Proceedings of FRIEND-Water 2014, Montpellier, France, October 2014 (IAHS Publ. 363, 2014).

Projected climate change impacts on water resources in northern Morocco with an ensemble of regional climate models

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Abstract The Mediterranean region is considered as a hot spot of climate change, where precipitation is likely to decrease with the rise of temperature. These changes could have a strong effect in north Africa and notably in Morocco where the agricultural sector is of high importance and very dependent on surface water resources. Therefore, there is a need to quantify the possible climate change impacts on water resources of this region. The most common approach to conduct hydrological impact studies of climate change is to run hydrological models with climate scenarios, usually provided by climate model outputs downscaled to the catchment of interest. In the present study an ensemble of six regional climate model (RCM) simulations from the European project ENSEMBLES at a 25 km resolution is considered to evaluate the climate change impacts on the inflows of the sixth largest dam located in northern Morocco. A quantile perturbation method is used to generate future temperature and precipitation series under the emission scenario A1B. The GR4J hydrological model is first calibrated on different climatic conditions to assess the temporal transferability of its parameters and then run with the perturbed temperature and precipitation series. The ensemble approach allows the projection uncertainties to be evaluated from the spread in the individual RCM simulations. All RCM simulations project a decrease in surface water resources during the extended winter season (November to May), from –9% to –54% depending on the model.

Key words climate variability; climate downscaling; hydrological modelling; Morocco

INTRODUCTION

Morocco is highly dependent on water resources notably for its agricultural sector (Bouaicha & Benabdelfadel, 2010; Schilling *et al.*, 2012). However, very few studies have evaluated the possible climate change impacts in north African catchments (Bargaoui *et al.*, 2013). A large scale assessment over the Mediterranean region provided by Milano *et al.* (2013) indicated a possible future decrease in surface water resources by –30% to –50% by 2050. The main methodological issues associated with impact studies rely on the calibration of rainfall–runoff models for changing climatic conditions and the uncertainties related to the downscaling methods.

In a previous study, Tramblay *et al.* (2013) compared the simulations from one RCM at different resolutions over the Makhazine catchment, which is the sixth largest storage-dam in Morocco. The analysis is extended here to consider a multi-model ensemble. In the present study, an ensemble of six different RCM simulations at 25 km is considered to estimate the uncertainties in future projections in the different RCM/GCM model combinations. The GR4J hydrological model (Perrin *et al.*, 2003) is calibrated to reproduce monthly discharge using a differential split sample test between dry and wet years to assess the stationarity of its parameters (Coron *et al.*, 2012). In addition, a quantile perturbation approach (Chiew *et al.*, 2009; Liu *et al.*, 2012; Tramblay *et al.*, 2013) is considered to include the climate change signal into hydrological simulations.

DATA

Hydro-meteorological data in the Makhazine catchment

The catchment of the Makhazine dam is located in north Morocco and drains an area of 1808 km^2 (Fig. 1). The observation study period is 1984–2010 (27 hydrological years from September to August). The daily dam inflows are available since 1984 at the Makhazine station. The available monthly air temperatures between 1975 and 1996 were used to compute a mean interannual potential evapotranspiration (PET) using the Oudin *et al.* (2005) formula. Daily precipitation data were interpolated using the nearest neighbour approach applied on 11 stations spread over the catchment.

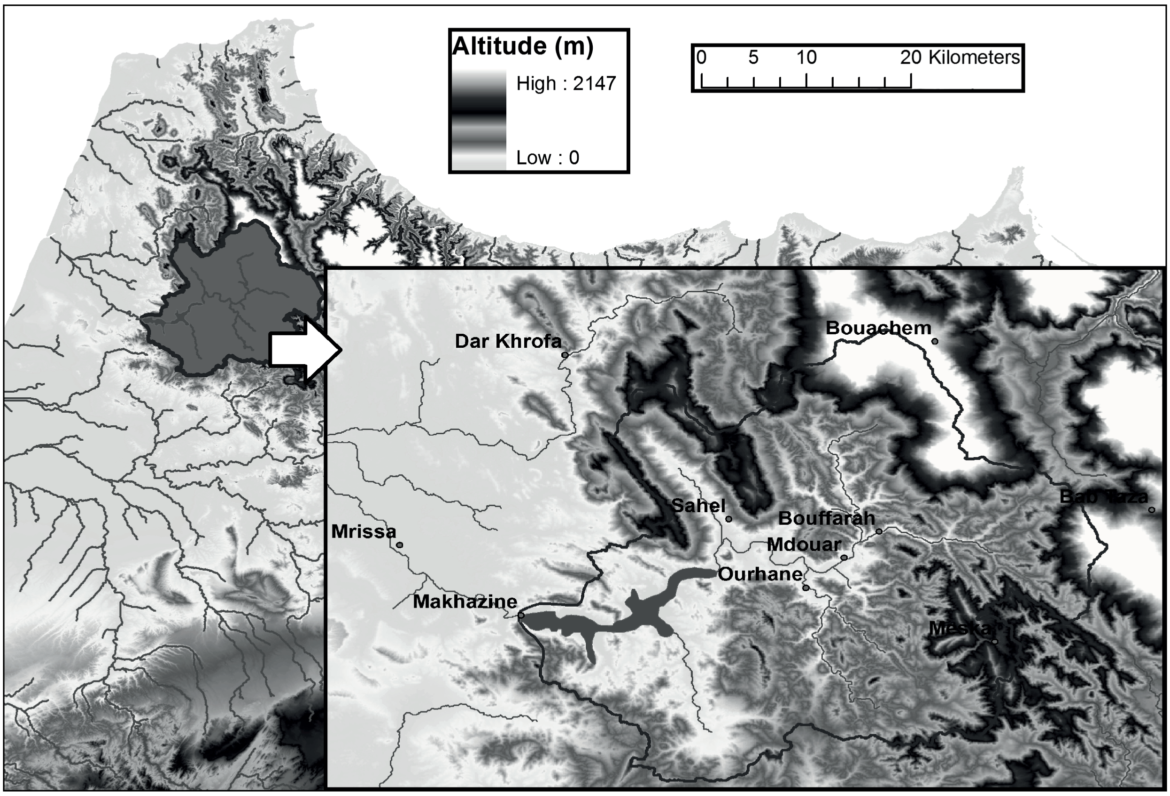

Fig. 1 The Makhazine catchment (1808 km^2) in Morocco: location of the hydro-climatic stations.

Regional climate simulations

Since the main source of uncertainty is usually inherited from their forcing GCM, the RCM simulations from the ENSEMBLES database have been chosen to have the same number of simulations driven by each GCM. A total of six RCM simulations provided by the ENSEMBLES project at a 25 × 25 km resolution were considered under the emission scenario A1B. These RCM simulations are driven by three different GCMs (two simulations driven by ARPEGE, two by BCM and two by ECHAM) to evaluate the projection uncertainties given by different model configurations (Déqué *et al.*, 2012).

Table 1 Regional climate model simulations at a 25 × 25 km resolution under the emission scenario A1B.

Institute	Driving GCM	RCM	Acronym
CNRM	ARPEGE	Aladin	CNR_A
DMI	ARPEGE	HIRHAM	DMI_A
DMI	BCM	DMI-HIRHAM5	DMI_B
SMHI	BCM	RCA	SMH_B
ICTP	ECHAM	RegCM	ICT_E
MPI	ECHAM	REMO	MPI_E

METHODS

Hydrological model

The GR4J model developed by Perrin *et al.* (2003) was used to simulate discharge from the Makhazine catchment. Its four parameters were calibrated with daily inflows measured at the dam using the Nelder-Mead search method with a warm-up period of 365 days for the correct initialization of the conceptual reservoirs. The model was run at a daily time step and evaluated at a monthly time step. The multi-objective function, for which the lowest value indicates a good model agreement with observations, combines the Nash-Sutcliffe efficiency coefficient (NSE) on simulated mean monthly discharge and the bias (BIAS) on runoff volume over the full time period considered. This function gives weight to both dynamic representation and water balance (Coron *et al.*, 2011; Ruelland *et al.*, 2012; Tramblay *et al.* 2013). The hydrological model was calibrated and validated using a differential split-sample test (DSST). The model was calibrated on the wet years and validated on dry years, and then reversed for calibration and validation.

Quantile perturbation

A variant of the quantile-perturbation method (Chiew *et al.* 2009; Liu *et al.* 2010) introduced by Tramblay *et al.* (2013) was used in order to overcome the output bias from the RCM simulations. The method determines change factors for all the quantiles of the distribution, therefore including extremes, based on the climate change signal simulated by the different RCM simulations. This perturbation approach was chosen since previous studies indicated that standard bias-correction methods for RCMs may not be appropriate to the semi-arid regions of north Africa (Maraun, 2012; Tramblay *et al.*, 2013). The daily precipitation series were thus perturbed with the method described in Tramblay *et al.* (2013). For temperature, only monthly change factors were considered. For precipitation, 100 modified daily precipitation series were generated from each RCM simulation by this approach. They were then used as inputs in the GR4J model, together with the PET series modified according to the change in temperature. The resulting 100 runoff simulations were averaged into one single monthly series per RCM, thus corresponding to each RCM climate change signal.

RESULTS

Calibration/validation of the hydrological model

The hydrological model calibration results are presented in detail in Tramblay *et al.* (2013). When considering the whole period for calibration, the NSE coefficient on monthly discharge is 0.96 and BIAS is 0.4%. When the model is calibrated on wet years, validation on dry years leads to a NSE coefficient of 0.94 and a BIAS of –3.55%. When the model is calibrated on dry years, validation on wet years leads to NSE is equal to 0.91 and a bias of +3.28%. As a result, the DSST approach indicates only a moderate degradation of the model efficiency between dry and wet periods, which shows that the model parameters are suitable for different hydro-climatic conditions.

Regional climate model simulations

Figure 2(a) shows the monthly mean precipitation as simulated by the different RCM. There is a great variability in the model performances at reproducing the observed patterns. In particular, the models driven by ECHAM overestimate precipitation between January and May, while the other models tend to underestimate precipitation in all months. The ensemble mean of the different RCM simulations is better at reproducing the seasonal dynamics, but still with a 23% underestimation of precipitation. The projected changes by the ensemble of RCM simulations indicate a possible decrease of 20% in precipitation for the projection period 2041–2068 under the scenario A1B (Fig. 2(b)).

For temperature, the comparison is limited since only one station with monthly data is available. All RCM models reproduce the strong seasonality of temperatures with an average bias of 6.7% (Fig. 3(a)). Simulations for the period 2041–2068 project an increase by +2° on average, which could be particularly marked during the summer season (Fig. 3(b)).

Projected changes on surface water resources

As shown in Fig. 4 with the observed PET and precipitation series perturbed with the different RCM simulations, all models lead to a strong decrease in surface runoff for the months of November and December. In contrast, the period between the months of January and April

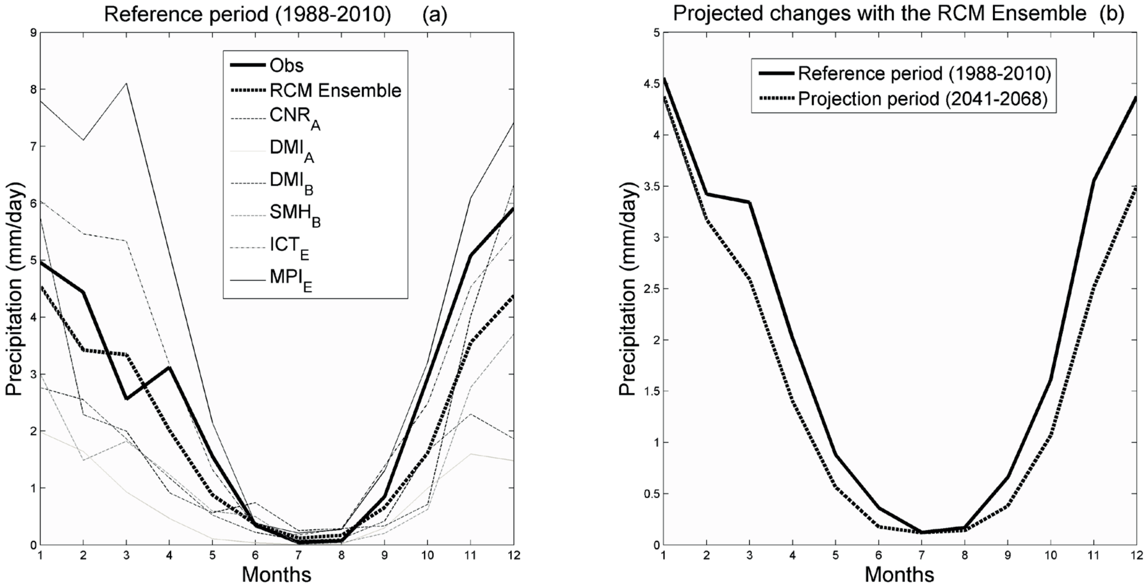

Fig. 2 Monthly precipitation in RCM simulations over the reference period 1988–2010 (a) and projected change with the multi-model ensemble by the 2050 horizon (b).

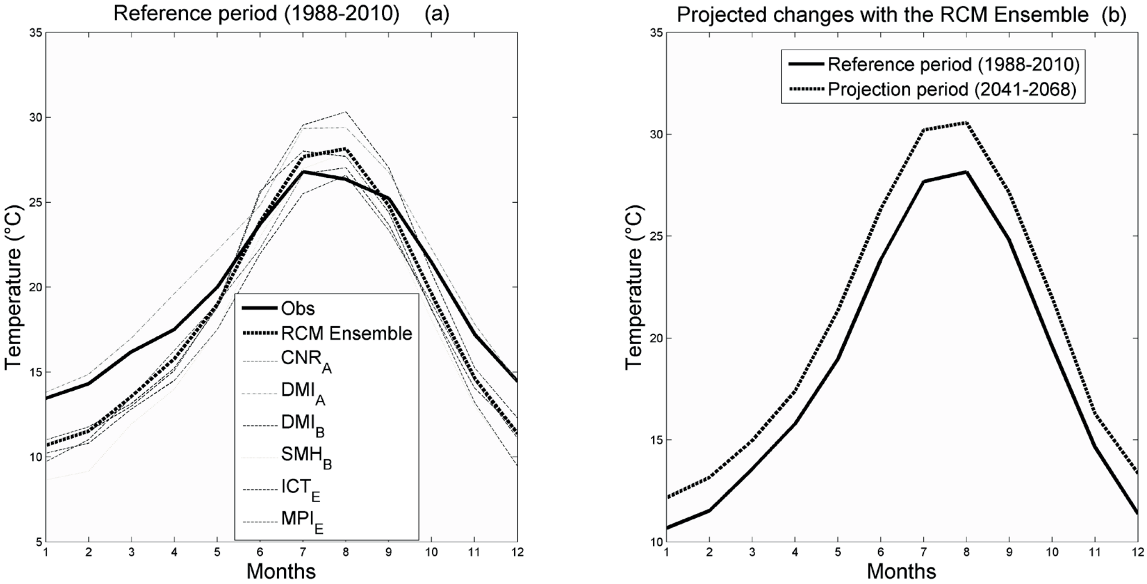

Fig. 3 Monthly temperature in RCM simulations over the reference period 1988–2010 (a) and projected change with the multi-model ensemble by the 2050 horizon (b).

presents much more discrepancy for the different simulations. However, as shown by the multi-model ensemble, the climate change signal under scenario A1B is towards a decrease in surface water for the whole wet season (November to May). The climate change signal is different depending on the GCM forcing: a much lower decrease is projected with the RCMs driven by ARPEGE (–9% and –21%) than with those driven by BCM or ECHAM (up to –55% with DMI_B). The mean projected changes as provided by all simulations indicate a decrease of –35% in surface water resources (Fig. 5), which reinforces results provided by other studies in the same region (Schilling *et al.*, 2012; Milano *et al.*, 2013) and is in the range of projections obtained by Tramblay *et al.* (2013) in the same catchment with the ALADIN-Climate RCM from the MED-CORDEX experiment.

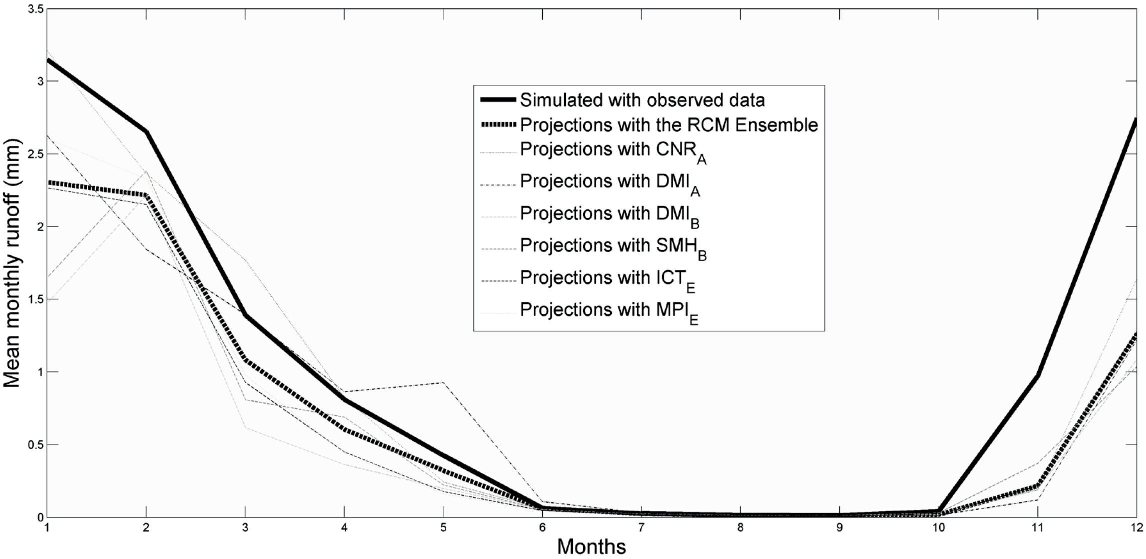

Fig. 4 Monthly runoff simulated after quantile-perturbation of precipitation and temperature series according to the different RCM projections.

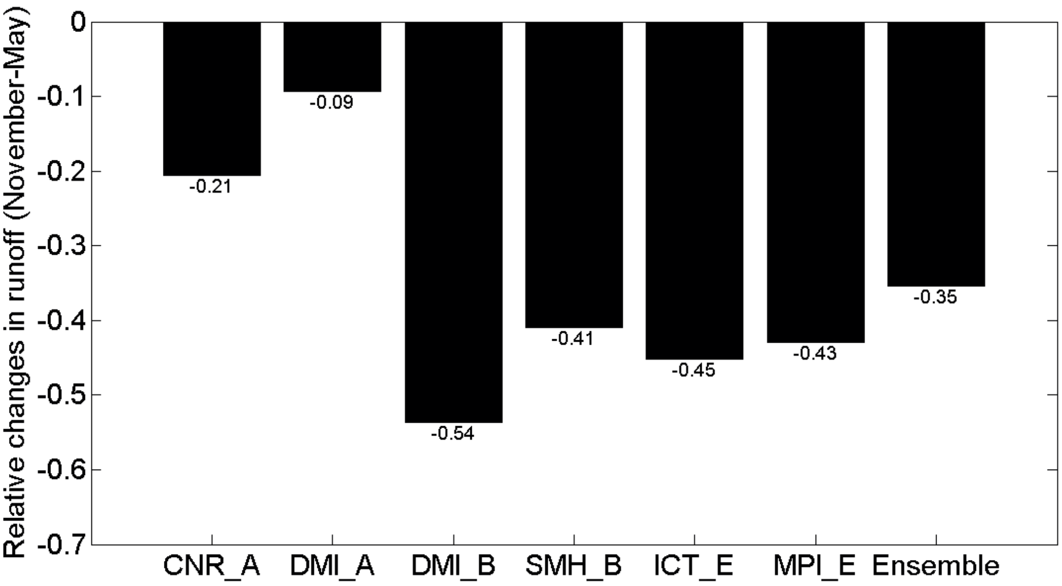

Fig. 5 Relative changes in runoff during the wet season (November–May) by 2050 with the different RCM simulations.

CONCLUSIONS

In this study, the projected changes in surface water resources for a catchment located in northern Morocco were analysed using an ensemble of different RCMs. The results in the catchment indicated a future decrease in surface water resources ranging from 9% to 54% depending on the RCM considered. These projections agree with those obtained by Milano *et al.* (2013) at the Mediterranean scale. The methodological issues related to this type of assessment have been circumvented by testing the stability of the hydrological model parameters under contrasting climatic conditions and also by using a downscaling method that does not rely on strong assumptions, such as the stationarity hypothesis in bias-correction methods. However, it must be noted that the projected changes in the present study do not take into account the possible changes in land use in the catchment, which could possibly induce changes in the rainfall–runoff relationship. There are also large differences between the different climate model simulations, which encourages using a larger number of models with different scenarios of emission to evaluate the uncertainties of such projections.

Acknowledgements The authors are grateful to the department of Water Research and Planning (DRPE) of Morocco and the Hydraulic Basin Agency of Loukkos-Tetouan that provided the observed data for this study.

REFERENCES

Bouaicha, R. & Benabdelfadel, A. (2010) Variabilité et gestion des eaux de surface au Maroc. *Sécheresse* 21, 1–5.

Chiew, F. H. S., Teng, J., Vaze, J., Post, D. A., Perraud, J. M., Kirono, D. G. C. & Viney, N. R. (2009) Estimating climate change impact on runoff across southeast Australia: Method, results, and implications of the modeling method. *Water Resour. Res.* 45, doi:10.1029/2008WR007338.

Coron, L., Andréassian, V., Perrin, C., Lerat, J., Vaze, J., Bourqui, M. & Hendrickx, F. (2012) Crash testing hydrological models in contrasted climate conditions: an experiment on 216 Australian catchments. *Water Resour. Res.* dx.doi.org/10.1029/2011WR011721.

Déqué, M., Somot, S., Sanchez-Gomez, E., Goodess, C.M., Jacob, D., Lenderink, G. & Christensen, O.B. (2012) The spread amongst ENSEMBLES regional scenarios: Regional Climate Models, driving General Circulation Models and interannual variability. *Clim. Dyn.* 38, 951–964.

Bargaoui, Z., Foughali, A., Tramblay, Y. & Houcine (2013) A. Study of two bias-corrected regional climate models for water budget simulations in a Mediterranean basin. In: *Climate and Land Surface Changes in Hydrology* (ed. by Eva Boegh *et al.*). Proc. of Symposium H01, IAHS-IAPSO-IASPEI Assembly, Gothenburg, Sweden, July 2013. IAHS Publ. 359, 73–79. IAHS Press, Wallingford, UK.

Liu, T., Willems, P., Pan, X. L., Bao, An. M., Chen, X., Veroustraete, F. & Dong, Q. H. (2011) Climate change impact on water resource extremes in a headwater region of the Tarim basin in China. *Hydrol. Earth Syst. Sci.* 15, 3511–3527.

Maraun, D. (2012) Nonstationarities of regional climate model biases in European seasonal mean temperature and precipitation sums, *Geophys. Res. Lett.* 39, L06706, doi:10.1029/2012GL051210.

Milano, M., Ruelland, D., Fernandez, S., Dezetter, A., Fabre, J. Servat, E., Fritsch, J.-M., Ardoin-Bardin, S. & Thivet, G. (2013) Current state of Mediterranean water resources and future trends under climatic and anthropogenic changes. *Hydrol. Sci. J.* 58, 498–518.

Oudin, L., Hervieu, F., Michel, C., Perrin, C., Andreassian, V., Anctil, F. & Loumagne, C. (2005) Which potential evapotranspiration input for a lumped rainfall-runoff model? Part 2: towards a simple and efficient potential evapotranspiration model for rainfall–runoff modelling. *J. Hydrol.* 303, 290–306.

Perrin, C., Michel, C. & Andreassian, V. (2003) Improvement of a parsimonious model for streamflow simulation. *J. Hydrol.* 279, 275–289.

Ruelland, D., Ardoin-Bardin, S., Collet, L. & Roucou, P. (2012) Simulating future trends in hydrological regime of a large Sudano-Sahelian catchment under climate change. *J. Hydrol.* 424–425, 207–216.

Schilling, J., Freier, K. P., Hertig, E. & Scheffran, J. (2012) Climate change, vulnerability and adaptation in North Africa with focus on Morocco. *Agr. Ecosyst. Environ.* 156, 12–26.

Tramblay, Y., Ruelland, D., Somot, S., Bouaicha, R. & Servat, E. High-resolution Med-CORDEX regional climate model simulations for hydrological impact studies: a first evaluation in Morocco. *Hydrol. Earth Syst. Sci.* 17, 3721–3739.