Sub-chapter 2.3.2

# Water resources in South Mediterranean catchments

## Assessing climatic drivers and impacts


*Lionel* JARLAN
IRD, UMR CESBIO, France

*Saïd* KHABBA
FSS/UCAM, Morocco

*Camille* SZCZYPTA,
CNRS, UMR CNRM, France

*Zohra* LILI-CHABAANE,
Carthage University/INAT, Tunisie

*Fatima* DRIOUECH,
NCC/DMN, Morocco

*Michel* LE PAGE,
IRD, UMR CESBIO, France

*Lahoucine* HANICH,
FST/UCAM, Morocco

*Younes* FAKIR,
FSS/UCAM, Morocco

*Aaron* BOONE,
CNRS, UMR CNRM, France

*Gilles* BOULET,
IRD, UMR CESBIO, France


## Climate change

Positive trends in mean temperatures and a decrease in the number and amplitude of cold outbreaks have already affected all North African countries (Driouech et al., 2013). A global data set of near-surface meteorological variables was used to assess the long-term changes in temperature and precipitation in North Africa in the 20th century (Szczypta et al. in prep). The analysis revealed a significant increase (0.9 °C) in mean temperature between 1900 and 2010 (Figure 1). The increase was larger in spring (+1 °C) than in winter (+ 0.4 °C), except over the northeastern part of the region, where the increase remained high (+ 1.2 °C) throughout the year. The observed change in precipitation was less homogeneous over space and time but identified a hot-spot in northern Morocco. In addition to the aforementioned historical study, under the RCP2.6 low emission scenario, projected warming should reach 2 °C to 3.5 °C (from the coasts to inland areas) by mid-century and under the RCP8.5 high emission scenario, 3.5 °C to 5.5 °C. This goes hand in hand with an increase in the mean annual number of hot days. The original climate scenarios have been downscaled for two local stations (Marrakech, Morocco and Kairouan, Tunisia) in order to debias the original model simulations. In the moderate emission scenarios, similar trends are highlighted locally with an average increase in temperature of 1 °C by 2030, and of up to 1.5 °C by 2050 for both Marrakech and Kairouan. This increase should affect the warmest months of the year the most. Over Morocco, the projected increase in evapotranspiration varies from 10% to 20% under the RCP8.5 scenario for the whole crop season and should be also higher in spring. At the regional scale, the change in precipitation is more uncertain due to an observed divergence between model simulations compounded by significant inter-annual variability. However, significant reductions in precipitation are projected over the northern parts of Algeria and of Morocco; the wettest and largest agricultural areas in the region. A decrease of about 15% to 20% is projected by the mid-century under the RCP8.5 scenario and more severe reductions are projected for the second half of this century. The reduction is projected to be the most pronounced in spring and fall with probably dramatic consequences for water availability in these key periods of the agricultural season.

## Anticipated societal changes

The population of southern Mediterranean countries will almost double by 2050, thereby threatening the fragile balance between water availability and human demand and, more specifically food security. At the 2025 horizon, agricultural demand could increase by 25% in response to the predicted population growth combined with the expected decrease in precipitation and rise in temperature at key phenological stages of crops in spring, while urbanization and economic development will encourage competition among sectors. The replacement of traditional Mediterranean crops (wheat) by more financially attractive crops but that also consume more water (maize, tree crops) will lead to major changes in water use patterns. In particular, the current extension and intensification of tree crops will further constrain agricultural water demand, especially during the hottest months. In addition, secure access to water from dams and water transfer channels is now threatened by dam silting and recurrent droughts like those at the beginning

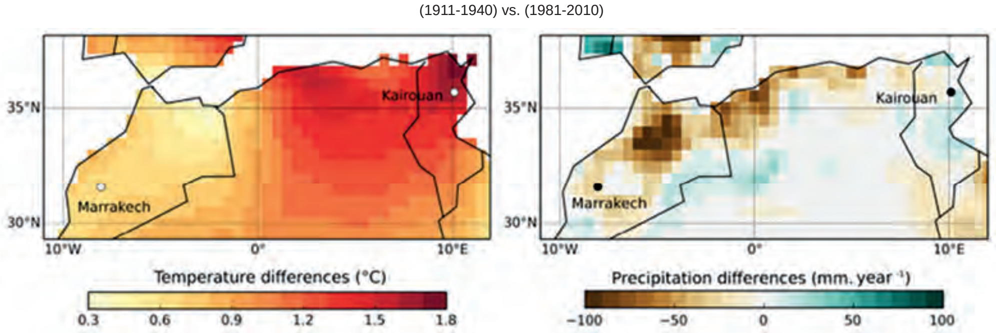


*Figure 1*
*Historical analysis: differences of mean temperatures (left)/precipitation (right) between 1911-1940 and 1981-2010 at a 0.5° resolution from the Global Soil Wetness Project Phase 3 (GSWP3) from Szczypta et al., in prep.*

## Box 1
## Observational issues

Long term observations are essential both for resource management and for hydrological model development and calibration over a wide range of climate conditions including extremes that are likely to become frequent in the future. Current water resources observation systems were thought to provide a good picture of available supply at the catchment outflow locations but are affected by loss of data quality, a decrease in the number of gauging stations, and the lack of available data since the 1980s. Upstream processes such as snowpack dynamics and subsurface flows that contribute to groundwater recharge, and downstream usage, are poorly monitored. Some integrated, long-term observatories of water resources that aim to complement the actual operational network exist, in particular in the Tensift and the Merguellil regions, but these successful initiatives need to be multiplied, strengthened and unified around an integrated regional observation system. Groundwater recharge processes (along *wadis*, by return of irrigation water, by subsurface flows or artificial through augmented streambeds) are currently largely unknown and should be the focus of scientific studies, in particular based on geochemical tracers. Non-conventional observations such as remote sensing and new innovative experimental designs based on low-cost *in situ* sensors should be promoted in these ungauged basins. Remote sensing will undergo a true revolution with the recent launch of the Copernicus constellation that will provide - free of charge - a large quantity of observations to enable monitoring of key variables for water resources management such as the extent of snow covered areas, soil moisture, land cover and use, surface water reservoirs, or crop dynamics. Despite the unprecedented availability of remote sensing data, their use by managers and stakeholders is still limited by their belief that the products are not suited to their specific needs. In practice, however, this is mostly due to lack of adequate training.

of the 2000s. As a result of the reduction in surface water, of agricultural extension and of easier access to water through boreholes (which are often neither registered nor monitored), groundwater is facing increasing pressure leading to groundwater depletion in the order of one to two meters per year with complete exhaustion at several locations. One of the potential consequences is farmer fragmentation resulting from the exclusion of small-scale farmers who do not have financial means to dig deeper and deeper wells. The intensification of agriculture in the plains may also increase societal tensions as the associated increase in water demand could become incompatible with the allocation of water to other sectors and with the ancestral water rights of upstream populations. Finally, the rapid pace of observed and anticipated societal changes are likely to have more effect on water resources than climate change in the medium term (2030), but the latter could have a greater impact at longer time scales.

## The water tower in the mountain range

Each winter, large amounts of water are stored as snow in the highest mountainous areas of the Mediterranean. In the Tensift region, up to 50% of runoff is attributed to snow melt. Due to already observed rise in temperature, the snowline is rising in the Tensift region, with less water being stored as snow. This could be associated with a more rapid transfer of a larger proportion of precipitation downstream, which could rapidly challenge the existing storage capacity. Due to the rise in temperature, melt rates are also increasing and the snow is melting earlier than in the past in lower elevation areas. Early melt and reduced snow storage further reduce low flow discharge, could increase the number of days the *wadis* are dry and threaten the use surface irrigation systems in particular for tree crops in summer. In addition, in contrast to rainfall, the slow release of water due to melting enhances infiltration over runoff and reduces the return of water to the atmosphere by evaporation. Sublimation, loss of snow that does not contribute to runoff, is usually small, but is subject to marked interannual variability (Boudhar et al. 2015); it is not yet clear if climate change (through changes in wind intensity and air humidity) will increase or reduce sublimation, while current best estimates are that can account for up to 20% of total snow loss.

A better understanding of the links between upstream and downstream processes is essential to enable water planning, as water use and the upstream supply can significantly affect water availability downstream. On the other hand, a change that occurs upstream can also sometimes address an issue that occurs downstream. Several key processes that contribute to groundwater recharge occur at the upstream/downstream interface since recharge of basin aquifers through direct infiltration of rainfall is generally limited, as observed in Tensift region (Boukhari et al. 2015). Population density and upstream water use is increasing with unmonitored uptakes along the river to irrigate agriculture in the foothills. The expected changes in the snow/rain partition and uncontrolled water uptake may directly affect the timing and amount of water available downstream as well as indirectly through changes in the groundwater recharge rates.

## Improving water irrigation planning

Although ambitious policies to convert to water saving techniques are currently being promoted, the traditional flood irrigation method, whose efficiency does not exceed 50%, remains the dominant practice in the southern Mediterranean. Improving this efficiency could be one way to tackle the expected reduction in water allocated to agriculture in the future.

Experimental studies on the main crops grown in the Mediterranean region (wheat, olives, oranges, etc.) carried out in the Tensift (Morocco) and Merguellil (Tunisia) regions called the efficiency of drip irrigation into question by showing that percolation losses from fields equipped with drip irrigation can equal and even exceed evaporation losses from flood-irrigated fields (Chehbouni et al., 2008; Jarlan et al., 2015). The lack of farmer training combined with the absence of complementary water regulation policies could thus have the unexpected consequence of increasing water losses for the plant. Another risk associated with conversion is agricultural intensification, which has already taken place in some locations and could also weaken or even negate the intended effect. Another important issue is related to the optimal choice of sowing date: fields in which the crops are sowed early would benefit from rainfall that is more effective at the beginning of the season and avoid the high evapotranspiration losses at the end of the season (April–May) which coincide with the grain filling stage of wheat, a critical stage for grain production. Modeling and experimental studies on wheat in Morocco revealed that the quantity of irrigation water required was always more than 100 mm (38%) higher in the case of late sowing. Deficit irrigation is also a promising technique but its implementation at large scales will be hampered by the lack of adequate tools for monitoring plant water stress plus it implies a drastic switch in irrigation planning from the existing supply-oriented system to a more plant demand-oriented system. A case study in Tunisia showed that irrigating cereals at 70% of their actual water requirement levels resulted in only a very slight drop in yield. Despite these encouraging results, farmer's awareness raising and training sessions will be needed for this technique to be widely adopted.

Targeted research work in Morocco and Tunisia aims to promote the use of remote sensing observations to monitor plant demand and water stress. The added value of a decision support system designed to plan irrigation has been successfully demonstrated in real-life conditions at the plot scale (Le Page et al., 2014). One of the main limitations to its implementation at a larger scale (i.e. that of an irrigated perimeter) are the many existing constraints to on-time water delivery: the network of concrete channels extensively used for modern irrigation sectors, requires the sequential application of water to parcels; the channel flow is limited; the workforce is also a constraint. Recent preliminary simulation studies demonstrated that water saving could reach 25% even in a highly constrained irrigated perimeter, if information on actual plant water demand is taken into account in the irrigation planning strategy (Belaqziz et al. 2014).

## Summary and conclusion

The executive summary of this chapter is as follows:

Global warming could increase freshwater water availability in spring during the transition period, and this should be taken into account in future watershed management policies. This could happen through increased snow melt and an already observed change in the rain/snow partition.

Long term monitoring of the water resource is of prime importance both for sustainable management and for model calibration. Given the weakness of existing *in situ* networks, remote sensing is an essential tool in these areas.

The groundwater depletion already observed in many southern Mediterranean catchments could negatively affect the poorest farming communities, who do not have financial means to deepen their wells.

Planning irrigation based on plant demand rather than the actual supply-oriented approach could enable substantial water savings even in the case of highly constrained existing modern irrigation systems.

Policies that promote water saving techniques including drip irrigation and deficit irrigation should be added to farmer training, control of water usage, and monitoring of agricultural intensification to fulfil the objective of saving water.

Foreseeing, monitoring and developing measures for adaptation to the expected changes requires an integrated catchment-wide approach to water management that brings together researchers and stakeholders. This requires building properly calibrated numerical modelling platforms, taking advantage of long-term observations including remote sensing data, to construct different scenarios of climate and anthropogenic changes (land use, irrigation methods, catchment planning) and their associated impact on water resources.

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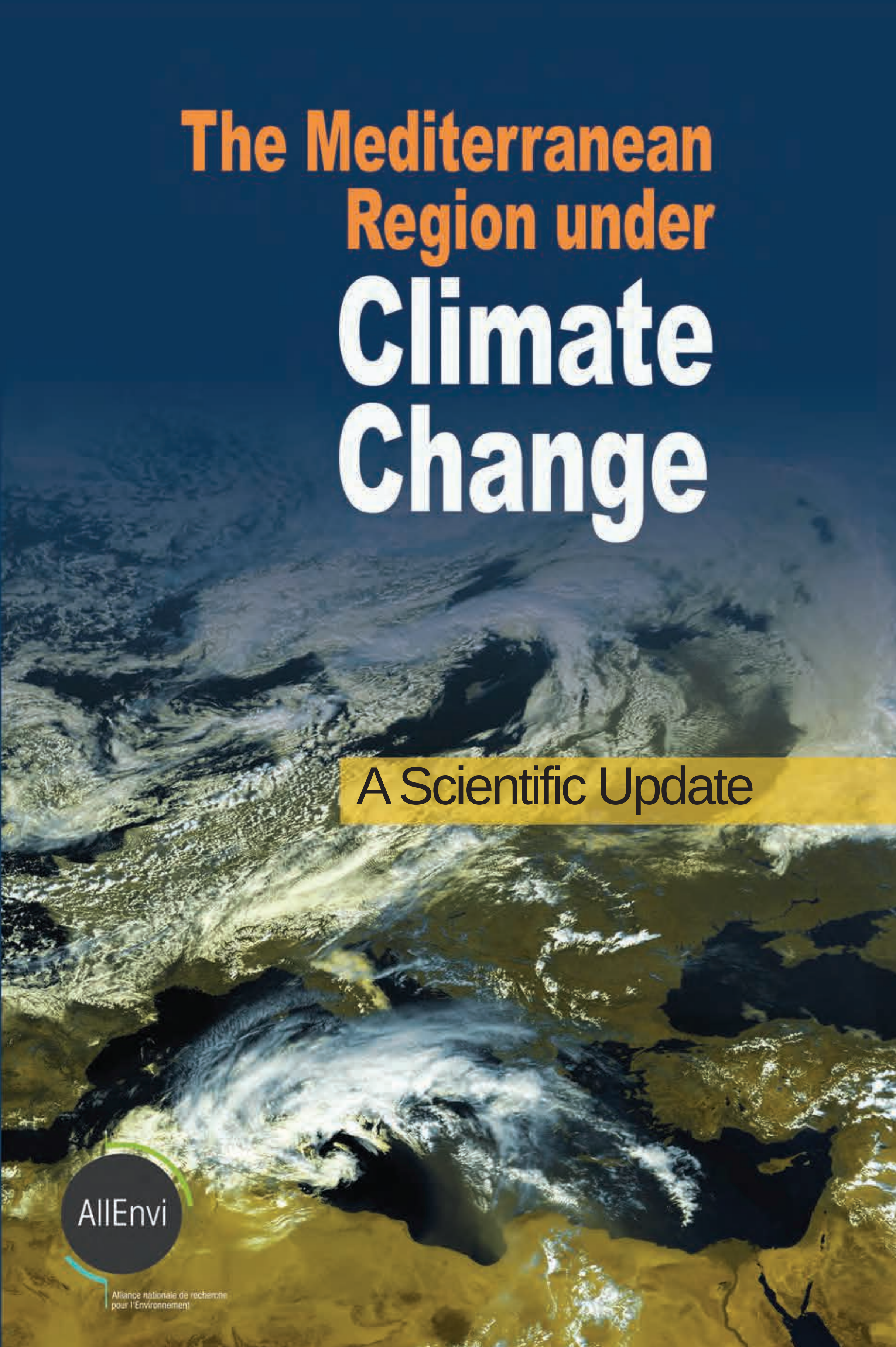
# The Mediterranean Region under Climate Change



## A Scientific Update

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# The Mediterranean Region under Climate Change

## A Scientific Update

Preface by

Hakima El Haité

Postface by

Driss El Yazami

Address by

HSH the Prince Albert II of Monaco

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Daphne Goodfellow
Andrew Morris

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Michelle Saint-Léger
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