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PAGES 105–116

Program Focuses on Climate of the Mediterranean Region

PAGES 105–106

Located between subtropical and midlatitude climates, the Mediterranean region acts as a transition area and is very sensitive to global climate change: As global temperatures have risen, the Mediterranean region has warmed, particularly in the west and in the summer, where surface temperatures in some locations increased at a rate greater than 0.4°C per decade during the second half of the twentieth century. Model simulations give a collective picture of substantial drying and warming of the Mediterranean region in the future, especially summer, with average precipitation expected to decrease by 25–30% and temperatures expected to rise by 4°–5°C by the end of this century, approximately. These changes will likely be accompanied by increased intensity in heat waves and dry spells along with important changes in Mediterranean water masses, which will become warmer and saltier. This future climate change can pose very serious problems to ecosystems and human societies.

Roughly 400 million people live in the countries surrounding the Mediterranean Sea; one third of them currently inhabit coastal regions. Further, North African and Middle Eastern countries are expected to double their population by the mid-21st century, with this rise concentrated in the busy coastal areas. To help prepare these populations for the changes that will come, the Mediterranean Climate Variability and Predictability (MedCLIVAR) program was established 6 years ago.

MedCLIVAR serves as a scientific network to initiate better communication among different scientific disciplines and to develop a multidisciplinary vision of the evolution of the Mediterranean climate through studies that integrate atmospheric, marine, and terrestrial climate components at time scales ranging from paleoreconstructions to future climate scenarios. The program deals with scientific issues including past climate variability; connections between the Mediterranean and global climate; Mediterranean Sea circulation and sea level; feedbacks on the global climate system; and regional responses to greenhouse gases, air pollution, and aerosols.

In the past 6 years, with support from the European Science Foundation, MedCLIVAR has contributed to scientific progress, new scientific synthesis, the education of a new generation of scientists, and the promotion of awareness of the interdisciplinary nature of regional climate change. To ensure future progress, MedCLIVAR aims to continue acting as a neutral forum in which analysis and prioritization of scientific issues are achieved through open discussion and cooperation is strongly promoted.

Regional Climate Change in Detail

In the Mediterranean region, complex land-sea distribution, steep orography, and mountain ridges add crucial mesoscale features to the regional atmospheric dynamics, which include highly cyclogenetic areas, strong local winds, and other intense processes. The location of the Mediterranean region in a transitional zone between subtropical temperate and continental climates makes it particularly sensitive to large-scale dynamics, but the climate of the region is also and uniquely characterized by the Mediterranean Sea.

Multiple driving forces and complicated bathymetry characterized by subbasins, peninsulas, islands, and steep bottom topography determine three predominant and interacting circulation scales in the Mediterranean: a basin-scale thermohaline cell, subbasin-scale circulations, and energetic mesoscale features. The only connection between this complex system and the open ocean is the narrow and shallow Strait of Gibraltar, which severely limits water exchanges. The relatively fresh Atlantic Ocean water entering through Gibraltar at upper layers propagates eastward and becomes progressively saltier due to the excess of evaporation over precipitation. This thermohaline cell closes with salty Mediterranean waters exiting through the bottom layers of the Strait of Gibraltar.

Climate change impacts are expected to be particularly strong in the Mediterranean region in terms of mean precipitation reduction, larger than global average temperature increase, increased interannual variability of precipitation and temperature, major increases in warm temperature extremes, rising intensity of hydrological cycle extremes (droughts and heavy rainfall events), and increased salinity and temperature in the sea. The amplitude of these changes and the large coherence among different models have led to the widely accepted notion of the Mediterranean region as a climate change "hot spot."

These climate change pressures meet an already stressed environmental situation characterized by the large socioeconomic differences between the northwestern and the southeastern Mediterranean countries. The latter are rapidly increasing their energy demand, population, and urbanization and are particularly vulnerable due to the overexploitation of water and land.

MedCLIVAR History and Highlights

The MedCLIVAR initiative was first proposed at the 2003 European Geosciences Union assembly in Nice, France. The initiative was subsequently endorsed by the international Climate Variability and Predictability (CLIVAR) office, and the MedCLIVAR Research Network Project was formally approved by the European Science Foundation and launched in May 2006 with the support of funding agencies from 12 countries.

Since then, MedCLIVAR has promoted scientific dissemination by many publications and by two books that review the state of the art in Mediterranean climate research: *Mediterranean Climate Variability*, published at the beginning of the project, and *The Climate of the Mediterranean Region: From the Past to the Future*, now in press. A systematic archive of observations and model simulations of the Mediterranean climate is presently being organized at the World Data Center for Climate, in Hamburg, Germany (http://cera-www.dkrz.de/CERA/MedCLIVAR.html), and it will be enriched with new data in the next 2 years. The aim of the archive is to share data across the scientific community and to ensure their availability for at least 10 years.

The network established by MedCLIVAR has held one major conference, six workshops, and two summer schools for young scientists. In addition, the program has awarded exchange grants to 31 young scientists, funded 7 senior scientists to visit different universities and research centers for

short periods, sponsored or cosponsored 11 scientific meetings, and organized annual sessions during the European Geosciences Union general assembly.

Main Scientific Issues of Importance to MedCLIVAR

MedCLIVAR provides opportunities to discuss and disseminate scientific progress between different disciplines in areas where research is needed and scientific integration across disciplines should take place. The following points briefly address the status and perspective of several key issues considered by MedCLIVAR:

Reconstruction of past climate variability has improved, thanks to longer digitalized time series, as well as good-quality natural and documentary proxies (such as chronicles, diaries, tax records, etc.), which have allowed more robust climatic data sets. However, further important progress is expected, because there is a large amount of unexplored data. A substantial effort is also needed to generate finer-scale reanalyses of historical data sets and simulations of past climate, because the data currently available have not yet fully resolved the high variability in the region.

Understanding the connections between Mediterranean and global climate variability has progressed with the extension of the role of the North Atlantic Oscillation (NAO) to other seasons besides winter and the wide spectrum of hydrological, ecological, and even socioeconomic impacts considered in recent scientific studies of NAO. Knowledge has evolved on the role of the El Niño–Southern Oscillation (ENSO), the Indian monsoon, the analysis of tropical cloud plumes, remote sources of moisture, and tropical-extratropical transition mechanisms of storms. However, possible feedbacks of the Mediterranean dynamics with the global climate system still need to be identified and discussed. Characterization of internal climate variability, better understanding of the variability of extreme events, and better integration with research on disaster risks have been identified by MedCLIVAR as important areas of future work.

Advances have been achieved in understanding the response of the Mediterranean Sea circulation to atmospheric forcing and internal dynamics. Evolution of the Eastern Mediterranean Transient (EMT), an abrupt event that occurred from 1987 to 1993 during which the main source of the deep water of the eastern Mediterranean changed from the Adriatic to the warmer and saltier Aegean Sea, as well as the variability of the thermohaline circulation have been satisfactorily reproduced by numerical modeling. However, the relative importance of external and internal forcing has not yet been fully understood. The EMT's contribution to the recent increase in salinity in the western Mediterranean is likely to be a key focus in future studies. Sea level trends and their different contributions (atmospheric, steric, and mass changes) have been quantified, and the significant differences with respect to global trends have been explained. A better characterization of future sea level changes obtained on the basis of regional models and mass addition coming from the melting of ice sheets are currently subjects of intense research.

Regional anthropogenic influences include massive land use changes during the past few millennia due to agriculture, forestry exploitation, urbanization, river and lake management, and heavy demographic pressure. They also include the effects of air pollution, aerosols, and cirrus contrails from aircraft and ships. Future work will analyze the importance of anthropogenic influences on climate at the regional scale since ancient time, which has been only marginally explored so far.

Understanding and predicting the response of the Mediterranean climate (including extreme climatic events) to global climate change can now be based on models that have higher resolution and are thus more realistic than before. In particular, those that couple to a high-resolution model of the Mediterranean Sea circulation will provide a wealth of information about specific regional effects predicted by climate models. Coordinated modeling efforts, such as the Mediterranean Coordinated Regional climate Downscaling Experiment (MedCORDEX), will be helpful to such endeavors. Uncertainties in projections have to be characterized and possibly reduced to achieve a strong link between climate models and models of how expected climate scenarios will affect populations. This requires increased model resolution and a better representation of processes, in particular, those associated with atmosphere-land-ocean interactions. Climate change attribution at the regional scale has recently produced new evidence of anthropogenic effects and is expected to progress greatly in the next few years, which will significantly help communities plan for upcoming changes.

The development of regional observational networks for process studies and long-term monitoring of key oceanic and atmospheric parameters is a major prerequisite for successfully identifying climate change in the region. Satellite imagery is an increasingly useful tool to analyze climate and its impacts and is expected to be better integrated into Mediterranean climate research.

In the next few years, MedCLIVAR aims to continue its networking and scientific dissemination activity, acting as a bottom-up organization of scientists open to all. International coordination of such efforts is in some cases hampered by political differences and is becoming more difficult due to the present economic situation. Thus, international coordination of observational and research efforts is a crucial contribution to overcoming some of the political and cultural differences across this region and optimizing the use of regional resources. In this framework, more emphasis will likely be given to the integration of North African and Middle Eastern scientists into the MedCLIVAR network. Information on these and other ongoing MedCLIVAR activities can be found on the MedCLIVAR Web page (www.medclivar.eu).

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