Symposium

"Climate extremes during recent millennia and their impact on Mediterranean societies"

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Summary

The symposium was held in September (13-16) 2008 at the premises of the National and Kapodistrian University of Athens under the sponsorship of the European Science Foundation (MedCLIVAR program; www.medclivar.eu), Mariolopoulos-Kanaginis Foundation for the Environmental Sciences, IGBP-PAGES, National Observatory of Athens and Academy of Athens. It was attended by 51 scientists from Europe and the US from different disciplines such as: paleoclimatology, climatology, anthropology, geology, archaeology, and historians working on the Greater Mediterranean Region.

The symposium focused on the detection and analysis of significant climate anomalies in the Mediterranean region from different epochs, timescales and disciplines. It built on the results of the previous ESF-MedCLIVAR / PAGES workshop on "Reconstruction of Past Mediterranean climate" that was held in 2006, but was focused on natural proxies over the Eastern part of the region. This symposium was organised through the following themes / sessions: "Mediterranean climate change in the instrumental period", "Natural and documentary proxies", as tools for detection of climate extremes, the "Influence of volcanoes", the "Multiproxy approach" including integration between "Proxies and models" and the "Impacts of climate changes and extreme events in the Mediterranean societies".

Scientific content of and discussion at the symposium, assessment of the results and impact of the event on the future direction of the field

The complex Mediterranean climate was addressed in the session on "**Mediterranean climate change in the instrumental period**". The climate variability in the Mediterranean basin during the twentieth century, and projected climate change during the 21st century from the IPCC scenarios with multidisciplinary impacts were discussed. The relationship between the North Africa-West Asia (NAWA) Index, the Northern Annular Mode and the Polar Vortex Oscillation were presented. During the 21st century more NAWA positive phases are expected connected with a decrease of Eastern Mediterranean winter precipitation and temperature. Further another circulation feature, the Eastern Mediterranean Pattern (EMP) and its linkages with climate variability over the Eastern Mediterranean region were introduced. Positive (negative) phases of EMP are associated with decrease (increase) of temperature and increase (decrease) in precipitation being most prominent in the mean temperature regime in particular over the south-eastern part of the basin. By means of a Canonical Correlation Analysis, the simultaneous relationship between the winter temperature and precipitation and the large-scale SLP since 1750 was assessed. The first winter canonical mode, similar to the Eastern Atlantic/Western Russia (EA/WRUS) pattern, is connected with warmer (cooler) and dryer (wetter) conditions in the Mediterranean northern (southern) rim of the Mediterranean Basin for the periods 1820-1920 and 1930-1990, respectively. The most recent positive phases of the North Atlantic Oscillation (NAO) and EA/WRUS have strongly contributed to the overall winter dryness and warming of the northern rim. Sea level in the Mediterranean Sea has been rising at about 1.2 mm/yr but with a large spatial variability. The variability in time of extremes is caused by mean sea level changes, possibly linked to the NAO variability.

The discussion that followed this session raised the necessity of reconsidering the large number of circulation indices associated with the Mediterranean climate variability at different spatio-temporal scales. The circulation indices alone capture only a small fraction of the climate variability in the complex environment of the Mediterranean basin, while considering of the full large-scale atmospheric circulation patterns could provide additional and more complete information for the interpretation and analysis of physical mechanisms at stake. The Mediterranean marks a transitional zone between the deserts of North Africa situated within the arid zone of the subtropical high and central and northern Europe affected by the westerly flow during the whole year. The intriguing complexity of the basin and the surrounding lands, the proximity to the sea and the strong influence of local and smaller scale factors raise the requirement of better understanding of the regional climate variability and associated regimes especially in a future climate change context where water resources, food availability, energy supply, public health, and tourism are going to be strongly impacted.

The complexity of the Mediterranean climate due to topography and its location close to the subtropics makes the reconstruction of its climate a highly challenging task, as shown throughout the symposium. Two sessions on discussed the availability of the different **natural proxies** in the region. It was recognized that there is a strong need for many more high quality and high resolution paleo-records of all types from the Greater Mediterranean Region together with longer instrumental data, required for the calibration of proxy data (initiative undertaken in the MEDARE project, www.omm.urv.cat/MEDARE/). The spatial coverage is quite lopsided, as at present there is very little information available from the southern part of the basin (i.e. North Africa). Also, the current tree-ring record, over time and space, is adequate for the north-eastern quadrant of the Mediterranean, but spotty in the northwest quadrant, and is limited to Morocco in North Africa. Further research identifying latitudinal variance over time is underway from Crete eastward to Israel, but more data from all regions are needed for more complete tree-ring analyses. Most tree-ring series from the northeast contain a clear record of growing season precipitation. Spatial variability in precipitation was shown and the possible influence of volcanic activity and solar variability were discussed. Initial oxygen and carbon isotope analyses show promise for estimating the annual precipitation total. While the tree-ring record does indicate mainly single years of extremes in growing-season precipitation that are reflected in human history, other periods of extreme spatial variability, evident in the tree-rings, such as a shift from regional to local precipitation patterns that occurred mainly during periods of increasing sunspot numbers, did not have a clear impact on societal behaviour.

Unsurprisingly, the need for a multi-proxy approach was reaffirmed given that every natural proxy has its limitations and uncertainties, and responses are often non-linear. Concurrent examination of a second (or third, or fourth, etc.) proxy will generally help clarify an ambiguous result interpreted from a single proxy. While anthropogenic impacts and influence are often seen as limitations for certain proxies like pollen, there may be many subtle and non-obvious effects on even apparently “objective” proxies like carbon and oxygen isotopes from speleothems. For example, the isotopic signal of water is clearly influenced by the amount of time it spends percolating through the meteoric system before actually entering a cave and this is intimately tied to the amount and quality of the soil cover in a region. However, it is obvious that the thousands years of slope terracing by humans and/or grazing by animals in the Mediterranean must have had an effect on ground cover vegetation, soil chemistry, water saturation capability and/or retention time of water in soils. Until now speleothem studies have not really taken this consideration into account. While the example presented here is specifically about speleothem work, other similar subtle considerations must be made for many other proxies, and not just for pollen where it has generally been accounted for.

The session on **documentary sources** showed different examples of documentary proxies from Iberia. In fact, the NW Mediterranean (Spain,-France-Italy) area shows a high availability of documentary proxies for the last 500-1000 years. Arabic sources, mostly unexplored in the region, have potential to provide information on climatic extremes during the historical period for the North African and Middle Eastern countries and up to the fifteenth century for Iberia, even though there are several problems to be solved such as the dating of the events due to the ambiguities in the Arabic calendar. Interestingly, the increasing availability of natural proxies in the Eastern Mediterranean, especially in Turkey, could help to compensate for the scarcity of documentary records in the area. The need for a multi-proxy approach, reconciling information from diverse sources, was reaffirmed given that all natural and documentary proxy data have limitations and uncertainties, and responses of proxies to climate variability and forcings are often non-linear and do not necessarily occur in conjunction in time or in space. Focusing on specific time periods and involving the whole range of spatial and temporal scales of proxies and climate parameters along with enhanced integration of knowledge across the research disciplines will help to bridge the communication gap between the various research communities, e.g., scientists producing the paleo records, and those involved in the dynamical and modelling communities, as shown in the session on "**Multi-proxy and data model comparison**". This session comprised three talks*:* two dealt with new methods to spatially reconstruct climate patterns and one gave insight into the importance of synoptic (weather-related) variability in the Mediterranean area. A matching method using modelled climate patterns, which are constrained by proxy data, was used to hypothesize that the so-called Medieval Climate Anomaly was dominated by the positive phase of the NAO. The information provided by this reconstruction together with a global array of proxy data suggest that this positive phase could have been driven by prevailing La Niña-like conditions which were initiated by high levels of irradiance and amplified by intensified Atlantic Meridional Overturning Circulation (AMOC). Part of the discussion dealt with the problem that the NAO is often used to explain "almost everything". It was noted that the NAO only explains part of the total variability, the influence is not stationary through time and space and that it is a dominant mode only in winter. An analogue method using different proxies for different frequency domains, e.g., tree rings only for high frequency variability and pollen data for the low-frequency variations was shown and its application to fill gaps in the frequency domain. The problem of how to constrain either model climate patterns or analogues in the frequency domain by proxy data was also addressed. A better understanding of the changes in the synoptic scale variability, e.g., low pressure systems and their interaction with the mean flow (or low frequency modes), is needed to understand variations in monthly to seasonal climate patterns, e.g., precipitation extremes. However there is still a lack of proxy information on these time scales.

The **impact of volcanoes** on climate was addressed in another session. A combination of observations and proxy reconstructions can be used to pinpoint the climatic effects of volcanoes. However, there are still difficulties in precisely dating unknown / undocumented volcanic eruptions; the importance of the famous Vesuvius eruption in AD 79 for dating volcanic eruptions in antiquity was stressed. For more recent historical times, documentary sources from different parts of the world can be used to describe the regional effects of volcanoes on climate and society around the world, as was discussed for the 1600 eruption of Huaynaputina volcano in Peru, which might have had some impact on Russian history and politics. Finally, the effects of tropical and extratropical volcanic eruptions over the last centuries and their impact on Mediterranean climate were examined. Composite averages over 15 volcanic eruptions in the last half-millennium clearly show a general summertime cooling for two years following the eruption and a tendency for wet conditions in the first summer following the eruption. The summertime cooling is consistent with direct radiative effects of volcanic aerosols injected into the stratosphere. A volcanic winter signature is different; it is dominated by a cooling over the Mediterranean and a strong warming over northern Europe caused by circulation changes associated with a stronger westerly component over the eastern North Atlantic. The precipitation patterns in winter following tropical eruptions are often associated with these circulation changes resulting in wet conditions over northern Europe and dryness over the Iberian Peninsula and south-eastern Europe. GCM experiments presented during the symposium support the findings of the reconstructions showing a similar temperature response to tropical eruptions and a physically consistent reaction of the atmospheric circulation.

The workshop ended with a session devoted to the **impacts of climate extremes on Mediterranean societies**. It included topics of impact and adaptation practices from climate change events from the last few millennia until today. In particular, regarding the abrupt climate changes, the events of 8.2, 5.2 and 4.2 ka BP were discussed. Such events appear to have had severe impacts on Neolithic societies in the Mediterranean, including changes in mobility patterns or even a demographic drop mainly due to reduced food supplies. The underlying cause for the abrupt climate change events seems to be the synchronous deflection of the Mediterranean westerlies and the Indian monsoon resulting in two-to-three hundred years of reduced precipitation. To better understand the changes in the Mediterranean climate, paleoclimate model integrations spanning the last 12,000 years were also presented. These integrations also attributed the 8.2 ka BP event to the weak circulation over the Atlantic and associated storm track changes but the seasonal cycle is still poorly understood. Tentative indications are evident for cooler winters and warmer summers during these events. Future impacts of climate change in the Mediterranean encompass sectors ranging from water and agriculture to tourism, public health, forest fire risk, and energy demand. Limited water availability and higher temperatures may result in reduction in crop yields. Moreover, the tourism season might shift to autumn and spring when temperatures are less extreme and population health risks associated with reduced heat waves. Extended drought conditions translate to a greater forest fire risk by the end of the 21st century. Energy levels required for cooling are also expected to rise sharply, but this increase will be followed by a subsequent energy demand decrease during anticipated future warmer winters. Impacts and adaptation practices used in the last few millennia were also discussed. More specifically, these include movements of population to the north or to the south depending on the river irrigation, abandonment of specific agricultural production and shifts to pastoral nomadism. Such forced adaptation measures appear to be due to each society's level of dependence on their immediate environment and the severity of climate change. These climatic change consequences, including social upheaval, civil war and regime change, apply also to the present day, although the technological infrastructure available, and are possibly due to expand globally due to the more globally-coordinated nature of the anthropogenically induced global warming.

From the discussions in the different sessions several issues were identified as relevant to improve the research on past Mediterranean climate extremes.

- Additional high quality and high resolution records are needed. While this is a task that will take many years, some type of "location sensitivity analysis" in conjunction with the climate system dynamics and modelling community is suggested that may help indicate areas that are particularly sensitive.
- While currently used proxies are still of great importance, the development of new proxies with great potential such as trace element and fluid inclusion analysis of speleothems is of the highest priority.
- It seems clear that a stronger effort is necessary to integrate pre-existing records and help understand the spatial distribution (especially inhomogeneities) and magnitude of possible abrupt climate events. It should be noted that such data interchange will be greatly improved by the MedCLIVAR meta-database (www.medclivar.eu) as it becomes more active.
- Future research should focus on developing stronger integration and exchange between the paleo-data researchers and the dynamicists/modellers. It should be emphasized that the benefits will extend both ways; for example, paleoclimatologists could provide results that serve to validate model results, or provide actual initial and/or boundary conditions for actually forcing models. In turn, the dynamicists/modellers could provide important insight into understanding and interpreting the signals seen in paleo-records.
- Focussing on specific time slices and involving the entire range of spatial and time scales will provide important information about the variability and contributions of different mechanisms at different frequencies.
- Continuous caution and re-evaluation of the possible human impact on the actual proxy recording process and resultant signal for all proxies are of great importance.