

The climate of the Mediterranean region: research progress and climate change impacts

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Introduction

This special issue was proposed at the second MedCLIVAR conference (which was held in Madrid, Spain, 26–29 September 2012) and has received a wide range of contributions covering different and complementary topics: paleo-climate, present climate variability and trends, extremes, climate projections, and impacts of future climate change on the regional environment and societies. All these topics (see Lionello et al. 2012b, for a synthesis) are

subject of a rapidly evolving research, which has the sensitivity of the Mediterranean region to climate change as a main motivation. In fact, in the last decades in the Mediterranean region, temperatures have risen faster than the global average and model projections agree on its future warming and drying, with a likely increase of heat waves and dry spells. Further, countries around the Mediterranean basin are characterized by strong differences, as shown by various socioeconomic and environmental indicators, such as per capita gross domestic product (GDP), energy supply, CO₂ emissions, and water availability. Environmental issues are exacerbated by societal aspect, as the whole region is densely populated with many Middle East and North African (MENA) countries expected to double their population by the mid-twenty-first century. A growing dependence on irrigation in MENA countries will likely increase their economic and social vulnerability, because of future reduced total water availability and rapidly growing competing urban water demands.

This issue is an outcome of the work carried on within the MedCLIVAR network. It describes recent progresses on the understanding of the climate of the Mediterranean region and the impacts of its future evolution on the environment and people. MedCLIVAR (Mediterranean CLimate VARIability) has been running continuously for about 10 years. It was initially proposed at the 2003 European Geosciences Union assembly in Nice (France), endorsed by the international Climate Variability and Predictability (CLIVAR) office in 2005, and supported by the European Science Foundation for the period 2006–2011. This special issue is the latest contribution to the MedCLIVAR dissemination activity, which has already produced three books (Lionello et al. 2006; Vicente-Serrano and Trigo 2011; Lionello 2012) and 4 special issues (Lionello et al. 2008; Jones et al. 2011; Lionello 2012;

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Garcia-Herrera et al. 2014). More information on the MedCLIVAR initiative can be found in Lionello et al. (2012a).

Paleo aspects

MedCLIVAR aims at a complete view of Mediterranean climate evolution considering both paleo-conditions and future projections, and it has always put a strong emphasis on the need for paleo-climate reconstructions. Longer digitalized time series, as well as good quality proxies, have recently produced substantial new knowledge (Abrantes et al. 2012; Luterbacher et al., 2012), and further important progress is expected. This issue includes two contributions to the reconstruction of the paleo-climate in the Mediterranean region. Revel et al. (2014) present a high resolution multi-proxy analysis of a site recovered on the Nile margin and examine the Ethiopian African monsoon regime intensity and Nile freshwater input into the Mediterranean during the last 21 cal ka BP. Their results define the timings of humid and arid conditions in North Africa and highlight the importance of monsoon rainfall fluctuations for the state of the Mediterranean thermo-haline circulation. Triantaphyllou et al. (2014) concentrate on the Mid-Holocene (5.5–4 cal ka BP) record of the North East Mediterranean (Aegean and northern Levantine Seas) and reveal warm and humid conditions, which imply the reorganization of the general atmospheric circulation and a southward migration of the ITCZ in the tropics.

Climate variability

Internal climate variability is characterized in two articles. Romanski et al. (2014) analyze daily wintertime cyclone variability in the central and eastern Mediterranean during 1958–2001. They identify four distinct “cyclone states,” corresponding to the presence or absence of cyclones in each basin, whose relative frequency of occurrence determines the heat loss from the Aegean Sea. Largest heat losses occur when there is a storm in the eastern, but not in the central Mediterranean, and the smallest losses occur when there is a storm in the central, but not in the eastern Mediterranean. Both these conditions are anti-correlated with the North Atlantic Oscillation, whose trend toward more frequent positive phase has consequently increased the number of days with strong cooling of the Aegean Sea surface waters. Norrant-Romand and Douguédroit (2014) analyze the link between Mediterranean rainfall decrease and atmospheric circulation for the period 1950–2000 and find that the relationship between significant rainfall decreases, and the corresponding 500 hPa level is

nonlinear, with the 1970s separating two different sub-periods. Rainfall decrease is due to the higher frequency of rainy weather types in the first than in the second period.

Trends and climatology of precipitation and temperature

Several studies have considered the present climatology and trend of precipitation in various areas of the Mediterranean region. Precipitation is a key variable in the Mediterranean region as its future decrease can be very critical for human activities, and, as if further exacerbated by increased temperatures, it can lead to more frequent droughts. Cortesi et al. (2014) evaluates the spatial variability of annual and seasonal precipitation in Spain by using correlation decay distance analysis (CDD), which explores how the correlation between neighboring stations varies according to distance. At annual scale, neighboring stations with 50 % of common variance are located within an average distance of about 105 km, with actual values varying from 28 to 251 km. The results of this study suggest that the current density of climate stations is sufficient to study inter-annual precipitation variability in winter, spring, and autumn, but not in summer. Luković et al. (2014) examine spatial patterns of annual, seasonal, and monthly rainfall trends in Serbia using data from 63 weather stations between the period of 1961–2009. They suggest that only weak, mostly nonsignificant trends are present in Serbia in the period 1961–2009. Espírito Santo et al. (2014) describe seasonal variations in the intensity, frequency, and duration of extreme precipitation events in mainland Portugal for the period 1941–2007 and find a statistically significant reduction in extremes for spring. Further, their results confirm that, over mainland Portugal, the North Atlantic Oscillation is one of the most important tele-connection patterns in any season, and it has the greatest influence on precipitation extremes. Ziv et al. (2014) analyze changes in the precipitation regime of Israel for 1975–2010 period. They show that a negative trend prevails in most of the country, being particularly significant during spring with longer dry spells in most of the stations, with important consequence on the latitudinal variations of the aridity lines. These changes are linked with those of atmospheric circulation features, such as the Cyprus low. Further, global average temperature explains up to 50 % of the variance of precipitation in Israel for the inter-decadal timescales. De Luis et al. (2014) describe the trends in seasonal precipitation and temperature in Slovenia, a transitional area between Mediterranean, Alpine and continental climatic regimes, for the period 1951–2007. Warming has been most intense in summer and spring and weakest in autumn. Precipitation trends are heterogeneous,

but with some subregional relevant decreases in winter and summer. The strong warming in summer and spring, which in Slovenia is about twice as large as the trend observed in neighboring countries, could be the result of the dry soil conditions caused by decreased winter precipitation. Turco et al. (2014) propose and evaluate a new methodology to reconstruct homogeneous long-range temperature series from station observations that does not need a comparison with nearby stations.

Extremes

Different types of extremes that occur in the Mediterranean region (Xoplaki et al. 2012; Ulbrich et al. 2012) are considered in this issue: warm summers, explosive cyclones, extreme dust events, and stormy wind-wave heights. The increasing frequency of warm summers in the Mediterranean area, including extreme events, is investigated at the seasonal level between 1960 and 2007 by Simolo et al. (2014). The approach is based on an existing theoretical model of the same authors, which shows how the average properties and long-term trends observed in probability density functions of daily temperatures can explain changes in the frequency of severe, isolated events. In this context, the recent rise in extreme warm events in the Mediterranean basin is consistent with a pure shift of seasonal mean temperatures. Kouroutzoglou et al. 2014 analyze the dynamic and kinematic characteristics of surface explosive cyclones in the Mediterranean and compare them with those of ordinary cyclones. Explosive cyclogenesis in the Mediterranean is mainly a maritime phenomenon, occurring along the northern Mediterranean coast during the cold season. On the contrary, the ordinary cyclogenesis exhibits significant maxima in both continental and maritime environments throughout the year. The explosive cyclones are characterized by longer lifetime and greater propagation speed than ordinary cyclones. Both explosive and ordinary cyclones have become less frequent in the analyzed period (1962–2001) in the Mediterranean basin. Gaetani and Pasqui (2014) identify extreme dust events in the Mediterranean Basin during the period 2001–2010 using aerosol remote-sensed optical depth and model simulations. Dust events in the western Mediterranean are associated with high-pressure conditions, limiting the development of lows to the western North Africa, while the eastward evolution of cyclones over the central Mediterranean and Northern Africa accompanies dust events in the central and eastern Mediterranean. Polonsky et al. (2014) have evaluated monthly anomalies of stormy wind-wave heights and return periods using secular routine observations in the coastal zone of the northern Black Sea. Wind-wave anomalies in this region are characterized by

high-amplitude quasi-periodical variability with typical time scale of about 50 years. Thus, statistics of dangerous events should be estimated using sufficiently long multi-decadal time series.

Climate projections

Significant progresses has been made on climate projections for the Mediterranean region, both through new models (e.g., Li et al. 2012) and new simulations (e.g., Planton et al. 2012; Gualdi et al., 2013). Besides dynamical downscaling by regional climate models, statistical downscaling is a major tool to derive climate change projections at regional or even local scales. For the Mediterranean area, an increasing number of downscaling studies based on different statistical techniques have been published in the last two decades with a broad range of sometimes differing results relating to different variables and regional domains. Jacobeit et al. (2014) give a short review of the statistical downscaling studies in the Mediterranean region, describing their progress since the early 1990s, the main regional climate change signals, agreed and controversial points. Best accordance among future projections can be found in seasonal temperatures with lower rates of warming in winter and spring and higher rates in summer and autumn. High-temperature conditions are generally expected to become increasingly frequent. Regarding seasonal precipitation, predominant reductions are indicated for spring, summer, and autumn. For winter, however, there is no agreement on the northern part of the Mediterranean. Different results are obtained for rainfall extremes, but the entire precipitation distribution tends to shift toward both higher and lower values. Apart from some subregional deviations, there is a predominant increase of dry period durations.

Future climate conditions for the Mediterranean Region are analyzed by Dubrovský et al. (2014) on the basis of on an ensemble of 16 Global Climate Models. Their results confirm previous findings (Giorgi and Lionello 2008) and show an increase in temperature in all seasons and for all parts of the Mediterranean with good inter-model agreement. Precipitation is projected to decrease in all parts and all seasons (the most significant percent change occurs in summer) except for the northernmost parts in winter. The inter-model agreement for the precipitation changes is lower than for temperature. Further, their results indicate high inter-model agreement on a significant decrease of soil moisture in all seasons, with the most significant decrease occurring in summer. Temperature maxima will increase not only because of an overall rise in mean temperature, but partly (in some areas) also because of increases in temperature variability and daily temperature

range. Increased mean daily precipitation sums on wet days occurring in some seasons and some areas of the Mediterranean may imply higher daily precipitation extremes, while decreased probability of wet day occurrence will imply longer drought spells all across the Mediterranean. Considering subregional domains, Öno \ddot{u} l and Unal (2014) analyze projected climate change over Turkey and find that average temperature warms in the range of 2–5 °C and that over southeastern Turkey precipitation decreases very significantly (24 %). As this part of Turkey includes most of the upstream of Euphrates and Tigris river basins, this projected decrease could be a major source of concern for Turkey and the neighboring countries. Considering future storms, Nissen et al. (2014) analyze climate model integrations performed with two coupled global models (ECHAM5 MPIOM and INGV CMCC). They conclude that high impact weather systems will remain an important risk in the Mediterranean Basin in spite of the general reduction in total number of cyclones.

Climate change impacts

A final set of papers describe the effects of climate change on air, crops, tourism, and bioclimatic conditions, also in relation to public reactions and perceptions. Through a modeling study of climate and air quality changes, Lelieveld et al. (2014) show that future heat extremes may have strong impacts, especially in the Middle East, where environmental stresses are largest. Further, their model results suggest strongly increasing ozone formation, which, associated with high concentrations of particulates by desert dust and anthropogenic aerosols, is expected to considerably reduce air quality during heat wave conditions. Bafaluy et al. (2014) analyze projections obtained from a suite of regional climate models run under the A1B emissions scenario and derive a local climate tourism index for the Bay of Palma. Using this index for exploring the possible future evolution of climate potentials for tourism, authors show that its seasonality might be affected: optimal conditions are projected to degrade during the present summer peak visitation period, while improving in spring and autumn. Appiotti et al. (2014) conducted an integrated analysis of recent climate change (including atmosphere, sea and land) and social reaction and adaptation in central Italy and the northern portion of the Adriatic Sea. Changes, combined with anthropogenic effects, appear to influence the northern Adriatic marine environment and ecosystem with impacts that are also evident inland. The analysis of social data revealed that local residents are aware of climate change impacts and risks, but this is not currently translated into preventive and protective actions. Ble \acute{t} a et al. (2014) analyze the human bioclimatic conditions in

Crete Island, by applying two thermal indices: physiological equivalent temperature (PET) and Universal Thermal Climate Index (UTCI). This is meant to provide a framework for considering the effects of climatic conditions on human beings and to help stake holders to make any necessary adaptations and become more resilient to the foreseen climate change.

Grapes, olives and wheat are economically very important and typical Mediterranean crops. Lereboullet et al. 2014 focus their study on the wine producing area C \acute{o} tes-du-Roussillon-Villages near Perpignan, in southern France, where temperatures during the growing season and summer temperature extremes have been increasing continuously since the mid-1980s and are projected to increase faster from the mid-2040s. Further, summer precipitation is highly variable and very low, and projections suggest greater uncertainty and more extreme drought events in the future. The authors have analyzed the roles of non-climatic factors in the generation of vulnerability for Mediterranean agricultural systems facing rapid climate change and show that Mediterranean viticulture could suffer from hotter and drier growing seasons over the coming decades. Gonz \acute{a} lez-Zeas et al. (2014) show that average productivity of crops provides limited information regarding the risks associated with future changes in climate variability that may affect agriculture. Authors highlight the importance of considering both regional average impacts as well as the variability in crop productivity in setting priorities for the adaptation and maintenance of rural incomes. Lionello et al. (2014) describe the evolution of seasonal temperature and precipitation in the Apulia region (South Italy) from the recent past to the next decades and estimate future potential impacts of climate change on three main agricultural products: wine, wheat, and olives. The evolution of these seasonal climate variables in the first half of the twenty-first century could decrease wine production and, to a lesser degree, harvested olives, but has a negligible effect on harvested wheat.

Final comments

This special issue presents a set of new studies covering different topics that are included among the MedCLIVAR general scientific objectives. The articles show that past climate reconstruction remains a great opportunity and an important challenge. Further they document progresses that are being achieved on further characterization of internal climate variability, with an emphasis on extreme events. Articles show that systematic recovery and analysis of in situ observations at subregional scale, such as those provided by rain gauges, represents an important contribution and remains an incomplete task in many areas.

Comparison among different model simulations and among statistical and dynamical downscaling methods is used for identifying robust regional features among different climate projections and for a systematic analysis of agreed and controversial points. Finally, contributions show how it is possible to use climate projections to derive the impacts of climate change on the environment, tourism, and agriculture.

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