depend on precipitation which influences also the agricultural production. To elaborate adapted strategies and manage future problems with water supply for different regions, decision-makers are interested in more detailed information such as precipitation features at local scale.

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Following this idea, in Born et al. (2008), the impact of different climate periods on vegetation was studied from the experiments issued from the regional climate model (RCM) REMO (Jacob et al., 2001) over the Northwestern Maghreb, by means of Köppen climate classification (Köppen, 1936). They showed a climate shift of climates in three Moroccan regions (Knippertz et al., 2003) towards warmer and dryer conditions. In Knippertz et al. (2003), Moroccan winter precipitation association with North Atlantic Oscillation (NAO, Hurrell, 2005) variability and circulation weather types were investigated by means of correlation and composite analysis. The negative correlation between the precipitation and the NAO is relatively strong during the high precipitation months (December, January, and February) mainly in the north-western region. The influence of the NAO on precipitation in Morocco was primarily investigated by Lamb and Peppler (1987), Lamb et al. (1997), and Portis et al. (2001). Terray et al. (2004) suggest, in a study based on an ensemble of climate change scenarios performed with a GCM, an increase of the positive phase of the NAO during wintertime and a reduction of the negative phase occurrence. In Driouech et al. (2008), hereafter D08, Moroccan rainfall simulated by the variable resolution configuration of the GCM ARPEGE-Climate has been examined by comparison with daily observed values from several Moroccan meteorological stations. D08 showed a rather well ability of the model in reproducing main precipitation features and also a set of climate indices (STARDEX indices, Goodess, 2003) related to extreme events. The horizontal resolution of the model ranged between 50 and 60 km over the whole country. The links between Moroccan precipitation and large-scale atmospheric dynamics (NAO in particular) were also investigated in D08 by using an approach based on circulation weather regimes (WR) (Vautard, 1990; Michelangeli et al., 1995).

In this study we go further and we investigate whether the weather regimes approach is appropriate for estimating local changes of precipitation under global warming conditions using statistical downscaling methods (von Storch, 1995). The goal of this work is also to improve our knowledge of the impact of climate change on precipitation and extreme events in Morocco using a high resolution model. Uncertainties related to the choice of the model are also investigated using a database built by the EU FP6-ENSEMBLES project (http://www.ensembles-eu.org).

In Section 2 we give a short description of the numerical experiments. In Section 3 we study the links between the weather regimes and the precipitation in Morocco. We present a statistical downscaling approach using weather regimes and then we assess the model response to anthropogenic climate change in Section 4. The model dependence of the results is analyzed in Section 5. The discussion of results and the conclusion are presented in Section 6.

2. Model experiments

The recent version 4 of the GCM ARPEGE-Climate has been used in the variable resolution configuration with the pole of the stretched grid located over Morocco at 28°N, 8°W and with a stretching factor of 3. The resulting horizontal resolution ranges between 50 and 60 km over the whole country. We have performed a 30-year simulation of the present climate for the period 1971–2000 (hereafter MORC). This experiment was validated in D08 where also a short description of Version 4 of the model and the experimental set up can be found. A second 30-year time-slice experiment for the future climate covering the period 2021–2050, (hereafter MORS), has been carried out with the SRES scenario A1B. The model was forced by monthly mean sea surface temperature (SST), produced by the CNRM-CM3 coupled model (Salas-Mélia et al., 2005) contribution to the fourth IPCC report (IPCC-AR4). The greenhouse gases (GHGs) and sulfate aerosol concentrations used here are the same as in the CNRM-CM3 experiments. This forcing data was prescribed for both, MORC and MORS experiments.

3. Weather regimes and local precipitation

To understand changes in Moroccan precipitation, the knowledge of the links between the large-scale modes of variability and local climate is an important way. Morocco is situated at the southern edge of the mid-latitude storm track. The region located north of the Moroccan Sahara desert comprises the main agricultural zone of the country and the main rainy regions of Morocco. The north Atlantic large-scale circulation (extratropical circulation modes) exerts a strong influence on the climate of this region. During wintertime, most precipitation is generated as a result of low pressure weather systems being steered southward during mid-latitude blocking episodes (Ward et al., 1999).

We focus, in this section, on daily precipitation in the region north of the Moroccan Sahara desert represented by fourteen stations (the names of the stations are given in Table 1 and their locations are indicated in Fig. 1). These stations have been clustered into five rainfall regions by Ward et al. (1999). They have also been clustered into three regions by Knippertz et al. (2003). In this work we use the individual stations since we are interested also in precipitation extremes. We consider only winter months (DJF) when most of the stations show a precipitation maximum. The daily observations at the fourteen stations are provided by the Direction de la Météorologie Nationale (Moroccan national meteorological service).

3.1. Classification into weather regimes

The centroids of the four main classical weather regimes (Vautard, 1990) over the North Atlantic basin are obtained by applying the dynamical cluster algorithm described in Michelangeli et al. (1995) to the geopotential height at 500 hPa (Z500) from the ERA40 reanalysis (Uppala et al., 2005). The calculations are done for the period 1958–2001 for winter months (DJF) and over a domain covering the extratropical North Atlantic, Western Europe and North-Western Africa (80 °N–20° N, 90° W–30° E), (Sanchez-Gomez et al., 2008). These weather regimes are the Zonal regime (ZO), the Greenland Anticyclone (GA), the Blocking cell (BL) over Scandinavia and the Atlantic Ridge (AR) located in the centre of the North Atlantic Ocean. The classification for the daily observed and simulated data for the actual period (1971–2000) has been done basically in the same way as was described in D08, that is, the Z500 anomalies are projected on the weather regimes centroids from ERA40 by using the Euclidean distance. The attribution of days to a weather regime is then done by minimizing this distance. In this study the spatial average of Z500 has

Table 1
Name of the grid boxes from ARPEGE-Climate together with the location of the centre of each grid (longitude and latitude) box and the name of the nearest station.

Box name	Latitude of the box centre	Longitude of the box centre	Nearest station
TN	35.41	−5.72	Tangier (TNG)
OJ	34.40	−1.65	Oujda (OJD)
KN	34.04	−6.61	Rabat (RBT)
RB	34.04	−6.61	Kenitra (KNT)
FE	33.69	−4.48	Fès (FES)
MK	33.46	−5.16	Meknès (MKN)
CS	33.16	−7.33	Casablanca (CSB)
IF	33.46	−5.16	Ifrane (IFR)
SF	32.34	−9.00	Safi (SAF)
MD	32.41	−4.51	Midelt (MDL)
ES	31.33	−9.34	Essaouira (ESS)
MR	31.22	−7.98	Marrakech (MRK)
AG	30.32	−9.31	Agadir (AGD)
OR	30.53	−6.48	Ouarzazate (ORZ)