Introduction

The Mediterranean Climate: An Overview of the Main Characteristics and Issues

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1. The Mediterranean Region: Climate and Characteristics

The Mediterranean Region has many morphologic, geographical, historical and societal characteristics, which make its climate scientifically interesting. The purpose of this introduction is to summarize them and to introduce the material extensively discussed in the succeeding chapters of this book.

The connotation of "Mediterranean climate" is included in the qualitative classification of the different types of climate on Earth (e.g. Köppen, 1936) and it has been used to define the climate of other (generally smaller) regions besides that of the Mediterranean region itself. The concept of "Mediterranean" climate is characterized by mild wet winters and warm to hot, dry summers and may occur on the west side of continents between about 30° and 40° latitude. However, the presence of a relatively large mass of water is unique to the actual Mediterranean region. The Mediterranean Sea is a marginal and semi-enclosed sea; it is located on the western side of a large continental area and is surrounded by Europe to the North, Africa to the South and Asia to the East. Its area, excluding the Black Sea, is about 2.5 million km^2; its extent is about 3,700 km in longitude, 1,600 km in latitude. The average depth is 1,500 m with a maximum value of 5,150 m in the Ionian Sea. It is surrounded by 21 African, Asian and European countries. The Mediterranean Sea is an almost completely closed basin, being connected to the Atlantic Ocean through the narrow Gibraltar Strait (14.5 km wide and less than 300 m deep). These morphologic characteristics are rather peculiar. In fact, most of the other marginal basins have much smaller extent and depth or they are connected through much wider openings to the ocean. An example of the first type is the Baltic. Examples of the second type are the Gulf of Mexico and the Arabian Sea. The closest analogue to the Mediterranean is possibly the Japan Sea, which, however, does not have a similar complex morphology of basins and sub-basins and is located on the eastern side of the continental area.

A specific characteristic of the Mediterranean region is its complicated morphology, due to the presence of many sharp orographic features, the presence of distinct basins and gulfs, islands and peninsulas of various sizes (Fig. 1). High mountain ridges surround the Mediterranean Sea on almost every side and tend to produce much sharper climatic features than expected without their existence. The highest ridge is the Alps, reaching a maximum high of 4,800 m, which contains permanent glaciers and presents a thick and extended snow cover in winter. Islands, peninsulas and many regional seas and basins

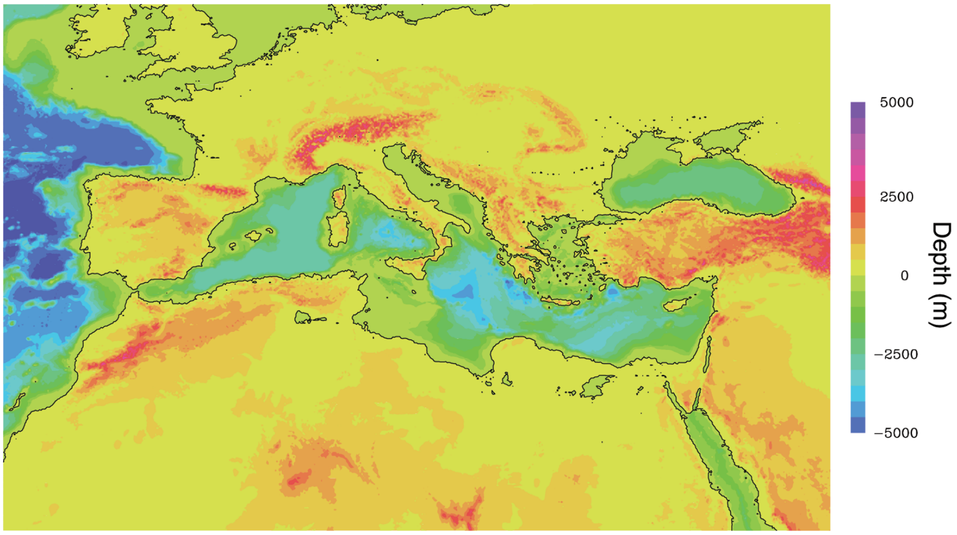

Figure 1: Orography and Sea-depth of the Mediterranean region.

determine a complicated land–sea distribution pattern. These characteristics have important consequences on both sea and atmospheric circulation, because they determine a large spatial variability and the presence of many subregional and mesoscale features. The oceanic topography is similarly complicated with deep basins linked through much shallower straits. The Mediterranean Sea circulation is characterized by sub-basin scale gyres, defined by the geometry and topography of the basin, and dense water formation processes, which are responsible for its deep circulation (Tsimplis et al., Chapter 4 of this book).

Geographical Elements in the Map

Straits (denoted with white arrows)
1-Strait of Gibraltar
2-Strait of Sicily
3-Strait of Otranto
4-Cretan Strait (West)
5-Cretan Straits (East)
6-Dardanelles
7-Bosporus Strait

Mountains
-Alps
-Anatolian mountains
-Apennines
-Atlas mountains
-Balkans
-Dinaric Alps
-Pyrennees

Lakes
-Sea of Galilee
-Dead Sea

Gulfs (denoted with circles)
1-Gulf of Lion
2-Gulf of Genoa
3-Gulf of Venice
4-Gulf of Sirte

Islands
-Balearic Islands
-Corsica
-Crete
-Cyprus
-Rhodes
-Sardinia
-Sicily

Peninsulas
-Balkan peninsula
-Crimea
-Iberian peninsula
-Italian peninsula

Seas and Basins (denoted with boxes)
1-Alboran Sea
2-Algerian basin
3-Tyrrhenian Sea
4-Adriatic Sea
5-Ionian Sea
6-North Aegean Sea
7-Cretan Sea
8-Cyclades Plateau
9-Levantine basin
10-Black Sea
11-Red Sea

Rivers (mouths are denoted with black arrows)
-Ebro
-Nile
-Po
-Danube
-Jordan

Others
-The Negev desert

Figure 2: Map with labels denoting most relevant geographical features of the Mediterranean region.

The atmospheric circulation is strongly affected by the complex land topography which plays a crucial role in steering air flow, so that energetic mesoscale features are present (Lionello et al., Chapter 6 of this book). The large environmental meridional gradient is shown by the transition from hot and arid regions to humid mountain climate and permanent glaciers in about 2,000 km. Furthermore, strong albedo differences exist in south–north directions (Bolle, 2003). Figure 2, which provides a reference for the geographic features mentioned in this book, shows the large amount of details involved in the description of the mesoscale forcings in this region.

Because of its latitude, the Mediterranean Sea is located in a transitional zone, where mid-latitude and tropical variability are both important and compete (Alpert et al., and Trigo et al., Chapters 2 and 3 of this book, respectively). Thus, from a Koppen classification perspective, the northern part of the Mediterranean region presents a Maritime West Coastal Climate, while the Southern part is characterised by a Subtropical Desert Climate. Further, the Mediterranean climate is exposed to the South Asian Monsoon in summer and the Siberian high-pressure system in winter. The southern part of the region is mostly under the influence of the descending branch of the Hadley cell, while the Northern part is more linked to the mid-latitude variability, characterized by the NAO (North Atlantic Oscillation) and other mid-latitude teleconnection patterns (e.g. Dünkeloh and Jacobeit, 2003; Xoplaki et al., 2003, 2004; Hoerling et al., 2004; Hurrell et al., 2004). An important consequence is that the analysis of the Mediterranean climate could be used to identify changes in the intensity and extension of global-scale climate patterns, such as NAO, ENSO (El Niño Southern Oscillation) and the Monsoons. The teleconnections in the Mediterranean region present a large amount of both spatial variability (ranging from synoptic to mesoscale) and time variability (with a strong seasonal cycle modulated on multi-decadal to centennial time scales, as described in the Chapters from 1 to 6 of this book). Moreover it is important to consider the role of the Mediterranean Sea as heat reservoir and source of moisture for surrounding land areas; as source of energy and latent heat for cyclone development (Lionello et al., Chapter 6), and its possible effect on remote areas (such as the Sahel region in, Li et al., Chapter 7 of this book) and on the Atlantic overturning circulation (Artale et al., Chapter 5).

Another important characteristic of the Mediterranean region is the large amount of climate information from past centuries (Luterbacher et al., 2004, Chapter 1 of this book; Guiot et al., 2005; Xoplaki et al., 2005). This characteristic is shared with other European regions, but apart from them, is presently unique on the global scale and has not yet been fully exploited. The continuous presence of well-organized local states and the long tradition of scholarship and natural science produced documentary proxy evidence, which allows the reconstruction of some aspects of climate since the Roman period and possibly further back in time. Some millennial-long climate series have already been reconstructed (e.g. of the freezing of the Venetian lagoon and of storm surge in Venice; Camuffo, 1987, 1993). This availability of documentary evidences is complemented with natural proxies (tree ring data, corals, etc., Felis et al., 2000; Touchan et al., 2003, 2005) as well as with remarkably long observational records (associated with old universities and observatories of municipalities, kingdoms and counties) mostly on the central and western-European part of the Mediterranean region (e.g. Buffoni et al., 1999; Barriendos et al., 2002; Camuffo, 2002; Maugeri et al., 2002; Rodrigo, 2002). On the basis of documentary and/or natural proxies it has been possible to obtain multi-centennial regional temperature and precipitation reconstructions (e.g. Guiot et al., 2005; Luterbacher et al., 2004; Mann, 2002; Till and Guiot, 1990; Touchan et al., 2003, 2005) allowing to study of past climate variability, trends, uncertainties and to compare the Mediterranean region with other areas. This rich data gives a unique opportunity for reconstruction of climate (including extremes) in past historical and recent instrumentally developed times.

An important characteristic of the Mediterranean region is the emergence of highly populated and technologically advanced societies since, at least, 2000 BC. Because of the demographic pressure and exploitation of land for agriculture, the region presents, since ancient times, important patterns of land use change and important anthropic effects on the environment, which are themselves interesting research topics. For example, it has been suggested that the albedo change due to the change in vegetation since Roman times significantly alters the atmospheric circulation over northern Africa and the Mediterranean Sea, so that deforestation around the Mediterranean during the last 2,000 years may be a major factor in the dryness of the current climate in these regions (Reale and Dirmeyer, 2000; Reale and Shukla, 2000). The importance of deforestation in the Mediterranean region has been confirmed by other modelling studies suggesting that lower plant evapotranspiration and lower evaporation from soils, due to erosion, are likely to reduce precipitation in summer (Dümenil-Gates and Liess, 2001).

The Mediterranean Sea general circulation has been described through a series of observational programmes and modelling studies over the past 20 years (e.g. POEM, PRIMO, WMCE, EU/MAST/MTP I and EU/MAST/MTP II). The modern reconstruction of the basin-wide general circulation (POEM Group, 1992; Millot, 1999) and its variability results much more complicated than that described before (Ovchinnikov, 1966), spanning over multiple scales in space (from the basin-scale to the sub-basin and mesoscale) and in time (from the seasonal to the interannual and decadal variability). Fundamental components of the basin-scale circulation are three major thermohaline cells. The first one is the "open" circulation cell that connects the eastern to the western Mediterranean and is associated with the inflow of Atlantic Water at the Gibraltar in the surface layer and the outflowing return flow of Levantine Intermediate Water (LIW) in the intermediate layer below. The others are two meridional vertical cells confined to the eastern and western Mediterranean basins. They are driven by localized deep convective events, which occur in the Northern Mediterranean areas, leading to the formation of dense water masses, which spread in the deepest layers, with subsequent upwelling and return flow at the intermediate layer into the convection region. The importance of localized convection processes is determined by air–sea interaction and long-term preconditioning. Intense cooling and evaporation over restricted areas in the north-western Gulf of Lion, the southern Adriatic Sea and, in the 1990s, the Aegean/Cretan Sea control the formation of dense waters filling the bottom of the basin. The western and eastern sub-basins are disconnected at deep levels, hence their thermohaline circulations are independently driven by the respective sources. The eastern Mediterranean thermohaline circulation is a closed cell endowed with multiple equilibria. Analogous observational evidence and related modelling studies, for the Western Mediterranean are lacking. Intense evaporation in the Levantine basin determines the formation of LIW which is part of the open thermohaline cell constituted by two branches: Atlantic Water entering at Gibraltar and making its way to the Levantine, being transformed into LIW by intermediate convection processes (mainly in the Rhodes gyre area), and returning all the way to Gibraltar, where it finally exits forming the North Atlantic salty water tongue.

2. Regional Processes and Links to the Global Climate

The climate of the Mediterranean region is to a large extent forced by planetary scale patterns. The time and space behaviour of the regional features associated with such large-scale forcing is complex. Orography and land–sea distribution play an important role establishing the climate at basin scale and its teleconnections with global patterns. In fact, the complexity of the basin topographic structures, which have been described in the previous section, implies the presence of mesoscale features and inter-seasonal variability in patterns that would be otherwise much more homogeneous and persistent. Most studies consider winter and summer regimes, while characterization of spring and autumn is more uncertain, revealing, presumably, the transient nature of these two seasons in the Mediterranean region.

The large-scale mid-latitude atmospheric circulation exerts a strong influence on the cold season precipitation over the Mediterranean, though the strength of the relation varies across the region and depends on the considered period (see Chapters 1, 2 and 3). The largest amount of studies refer to the role of the NAO, which determines a large and robust signal on winter precipitation, which is anti-correlated with NAO over most of the western Mediterranean region (Hurrell, 1995; Dai et al., 1997; Rodo et al., 1997; Xoplaki, 2002; Trigo et al., 2004). This strong link is due to the control exerted by NAO on the branch of the storm track affecting the Mediterranean, mainly in its western part. Besides the NAO, other patterns influence the Mediterranean climate (Corte-Real et al., 1995; Dünkeloh and Jacobeit, 2003; Xoplaki et al., 2004). The role of the Mediterranean Sea itself as source of moisture and the subsequent eastward advection by the atmospheric circulation imply a more complex picture for the Eastern Mediterranean, where the EA (East Atlantic) pattern plays an important role (Krichak et al., 2002; Fernandez et al., 2003). In general, EA describes much of the precipitation anomalies in the whole basin that cannot be ascribed to the NAO (Quadrelli et al., 2001). Moreover, in the central Mediterranean the Scandinavian pattern has a strong influence (e.g. Xoplaki, 2002).

The influence of ENSO in the North Atlantic–European area has been identified mostly in winter during its extreme events (Pozo-Vázquez et al., 2001). In fact, ENSO has been found to play an important role in winter rainfall in the eastern Mediterranean, where the role of NAO is weak (e.g. Yakir et al., 1996 and Price et al., 1998). Specifically, higher/lower than normal precipitation in Israel have been shown for El Niño/La Niña years. This is associated with the meridional shift of the jet above the Eastern Mediterranean region, observed during El Niño/La Niña years. In the western Mediterranean, as, in general, for the North Atlantic/European regions, it is difficult to identify the ENSO signals by using common statistical techniques mainly due to their spiky nature with respect to the dominating mid-latitude dynamics (Rodó, 2001). Their importance for the Mediterranean climate is not clear, though it might be large for selected intervals and vanish elsewhere (Rodó et al., 1997; Rodó, 2001; Mariotti et al., 2002a). The most robust link is that of western Mediterranean-autumn-averaged rainfall, which has a significant positive correlation with ENSO. A weaker correlation, with opposite sign, is present in spring, but it is confined to a small region in Spain and Morocco (Mariotti et al., 2002a).

In summer, when the advection of moisture from the Atlantic is weaker and the Hadley cell moves northward and its strength diminishes, there are evidences of connections (stronger in the eastern Mediterranean and at the North African coast) with the Asian and the African monsoons. Rodwell and Hoskins (1996) pointed at the linkage between the appearance of the semi-permanent subsidence region over the eastern Mediterranean and the onset of the monsoon. A consequence could be that the very dry summertime climate of the Eastern Mediterranean and the surrounding lands may be strongly related to the characteristics of the Asian monsoon regime. Ziv et al. (2004), in their study of the summer atmospheric circulation, pointed out also to the role of the Hadley cell over eastern North Africa, connecting the eastern Mediterranean with the African Monsoon. Such influence does not extend to the Northern Mediterranean rainfall variability, which in summer has been shown to be related with the EA Jet pattern (Dünkeloh and Jacobeit, 2003).

The influence of NAO on the Mediterranean winter temperature is smaller than that on precipitation. Above the North-western Mediterranean region the spatial distribution of correlation with temperature has a positive feature which is weaker than the negative one of the correlation with precipitation. The effect of NAO has been found to be non-linear and non-stationary (e.g. Pozo-Vázquez et al., 2001). Moreover, the strong control exerted by NAO on cloud cover and surface radiation balance over the Mediterranean implies the appearance of asymmetric NAO impact patterns for maximum and minimum temperature (Trigo et al., 2002). Other studies (Sáenz et al., 2001; Frías et al., 2005) suggest that the variability of monthly mean winter temperature over the western part of the Mediterranean basin is mainly controlled by the variability of the EA pattern, with the NAO only playing a secondary role. The reason behind this is that this variability is controlled by sensible heat transport by mean stationary waves, with eddy heat fluxes playing a less significant role. However, the influence of EA cannot be extended to the eastern part of the basin (Hasanean, 2004).

Mediterranean summer temperatures are not related with NAO neither with monthly indices of other large-scale patterns. Rather, generally, warm Mediterranean summers are connected with a main mode, characterized by strong positive geopotential anomaly covering large parts of Europe including the Mediterranean area, associated with blocking conditions, subsidence, stability, a warm lower troposphere, small pressure gradients at sea level as well as above-normal Mediterranean SST (Xoplaki et al., 2003).

An important role of the Mediterranean Sea on the climate of other regions is associated with the connection between the Mediterranean SST (Sea Surface Temperature) and the Sahel precipitation. The dry and hot summers in the western Mediterranean and the Monsoon regime over West Africa, are correlated through a positive mechanism. When the Mediterranean SST is higher than normal, moisture from the western Mediterranean is fed into the Sahel favouring precipitation (Semazzi and Sun, 1997; Rowell 2003). In turn, abundant rainfall in the Sahel increases the high pressure upstream the western Mediterranean via Rossby waves (Rodwell and Hoskins, 1996), enhancing the subsidence in the western Mediterranean, favouring the penetration of moisture air from the Atlantic into the Sahel and increasing further the rainfall in this region. The effect of SST anomalies in summer has been investigated with a relatively high-resolution (T159L40) version of the ECMWF model in relation with the situation which took place in summer 2003 (Jung et al., 2005) confirming that anomalously warm Mediterranean SSTs are associated with an intensification of Sahel rainfall. Also other modelling studies suggest that changes of SST in the Mediterranean can have consequences for atmospheric circulation, affecting relatively remote regions (Li, 2005).

The dynamics of the Mediterranean climate includes also the identification of processes acting internally to the region. With respect to the moisture balance, the western Mediterranean Sea represents a source for the surrounding land areas and for the eastern part of the basin, as the moisture released by evaporation is redistributed by the atmospheric circulation (Fernandez et al., 2003). These processes could play a role in coupled atmosphere–ocean variability modes, which could be important for the regional hydrological cycle, and the water budget of the eastern Mediterranean region. In fact, wet and dry winter months in the Eastern Mediterranean region are characterized by circulation patterns with north-westerly and north-easterly air flow in the lower troposphere above the Eastern Mediterranean (Krichak and Alpert, 2005a).

Regional weather regimes are a basic element of the Mediterranean climate. These regimes are characterized by energetic mesoscale features, several cyclogenesis areas (e.g. Alpert et al., 1990; Trigo et al., 1999; Lionello et al., 2002) and are generally characterized by shorter life-cycles and smaller spatial scales than extra-tropical cyclones developed in the Atlantic. Extremely diversified classes of cyclones are present in the Mediterranean region, since it presents geographic factors that can substantially influence the cyclogenesis mechanisms. A tentative list, based partially on the mechanisms producing cyclogenesis and partially on the geographical characteristics, would include lee cyclones, thermal lows, small-scale hurricane-like cyclones, Atlantic systems, African cyclones, Middle East lows. Though NAO plays a basic role and many Mediterranean cyclones are triggered by synoptic systems passing over Central and Northern Europe along the Northern Hemisphere storm track, also other teleconnection patterns with centres of action located closer to or above Europe have to be considered (e.g. Rogers, 1990, 1997).

Studies of the variability of the Mediterranean Sea circulation have aimed to identify the forcings that are responsible for the variability of the circulation patterns, especially in relation to long-term trends in water mass characteristics, sea level changes and the EMT (Eastern Mediterranean Transient) event during which the source of the Eastern Mediterranean deep water temporarily moved from the Southern Adriatic to the Aegean/Cretan Sea. Various factors have been identified by different authors, without reaching definitive conclusions on the dominant mechanism for the EMT. The wind stress climatology over the eastern Mediterranean was quite different in the 1980s and the 1990s

(Samuel et al., 1999) and this forcing variability may have induced the observed important change in the eastern Mediterranean upper thermocline circulation which affected the LIW pathways (Malanotte-Rizzoli et al., 1999). Internal mechanisms may equally be at play, such as an internal redistribution of salt in the eastern basin (Roether et al., 1996). The construction of the Nile dam and the diversion of Russian rivers are argued to have had an impact in the EMT event (Boscolo and Bryden, 2001; Skliris and Lascaratos, 2004) as well as to have increased the overall salinity of the whole Mediterranean basin (Rohling and Bryden, 1992). As regard air–sea fluxes, severe heat loss in two winters in the early 1990s affected the surface heat budget and increased surface buoyancy loss (Josey, 2003). The Black Sea outflow plays a role in the Aegean hydrographical conditions. The induced freshening of the surface layer of the North Aegean hinders dense water production in that region (Plakhin, 1972); where, however, particular events of massive dense water production have been recorded in 1987 and 1993 (Theocharis and Georgopoulos, 1993; Zervakis et al., 2000). Evidence suggests that when dense water production takes place in the North Aegean, it is partly induced by a decrease of the Black Sea buoyancy input (Zervakis et al., 2000; Nittis et al., 2003). Whether the dense water production of the North Aegean affects the Cretan Deep Water production (and thus the EMT) is still a matter of investigations. The links between these mechanisms and large-scale patterns of atmospheric climate variability still needs to be properly assessed.

A possible feedback of the Mediterranean Sea on the global climate could derive from an effect of air–sea interaction in the Mediterranean region on the Atlantic Meridional Overturning Circulation (MOC) via the Mediterranean outflow across the Gibraltar Strait, which determines the presence of a well-known tongue of very salty water in the entire Northern Atlantic at intermediate depths (1,000–2,500 m). This water introduces an important signature in the salinity field and has potentially important large-scale climate implications (Chapter 5 of this book). Two mechanisms are presently envisioned through which the salty Mediterranean water may influence the convective cells in the Greenland and Labrador seas where North Atlantic Deep Water (NADW) is formed. The first mechanism involves a direct advective pathway from the Strait of Gibraltar to the polar seas (Reid, 1994). The second mechanism involves a progressive lateral mixing of the Mediterranean water with Atlantic intermediate water and entrainment in the North Atlantic current that reaches the polar seas (Lozier et al., 1995; Potter and Lozier, 2004). Both mechanisms imply a significant role for the Mediterranean water in preconditioning the surface water column of the convective cells, thus increasing the volumes of newly formed NADW, and increasing the stability of the MOC. The interaction of the Mediterranean outflow with the thermohaline circulation of the North Atlantic raises the possibility for feedback mechanisms, eventually active both at decadal and millennial time scales, involving the North Atlantic, the Mediterranean and the overlying atmosphere, which have potentially important climatic implications (Rahmstorf, 1998; Artale et al., 2002).

3. Climate Trends and Change at Regional Scale

Precipitation and temperature in the Mediterranean during the 20th century show significant trends. Negative precipitation trends have been present at different time and space scales (e.g. Folland et al., 2001; New et al., 2001). Giorgi (2002a) found negative winter precipitation trends over the larger Mediterranean land area for the 20th century. However, sub-regional variability is high and trends in many regions are not statistically significant in view of the large variability (e.g. Xoplaki, 2002). Giorgi (2002a) analysed also the surface air temperature variability and trends over the larger Mediterranean land area for the 20th century based on gridded data of New et al. (2000). He found a significant warming trend of 0.75°C in one-hundred years, mostly from contributions in the early and late decades of the century. Slightly higher values were observed for winter and summer. The structure of climate series can differ considerably across regions showing variability at a range of scales. Over most of western Mediterranean for instance, warming has been mainly registered in two phases: from the mid-1920s to 1950s and from the mid-1970s onwards (e.g. Brunet et al., 2001; Galan et al., 2001; Xoplaki et al., 2003). Moreover, the availability of documentary and natural proxies in the Mediterranean region has allowed constructing seasonally resolved temperature and precipitation maps over the Mediterranean area for more than 500 years with associated uncertainties (Luterbacher et al., 2004; Pauling et al., 2005; Xoplaki et al., 2005). In this context, the analysis of winter temperature and precipitation reveals that the recent winter decades (end of twentieth, beginning of the twenty-first century) were the warmest and driest, in agreement with recent findings from Europe and the Northern Hemisphere. It is obviously important to investigate the future evolution of these trends and produce reliable model simulations.

Important environmental changes have been observed in the Mediterranean Sea circulation during the last decades. Warming trends have been observed both in deep and intermediate water (e.g. Bethoux et al., 1990, 1998). Sea level has increased in line with the mean estimated global value (1.8mm/year) till the 1960s, but it has subsequently dropped by 2–3 cm till the beginning of the 1990s (Tsimplis and Baker, 2000). During the last decade of the 20th century, sea level has increased 10 times faster than on global scale. The EMT, already discussed in the previous section, is a major change which has characterized the eastern Mediterranean deep water formation with a transition in the structure of its closed internal thermohaline cell. Historically, the eastern Mediterranean thermohaline circulation has been driven by a deep convection site for dense water formation localized in the southern Adriatic Sea (Roether and Schlitzer, 1991). This was, in fact, the situation in the 1980s. Between 1987 and 1991, however, the ‘‘driving engine’’ of the thermohaline circulation shifted to the Southern Aegean/Cretan Sea. In 1995, almost the 20% of the deep and bottom waters (below the 1,200 m) of the eastern Mediterranean were found to be replaced by the much more dense waters that spread out from the Aegean Sea through the Cretan Arc Straits (Roether et al., 1996; Malanotte-Rizzoli et al., 1999). This major climatic event, better known as the Eastern Mediterranean Transient (EMT), ceased after 1997. In fact, in 1998 the dense waters of Aegean origin were no longer dense enough to reach the bottom layer and the Adriatic Sea regained its role as primary source of dense water (Theocharis et al., 2002; Manca et al., 2003). This observational evidence has led to postulate different equilibria for the thermohaline circulation, which have also been found through box models of the basin (Ashkenazy and Stone, 2003). The implications of these variations for the Mediterranean environment have not been resolved yet.

Quantifying and understanding climatic changes at the regional scale is one of the most important and uncertain issues within the global change debate. To date, projections of regional climate changes for the 21st century have been based on coupled atmosphere–ocean global climate model (AOGCM) simulations of the climate system response to changes in anthropogenic forcing (e.g. Kattenberg et al., 1996; Cubasch et al., 2001). An important step towards the understanding of regional climatic changes and impacts is the assessment of the characteristics of natural climate variability and of the AOGCM performance in reproducing it (Giorgi, 2002a,b). Probably, the Mediterranean is one of the few regions where most global simulations carried out with different models give relatively consistent climate change signals. In fact, the various model simulations of the anthropogenic effect on climate tend to agree in their prediction in the Mediterranean region a temperature increase larger than the global average and a large precipitation decrease in summer, but controversial in winter, because of differences among models and between western and eastern areas (see Chapter 8 of this book). In general, in the Mediterranean region, climate change simulations produce a signal in the range from $+3$ to $+7$K for temperature and from -40 to $+20\%$ for precipitation (Giorgi and Francisco, 2000a,b) in one century. Values obviously depend on the emission scenario. Simulations with five different GCM predict for a A2 scenario an increase in the range 4–5 K in winter and 6–7 K in summer, which in a B2 scenario are reduced to 1 and 2 K, respectively (Parry, 2000). The climate change signal in winter precipitation depends critically on the northward deviation of the storm track associated with the shift and intensification of the NAO predicted by some simulations (Ulbrich and Christoph, 1999), which produce decreased and increased precipitation in the southeastern and northwestern Mediterranean region, respectively (Parry, 2000). In summer, all models tend to agree predicting a drier climate with a reduction of precipitation as large as 50% (Parry, 2000).

The spatial resolution used for most global climate simulations does not describe adequately the basins that compose the Mediterranean Sea and the mountain ridges surrounding it. The characteristic structures of the Mediterranean region can be identified on the model land–sea mask and surface elevation grid, only if the grid cell size is at least smaller than 50 km. Additionally, even a finer grid is required for describing surface winds and precipitation, whose spatial variability involves scales smaller than 10 km. The information of most environmentally relevant quantities (like temperature, winds, precipitation) in the Mediterranean region is characterized by large spatial variability, as well as high seasonality. Therefore, to extract this from current Global Circulation Models requires some type of ‘‘regionalization’’ of the information, meaning ‘‘downscaling’’ with nested Regional Climate Model (RCM), (e.g. Giorgi and Mearns, 1991; Giorgi et al., 1992, 2001; Marinucci and Giorgi, 1992; Machenhauer et al., 1996, 1998; González-Rouco et al., 2000) or the use of global model with variable grid resolution (e.g. the ARPEGE model, Déqué and Piedelievre, 1995; Gibelin and Déqué, 2003).

Many studies, research programmes and European projects have analysed the problem of climate simulation over Europe, but the Mediterranean Sea was most of the times included only partially or in the southern part of the domain, where the model response was likely to be strongly affected by the boundary conditions. Moreover, the quality and reliability of these simulations is currently the object of discussion. It is well known that such RCMs simulations are affected by errors due both to their own dynamics and to those of the global model that provide the boundary conditions. (Christensen et al., 1997; Machenhauer et al., 1996, 1998) and only increasing the resolution itself does not ensure more realistic regional climate scenarios. Regionalization studies confirm the warming in the Mediterranean region predicted by AORCM, stronger is summer than in winter, over land than over sea, and increasing with the intensity of the radiative forcing produced by the emission scenario (Déqué et al., 1998; Giorgi et al., 2004). The strong reduction of summer precipitation is confirmed using RCM, but the uncertainty on winter values remains high, as the extension of the north western Mediterranean area with higher precipitation depends on the global simulation used to provide the boundary conditions (Raisänen et al., 2004).

Recent model simulations (Chapter 7) in which a Mediterranean Sea General Circulation Model has been driven by a climate change scenario for the end of the 21st century show large possible changes of the Mediterranean Sea circulation. (Somot et al., 2005), with a 3 K temperature and 0.43 psu salinity increase at the sea surface. The lower part (from 500 m depth to the bottom) of the Mediterranean Sea presents a lower increase (0.9 K for temperature 0.18 psu for salinity). The stronger stratification corresponds to a weaker and shallower Mediterranean Thermohaline Circulation.

Trends of weather extremes and their changes in future climate scenarios are controversial. During the second half of the 20th century, there is a well-documented trend showing the reduction of overall winter precipitation in the Mediterranean basin related with significant decrease of intense cyclones (Trigo et al., 2000). At the same time an increase of the relative frequency of torrential rains has been suggested but only for some areas of the western Mediterranean region (Alpert et al., 2002). There are consistent indications of a negative present trend in cyclones, which simulations suggest to continue in future climate scenarios (Lionello et al., 2002), but no clear change of frequency of extreme cyclones has been identified. Critical coastal areas could be heavily affected by changes of marine storminess, extreme storm surge and wind waves events (e.g. the northern Adriatic Sea; Lionello et al., 2003; Lionello, 2005) with large impacts on societies in the Mediterranean region. Because of the difficulty to resolve regional-scale features in global climate simulations, the identification of teleconnections with large-scale circulation patterns is a basic tool for the prediction of future climate extremes (Muñoz-Díaz and Rodrigo, 2004). Moreover, the regional factors (e.g. Mediterranean Sea surface temperature, moisture content of the air column) are expected to play an important role.

4. Socio-environmental Aspects

At present, about 400 million people live in the countries around the Mediterranean Sea and about 145 million (that is 34% of total) people live in the coastal region. The largest number of people live in Italy (32 million), Egypt (24 million), Turkey (11 million), Algeria (10 million) and Greece (9 million). The largest fraction of the total coastline (46,000 km) is in Greece (15,000 km), followed by Italy (8,000 km), Croatia (6,000 km) and Turkey (5,000 km). This densely populated area has large economic, cultural and demographic contrasts[1]. There are approximately 10-fold differences in GDP (Gross Domestic Product) between the largest economies of the European Union countries and Middle East nations, and a 3- to 6-fold difference in the GDP per-capita between Western European countries and the other nations. The largest economies are those of

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[1] Information on economic situation, water resources, demographic trends and environmental risks are available at the web page of "Le plan Bleu": http://www.planbleu.org

France and Italy (about 1,500 and 1,200 trillion $ GNP, respectively). At the same time 8 countries have less than 20 trillion $ GNP. While the same two countries have a per-capita GNP larger than 20,000 $, there are 6 countries with less than 2,000 $[2]. Demographic trends are also quite different in the area. European countries (also including non-EU nations) are close to null growth and expected to stabilize or even decrease their population, while North African and Middle East countries are growing and are expected to double their population by mid 21st century. In contrast with European Countries, urbanization in most African and Middle East Nations is an ongoing process that is changing the socio-economic structures of these regions. In the second half of the 20th century, a 5- to 10-fold increase in population of large towns has been common for African and Asian countries, with respect to the lower than 2-fold increase of southern European countries. At present, Cairo (which increased 4-fold since 1950) and Istanbul (which increased 8-fold) are the twentieth and twenty-second largest city of the globe, respectively.

Population increase is exerting a demographic pressure with an estimated increase from 420 million in 2000 to 530 million in the year 2025 (Tsiourtis, 2001). Migration, caused by soil degradation or even desertification is a very important issue in the Mediterranean area, the southern part of which is mostly dry and vulnerable to climate change. Desertification is not only caused by climate, but also by decisions at all levels in society regarding land use. In fact, natural and human systems are vulnerable to the scarcity and irregular availability of water resources that characterize the region's climate. Presently, 60% of water-poor world population live in the Mediterranean region (i.e. disposing of less than 1,000 m^3 per-capita per year) concentrated in the eastern and southern countries. In fact, about 1,200 km^3 are available per year in the whole Mediterranean region (about 50% of them are truly exploitable) and they are very unevenly distributed, so that 71, 20 and 9% of water resources are present in the northern, eastern and southern countries, respectively. Presently 30 million people do not have access to safe water, and structural water shortages are expected to affect 60 million people in 2025. This situation might become very critical if climate change would imply a reduction in precipitation.

At present, agriculture still constitutes a major economic activity in the region, corresponding to 20% of the GNP of southern Mediterranean countries, precisely those that are most affected by the variation in water availability. Roughly 50% of the total land area is used for agriculture, absorbing over 80 and 60% of total water demand in the African and European countries surrounding the Mediterranean Sea, respectively. Critical situations of water shortages and extended droughts are mostly due to high values of seasonal and year-to-year

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[2] All data refer to year 1998

variability in precipitation. In the Mediterranean region, where most of the annual rainfall occurs during the winter half-year, severe water deficits can occur during the growing season even when there is sufficient annual precipitation, so that the impact of temperature and precipitation on most crop yields is mostly dependent on changes in the seasonal cycle of these parameters, rather than on fluctuation in their annual average value (Rötter and van de Geijn, 1999). This is especially true in the eastern Mediterranean and Near East (e.g. Tarawneh and Kadioglu, 2003). The hot and dry spell of summer 2003 produced noticeable damage to agriculture in Spain, Italy and France, where reduction was largest for fodder (−30, −40, and −60% respectively) and maize (−10, −25, −30%, respectively), but also heavily affected wheat and potatoes. The generalized dry and hot conditions throughout Europe also had a major impact in increased mortality in the livestock and poultry stocks. The combined effect on reduced crop yields and animals stocks to farmers in Western Europe financial losses up to 13 billion Euros (Fink et al., 2004). There is the fear that climate change could increase the stress due to recurrent droughts and have strong negative effects on crops and on the capability to satisfy internal food demand.

Heat waves are also perceived to be a major health danger after the 2003 episode that hit Central Europe, heavily affecting north western Mediterranean countries such as Spain, France and Italy. The average summer temperature in Europe exceeded, very likely, the average temperature of any previous summer over the last 500 years (Luterbacher et al., 2004). Unusually high temperature began in June and persisted for the whole July until mid-August. However, from a public health and forest protection perspective, it was the relatively short-lived heatwave that occurred during the first fortnight of August 2003 that had a major impact in Europe (Trigo et al., 2005). The extremely high temperatures in early August were responsible for about 30,000 casualties in Western Europe, half of these in France alone, about 4,200 in Spain, 4,000 in Italy, 2,000 in Portugal and 1,000 in Switzerland. Elderly people, aged over 65 years, children under 4 years, and patients with cardiovascular and chronic respiratory diseases were the most vulnerable categories during such events (Díaz et al., 2005).

Sea level rise (SLR) represents another potential threat, though the projected SLR, accounting for several possible scenarios, is from 0.09 to 0.88 m by 2100 and should affect only restricted coastal zones. Moreover, also local soil subsidence contribute to increasing the vulnerability of parts of the Mediterranean coast. The most vulnerable situation is in Egypt, where it has been evaluated that a 150 cm sea level rise would imply the loss of 20% of agricultural areas, because of the low lying Nile Delta. Other situations at risk are the Camargue in France and the Venice Lagoon in Italy, where a critical area in the central part of the town is at a level between 70 and 80 cm above the mean sea level (MSL), with a tidal range of about 50 cm.

Extreme adverse weather events have a high social and economic impact in the Mediterranean area. Especially heavy rainfall and floods, because of many steep river basins which are present in a densely populated territory, are a major concern. On the basis of 166 cases of heavy rainfall and floods and 104 cases of strong winds during 10 years of data, total number of victims above 1,900 and economic losses over 6,000 M Euro have been estimated. This figure is likely to be an undervaluation. For Spain alone, and only in four years (1996–1999), the Programme of Natural Hazards of the Spanish Directorate of Civil Defence has accounted 155 deaths by heavy rain and flood events and 28 deaths by storms and strong winds (Jansa et al., 2001a). In Greece, according to the data published from the Hellenic Agricultural Insurance Organization (ELGA) for the year 2002 alone the economic losses from heavy precipitation, hail, floods and extreme winds were over 180 MEuro. Single disastrous events have been recorded, such as the 4th November 1966 storm which hit central and north eastern Italy, causing more than 50 deaths. The widespread, huge damages in the eastern Alps, Florence and Venice have been estimated to be more than 1 MEuro present-day (De Zolt et al., 2006). Several studies show that the overall cyclonic activity in the Mediterranean region is expected to decrease as an effect of climate change in this century, but extremes could behave differently. The frequency of intense precipitations have been observed to increase in the second half of the 20th century in some regions (e.g. Alpert et al., 2002; Kostopoulou and Jones, 2005) and some simulations show that these events will be more intense in a future emission scenario (Giorgi et al., 2004).

This 4th section shows that there are reasons for concern as climate change in the Mediterranean region could affect economically relevant activities and determine social problems related to health and wealth of people. Different level of services, of readiness to emergencies, technological and economic resources, are likely to result in very different adaptation capabilities to environmental changes and new problems. The different economic situations and demographic trends are likely to produce contrasts and conflicts in a condition of limited available resources and environmental stress. Besides description of adaptation strategies, and evaluation of costs, which are needed to reduce such risks, research for understanding of climate mechanisms and the best possible prediction of future climate scenarios has to be continued in order to provide the most reliable information on the evolution of the Mediterranean climate.

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Notes

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