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EDITORIAL

Climate change impacts on water resources in the Mediterranean

Yves Tramblay[1] · Maria Carmen Llasat[2] · Christophe Randin[3] · Erika Coppola[4]

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More than ever, there is a need to understand and predict the trajectory of the environment and human societies in the prism of climate and its evolution in one of the most history- and biodiversity-rich regions. Indeed, global warming is occurring at a greater pace in the Mediterranean region than in other parts of the world, inducing marked changes in temperatures and precipitation but also other climate variables (Lionello and Scarascia 2018). There is a strong need to assess the potential impacts of this climate change in different sectors such as agriculture, energy production, or water resources but also their possible societal repercussions. In particular, for countries located in the south and east of the Mediterranean basin, the potential impacts can be very strong (Cramer et al. 2018). In this context, the MISTRALS (Mediterranean Integrated Studies at Regional and Local Scales) initiative was launched in 2008 and ended in 2020[1]. The MISTRALS program was devoted to the study of the Mediterranean basin and its environment, with the objective to better understand the impact of global changes in this region and to anticipate its evolution over a century. More than 1000 scientists participate in the different MISTRALS programs, from different countries around the Mediterranean and spanning a great variety of scientific domains including marine and terrestrial ecosystems, fishing, climate, geology, agriculture, freshwater availability, economics, and sociology.

This Topical Collection includes contributions from an international conference held in Montpellier, France, in October 2017. The goal of this conference was to present recent results on climate change impacts in the Mediterranean region produced within the various MISTRALS programs and also to improve the interactions between climate modelers and the different scientific communities working on climate change impacts. The papers of this Topical Collection are representative of the diversity of topics covered during the conference. They can be organized in three main categories: the first related to the sustainability of groundwater resources facing increasing aridity, the second about the main climate drivers and the third about their impacts on water resources and agriculture.

Sustainability of groundwater resources

Gonçalvès et al. (2020) provide a long term assessment of the aquifer recharge of the North-Western Sahara Aquifer System spread across Algeria, Tunisia, and Libya. Using data from the Gravity Recovery and Climate Experiment (GRACE), they reconstructed the aquifer recharge between 1950 and 2016 and compared it with water withdrawals. They observed an unsustainable exploitation of groundwater with water withdrawals exceeding recharge rates, starting in the 1975–1980, mostly for agricultural purposes. Given the most up to date projections, indicating a future precipitation reduction and a population growth in the region, these results are calling for an optimization of current irrigation practices.

Focusing on the Lake Azigza located in the Atlas Mountains of Morocco, Adallal et al. (2019) developed a mass balance model based on meteorological measurements and isotopic analyses of precipitation and lake and spring levels.

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✉ Yves Tramblay
yves.tramblay@ird.fr

[1] HydroSciences Montpellier, Univ. Montpellier, CNRS, IRD, Montpellier, France

[2] Department of Applied Physics, University of Barcelona, 08028 Barcelona, Spain

[3] Department of Ecology and Evolution, University of Lausanne, CH-1015 Lausanne, Switzerland

[4] International Centre for Theoretical Physics, Trieste, Italy

Their analysis reveals the importance of groundwater exchange processes in the water balance of the lake, which can be strongly modulated by the inter-annual variability of precipitation. Under the prevailing dry climate conditions of the last decades, this model is useful to better understand the functioning of such a Karstic system that are widespread across Mediterranean countries and providing an important contribution to water resources.

Climatic drivers towards increased aridity

Raymond et al. (2019) provide a pan-Mediterranean analysis of dry spells under different climate scenarios using an ensemble of Med-CORDEX regional climate simulations. As an alternative to standard drought indices computed on a monthly basis, their analysis is based on long sequences of consecutive dry days that can have strong impacts on agriculture and vegetation when occurring during the wet winter season. For both climate scenarios considered, RCP4.5 and RCP8.5, their results indicate an increasing number of events and duration of very long dry spells together with their spatial spread. The projected changes are the most important for regions of North Africa, Southern Spain, and the Middle East, which are already among the most arid regions in the Mediterranean basin.

Analyzing the causes of these observed and simulated changes, Drobinski et al. (2020) used an ensemble of Euro-CORDEX and Med-CORDEX simulations to evaluate the controls of land surface and dynamical processes on temperature and humidity changes. Warming and drying over land is projected for the entire region but with high spatial variability. Drying is caused by the temperature increase over land, but soil moisture in northern parts of the Mediterranean basin can reduce this effect. However, the higher occurrence of heat lows can aggravate the drying by preventing humidity advection for the most arid regions. In these regions, more frequent and severe heatwaves are expected to cause an increasing threat to human health.

Impacts on water resources and agriculture

Impacts of climate changes on water resources are analyzed by coupling climate models and hydrological models. Dakhlaoui et al. (2020) investigated the influence of evapotranspiration on future hydrological projections in Tunisia, by comparing different formulations of potential evapotranspiration (PET) as inputs of hydrological models. Their results indicated that different PET formulas provided similar hydrological projections, pointing towards a reduction of surface water resources with Euro-CORDEX simulations under scenarios RCP4.5 and 8.5. Indeed, for these semi-arid water-limited basins, the precipitation changes have more impact on water availability than evapotranspiration changes. This study indicates that simple temperature-based PET formulas can be applied for climate change impact studies in this region, where the lack of observed data in many basins prevent the use of more complex PET equations.

Among the different agricultural productions in Mediterranean regions, wine grape is an important economic sector in particular in France, Italy, and Spain. Cardell et al. (2019) analyzed the future suitability of grape wine production in Europe using an ensemble of bias-corrected regional climate model simulations from the Euro-CORDEX ensemble. They computed several bioclimatic indices related to grapevine phenology with the climate model outputs. Their results showed that grape vine production is likely to be negatively impacted in Southern Europe in all climate scenarios, with a reduction of the quality linked to higher temperature and dryness during the growing season, also raising the plant's water requirements.

Schilling et al. (2020) provided a review of the vulnerability of countries located in North Africa (Algeria, Egypt, Libya, Morocco, and Tunisia) to climate change, based on the exposure to these changes, water resources, and adaptation capacity. Their analysis revealed various degrees of resilience to climate change depending on the countries socio-economic context. Overall, the combination of climate change effects with population growth is a major challenge for these countries in the upcoming years, which could become indirect drivers of social instability. One way to mitigate the negative impacts of climate change in this region could be to reduce the dependency on rain-fed agriculture and encourage sustainable land planning and adaptive capacity. There is also a need for a better regional cooperation on adaptation strategies including the sub-national levels to facilitate the dissemination of adequate management practices.

Conclusions and future avenues

Given the high diversity and vulnerability of Mediterranean ecoregions, results from this Topical Collection call for a better integration of two-way interactions and feedback loops between climate and socio-ecological systems when modeling and predicting their future trajectories. In this context, adaptive and iterative loops including modeling and large-scale monitoring with Earth observation systems should help in validating model projections and give more credibility to them for their integration in decision-making.

Depicting the impacts of climate change on Mediterranean socio-ecological systems in model simulations requires holistic approaches and can be achieved by coupling climate and impact models. Results from this Topical Collection suggest an increasing intensity and also variability of climate extremes

for the twenty-first century. There is thus a need for producing assessments of the impact of climate extremes and variability on the resilience of socio-ecological systems by a suit of realistic and coupled models. Such realistic projections can further be used to assist regional coordination and cooperation on adaptation strategies between and within countries of the Mediterranean basin and to increase the effectiveness and efficiency of ongoing and future environmental policies.

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