Sub-chapter 2.3.1

Hydrological impacts of climate change in North African countries

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Introduction

Countries in North Africa with a semi-arid Mediterranean climate are facing water scarcity and high inter-annual variability of their water resources. Many dams and reservoirs have been built in recent decades to collect surface water and improve the management of existing water resources (Figure 1). However climate projections for this region indicate a possible decrease in precipitation together with an increase in temperature that could result in increased evaporation (Schilling et al., 2012). Evaluating the potential impacts of climate change on water resources is thus of particular importance in this region. To quantify the impacts of climate change on hydrology, climate model outputs need to be combined with the outputs of hydrological models. Climate models provide simulations up to the year 2100, either at large scale (global circulation models) or at regional scale (regional climate models). Most climate models outputs cannot be used directly in hydrological models because the spatial scales do not match or because of a systematic bias in the model outputs, particularly for precipitation. Downscaling or bias-correction techniques thus need to be applied before making future hydrological projections. This chapter presents the main results obtained in the ENVIMED 'CLIHMAG' project funded by MISTRALS for the period 2014-2015. Three different issues are addressed: the validity of standard downscaling methods in a semi-arid context, the reliability of hydrological models in different climate conditions, and effect of the climate change signal on water resources in North African basins.

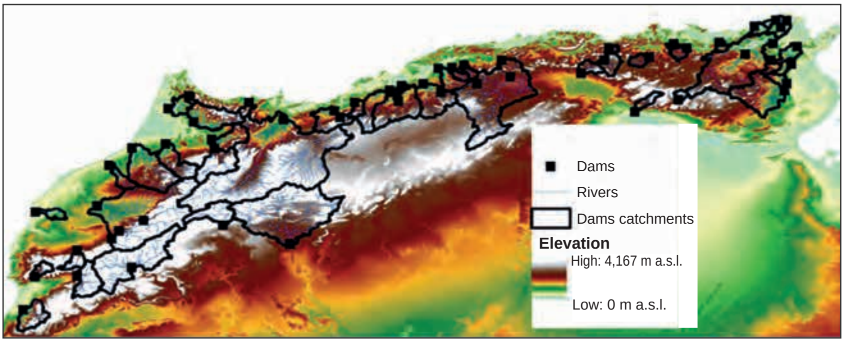

Figure 1
Map of the 47 biggest dams in North Africa.

The observed data needed to run the hydrological model used to address these issues came from a variety of representative catchments. These include the Loukkos (1785 km²) catchment, upstream of the Makhazine dam (the 6th largest dam in the country) in northern Morocco, the main tributary of the Oum Er Rbia basin, the El Abid (4980 km²) catchment, upstream of the Bin Ouidane dam (largest hydro-power production in Morocco), and in the high-altitude (up to 4167m) Rheraya catchment (225 km²) upstream of the Tensift catchment in southern Morocco. In Tunisia, the catchments selected are representative of the main hydrographical basins that produce most surface water resources. They include the Rhezala catchment (138 km²) in the Medjerda basin, upstream of the Sidi Salem dam (the largest in Tunisia), the Sejnane (376 km²), Joumine (231 km²), Melah (315 km²) and Maaden (145 km²) catchments in the north and Ichkeul basins and the El Abid catchment (81 km²) in the Cap Bon region.

Are bias-correction methods for climate model outputs valid under semi-arid conditions?

Two kinds of climate simulations are available for studies on climate change impacts, general circulation models (GCM) running at a large scale (100-300 km) or regional climate models (RCM), driven at their boundary conditions by GCMs and running at the regional scale (12-25 km). In the Coordinated Regional Climate Downscaling Experiment (CORDEX, www.cordex.org), RCM simulations at a fine spatial scale (12 km) are becoming available for most regions of the world. North Africa is covered both by the EuroCORDEX and the MedCORDEX domains at a high resolution (12 km). This fine spatial scale allows orographic processes to be more realistically represented and improves the simulation of extreme rainfall events, which contribute a significant proportion of total precipitation in semi-arid areas. However, despite improvements in the models thanks to finer spatial resolution, precipitation is generally underestimated by models and cannot be used directly in hydrological models. For that reason, impact studies require downscaling and/or bias correction to reduce the gap between model outputs and observations, usually averaged or interpolated at the catchment scale for hydrological applications. A correction or a transfer function is often applied to climate model outputs, estimated in the past and applied to future simulations, assuming that the correction will remain valid in the future.

This rather strong assumption of stationarity of the correction applied to climate model outputs can be validated at least during historical periods; such validation has been performed for different catchments in North Africa. The results suggest that bias correction methods such as the quantile-mapping method, which is widely used in hydrological impact studies, may be difficult to validate in semi-arid climates due to the limited number of rainy days, in particular during summer, and to the significant inter-annual variability of precipitation, which is typical of the Mediterranean climate (Tramblay et al. 2013; Foughali et al. 2015). In the case of a shift towards drier conditions or different time periods, the methods may not be able to correct the model bias with sufficient accuracy, particularly for precipitation. If the bias correction methods are not properly validated using historical climate conditions prior to being used in future projections, this could affect the climate change signal. As an alternative to correction methods, other methods can provide climate scenarios based on the perturbation of the observed data series by a climate change signal.

A method that is commonly used for climate change impact studies is the change factor method sometimes referred to as the "delta change" method. It consists in modifying the observed data series (temperature, precipitation, etc.) by a climate change factor in order to produce climate scenarios (Tramblay et al. 2013). These types of methods range from simple ones that assume a monthly change factor, to more complex approaches perturbing the whole distribution of observations and resampling of the original sequences to account for changes in temporal variability. These methods do not rely on the stationary assumption of model biases and do not modify the climate model outputs. Consequently, they can be considered as more robust and should be preferred in cases where other approaches cannot be satisfactorily validated.

Are hydrological models sufficiently robust to make future projections?

Different types of hydrological models exist that rely either on conceptual or physically-based structures. Physically-based models rely on the characteristics of the catchments and require many field observations, but these are rarely available, particularly in data-sparse regions and developing countries. Conversely, conceptual models usually require only time series of precipitation, evapotranspiration and discharge and are widely used in operational applications such as water resources or dam management. We tested a range of hydrological models (GR4J, GR2M, IHACRES, HBV, MWBM, BBH) commonly used for water resources management and research applications in North Africa under contrasted climatic conditions. Most hydrological models used in practical applications have a conceptual structure and require calibration (i.e. the model parameters are inferred using observed discharge data). However, calibration may be influenced by the choice of the time period of observations and therefore strongly impact the climate change projections.

The analysis of model robustness for the test catchments indicated that the difference in climate between calibration and validation gradually affect model performances. Although the model parameters tested were shown to be transferable towards wetter and/or colder conditions, their efficiency decreased when more contrasted climate conditions than those in the period used for calibration are experienced (for example in Tunisia, a threshold of transferability has been identified when the future change in temperatures exceeds +1.5 °C and the decrease in precipitation is more than -20%, Dakhlaoui et al. 2015). As a consequence, in studies on the impacts of climate change, we recommend choosing calibration periods when the climate conditions resemble future climate conditions, as this could significantly reduce hydrological modelling uncertainty.

How will projected climate change affect water resources?

The projected impacts on water resources were analyzed using an ensemble of medium (50 km) and high (12 km) resolution simulations from the EuroCORDEX and MedCORDEX experiments. The multi-model ensemble composed of different RCMs driven by different GCMs made it possible to evaluate the uncertainties stemming from the different simulations. Two emission scenarios were used, the representative concentration pathways (RCP) 4.5 and 8.5. They describe future climates that are considered possible depending on the quantity of greenhouse gases emitted in the years to come. In RCP 4.5 emissions peak around the year 2040, whereas in the most pessimistic scenario (RCP 8.5), emissions continue to rise throughout the 21st century.

The results at regional scale confirmed those of previous studies indicating a general increase in temperature associated with a decrease in precipitation (Bargaoui et al. 2014). However, the high resolution simulations enabled better spatial characterization of the projected changes. As shown in Figure 2, the relative changes in precipitation follow a clear east-to-west gradient with precipitation projected to decrease by 10% on average in basins in northern Tunisia to a 40% decrease in southern Morocco. On the opposite, the projected changes in temperature are much more homogeneous over North Africa (Figure 3) and depend mainly on the different emission scenarios considered (RCP 4.5 and RCP 8.5). In addition, potential evapotranspiration is projected to increase (+10% to +30%) in most areas, these changes being modulated by both land cover and land use. As a consequence, reduced precipitation associated with increased evaporation leads to less surface water resources in all North African catchments in both scenarios. According to the multi-model ensemble, these changes are robust since all models agree on the same decreasing trend. The change in precipitation will have the strongest impact on water resources, since North African catchments are water-limited rather than energy-limited.

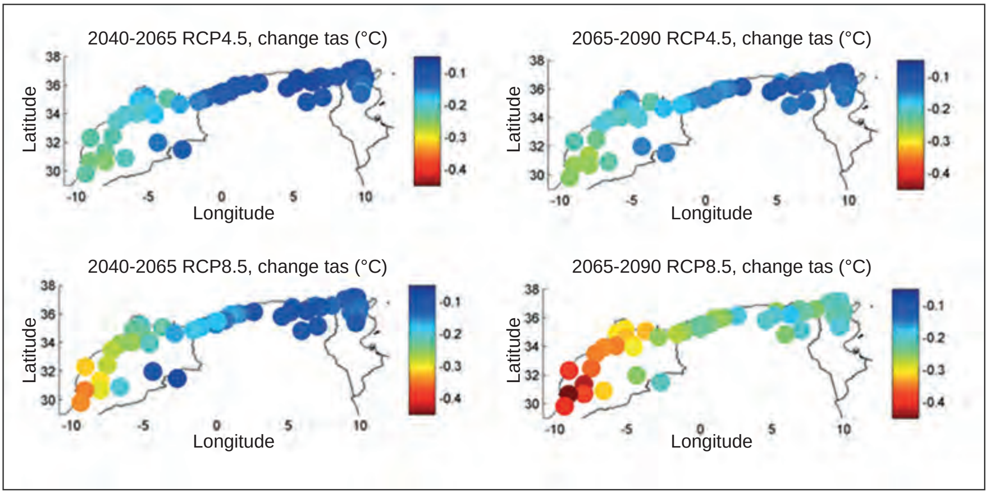

Figure 2
Future changes in precipitation in the 47 main dam catchments in North Africa, simulated by the SMHI-RCA4 regional climate model driven by 5 global climate models (CNRM, IPSL, HADGEM, ECEARTH, MPI) under the emission scenarios RCP 4.5 and 8.5.

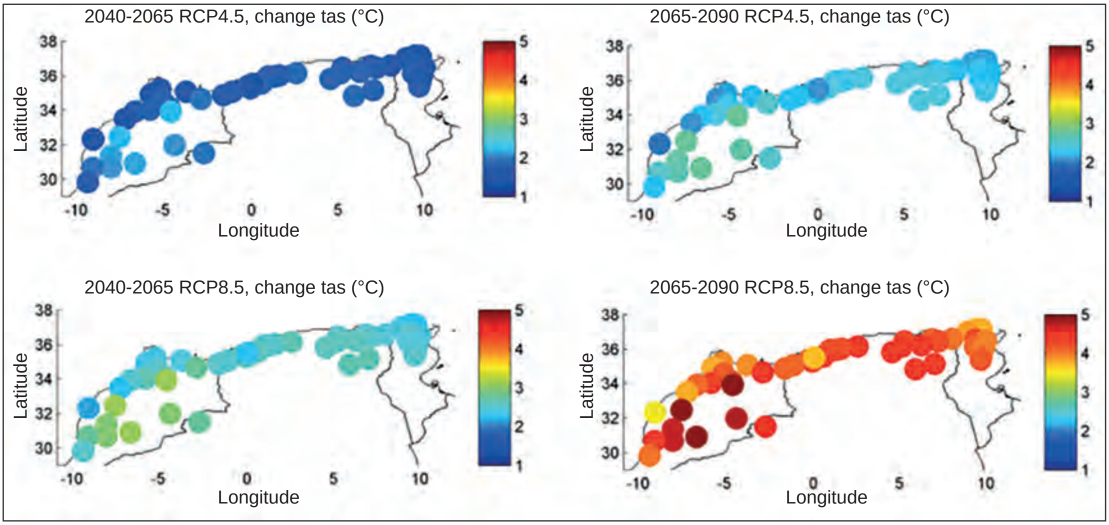

Figure 3
Future changes in temperature in the 47 main dam catchments in North Africa, simulated by the SMHI-RCA4 regional climate model driven by 5 global climate models (CNRM, IPSL, HADGEM, ECEARTH, MPI) under the emission scenarios RCP 4.5 and 8.5.

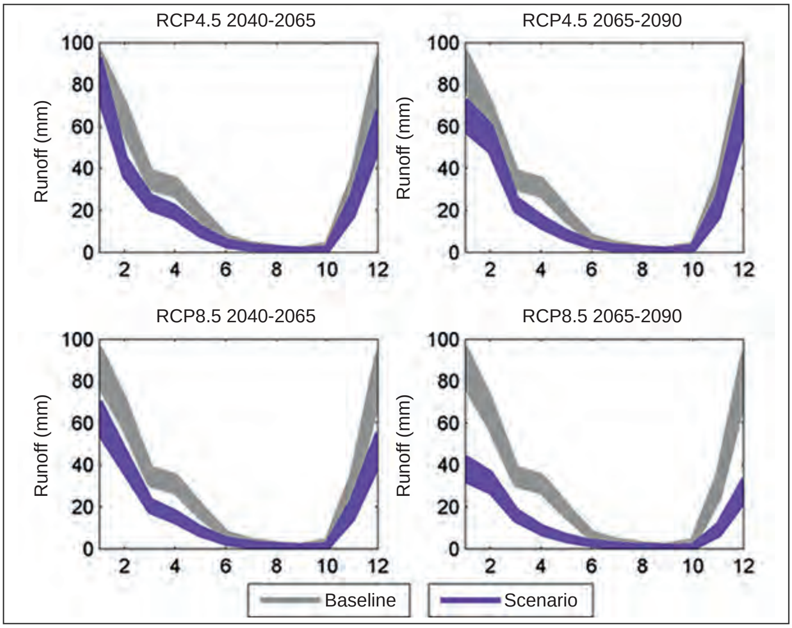

Figure 4
Future changes in mean monthly runoff at the Makhazine dam (north Morocco). The band width indicates the uncertainty on model projections (simulated by the SMHI-RCA4 regional climate model driven by 5 global climate models: CNRM, IPSL, HADGEM, ECEARTH, MPI).

We also analyzed the hydrological impact of the projected changes at the scale of the representative catchments considered in the ENVIMED CLIHMAG project. The results we obtained are illustrated by two examples of runoff projections presented for a catchment located in northern (Figure 4) and southern Morocco (Figure 5). For catchments located in the most humid areas, covering north Morocco, Algeria and Tunisia, the climate change signal is toward a reduction of 10% to 20% in precipitation, and as shown in Figure 4 for the mid-term time horizon (2040-2065), and in RCP 4.5, in most seasons, it is hard to distinguish between climate change, natural variability and modelling uncertainties. However in the most pessimistic emission scenario (RCP 8.5), the projected decline in surface water is significant in winter and spring. Conversely, in the snow-dominated catchments mainly located in the Atlas Mountains in southern Morocco (Marchane et al. 2016), a much stronger climate change signal points to a major decrease in spring runoff associated with a reduced snow cover (Figure 5). This could have serious consequences since these arid regions depend to a large extent on the water resources provided by the mountain ranges.

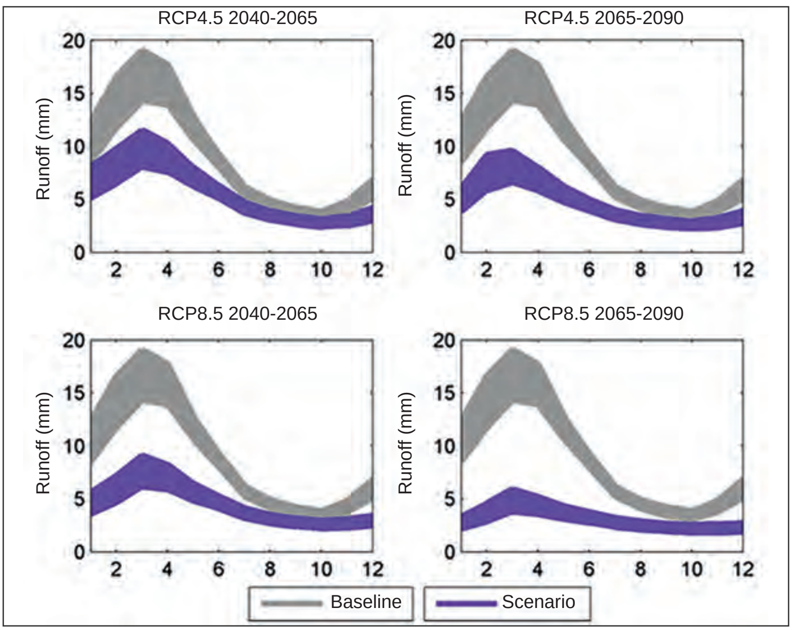

Figure 5
Future changes in mean monthly runoff for the Bin Ouidane dam (south Morocco). The band width indicates the uncertainty on model projections (simulated by the SMHI-RCA4 regional climate model driven by 5 global climate models: CNRM, IPSL, HADGEM, ECEARTH, MPI).

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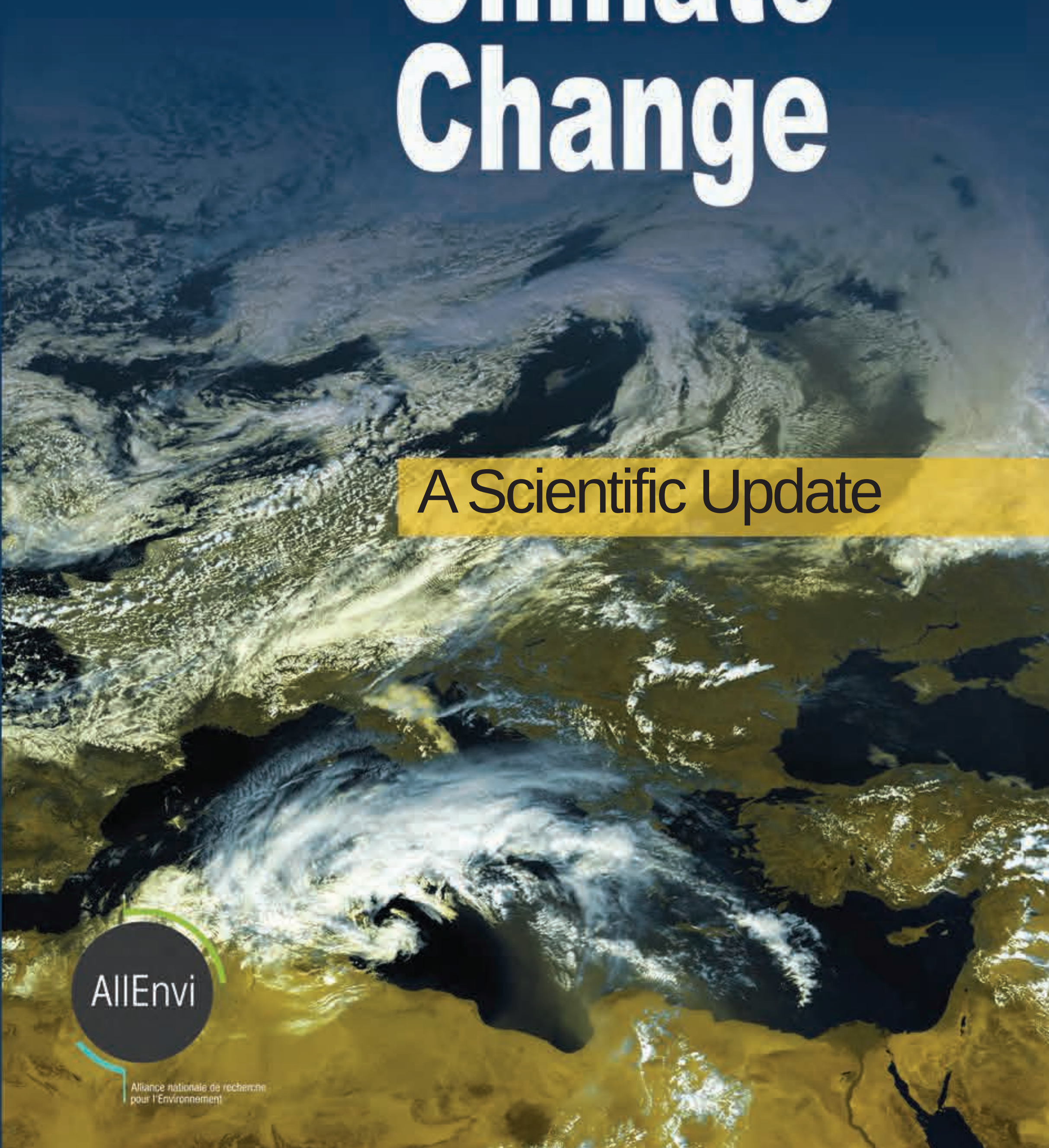
The Mediterranean Region under Climate Change



A Scientific Update

AllEnvi

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The Mediterranean Region under Climate Change

A Scientific Update

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