White Paper on Mediterranean Climate Variability and Predictability

Positioning MedCLIVAR as coordinated scientific activities under CLIVAR umbrella.

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Contents

0. The Mediterranean Climate: Basic Issues and Perspectives

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The Mediterranean Region has many morphologic, geographical, historical and societal characteristics which make its climate scientifically interesting per se (e.g. Bolle 2003). At the same time, the connotation of "Mediterranean climate" has been extended to define the climate of other (generally smaller) regions and hence it has its own role in the qualitative classification of the different types of climate on Earth (e.g. Köppen, 1936). In general, the qualitative 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.

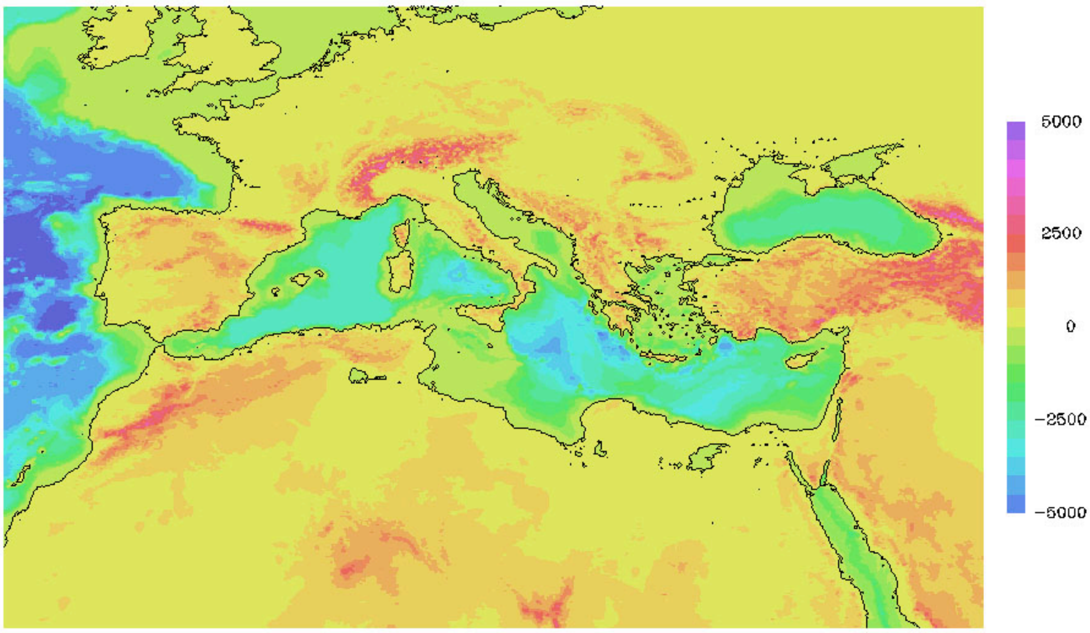

Figure 1. Sea floor data based on Smith, W. H. F., and D. T. Sandwell, Global seafloor topography from satellite altimetry and ship depth soundings (Science, v. 277, p.1957-1962, 1997). Land elevation data based on the GTOPO30 global digital elevation model, developed through a collaborative effort led by staff at the U.S. Geological Survey's EROS Data Center (EDC).

The Mediterranean Sea (fig. 1), a marginal and semi-enclosed sea, 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 3700 km in longitude, 1600 km in latitude and surrounded by 21 African, Asian and European countries .

The average depth is 1500 m. with a maximum depth of 5150 m in the Ionian Sea. The Mediterranean Sea is an almost completely closed basin, being connected to the Atlantic Ocean through the narrow Gibraltar strait (14.5 km wide, less than 300m deep at the seal). These morphologic characteristics are rather unique. In fact, most of the other marginal basins have much smaller extent and depth or they are connected through much wider openings to the open ocean. Examples of the first type are the Black and Baltic seas, of the second the Gulf of Mexico and the Arabian Sea, among others. 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. Moreover, high mountain ridges surrounds the Mediterranean Sea on almost every side. Furthermore, strong albedo differences exist in south-north directions (Bolle, 2003). These characteristics have important consequences on air masses and atmospheric circulation at the regional scale (e.g. Xoplaki et al. 2003, 2004): the Mediterranean sea is an important heat reservoir and source of moisture for surrounding land areas; it represents an important source of energy and moisture for cyclone development and its complex land topography plays a crucial role in steering air flow, so that energetic meso-scale features are present in the atmospheric circulation; the ocean circulation is characterized by sub-basin scale gyres defined by the geometry and topography of the basin.

Because of its latitude, the Mediterranean Sea is located in a transitional zone where mid-latitude and tropical variability are both important and compete. Thus, the Mediterranean climate region evolves on the north to the Marine West Coast Climate (from 40° to sub-polar regions) and on the south to the Subtropical Desert Climate (southward of 30° or 25°). Further, the Mediterranean climate is exposed to the Sout Asian Monsoon (SAM) 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 and other mid latitude teleconnections patterns. However, the climate variability patterns (teleconnections) present a large amount of synoptic to meso-scale spatial variability, inter-seasonal and multi-decadal to centennial time variability (see sec. 0.1 and chapter 2). An important consequence is that the analysis of the Mediterranean Climate can be used to identify changes in the intensity and extension of global scale climate pattern like NAO, ENSO and the monsoons and their region of influence.

Another important characteristic of the Mediterranean region is the large amount of climate information from in historical times (see section 1.1). This characteristic is unique on the global scale and has not yet fully exploited. The continuous presence of well-organized local states and the long tradition of scholarship and natural science produced reliable chronicles, which might allow 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. the surge of Venice, Camuffo, 1987). This availability of chronicles (see chapter 2) is complemented 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, Maugeri et al. 2002; Camuffo 2002; Barriendos et al. 2002; Rodrigo 2002). Further, there are some regional temperature and precipitation reconstructions based on natural proxies (e.g. Till and Guiot, 1990; Mann 2002; Touchan et al. 2003). This richness of data gives a unique opportunity for reconstruction of climate in past historical and recent instrumentally developed times.

A further important characteristic of the Mediterranean Sea is the emergence of the first highly populated and technologically advanced societies since, at least, 2000BC. 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.

Nowadays, about 400 millions people live in the countries around the Mediterranean Sea. This densely populated area has large economic, cultural and demographic contrasts. There are approximately 10-fold differences in GDP between the largest economies of the European Union countries and small Middle East nations, and a 3 to 6-fold difference in the GDP per-capita between Western European countries and the other nations. Demographic trends are also quite different. European countries (also including non EU nations) are close to a null growth and expected to stabilize or even decrease their population, while North African and Asian countries are growing and are expected to double their population by mid 21st century. At difference with European Countries, urbanization for most African Nations and is an ongoing process that is changing the socio-economic structures of these regions. In the second half of the 20th, a 5 to 10-fold increase in population of large towns is common for African and Asian countries, with respect to the lower than 2-fold increase of southern European countries. Nowadays, Cairo (which increased 4-fold since 1950) is the 20th largest town of the globe and Istanbul (which increased 8-fold) is number 22. All these different trends are likely to produce contrasts and conflicts in a condition of limited available resources. Moreover, different level of services, of readiness to emergencies, technological and economical resources, are likely to result in very different adaptation capabilities to environmental and climate changes. Poorer societies with recently increased urbanization are likely to be critically vulnerable to weather extremes and incapable to adapt to changing climate patterns. Hence the need is paramount for the best possible prediction of future climate scenarios and descriptions of adaptation strategies and costs.

The document comprises seven chapters, beside this introductory one, which overviews the characteristics of the Mediterranean climate and summarizes the major issues more extensively described in the following chapters. Chapter 1 describes the past and present trends of Mediterranean Climate and the information that is available for its reconstruction. Chapter 2 describes the relations between climate variability in the Mediterranean region and the global and mid-latitude climate "teleconnection" patterns. Chapter 3 describes the climatology of the Mediterranean Sea circulation. Chapter 4 describes the regional characteristics of the weather patterns. Chapter 5 describes the role of the Mediterranean salty water on the North Atlantic Deep Water cell. Chapter 6 discusses the simulation of the regional Mediterranean climate and its prediction in the future scenario. Finally chapter 7 briefly deals with solar activity.

0.1 The Mediterranean and 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. In fact, an important factor in the analysis of the teleconnections with global patterns is the role of orography and land-sea distribution, whose complexity in the Mediterranean region implies the presence of meso-scale structures and inter-seasonal variability in patterns that would be otherwise much more homogeneous and persistent.

The whole picture has still to be focused and the physical processes involved need to be identified. In spite of this, important, though incomplete, knowledge has already been established, and it is summarized in this subsection.

However, the large-scale atmospheric circulation exerts a strong influence on the cold season temperature and precipitation over the Mediterranean, though the strength of the relation varies with region. The largest amount of studies on the effect of the mid-latitude variability refers to the role of NAO (North Atlantic Oscillation), which determines a large and robust signal on winter precipitation, which is anti-correlated with NAO over most of the western Mediterranean region (Hurrell, 1996, Dai et al, 1997, Rodo et al 1997; Xoplaki 2002). However, in its Eastern part the advection of moisture from the Mediterranean itself produces a more complicated situation, and eventually other large-scale patterns, like EA (East Atlantic), play an important role (Fernandez et al. 2003, Krichak et al., 2002), and in the central Mediterranean the Scandinavian pattern has a strong influence (e.g. Xoplaki, 2002). This is superimposed with the effect of tropical variability, specifically with a reduction of cyclones in the Mediterranean area during La Niña events. Tropical variability modes like ENSO (Rodó, 2001, Mariotti et al., 2002) can be important in the parts where

NAO influence is weaker (Rodo et al 1997). There are evidences that ENSO is significantly correlated with winter rainfall in the Eastern Mediterranean (Yakir et al., 1996 and Price et al., 1998). However it is still open for debate, what could be the physical mechanisms for these links. In summer, when the advection of moisture from the Atlantic is weaker and the Hadley cell moves northward and attenuates, there are evidences of connections with the Asian and the African monsoons (stronger in the eastern part).

The influence of NAO on the Mediterranean temperature is weaker than on precipitation and the observed correlation has been found to be non-linear and non-stationary (Pozo Vazquez et al 2001). Mediterranean summer temperatures have no relation with the NAO, and they are not adequately linked to larger scale patterns. Rather, warm Mediterranean summers are connected with blocking conditions, subsidence, stability, a warm lower troposphere and positive Mediterranean SSTs (Xoplaki et al., 2003).

The analysis of teleconnection with global scale patterns is very important in a climate change perspective. During the second half of the 20th century, there is a well-documented trend showing the reduction of overall precipitation and its concentration in intense events, resulting in a progressively drier summer season and more dangerous floods. These trends can have large impacts on societies in the Mediterranean region. Because of the difficulty to resolve it in global climate simulations, the identification of teleconnections with large-scale patterns is a basic tool for the prediction of future climate conditions.

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 1960’s, but it has subsequently dropped by 2-3 cm. till the beginning of the 90’s (Tsimplis and Baker, 2000). During the last decade of the 20th century, sea level has increased 10 times faster than on global scale. These trends are superimposed with a major change that has characterized the Eastern Mediterranean 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 (Roether et al 1983). This was in fact the situation in the 80’s. Between 1987 and 1991, however, the “driving engine” of the thermohaline circulation shifted to the Southern Aegean/Cretan Sea, and starting in 1991 through the late 90’s all the intermediate and deep water of the Eastern Mediterranean was observed to spread out from the Aegean Sea through the Greek Arch Straits (Roether et al. 1996, Malanotte Rizzoli et al 1999). This transition is known as the Eastern Mediterranean Transient (EMT). 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). All these features and the circulation of the Mediterranean Sea have been object mostly of modelling and process oriented studies, which have not addressed the problem of its relation to global climate variability patterns. The role of local and large-scale forcing remains presently unclear.

The Mediterranean outflow across the Gibraltar strait determines the presence of a well-known tongue of very salty water in the entire Northern Atlantic at intermediate depths (1000 to 2500 m). This water introduces an important signature in the salinity field and has potentially important large-scale climate implications. Two mechanisms are presently envisioned through which the salty Mediterranean water may precondition the convective cells of the Atlantic northern Greenland and Labrador seas where North Atlantic Deep Water (NADW) is formed and which drive the Atlantic Meridional Overturning Circulation (MOC). The first mechanism involves a direct advective pathway from the Strait of Gibraltar to the polar seas, which is observed on all isopycnal surfaces from sigma-1+ 31.938 to sigma-3+41.44 (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). 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. The interaction of the Mediterranean Outflow with the thermohaline circulation of the North Atlantic rises 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).

0.2 Mediterranean climate internal structure

The simulation of the Mediterranean climate is a typical problem requiring the downscaling of global climate scenarios, that is of simulations carried out with GCM (Global Climate Models). The resolution presently used for global climate simulations does not describe adequately the basins that compose the Mediterranean Sea and of 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 step is at least smaller than 50km. Actually, even smaller scales have to be introduced for describing surface winds and precipitation, whose spatial variability involves scales smaller than 10km. Therefore, the extraction of information on many environmentally important quantities (like temperature, winds, precipitation) in the Mediterranean region, which is characterized by a large spatial variability, requires a complicated processing of information provided by the global simulations, that is downscaling (e.g. Marinucci e Giorgi 1992, Giorgi et al.1992, Dèquèt e Piedelievre 1995; González-Rouco et al. 2000; Gibelin and Déqué 2003).

Many studies, research programs and European projects have analyzed the problem of climate simulation over Europe, including the Mediterranean in the southern part of the considered region. The comparison between the results of long simulations carried out with LAMs (Limited Area Models) and observations shows that relevant systematic bias are present also when the LAMs use "perfect" lateral boundary conditions, that is boundary conditions derived from observations (Christensen et al. 1997). Moreover, the reliability of regional climate scenarios is affected by errors in the large-scale circulation that is used by the RCMs as lateral boundary conditions (Machenhauer et al. 1996). In fact, with respect to global simulations, the use of RCMs produces improvements in the reproduction of the orographic precipitation, of the structure and intensity of the cyclones, but no clear progress on the structure of the large-scale circulation. It appears that, because of errors in the models and in the boundary conditions, only increasing the resolution itself cannot produce more realistic regional climate scenarios. Therefore, the results of climate change studies are only partly significant, because the resulting climate change signal is comparable to their systematic error, whose reduction is crucial for the evaluation of the climatic change in the Mediterranean region. However, the various model simulations of the anthropogenic effect on climate, tend to agree predicting in the Mediterranean region a temperature increase larger than the global average and a modest (and controversial) precipitation decrease. Climate change simulations produce a signal in the range from +3 to +7K for temperature and from –40% to +20% for precipitation (Giorgi and Francisco, 2000a; 2000b).

The correct analysis of climate mechanisms internal to the Mediterranean region is not only important to connect global scale and regional scale patterns, but also to identify internal modes. Particularly in reference to the moisture balance, the western Mediterranean Sea represents source for the surrounding land areas and the eastern part of the region, as the moisture released by evaporation is redistributed by the atmospheric circulation (Fernandez et al. 2003). It would be important to investigate whether these processes represent coupled atmosphere-ocean variability modes and their importance for the regional hydrological cycle. Regional weather regimes are a basic element of this variability. They are characterized by meso-scale features and several cyclogenesis areas (e.g. Alpert et al.1990, Trigo et al. 1999). Orographic cyclogenesis is a well-established process, which implies that many of them are triggered by synoptic systems passing over central and Northern Europe along the Northern Hemisphere storm track. The large scale patterns describing their variability are not well established and, though NAO plays a role, other teleconnection patterns with centres of action located closer to or above Europe are likely to be mostly responsible for it (Rogers 1990, 1997). The importance of regional factors (e.g.

Mediterranean Sea surface temperature, moisture content of the air column) has also to be assessed.

The importance of localized convection processes is determined by air-sea interactions and by the basin thermohaline circulations. Intense cooling and evaporation over restricted areas in the north-western Gulf of Lyon, the southern Adriatic sea and, in the 90's, the Aegean/Cretan sea determine the formation of dense waters filling the bottom of the basin (Western and Eastern Mediterranean bottom waters related to the respective sources). The two sub-basins are moreover almost disconnected at these deep/bottom levels, hence their thermohaline circulations are independently driven by the respective sources. As previously discussed, 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 (Levantine Intermediate Water) which is part of the open thermohaline cell constituted by two branches: Atlantic Water entering at Gibraltar and making its way to the Levantine, there been transformed into LIW by intermediate convection processes and returning all the way to Gibraltar where it finally exits forming the North Atlantic salty water tongue. External forcing mechanisms have been invoked as responsible for the variability of these processes. For instance, it has been shown that the wind stress climatology over the Eastern Mediterranean was quite different in the 80's and the 90's. This forcing variability may have induced the observed important change in the Eastern Mediterranean upper thermocline circulation which undoubtedly affected the LIW pathways. Internal mechanisms may equally be at play, such as an internal redistribution of salt in the Eastern basin (Roether et al., 1996) versus an overall change in the surface heat budget. The construction of the Nile dam and the diversion of Russian rivers were argued to have had an impact in the EMT event (Boscolo and Bryden, 2001) as well as induced an increase in the overall salinity of the whole Mediterranean basin (Rohling and Bryden, 1992) -though the competing effects of these various mechanisms is far from understood. The Black sea outflow undoubtedly plays a role in the Northern Aegean hydrographic conditions, even though how the Black sea induced freshening of Aegean waters may be confined to its northern areas and no affect the dense water formation processes of the southern Aegean/Cretan sea that led to the EMT. As a conclusion, the investigation, both from an observational and modelling perspectives, of the different processes occurring in the different parts of the Mediterranean, of their interactions and mutual feedbacks is far from having been explored and even less understood.

0.3 Scientific Issues and Goals of the MedCLIVAR project

The previous discussion suggests that the following activities are fundamental for the understanding of the Mediterranean climate and will be promoted by the MedCLIVAR project:

- To construct homogeneous sets of data for regional climate analysis and comparison with model simulations. Presently, often the single sets of data supply information, which is rich and very valuable, but fragmentary and local in its scope. These homogeneous data sets should consist of chronicle based, indirect climate reconstructions, and also include instrumental observations, which are often disperse in the archives of many different institution, and difficult to be accessed by researchers, with their use often being based on personal contacts. The sets of data should be extended to establish a permanent environmental monitoring network
- To correct for the fragmentary reconstruction of the Mediterranean Sea circulation as based on conventional oceanographic campaigns (with consequent time and space lack of resolution) via the establishment of a permanent observational system. The key observational objectives should include exchanges across the main straits and the identification of representative locations recommended for continuous monitoring. Data archive shall include satellite observations (post 1985, circa) and favour the parallel analysis of measurements campaigns, remote sensing and "in situ" observations
- To establish an archive of model simulations relevant at the regional Mediterranean scale and provide information that could be used for performing regional simulations. To support exchange of information and favour coordination and exchange of data among groups of modellers
- To provide a reference source of information to bridge the gap between research, on one side, and authorities, public opinion and "end users' in general, on the other side. Distribute the information on active projects and their main results, on climate research in general via a dedicated web-page and eventual press releases. Promote workshops and conferences on Mediterranean climate.

The tools developed by these activities will be a fundamental support for research on the following scientific issues and objectives, which will be addressed by the MedCLIVAR project:

- Identification of the physical mechanisms responsible for the statistically observed teleconnections between the Mediterranean and global scale climate patterns, with focus on the role of the meso-scale structures in the distortion of the effect of global patterns in the Mediterranean regions. This issue is important in a climate change perspective, as Mediterranean Sea is not adequately resolved in global climate simulation and the direct identification of climate change signal is uncertain.

- Understanding the link between Mediterranean weather patterns and large-scale variability modes and assess the role of regional climatic conditions (e.g. SST patterns and mean value, moisture content of the Mediterranean air mass) on the intensity and frequency of the Mediterranean weather events.
- Use the Mediterranean climate variations as a proxy for changes of the relative intensity and extension of mid-latitude and tropical climate variability patterns and of global regimes in general.
- Reconstruction of past Mediterranean climate using multiproxy data. Analysis of the nature of the past climate and of the causes of its variability, in order to establish if they are related to any forcing such as solar or volcanic, or they are random internal variations (the english structure is I think not yet correct).
- Analysis of the environmental and climatic effect of the strong anthropic influence. In the Mediterranean region, land use change has taken place since ancient time and is related to agriculture, forestry exploitation, urbanization, river and lakes management, and heavy demographic pressure. The importance of this regional anthropic forcing should be compared to that of shift and changes of global climate regimes.
- Understanding the role of solar variability and volcanism in the Mediterranean climate combining paleo-climate model simulations and proxy based reconstructions
- Identification of the links between water formation processes (both LIW and MBW) and large scale and Mediterranean internal climate variability modes. This involves studies of air-sea interaction, deep convection and of the strait exchanges between sub-basins (internal to the Mediterranean) and through the Gibraltar Strait, in order to understand the formation and the subsequent evolution of water masses. It moreover, includes the analysis of deep and intermediate-depth temperature of the Mediterranean Sea and of its mean sea level in order to identify mechanisms and relations to the large-scale climatic trends.
- Assessment of the role of the Mediterranean Sea as moisture and heat reservoir for the surrounding regions. Identification of the relevant time scales and spatial patterns.
- Evaluation of regional climate changes patterns and prediction of future scenarios. The analysis should include the identification of adaptation goals, with focus on the hydrological cycle, increased probability of intense floods, and decreased availability of water during the dry season.

0.4 Interactions with Other Projects and Initiatives

MedCLIVAR project will benefit from the cooperation with related ongoing efforts in the Mediterranean region. The project “Eau Mediterranee en Atlantique” (EMA) coordinated by X. Carton et al. (2004) is highly relevant to the objectives of the present effort. We have already established contacts with EMA scientists. Another ongoing activity that MedCLIVAR will seek linkages with is the Mediterranean Forecasting System (http://www.bo.ingv.it/mfstep/), a EU Framework 5 project coordinated by N. Pinardi that is contributing to the GODAE.

Plans are developing for a Mediterranean GEWEX Continental Scale Experiment proposed by Y. Tourre and J-H. Bolle. Contacts are already established with Y. Tourre for a close coordination during the planning phase.

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1. Past and Present Trends of Mediterranean Climate

1.1 Past Mediterranean Climate Variability

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Detailed insight into temporal and spatial patterns of climate change over the last centuries is important for assessing the degree to which late 20th century changes may be unusual in the light of pre-industrial natural climate variability. The Mediterranean area offers a broad spectrum and dense network of long instrumental series and natural proxies and documentary information, making this region ideal for climate reconstructions, as well as the analysis of changes in climate extremes and socio-economic impacts prior to the instrumental period. Scientific challenges for future research should include the collection of more, natural proxies especially from the eastern Mediterranean and the exploration of new climate information from Islamic archives, ship logbooks, and other documentary sources. Using multivariate calibration of all the proxy data against instrumental records will provide long reconstructions and uncertainties estimations for the larger Mediterranean area. The reconstructions will allow studying high and low frequency climate variability, trends, anomalies, abrupt changes, the relation to important atmospheric circulation patterns (e.g. NAO, AO) and how Mediterranean climate covaried with central and northern Europe. It will be of much interest to address the question on the causes and nature of past Mediterranean climate variability; are they random internal variations or related to any forcing such as solar or volcanic? Another focus will be the investigation of extreme events such as floodings, droughts, windstorms, frosts, etc. with socio-economic impact in different Mediterranean areas.

Another approach complementary to the reconstructions is the use of Global Climate Model simulations. GCM paleo simulations can be compared with the results inferred from proxy data.

1.1.1 Introduction

A necessary task for assessing the degree to which the instrumental period is unusual against the background of pre-industrial climate variability, is the reconstruction and interpretation of temporal and spatial patterns of climate change in prior centuries. Reconstructions of past climate can also help inform our dynamical and physical understanding of the relevant processes. To deduce a year-by-year chronology of pre-instrumental climate changes, we must rely upon high-resolution ‘proxy’ climate indicators from natural archives (corals, ice cores, tree rings, lake sediments, boreholes and speleothems, e.g. Mann et al. 1998, 2003; Jones et al. 2001; Briffa et al. 2001; Esper et al. 2002) and documentary evidence (chronicles and historiographies, narratives, annals, records of public administration and government, scientific writings, monastery records, information on religious processions and others--e.g. Martin-Vide and Barriendos 1995, Barriendos 1997, Rodrigo et al. 1999, 2000; Pfister 1999, Glaser 2001, Pfister et al. 2002; Garcia et al., 2003; Brázdil et al. 2002, 2004).

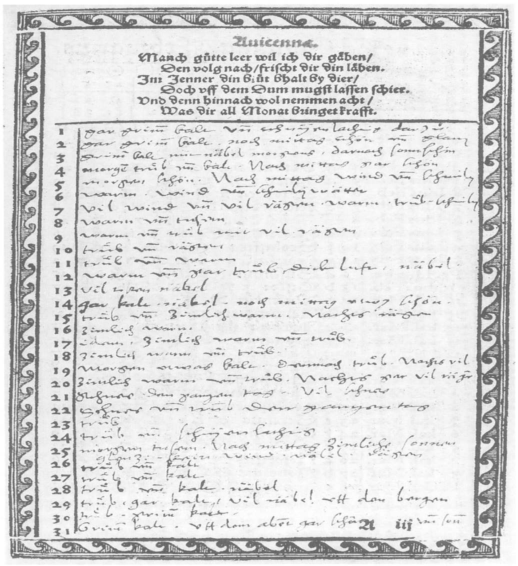

Figure 2. (left) Weather diary of Wolfgang Haller, January 1573, Zurich (from Pfister 1999) (right) Flood of September 1862 in Barcelona after removing the walled perimeter (from Amades 1984).

Documentary proxy information provide the only evidence that directly relates to socio-economic climate impacts, in particular with regard to rare but socio-economically significant natural disasters (e.g. severe floods, droughts, windstorms, frosts, hailstorms, etc.) prior to the period of instrumental measurement (e.g. Pfister et al. 2002, Brázdil et al. 2002, 2004). Figure 2 presents an example of a weather diary from Switzerland (Pfister 1999) and a past flood event in Barcelona 1862 (Amades 1984). The Mediterranean area offers a broad spectrum of both natural and documentary information, both in time and space making this area ideal for climate reconstructions of past centuries, as well as the analysis of changes in climate extremes and socio-economic impacts prior to the instrumental period. We first report on reconstructions of climate variables from documentary and natural data at local or regional scale including climate extremes and the incidence of natural disasters. We then turn to recent attempts of large-scale multi-proxy field reconstructions for the Mediterranean. Finally, we comment on the scientific challenges for future research on past Mediterranean climate variability.

1.1.2 Regional Mediterranean Climate Variability and Extremes Based on Documentary Evidence

SPAIN. The Spanish historical archives exhibit great potential for inferences into climate variability at different time-scales and for different territories. García et al. (2003) report on the main archives and discuss the techniques, strategies and potential to obtain climate-relevant information from documentary records. Martin-Vide and Barriendos (1995), Barriendos (1997) and Barriendos and Llasat (2003) used rogation ceremony records for climatic reconstructions for Catalonia. Rodrigo et al. (1999, 2000, 2001) reconstruct a 500-year seasonal precipitation record for Andalusia, derive a winter NAO index, and interpret its past variability. Precipitation in the Canary Islands has been reconstructed through the use of agricultural records for the period 1595-1836 (García Herrera et al. 2003). It is shown that the NAO correlates negatively with rainfall, even in this southern limit of the greater Mediterranean area. Barriendos and Martin-Vide (1998), Benito et al. (2003) and Llasat et al. (2003) investigated flood magnitude and frequency within the context of climatic variability for the last centuries for central Spain and Catalonia. The authors found evidence for high flood frequencies in the past similar to present conditions.

FRANCE. The extensive study of Pichard (1999) in Southern France (Provence) has shown that the 1550-1920 period was characterized by much more frequent floods of the Rhone and Durance rivers compared to the 20th century. Presence of floating ice on these rivers was not at all seldom while they are almost absent since one century. The wettest climate of the 'Little Ice Age' was, as for other parts of the Mediterranean (see Xoplaki et al. 2001 for Greece), during the periods 1650-1710 and 1750-1820.

ITALY. Also Italian archives, libraries and museums provide a great number of written historical sources on different aspects of past climate reaching back more than 1000 years. Camuffo and Enzi (1992, 1994, 1995) report on extreme events in Italy with specific emphasise on the Late Maunder Minimum period (1675-1715). A large number of citations, pictorial and literary representations have been used to study the freezing of the Venetian lagoon since the 9th century (Camuffo 1987) and its surges (Camuffo 1993, Enzi and Camuffo 1995, Camuffo and Sturaro 2003). Further, Camuffo et al. (2000abc) investigated fire risk, the storm frequency in the Adriatic Sea, as well as past hailstorms and thunderstorms over the last centuries. Finally, Piervitali and Colacino (2001) analysed drought events that occurred in western Sicily during the period 1565-1915 using historical information from the church.

SOUTHERN BALKANS and GREECE. The Balkan Peninsula (Greece, former Yugoslavian countries, Albania, Bulgaria and Romania) provides rich archives of documentary data. Repapis et al. (1989) investigated the frequency of occurrence of severe Greek winters based on evidence from monastery and historical records during the period 1200-1900. They found evidence, that the coldest periods occurred in the first half of the 15th century, in the second half of the 17th century and in the 19th century. Grove and Conterio (1994, 1995), Grove (2001) and Xoplaki et al. (2001) reported on the variability of climate and extremes during parts of the 'Little Ice Age'.

1.1.3 Natural Proxy-Based Reconstructions of Past Climate over Specific Regions of the Mediterranean

Many past studies have described the use of tree-ring or 'dendroclimatic' data to reconstruct past variations in precipitation, temperature, the frequency of extreme droughts, and atmospheric circulation indices.

Novau et al. (1995) used tree-ring information to reconstruct the climatic conditions in Galicia (north-western Spain) for the last centuries. Recently, Touchan et al. (2003) used tree-ring data from southwestern Turkey to reconstruct spring (May-June) precipitation several centuries back in time. They found, that spring drought (wetness) is connected with warm (cool) conditions and southwesterly (continental) circulation over the eastern Mediterranean. D'Arrigo and Cullen (2001) presented a 350-year dendroclimatic reconstruction of February-August precipitation for central Turkey (Sivas). Touchan et al. (1999) developed a reconstruction of October-May precipitation for southern Jordan back to 1600. These reconstructions show evidence of multi-year to decadal rainfall variations over the eastern Mediterranean.

Meko (1985) and Chbouki et al. (1995) discussed temporal and spatial variation of Moroccan drought. Till and Guiot (1990) published a 900-year reconstruction of October-September precipitation for three different areas in Morocco, indicating a continuous tendency towards a wetter climate during the 20th century, and drier conditions than present during the 16th, 17th and 18th century. Glueck and Stockton (2001) used climate-sensitive Moroccan tree-ring data to reconstruct the winter NAO index back to 1429. Tree-ring data have also been used to estimate seasonal and annual mean temperature at specific Mediterranean areas for the last centuries (Serre-Bachet and Guiot 1987; Serre-Bachet et al. 1992; Guiot et al. 1988). Briffa et al. (2001) presented an averaged southern European April-September temperature series back to the 17th century.

Felis et al. (2000) showed that coral records from the Northern Red Sea provide evidence that interactions between tropical/extra tropical modes of the global climate system had an important control on Middle East climate variability. Colder (warmer) conditions go along with more arid (less arid) conditions in the northern Red Sea and wetter (drier) conditions in the southeastern Mediterranean. It was shown that during winter the coral record is linked to the Arctic Oscillation (AO), which controls the advection of colder air from southeastern Europe towards the northern Red Sea (Rimbu et al. 2001). This finding is consistent with other evidence of a connection between the Northern Hemisphere (NH) annual modes (‘AO’ or ‘NAO’) and Middle East climate variability in past centuries (Cullen et al. 2002; Mann 2002).

1.1.4 Large Scale Climate Reconstructions for the Mediterranean

Complimentary in its focus to the local or regional reconstructions of changes in climate and climate extremes discussed above, large-scale reconstructions of climate fields, employing the multivariate calibration of the proxy data against instrumental records, allow insight into both the spatial and temporal details about past climate variations over the Mediterranean region. This approach of climate field reconstructions provides a distinct advantage over averaged climate reconstructions for instance, when information on the spatial response to external forcing (e.g. volcanic, solar) is sought (e.g. Fischer et al. 2004).

Briffa et al. (2002) have used tree-ring maximum latewood density data to reconstruct large-scale patterns of warm-season (April-September) mean temperature for the period 1600-1887 for the NH, including the Mediterranean. Mann (2002) used proxy data and long historical and instrumental records to reconstruct and interpret large-scale surface temperature patterns back to the mid-18th century for the Middle and Near East. This study suggested that interannual temperature variability in these regions in past centuries appears to been closely tied to changes in the NAO. Pauling et al. (2003) demonstrated that speleothems from Scotland and tree-ring data provided the greatest levels of skill in reconstructions of boreal cold-season (October-March) temperatures in the western Mediterranean, while historical documentary evidence provided the greatest skill for reconstructions of the northern basin and parts of northern Africa, and Red Sea coral data provided the greatest skill in reconstructions of the eastern basin. For boreal warm-season (April-September) temperatures, tree-rings, documentary data and the speleothem proved to be most important. Thus, large-scale climate reconstructions based on a careful selection of a combination of temperature/precipitation sensitive proxies from the whole of Europe, including the Mediterranean provide the most reliable means for reconstructing past regional and seasonal climate variability. Luterbacher and Xoplaki (2003) have produced multiproxy (instrumental station series, documentary evidence and single tree-ring data) winter mean spatially-averaged Mediterranean temperature (Figure 3) and precipitation (not shown) time series back to 1500. They found several cold relapses and warm intervals as well as dry and wet periods on the decadal timescale, on which shorter-period quasi-oscillatory behaviour was superimposed. They report also on the spatial temperature anomaly distribution for cold and warm winter extremes.

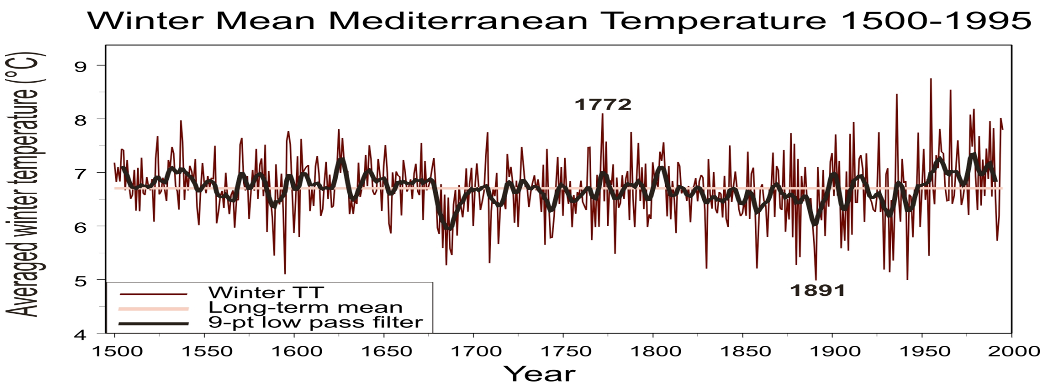

Figure 3. Winter (DJF) mean Mediterranean temperature time series from 1500-1995 defined as the average over 10°W-40°E; 30°N-47°N (thin green line). The winter values for the period 1500-1900 are the reconstructions, the values from the 20th century are taken from the New et al. (2000) data set. The thick dark green line is the 9-point low pass filtered time series. The long-term (1500-1995) winter temperature mean is given in yellow. The warmest and the coldest winters of the reconstruction period are denoted by black letters (Luterbacher and Xoplaki 2003).

Guiot (1991) used a combination of documentary proxy evidence and natural proxies to provide annual temperature estimates from 1068-1979 for Europe, including a large part of the Mediterranean area. He found a significant connection between Northwest Europe and the Central Mediterranean region during the ‘Little Ice Age’, while the Western Mediterranean region had not experienced any significant cooling.

1.1.5 Scientific Challenges for Future Research on Past Climate

- Collect further high resolution, accurately dated, natural and documentary proxy evidence, especially in areas with scarce information (North African coastal regions). Archives of the Islamic world are believed to provide evidence on past weather and climate. Attention should be paid to logbooks, since they provide relevant climate data over the sea areas. The abstraction of logbooks for other sea areas is currently under development (www.ucm.es/info/cliwoc). Logbook information should also be abstracted for the Mediterranean, since it has historically been a well-travelled sea. In Cyprus, Turkey and the near East there is potential for more tree-ring series.
- Combine all climate information in a ‘multiproxy’ approach to provide highly spatially and temporally resolved climate reconstructions for the Mediterranean and sub-regions, focusing on temperature, precipitation, and other parameters such as potential evapotranspiration, which is a key variable for agriculture and water-resource management.
- Estimation of uncertainties of the reconstructions, both in time and space.
- Study of high and low frequency climate variability over the Mediterranean area. Study of trends, anomalies and abrupt changes for different seasons.
- Relationship between independently reconstructed atmospheric circulation patterns (e.g. NAO, AO, EU, etc.) and Mediterranean climate. Are the relationships stable through time, if not, what might be the reasons?
- Can we obtain past information on the state of the Mediterranean Sea and its connection to the climate in the past?
- Analysis of single (extreme) events and investigations of trends in extremes.
- Relate natural disasters (extremes) from Mediterranean areas to the atmospheric circulation. Which flow patterns are relevant for climate extremes, do the patterns change through time both in frequency and in within-type characteristics? (e.g. Jacobeit et al. 2003).
- How does Mediterranean climate co-vary with central/northern Europe?
- Examination of causes and nature of past Mediterranean climate variability, extremes and rapid climate change. What are the roles of large volcanic eruptions (e.g. Fischer et al.

2004), solar variability and contributions from anthropogenic forcing factors in space and time?

- Examination of how climatic change over the Mediterranean has influenced society and human activities.
- Comparison of reconstructions of past Mediterranean variability and transient global climate simulations and regional climate models of the last millennium can bring a twofold benefit: Firstly, they can be used to validate climate reconstruction methods, which can be tested in the simulated climate states. Secondly, they can be used to identify the limitations of the model in reproducing climate variability and in simulating past climate changes (e.g. Zorita and González-Rouco 2002; González-Rouco et al. 2003; Zorita et al. 2004). They can, in turn, then be used to establish uncertainties in scenarios of future climate change.

1.2 Present Trends of Mediterranean Climate

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Instrumental data reveal significant trends of Mediterranean temperature and precipitation at different time and space scales. For instance, during the last 50 years of the 20th century large parts of the Mediterranean experienced winter and summer warming. For the same period precipitation over the Mediterranean decreased, though only partly statistically significant due to the large variability. These trends, however, differ across regions and periods under consideration showing variability at a range of scales in response to changes in the direct radiative forcing and variations in internal modes of the climate system. It is one of the main challenges for future research to understand the physical processes and causes responsible for these trends. They seem to be hemispheric to global (such as external forcings and changes in the large-scale atmospheric circulation), anthropogenic as well as local/regional (such as changes in earth surface and land use, orography). One part for instance will deal with the investigation of the important large-scale climate modes to explain regional temperature and precipitation variability and trends for different periods and seasons within the instrumental period using sophisticated statistical methods. These circulation-climate relationships derived in the instrumental period can then be used for past climate estimates, seasonal forecasts as well as for assessing future climate changes in dependence of scenario projections.

Further, analyses of climate model simulations of the 20th century with regional climate models driven by boundary conditions produced by global general circulation models will be performed using long integrations (e.g. 50 years) with different forcing factors (e.g. only solar variability and only changing anthropogenic greenhouse gas concentrations) in order to help to elucidate the origins of trends.

Apart from interannual to interdecadal considerations, future work will also deal with the analysis of climate extremes such as heat/cold waves, droughts, floods, etc. for different parts of the Mediterranean connected with socio-economic impact.

1.2.1 Introduction

Observational studies indicate significant climate trends on different time scales in the Atlantic-European area, including the larger Mediterranean area. The physical processes responsible for these trends and changes seem to be hemispheric to global (such as external forcings and changes in the large-scale atmospheric circulation) as well as local/regional (such as changes in earth surface and land use). It is one of the main challenges to understand the recent trends and changes over the Mediterranean region, both in space and time. The following sections summarize observed Mediterranean climate evolution and gives possible explanations followed by scientific challenges for future research.

1.2.2 Observed Temperature Trends over the Mediterranean

Giorgi (2002) analyzed 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 annual warming trend of 0.75°C, mostly from contributions in the early and late decades of the century. Slightly higher values were observed for winter and summer. Based on the same data, Jacobeit (2000) found a distinct summer warming for the 1969-1998 period. The structure of climate series can differ considerably across regions showing variability at a range of scales in response to changes in the direct radiative forcing and variations in internal modes of the climate system (New et al. 2001; Hansen et al. 2001; Giorgi 2002). Figure 4 (right) presents the linear trends of summer surface air temperatures (°C/50yr) for the period 1950-1999. It also shows the stations, which experienced a significant trend.

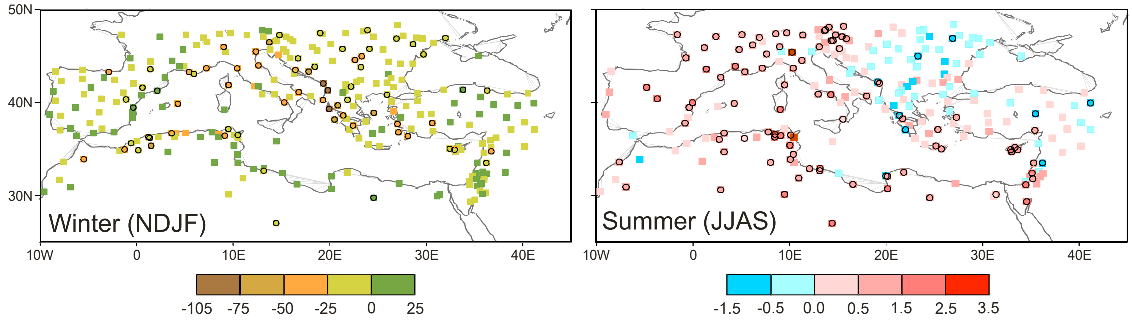

Figure 4. (left) Linear trends of winter (NDJF) station precipitation (mm/50yr) and (right) summer (JJAS) surface air temperatures (°C/50yr) for the 1950-1999 period. Stations with a significant trend (90% confidence level, based on the Mann-Kendall test) are encircled (from Xoplaki 2002).

A clear east-west differentiation in Mediterranean summer air temperature trends is visible. Cooling, though mostly not significant, was experienced over the Balkans, and parts of the eastern basin. In the other areas, there is a significant warming trend of up to 3°C/50yr. However, the warming in these regions did not occur in a steady or monotonic fashion. Over most of western Mediterranean for instance, it has been mainly registered in two phases: from the mid-1920s to 1950 and from the mid-1970s onwards (e.g. Brunet et al. 2001a, 2002, Galan et al. 2001). A glance at summer air temperature trends for the 1900-1949 period reveals that warming, though less extreme as in 1950-1999, was experienced in the western basin (not shown). A cooling trend over 1900-1949 was only prevalent over Libya and Egypt. The trend of winter temperature over 1900-1949 indicate a general cooling in the central basin but a warming in the east and west (not shown). For the 1950-1999 period, except for the eastern part, there was warming experienced (not shown). Xoplaki (2002) found a significant cooling trend of Mediterranean winter Sea Surface Temperatures (SSTs) east of 20°E over the period 1950-1999. The western basin experienced warming.

1.2.3 Observed Precipitation Trends over the Mediterranean

Recent studies revealed that the 20th century was characterized by significant precipitation trends at different time and space scales (e.g. New et al. 2001, Folland et al. 2001). Giorgi (2002) found negative winter precipitation trends over the larger Mediterranean land-area for the 20th century. Using the same data, Jacobeit (2000) showed for the last three decades some rainfall increases in autumn (western Iberia and southern Turkey), but dominating decreases in winter and spring.

A glance at the Mediterranean regional precipitation trends reveals a more detailed picture of the general findings. Sub regional variability is high, particularly in areas with contrasted topography near coastland where also significant trend in variability and monthly totals have been observed (e.g. Turkes 1996, 1998). The evaluation of regional data series (Figure 4, left) indicate, that trends in many regions are not statistically significant in view of the large variability (Xoplaki, 2002). However, significant decreases are prevalent in western, central and the eastern Mediterranean.

For the Mediterranean Sea, precipitation variability has been investigated using gauge-satellite merged products and atmospheric re-analyses (Mariotti and Struglia, 2002). NCEP re-analyses show that during the last 50 years of the 20th century Mediterranean averaged winter precipitation has decreased by about 20%, with the decrease mostly occurring during the period late 1970s to early 1990s.

1.2.4 Observed Daily Rainfall and Temperature Trends over the Mediterranean

Only few areas have been studied on a daily basis in the Mediterranean because high quality data are rather scarce (e.g. De Luis et al. 2000). Difficulties exist in determining trends of very rare events (e.g. Frei and Schär, 2001). One exception is the dense daily rainfall data-base for the east of the Iberian Peninsula (Romero et al. 1998, 1999) which show successive drying in western Catalonia and central and western Andalusia for the period 1964-1993. Brunetti et al. (2001ab) have found a negative trend for the number of wet days and annual rainfall in Italy, while the heaviest events class interval show a positive trends. Alpert et al. (2002), Brunetti et al. (2001ab), Goodess and Jones (2002) also report on a tendency to more intense concentration of rainfall to have occurred along some Mediterranean coastal areas, essentially Italy and Spain. Similar results were found in two long observatories in north-eastern inland of Spain (Ramos, 2001).

Over the western Mediterranean little change or even an increase of the day/night temperature differences has been highlighted for the last 130 years (Brunet et al. 2001bc) and for the 20th century (Brunet et al. 1999, Abaurrea et al. 2001, Horcas et al. 2001). Maximum temperature increased at larger rates than minimum temperature. This diurnal differential rate of warming, opposite to the observed on larger spatial scales, has been mainly intensified during the second half of the 20th century.

1.2.5 Possible Explanations of Trends

Trends in large-scale atmospheric circulation patterns affect trends in Mediterranean temperature and precipitation. The interaction with topography and land-sea contrasts can produce a variety of regional responses with different trend signs, although they have the same origin. Xoplaki et al. (2003) showed that the 300 hPa geopotential height, 700-1000 hPa thickness and Mediterranean

SST large-scale fields account for more than 50% of the Mediterranean summer temperature variability over the period 1950-1999. The most important summer warming pattern is associated with blocking conditions, subsidence and stability. This mode is responsible for the 0.4°C (0.5 °C) warming during the period 1950-1999 (1900-1999).

Xoplaki et al (2004) show that around 30% of the October-March precipitation variability can be accounted for by four large-scale circulation modes. The CCA of Dünkeloh and Jacobeit (2003) indicates that 76% of the October-March rainfall variability is accounted for by five coupled patterns with 61% explained variance for the five large-scale circulation modes. The most important mode is significantly correlated with the NAO and the AO (Arctic Oscillation) pattern. It is connected with above (below) normal precipitation over most of the Mediterranean with highest (lowest) values at the western coasts of the peninsulas and lowest (highest) in the southeastern regions. Figure 5 presents standardized values of October-March precipitation anomalies over 110 Mediterranean stations for the 1900-1999 period and the Gibraltar-Iceland NAO (Jones et al. 1997) with reversed sign. The correlation between both series is 0.6, suggesting that the North Atlantic climate variability plays a crucial role in driving long-term trends in the Mediterranean. Further, the NAO index correlates at 0.72 with a large-scale Mediterranean Oscillation pattern during October-March (Dünkeloh and Jacobeit 2003).

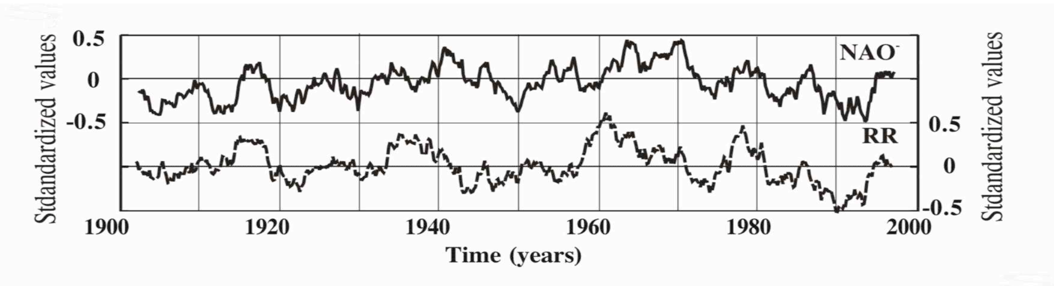

Figure 5. Gibraltar-Iceland NAO index (Jones et al. 1997) with reversed sign; RR: standardized average of precipitation anomalies over 110 sites over the Mediterranean region between 1900 and 1999. The time series is shown as a 4-year moving average filter (from Xoplaki et al. 2004).

The recently observed trend towards drier Mediterranean winter conditions is linked to particular circulation pattern changes including increased pressure south of 45-50°N since the 1970s, a weakening of the central Mediterranean trough since the late 1980s, and a long-term rising trend in the Mediterranean oscillation pattern (higher pressure in western and central Mediterranean) being connected to the AO and NAO (Dünkeloh and Jacobeit, 2003). Though the NAO/AO plays an important role in driving temperature and precipitation trends in the Mediterranean, its influence varies through different time periods. Thus, there are other modes which are of relevance for explaining seasonal sub-Mediterranean climate variability (e.g. Kutiel and Benaroch, 2002;

Dünkeloh and Jacobeit, 2003; Xoplaki et al. 2003, 2004) or indirectly through the effect over sea level pressure patterns (Ribera el al. 2000).

Solar variability and troposphere-stratosphere interaction (Perlwitz and Graf 1995, 2001; Shindell et al. 1999) as well as ocean dynamics (Sutton and Allen 1997; Rodwell et al. 1999) have also been suggested as potential sources of variability affecting the North Atlantic climate with impacts on the Mediterranean regions. Hoerling et al. (2001) found that much of the 500 hPa height changes in winter are recoverable from tropical SST forcing alone, thereby establishing that wintertime North Atlantic/European climate changes (dryness over the Mediterranean area) since 1950 are consistent with changes in the tropical SSTs. Recent findings of SST anomaly experiments by Hoerling et al. (2003) and Hurrell et al. (2003) indicate that SST variations have significantly controlled the North Atlantic circulation, related to the NAO, with the warming of the tropical Indian and western Pacific Ocean being of particular importance.

The nature of different rates of rainfall decrease in the east coast of Iberian Peninsula and parts of Italy might be related to the observed increasing precipitation intensity, owing to a general enhancement of the hydrological cycle (caused by an increase in surface temperature), and the reduction of the number of wet days which are consistent with the variation of the atmospheric circulation (Brunetti et al. 2001 a).

Minimum winter extreme temperatures across Peninsular Spain for the period 1955-1998 indicate that most of the extremes occurred under six synoptic patterns. A generalised decreasing trend in the annual frequency of extreme events is detected for most of the studied observatories. Prieto et al. (2004) showed, that it is due to a non-linear shift in the annual mean minimum temperatures associated to a generalised warming in the area. An explanatory hypothesis of the differential diurnal warming observed over the western Mediterranean can be found in Fernandez-Garcia and Rasilla (2001). They showed an increase of the geopotential height over the region, particularly intense during the second half of the 20th century. This was associated with increasing solar radiation, higher maximum temperatures and an intensified radiative lost at night, which have smoothed rising in daily minimum temperatures.

1.2.6 Scientific Challenges for Future Research

- Generate more reliable and consistent climate datasets (both on daily and monthly basis) over the entire Mediterranean basin.
- Investigate the change of the annual cycle in Mediterranean temperature and precipitation through the instrumental period.

- Investigate temperature and precipitation trends at different time and spatial scales over the Mediterranean and sub areas for different periods and seasons.
- What are the main reasons and explanations for the observed trends?
- What is the influence of tropical SSTs on Mediterranean climate?
- Investigation of the important large-scale climate modes to explain regional temperature and precipitation variability and trends for different periods and seasons within the instrumental period using sophisticated statistical methods.
- Determine coupled modes of circulation and climate variability at seasonal scale with respect to both the Mediterranean area and its sub regions.
- Analyze long-term changes in climate extremes (heat/cold waves, droughts, floods, etc.) over the Mediterranean region.
- Use the circulation-climate relationships from the instrumental period for past climate estimates, seasonal forecasts as well as for assessing future climate changes in dependence of scenario projections (e.g. Garcia et al. 2003).
- Analyses of climate model simulations of the 20th century with regional climate models driven by boundary conditions produced by global GCMs. Long integrations (e.g. 50 years), with different forcing factors (e.g. only solar variability and only changing anthropogenic greenhouse gas concentrations) could be of much help to elucidate the origins of trends (e.g. González-Rouco et al. 2000).

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2a. Relations Between Climate Variability In The Mediterranean Region And The Global Tropical Oceans: ENSO, The Indian And African Monsoons

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2a.1 Priority Issues and Future Challenges

ENSO Impact on Mediterranean (MED) Climate:

- To investigate the role of both transient and stationary waves in the atmospheric response in the Atlantic, Mediterranean & Europe to ENSO-events, separately for La Niña and El Niño events.
- To study the role of mid-latitude oceans in responding to tropical forcings and its effect on the MED climate, observationally and by modelling simulations.
- To apply advanced statistical techniques to address local phenomena, such as the new Scale-Dependent Correlation (SDC) technique.

Indian Monsoon Impacts on MED Climate:

- To study teleconnections for diurnal, seasonal and decadal time scales and to evaluate the range of influence of the Asian Monsoon over the entire MED basin.
- To study the detailed structure of the summer circulation over the EM associated with extreme episodes, such as heat waves or exceptional rain events in the EM.
- To study the long-term trends in a variety of meteorological variables.
- To perform a climatic study of continental polar outbreaks over the MED.
- To assess the statistical relationship between the variations in the EM rainfall distribution and intensity and the long-range variations in the characteristics of the air mass transport associated with the Indian Ocean Dipole.

African Monsoon Impacts on the Climate of the MED:

- To study the teleconnections between the summer climate in the MED and the African Monsoon through numerical simulations.
- To perform numerical simulations with the Regional Model on different spatio-temporal scales on a domain including Europe, the MED and Africa. This includes the effects of the SST in the Gulf of Guinea on the MED climate variability and the influence of the MED SST on the climate variability of the North Africa.
- To perform time-slice experiments for future climate evolution, using the regional model, according to various scenarios, simulating the evolution of the Hadley cell.
- To develop close link between CLIVAR VACS (Variability of the African Climate System) and AMMA (African Monsoon Multidisciplinary Activities).

Tropical Intrusions into the MED Basin:

- To define the general mechanisms associated with tropical intrusions into the EM, i.e., the Red Sea trough and Tropical Plumes.
- To find the role of the Red Sea trough and the tropical plume in the general circulation of the MED, in particular moisture and angular momentum transport.

2a.2 ENSO Impact on Mediterranean (MED) Climate

2a.2.1 ENSO and Eastern Mediterranean (EM) Rainfall

Yakir et al. (1996) and Price et al. (1998) showed significant connections between ENSO events and winter rainfall in Israel, both indicate increased rainfall occurring in El Nino winters. Price et al. (1998) also demonstrated that La Nina years were associated with below normal rainfall. The last rainy winter in Israel, coinciding with Nino event, supports the above. The analysis in Israel was extended to the Jordan River discharge, used as a proxy for regional rainfall, since the stream flow entering the Sea of Galilee is dominated by regional rainfall. The seasonal stream flow in the Jordan River is significantly correlated (r~0.6) with the seasonal NINO3.4 temperatures. This implies that the tropical Pacific temperature oscillations can explain approximately 36% of the inter-annual variability in winter rainfall in North Israel. It is hypothesized that the reason for this strong connection is related to the position of the winter jet in the EM. Israel is located at 30N, exactly the mean latitude of the winter jet. Small shifts, in the order of ~1 deg, in its mean position can have a major impact on the storm tracks, hence on the rainfall amounts. During El Nino/La Nina years meridional shifts of the jet in the EM have been observed. However, the intensity of the ENSO events is not directly related to the intensity of the rainfall anomalies in Israel. This is one of the reasons the correlation coefficient is only 0.6. However El Nino/La Nino years have been wet/dry for 75% of the ENSO events in the last 30 years. Stream flow data in the Jordan River are only available since the end of the 1960s. However, since individual rain gauge measurements watershed is highly correlated (r~0.9) with the catchment's-integrated stream flow, it is possible to go back to 1922. The ENSO signal appears in the rainfall data only after the mid 1970s. It is puzzling as to why these correlations are observed only in the recent record. This may be a result of the changes in the frequency and intensity of ENSO events since the mid 1970s. Trenberth and Hoar (1997) have shown that since the mid 1970s there has been a significant increase in the frequency of El Nino events relative to La Nina events, and the intensity and period of these events has also increased. It has also been suggested that there may have been a shift in the global climate system during the 1970s, which may have resulted in a stronger Pacific-mid-latitude link during the past two decades (Wuethrich 1995).

2a.2.2 El-Nino and Extreme Mediterranean Rainfall

Alpert et al (2002) calculated the relative contributions of 6 daily rainfall intensity categories to the annual rainfall amounts during 1951-1995, over Spain, Italy, Cyprus and Israel. Linear as well as monotone non-linear (Spearman's) time test show significant increases in heavy daily rainfall in spite of decreases in the annual totals. For instance, in Italy, torrential rainfall (%) above 128 mm/d increased by a factor of 4! in 1951-1995. Most interesting the torrential rainfall peaks were observed in the El-Nino years.

2a.2.3 Transient and Stationary Waves Approach

Previous work has shown an ENSO-impact during boreal winter with a trough (ridge) over southern Europe during El Niño (La Niña) events accompanied by more (less) cyclones reaching the Mediterranean (MED) region. That is, both the mean flow and sub-seasonal variations of the flow are affected by ENSO. In particular, the sub-seasonal variations tend to feedback on the anomalous mean flow. However, the impact in the Atlantic and Europe, and the MED region in particular, appear to be more robust during La Niña than during El Niño events. Previous work from the SINTEX-project indicated that the dominating mode of interaction - resembling the NAO - is only related to La Niña but not to El Niño events. Further, these modes - though defined in the Atlantic & Europe - appear to be connected to the N Pacific and N America. This suggests that the transient eddies are also important in “transporting” the ENSO-response from the latter regions into the Atlantic & Europe. The insight gained may improve the prospects of seasonal prediction in the

Atlantic/European region. Modelling experiments can cope with a complex response to ENSO through the alteration of mid-latitude internal modes of variability (e.g., NAO, EATL-WRU, etc.), in particular with respect to future scenarios (e.g. Timmermann et al. 1999).

2a.2.4 ENSO and Mid-Latitudes Relationship

Rodó et al. (1997) investigated the signatures of ENSO in Spanish precipitation and stated a coherent decrease in MAM(+1) following El Niño events, in accordance to that stated in pioneering studies (Ropelewski & Halpert 1987, Kiladis & Díaz 1989), and later confirmed and extended by van Oldenborgh et al. (2000) and Mariotti et al. (2002). This coherence appeared to increase in the second half of the 20th century. Regarding ENSO-signatures in the NAE sector, Rodó (2001) highlighted the difficulty in isolating ENSO signals using common statistical techniques, mainly due to their spiky nature with respect to the dominating mid-latitude dynamics. Their importance for MED climate might be high, though only for selected intervals and vanish elsewhere. Rodó (2001) showed this occurrence for SST anomalies in the western MED basin. The possibility of an ENSO influence through perturbations of the Atlantic Walker circulation was also highlighted by Rodó (2001), who stated the importance of a weak Atlantic Hadley cell as a response to anomalous warming in the eastern tropical Pacific (in accordance to Sutton et al., 2000; and Saravanan and Chang, 2000). Their results suggest that a fraction of the inter-hemispheric variability in the tropical Atlantic is forced by way of a tropical atmospheric bridge (Lau & Nath 1996, Klein et al. 1999).

2a.2.5 Recommended Future Research

- To investigate the roles of both transient and stationary waves in the atmospheric response in the Atlantic, Mediterranean & Europe to ENSO-events. In particular, their role in initiating the anomalies in the mean flow and in determining the specific characteristics during individual events.
- To investigate the difference between the atmospheric responses separately to La Niña events, which is much less robust with respect to the El Niño, starting from a description of the interactions between the transient eddies and the mean flow over the affected regions (since they are essential for determining anomalies in the mean flow).
- Advanced statistical techniques will be applied to address local phenomena, such as the new Scale-Dependent Correlation (SDC) technique (Rodó 2001, Rodó et al. 2002, Rodríguez-Arias & Rodó 2003), due to the complex fashion in which ENSO interacts with the mid-latitudes.
- The role of mid-latitude oceans in responding to atmospheric forcing of tropical origin (Lau & Nath 2001) and its effect on the MED climate will be studied, both observationally and by modelling simulations. Improvement is expected to be achieved in the resolution and accuracy of observational studies with the use of a denser, homogeneous set of records. Various

scenarios of future ENSO frequency and intensity related to climate change will be explored for assessing the relation to MED climate variability and extremes.

2a.3 Indian Monsoon Impacts on MED Climate

2a.3.1 Indian Monsoon and the Eastern Mediterranean

The study of the teleconnections between central Asia and the EM deals with the extreme seasons, the summer and the winter, separately.

Rodwell and Hoskins (1996) showed that the Asian Summer Monsoon dominates not only Mid-Asia, but also the EM. In numerical simulations they pointed at the linkage between the appearance of the semi-permanent subsidence region over the EM and the onset of the Monsoon. The climatic regime and the dynamic factors governing the EM in the summer season and their relationships with the Asian Monsoon were analyzed by Ziv et al. (2003), who found significant correlation on the inter-diurnal time-scale. They identified a circulation connecting the upward motion maximum over the Himalaya with the downward motion over the EM. Raicich et al. (2003) studied the relationship between the Asian and African Monsoon systems and found a high correlation between the intensity of each of them and the pressure distribution over the MED on the inter-annual time-scale.

The Indian summer Monsoon index is recorded for almost 200 years, while records of winter rain in Israel are relatively 'younger'; the longest record used is of 118 years in Jerusalem. The overall correlation between these two indices was found to be only -0.3 (for 118 years). However, in 73 years (62%) the indices sign were opposite. For extreme summer seasons, in which the index deviates by over 1.3 STDs, the correlation increases to -0.56 (Alpert et al., 2003). Similar results were found for other relatively long-record of rainfall stations in Israel. This illustrates the potential of the Indian Monsoon as a predictor for Israeli rainfall in the following winter season.

While the role of the Tropical Atlantic Variability (TAV), ENSO and associated changes in SST over the tropical Pacific and Atlantic oceans in the tropics, especially in the Indian monsoon, have been widely investigated, the role of the effect of the Indian Ocean is not well understood. The existence of the Indian Ocean Dipole (IOD) mode was demonstrated by Saji et al (1999), Webster et al. (1999) and Andersen (1999). A respective index was determined, though no statistical relationship between it and the monsoon rains has been established. It is suggested that the variations in the EM rainfall, distribution and intensity during the last decade are associated with variations in the characteristics of the air mass over the Indian Ocean via its transport toward the EM.

When the winter regime over the entire MED is considered, the focus is given to the Rossby waves and other extra-tropical factors, such as the NAO, as the dominating features. However, some attention has been given to continental polar outbreaks associated with the Asian winter Monsoon (e.g. Saaroni et al. 1996).

2a.3.2 Recommended Future Research

- To study teleconnections of the Indian Summer Monsoon with the EM for different time scales, i.e., diurnal, seasonal decadal, attempt to evaluate the range of influence of the Asian Monsoon over the entire MED basin.
- To study the long-term trends in various variables, as performed for summer temperature, Saaroni et al. (2003), in relation with long-term trends in the Asian Monsoon features along the entire year.
- To study the detailed structure of the summer circulation over the region prior to and during extreme episodes in which the EM undergoes heat waves or exceptional rain events.
- To incorporate into the seasonal prediction scheme for the Israel winter rainfall, data about the summer Asian Monsoon.
- To validate the suggested linkage between the Indian Ocean processes and the EM weather.
- To develop a climatologic basis for continental polar outbreaks events over the MED. This includes both synoptic detailed analyses and statistical study.
- To assess the statistical relationship between the variations in the EM rainfall amount, distribution and intensity and the long-range variations in the characteristics of the air mass transport associated with the Indian Ocean Dipole.

2a.4 African Monsoon Impacts on the Climate of the MED

2a.4.1 Background

The climatic variables in the various parts of the MED are correlated with each other as well as with external circulations. For instance, the MED SLP oscillation (MO), i.e., the difference between its western and eastern parts, is correlated with precipitation. In the winter, a fundamental role is played by the NAO index, whereas in summer the regional Hadley cell was found to be correlated with the conditions over the MED. There are also evidences for teleconnections with the Asian Monsoon and with the Sahel precipitation. The SLP is correlated to the precipitation indices of these 2 systems negatively in the EM and positively in the Western MED. The relevant governing mechanisms have been studied by several authors (see Baldi et al., 2002 for an extended bibliography), as well as the influence of the position and the strength of the Hadley cell (Dima and Wallace 2003).

Focusing on the summer case, Chen et al. (2002), showed evidence for strengthening of the tropical general circulation in the 1990s, and in particular the West Africa monsoon, reaching its northernmost extension in August, when the ITCZ, after the abrupt shift at the end of June and further slow northward migration, reaches its northernmost location (Sultan and Janicot 2000, 2003). Important mechanisms, such as heat and moisture advection in North America and Asia and anomalously high values of the surface albedo in northern Africa, limit a further extension towards northern latitudes (Chou & Neelin 2003, Rodwell & Hoskins 1996, 2001). The two regimes, the dry and hot summers in the MED and the monsoon regime over West Africa, are strictly correlated; interactions and feedback mechanisms between the two are not only possible, but also evident (Rowell 2003, Baldi et al. 2002, 2003a, 2003b).

Ziv et al. (2003), in their study of the summer regime, found a signature of the Hadley cell over eastern North Africa, connecting the EM with the African Monsoon. The relationship between them is manifested by a significant correlation between the ascendance in 15-20°N latitudes and the descendance in 30-40°N latitudes. This, together with the correlation between the EM subsidence and the Asian Monsoon was further validated through correlating the inter-diurnal variations of the vertical velocities in the two Monsoon systems, yielding $r = 0.33$, in spite of the ~6000 km distance.

2a.4.2 Recommended Future Research

- To study the teleconnections between the summer climate in the MED and the African Monsoon through numerical simulations. The major tools will be the NCEP-NCAR and ECMWF reanalyses, historical time series of atmospheric parameters in Southern Europe, Regional numerical model(s), scenarios for future climate produced by global climate models like from the Canadian Centre for Climate Modelling and Analysis (CCCma), and gridded precipitation data provided by the Global Precipitation Climatology Project.
- To perform numerical simulations with the Regional Model on different time-space scales on a domain including Europe, the MED Basin and the northern part of the African Continent north to the Gulf of Guinea. The effects of the SST variability in the Gulf of Guinea on the climate variability in the MED should be assessed using an approach similar to that presented by Vizy and Cook (2001, 2002). In turn, the influence of the MED SST on the climate variability of the North African Region should be studied.

- To perform time-slice experiments for future climate evolution, using the regional model, according to different available scenarios. Since the phenomena are embedded in the large scale circulation and in particular in the Hadley cell circulation, therefore a mathematical model of the evolution of the Hadley cell should be elaborated.
- To study the linkages between MED climate CLIVAR VACS (Variability of the African Climate System) and AMMA (African Monsoon Multidisciplinary Activities).

2a.5 Tropical Intrusions into the MED Basin

2a.5.1 Background

Rains in the Mediterranean basin take place mainly during winter, most of which is associated with Mediterranean baroclinic cyclones. However, processes originating from tropical regime are also significant in its eastern part (Krichak et al. 1997a,b, Krichak & Alpert 1998, Dayan et al. 2001, Kahana et al. 2002, Ziv et al., 2004) and along its western part, in north western Africa (Knippertz et al., 2003). The Red Sea Trough (RST) is one of the impressive manifestations of mid-latitude-tropical interactions in the EM especially during autumn and spring. The intensity and duration of rain-spells there highly depend on the interactions between the upper and lower-tropospheric jets as well as their positioning and orientation. Specific jet characteristics stimulate development of meso-scale convective complexes and cyclogenesis. Due to turbulence associated with strong wind shear, tropopause folding may allow intrusions of the stratospheric air into the troposphere. It was recently shown that frequencies of RST intrusions into the EM, have nearly doubled since 1970 from about 50 d/y to about 100 d/y (Alpert et al, 2004a,b)
Another type of rainstorms originating from the tropics is associated with "tropical plumes". This is a long cloud band that extends from the ITCZ down to 30^0-40^0N latitude, accompanied by a pronounced trough in the Subtropical Jet to its west combined with a ridge to the east, while no common distinct system at the surface or at the 500-hPa level, was found. Ziv (2001) found that prior to such type of rainstorm the tropical plume, extending toward the subtropics, injects moisture of tropical origin that is captured by the STJ, and if a pronounced trough develops there, extensive stratified cloudiness and widespread rains result. Zangvil and Isakson (1995) found in a rainstorm of the same type that the vertically integrated moisture convergence reached 1.8 mmh-1 over Israel, mostly above the 750 hPa level. Dayan and Abramski (1983) found an abnormal feature in the STJ's structure, i.e., a reversed position of its axis that leads to the formation of a large and humid warm air mass up to very high levels in the atmosphere above the Middle-East.

2a.5.2 Recommended Future Research

- To define general mechanisms of tropical intrusions into the EM of the Red Sea trough and the tropical plume.
- To find the role of the Red Sea trough and the tropical plume in the general circulation of the MED. In particular in transport of moisture and angular momentum.
- To study the physical mechanisms for the recent increase in tropical intrusions into the MED.

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2b. Relationships Between Climate Variability in the Mediterranean Region and Mid-Latitude Variability

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2b.1 State-of-the-Art.

Since the pioneering work by Lamb and Peppler (1988) on the influence of the North Atlantic Oscillation on Moroccan precipitation a great deal of effort has been made to characterize the influence of mid-latitude variability on the climate of the Mediterranean region. This region is located at the southern limit of the North Atlantic storm tracks, so that interannual shifts in storm tracks can lead to remarkable anomalies of precipitation and, to a lesser extent, of temperature. This is specially observed in the cold season in the Western Mediterranean, but it has also a signature clearly felt in the Eastern Mediterranean as well. One factor that complicates this simple picture is the complicated orography of virtually all regions surrounding the Mediterranean basin, that can modulate and even distort climate anomaly patterns that otherwise would be geographically much more homogenous. The interplay between orography and thermal contrast between advected Atlantic air masses and Mediterranean temperatures can produce at the end of the summer season violent precipitation extremes. The main lines of research so far have been directed at winter half-year precipitation and summer temperature.

Most of the analyses to date have been focused on one important extra tropical factor modulating the Mediterranean climate in wintertime- the North Atlantic Oscillation, the meridional pressure gradient along the North Atlantic. It is strongly related to the paths followed by extra tropical cyclones and to the intensity of the North Atlantic westerlies. Its influence on Mediterranean precipitation has been widely documented (Hurrell, 1996, Dai et al, 1997). Figure 6 shows the interannual correlation maps between the North Atlantic Oscillation index and winter precipitation and temperature in the Mediterranean basin, which clearly shows that a negative NAO state is responsible for positive precipitation anomalies over most land areas in this region. This relationships also holds to a large extent for longer time scales (Rimbu et al, 2001), so that the multiyear drought periods periodically suffered in the Western Mediterranean basin can be traced back to anomalous and persistent excursions of the NAO index towards positive values. Also the long-term trend towards drier conditions can be explained by trends in large-scale atmospheric circulation patterns (Dünkeloh and Jacobeit, 2003).

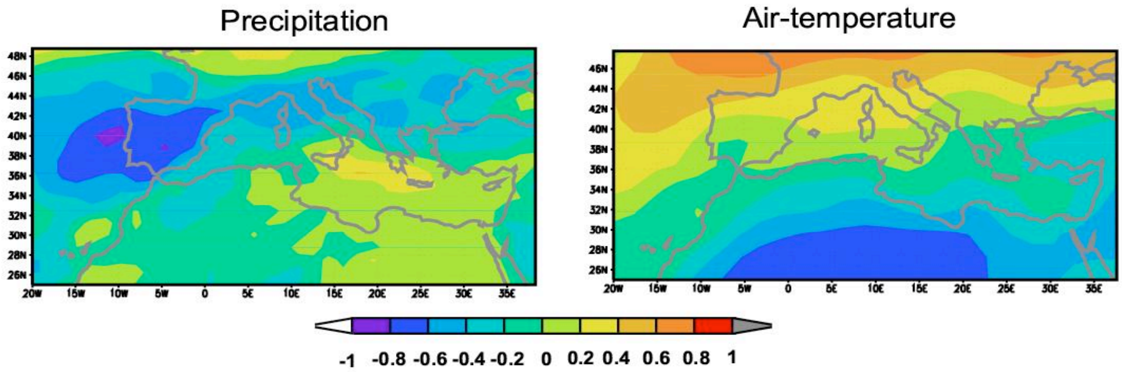

Figure 6. Correlation between the NAO index and Mediterranean precipitation (left) and air-temperature (right) in the cold season (December-February), derived from the CRU NAO index and the NCEP reanalysis.

The high correlation between NAO index and precipitation stresses the importance that a possible seasonal prediction of the state of the NAO could have on seasonal climate prediction in the regions near the Mediterranean (Eshel et al., 2000; Rodriguez-Fonseca and Castro, 2002). At still longer time scales, trends in winter precipitation have been linked to trends in the track of most intense cyclones originating in the North Atlantic, that have become less frequent in the last decades (Trigo et al, 2000; Hurrel and van Loon, 1997, Hurrel, 1995). The mechanisms that explain the connection between NAO and Mediterranean rainfall is also well known. In the Western Mediterranean the cyclones entering the basin from the North Atlantic are, together with regional cyclogenesis, one of the main sources of winter rainfall (Ulbrich et al. , 1999; Rogers, 1997) ; in the Eastern Mediterranean, the situation seems to be somewhat more complicated. In this region the North Atlantic atmospheric circulation influences the vertical stability of the atmosphere by temperature advection (Eshel and Farrel, 2000; Xoplaki et al, 2000), but internal eastward moisture advection within the Mediterranean basin also contributes to modulate Eastern Mediterranean rainfall (Fernández et al, 2003). More work is needed to achieve a complete understanding and prioritization of the relevant processes.

Nevertheless, the NAO is not the only player (e.g. the NAO has been found to play a secondary role in winter precipitation along the North Iberian coast, Sáenz et al., 2001) and the importance of other extra tropical modes, e.g. the Eastern Atlantic pattern should not be ignored. The EA pattern exerts a strong influence on the advection of more humid or warmer air masses to certain regions (Fernandez et al, 2003). This pattern is also responsible for the modulation of precipitation in the

Eastern Mediterranean (Krichak et al., 2002) and to describe much of precipitation anomalies in the whole basin that cannot be ascribed to the NAO (Quadrelli et al, 2001). .

Although the tropical connections are discussed in more detailed section 2a, we could mention here that a healthy and unclosed debate on the influence of the indirect effect, via extratropical modes, of El Nino-Southern Oscillation (ENSO) on precipitation in the Mediterranean region is going on :some authors report an influence on winter rainfall of ENSO through the NAO (Ribera et al, 2000), but perhaps only in areas where the NAO influence is weaker (Rodó et al., 1997) or in the spring or autumn season (Mariotti et al, 2002). Others find no influence of ENSO on winter rainfall (Quadrelli et al, 2001).

An outstanding problem in Western Mediterranean rainfall is also the intraseasonal distribution of daily precipitation and the occurrence of catastrophic torrential rains. These tend to occur in the autumn season along coastlines with heavy orography. Very little work has been done to link the probability of these events to large-scale extra tropical circulation (Valero et al, 1997), although some analysis of frequency and intensity of Mediterranean cyclones (Trigo et al, 2002) and modelling studies for individual events have been performed (Homar et al, 1999; Pastor et al, 2001; Romero et al, 1999). In the last decades a tendency to more intense concentration of rainfall seems to have occurred along some Mediterranean coastal areas , essentially Italy and Spain, (Alpert et al, 2002;Brunetti et al, 2001; Goodess and Jones, 2002), but this does not seem to be the case for inland areas. Certainly more work is needed to link event modelling, long-term modelling and observations analysis with the goal of a coherent long-term climatological perspective.

Analysis of Mediterranean cold season temperature has not been so intense as precipitation, probably reflecting the relevant role of water availability in this region. Cold season temperature is also affected by extra tropical atmospheric circulation patterns, although the effect seems to be weaker than for precipitation, and also weaker in the Western Mediterranean. Figure 7a shows for the cold season a high correlation between NAO and temperatures variations over Europe and North Africa, whereas the Mediterranean basin is only a transition region with poor correlation. In the Eastern Mediterranean a positive NAO is related to colder than normal temperatures (Ben-Gai et al, 2001; Hasanean, 2001). Stronger temperature signals seem to emerge at somewhat longer timescales than interannual (Ben-Gai, 2001). In the Western Mediterranean the link between the NAO and temperature has been found to be non-linear and non-stationary in time (Pozo-Vazquez et al., 2001). Spectral characteristics of the NAO time series are not replicated in the temperature evolution. In the case of Western Mediterranean temperature, other modes seem to be more important, e.g. the Eastern Atlantic pattern, and contrary to precipitation, transport by baroclinic eddies is not a controlling mechanism (Sáenz et al., 2001).

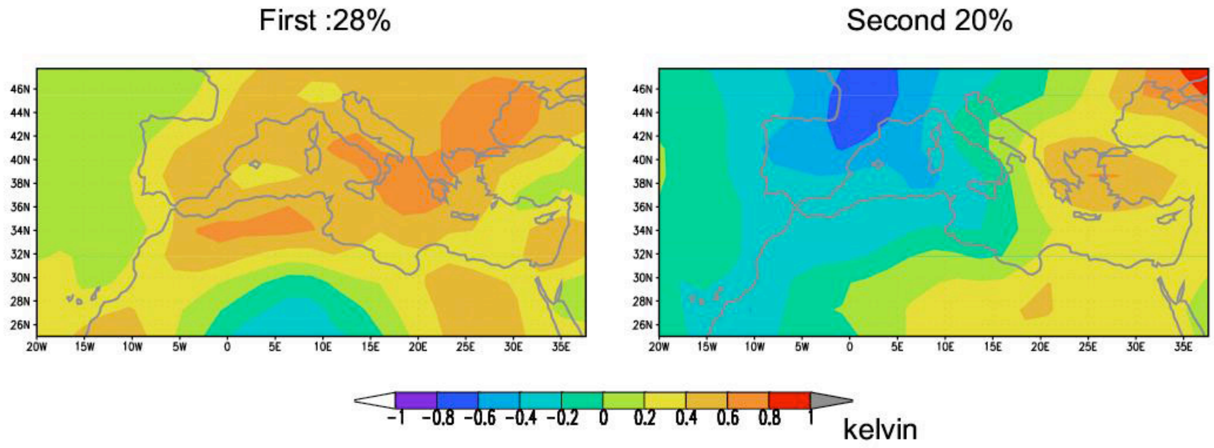

Figure 7. Leading Empirical Orthogonal Functions of the Mediterranean air-temperature in summer (June-August), derived from the NCEP reanalyses

In the summer season, on the other hand, temperature variability has received more attention, reflecting the widespread perception of heat-stress as a crucial climate factor on the human environment. Half of the variance of summer temperature variability can be explained by two variability modes (Xoplaki et al., 2003; Figure 7 shows the two leading Empirical Orthogonal Functions of the summer Mediterranean air temperature) the first one reflects uniform temperature anomalies in the whole basin whereas the second displays an east-west dipole pattern. The existence of both modes can be explained as a response of air temperatures to the location of highs and lows associated to planetary waves, connected to blocking situations, atmospheric stability and presumably stronger radiative heating. Trends in the large-scale driving patterns are especially relevant since they may enhance or damp the warming caused by increasing greenhouse gas concentrations. However, to our knowledge, work has just beginning in this direction.

Relevant questions in this context are the possible changes of these extra tropical modes under global climate change. The results to date seem to indicate that the so called Annular Modes-the Arctic Oscillation and the Antarctic Oscillation- to which the NAO is linked will tend to become more intense in the future (Guillet, 2002), although the ratio signal/variability could not very large (Zorita and Gonzalez-Rouco, 2002). In a more regional basis some work has been reported for the Western Mediterranean (Gonzalez-Rouco et al, 2000) and the Balcans (Busiuoc et al, 1999).

2b.2 Some Ideas for Future Research

Many studies have underlined the role of several teleconnection patterns (NAO, EA, EA/WR) over different parts of the Mediterranean basin. However, in general it is not clear whether there are significant differences in the physical mechanisms for the generation and dissipation of these planetary regimes, or whether the only difference lies simply in the geographical location of their centres of action. Furthermore, the underlying physical mechanisms (moisture and enthalpy advection, cyclogenesis and storm tracks, vertical stability, radiation and cloud cover, oceanic process etc..) that give rise to these statistical connections are not always completely understood. This question is threefold relevant:

- in the context of changes in the intensity of these circulation patterns under global climate change. Only with a sufficient understanding of the physical mechanisms will it be possible to estimate the effect of changes of extra tropical modes on the Mediterranean climate;
- For understanding the variability at decadal time scales (where persistent deviations of atmospheric indices have been observed), and estimate their influence on low-frequency changes in temperature and precipitation, in the frame of other possibly competing effects, such as land use changes.
- seasonal climate prediction would greatly benefit from research in this direction. A substantial fraction of the climate variability of the Mediterranean basin may be explained in terms of a few planetary flow regimes. Their predictability, though, is not well quantified, and their origin and possible relationship with oceanic process is very uncertain. Possibly, in order to make accurate predictions of variables like precipitation, some kind of downscaling method would be necessary to fill the gap between the large and the regional scales.

Concerning daily precipitation, most analysis has focused on limited areas in the Western Mediterranean. Furthermore, due to the large land-sea contrasts and the steep orography surrounding the Sea (Alps, Pyrenees, Carpatians...), the use of high-resolution climate data would be very interesting in the Mediterranean area. A very useful tool to advance the state of knowledge would be the production of high quality, high coverage, data sets. This precondition could be fulfilled by:

- Generating observational data products with smaller spatial resolution than currently available (30" of arc) over most part of the basin for at least the past 50 years, due to the large spatial density of observing sites in some areas and .
- The generation of pseudo-observational data with the help of high-resolution regional climate simulations driven by available coarse-resolution global meteorological reanalysis (.e.g., NCEP, ERA). To date, the number of re-analysis with high resolution and available for periods

of climatic importance is very limited (the HYPOCAS project seems to be the only one currently available). Such "regional reanalysis" could play a similar pivotal role than the global reanalysis are now playing in climate research.

The knowledge obtained from the analysis of observational or pseudo observational data set could be extended in two directions:

- the analysis of climate model simulations regarding the reproducibility of the main characteristics of the extra tropical modes, including its impact on the precipitation field and cyclonic activity (Osborn et al., 1999; Trigo and Palutikof, 2001, (Ulbrich and Cristoph, 1999). This work should be continued and intensified with the aim of determining to what extent climate models yield a realistic picture of the variability in the present climate and quantifying, if possible, the amount of expected regional climate change that can be ascribed to future rends in extra tropical modes, since this modes will probably be responsible for regional differences in the future climate..
- the analysis of empirically reconstructed fields of the last centuries, thus establishing a level of centennial natural variability, that can be serve as a perspective for changes simulated with climate models.

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3. Variability of the Mediterranean Sea Level and Oceanic Circulation and their Relations to Climate Patterns

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- The Mediterranean Sea is not at a steady state.
- Significant and largely unexplained changes in the water mass characteristics, sea level and circulation have been observed.
- The observed variability consists of long-term slow changes in the deep and the upper waters and rapid changes in the circulation.
- Large scale meteorological forcing for example the North Atlantic Oscillation, anthropogenic influences (for example the damming of rivers) as well as changes to the hydraulic conditions at the Strait of Gibraltar appear to be related to some of these changes.
- The variability observed is not uniform over the whole Mediterranean area but it varies at basin wide or even smaller scales thus demanding more intensive observation and analysis.

3.1 Climatic Forcing of Mediterranean Sea Level and Oceanic Circulation Variability

3.1.1 Background

The progressive improvement of existing climatological data sets indicates that the Mediterranean Sea is not in a steady state and is potentially very sensitive to changes in atmospheric forcing. The Mediterranean Sea acts as a miniature ocean when thermohaline circulation, dense water formation and the impact of environmental forcing are concerned (Bethoux *et al.,* 1999). The excess evaporation over precipitation and a negative heat budget (Garrett *et al.*, 1993; Gillman and Garrettt, 1994) are balanced by a two layer exchange at the Strait of Gibraltar (sill depth about 280m) comprising a relatively cool, fresh (15˚C, 36.2psu) upper water inflow and a relatively warm and saltier (13.5˚C and 38.4 psu) outflow to the Atlantic (Tsimplis and Bryden, 1999). The inflow of Atlantic water is highly modulated by the tidal signal and the atmospheric forcing at the Strait of Gibraltar but as it correlates well with the cross strait sea level component it is likely to be easily monitored (Tsimplis and Bryden, 1999). The eastward spreading Atlantic water becomes progressively warmer and saltier due to atmospheric forcing and to mixing with underlying water masses (Malannotte-Rizzoli and Hect, 1988 for a review and Font et al., 1998 for recent observations). The surface Mediterranean circulation as seen from altimetry is a complex combination of mesoscale and large-scale variations (Larnicol et al., 1995).

3.1.2 Water Formation

The most important Mediterranean water mass is the Levantine Intermediate Water (LIW) which is formed at the Levantine Basin while the Winter Intermediate Water (WIW) both cooler and fresher than the LIW is formed in the western basin (Send *et al.*, 1999). Deep water formation takes place in the Gulf of Lions (Stommel, 1972) where heat dominated local buoyancy flux appears to determine the depth of the deep water convection (Mertens and Schott, 1998). Deep water formation also takes place in the North Adriatic and up to 1987 it was clear that most of the deep water of the eastern Mediterranean was of that origin (Roether et al., 1983). Nevertheless between 1987 and 1995 water, probably formed within the Cretan Basin, filled in the deep Eastern Mediterranean demonstrating a new source of deep water formation (Roether *et al.* 1995; Brankart and Pinardi 2001).). The deep water outflow ceased after 1997 and thus the phenomenon was termed the Eastern Mediterranean Transient (EMT). There have subsequently been signs that the Adriatic will resume its role as the deep water formation of the Eastern Mediterranean (Klein *et al.,* 2000). Nevertheless it has become apparent that the deep water formation at the Eastern Mediterranean is not a regular event, or if it one was it is not any more

The mechanism by which the EMT was triggered remains unclear. It has been suggested that a combination of long term reduction in precipitation combined with exceptionally cold winters was responsible for the initiation of the deep water formation (Lascaratos *et al.,* 1999). Nevertheless other views exist. For example Mallanotte-Rizzoli et al., (1999) attribute the initiation of the EMT to changes in the circulation of the LIW while Zervakis *et al.* (2000) suggest that deep water formation started in the North rather than the Southern Aegean and was linked with reduced outflow from the Black Sea. Recently evidence for deep water formation at the eastern parts of the Chios Basin has also been suggested .Moreover there is disagreement on whether the EMT is a phenomenon which has never occurred before in observational records (Lascaratos *et al.,* 1999) or whether it has happened before (Theocharis *et al.*,1999, Josey, 2003). In addition (Josey, 2003) has shown that the primary contribution to buoyancy loss at the ocean surface during the exceptionally cold winters was due to severe heat loss and that reduced precipiation could only have played a minor role.

There is further disagreement on whether all the contributory factors i.e. the gradual preconditioning of the surface waters by reduced evaporation, the exceptionally cold winters and the reduction of fresh waters from the Black Sea are connected with large scale atmospheric forcing and in particular with the North Atlantic Oscillation. This suggestion originally made by Tsimplis and Josey (2001) on the basis of budget estimates of E-P and river outflow may be true in relation to the gradual preconditioning of the upper waters as it is established that cooling and increases in salinity accompanied the increase in the positive status of the NAO during the recent decades (Tsimplis and Rixen; 2002, Tsimplis et al., 2003). Nevertheless Josey (2003) demonstrates that the exceptionally cold winters which are likely to be responsible for the initiation of the EMT are uncorrelated with the NAO although anomalously high pressure over the North-East Atlantic has been identified as the driving mechanism for the strong buoyancy loss in the Aegean Sea at the time of the EMT In contrast Rixen et al. (2003) argue that the NAO was directly responsible for the initiation of the EMT. Moreover Boscolo and Bryden, (2001) suggest that river outflow reduction is likely to have played a role in the EMT. Thus there is scope in exploring the relationship between deep water formation in the Mediterranean and the larger scale forcing whether this is the NAO or one of the other principal components of atmospheric variability. Moreover, because it is unclear whether there have been previous shifts in the deep water formation mechanisms of the Mediterranean Sea, resolving whether and when they have happened is an issue of high priority.

3.1.3 Deep Water Changes

The temperature and salinity of the deep waters of the Western Mediterranean Sea have been increasing after 1960 (Bethoux *et al.*, 1990; Bethoux *et al.*, 1998; Leaman and Schott, 1991; Rohling and Bryden, 1992, Tsimplis and Baker, 2001). Rohling and Bryden (1992) suggest that increases have been caused by the damming of rivers and especially of the Nile while Bethoux (1990) and Tsimplis and Baker (2001) suggest that local atmospheric forcing is responsible for these changes. Very recently, even stronger trends were observed in the intermediate and deep water column of the southern Tyrrhenian as deep as 3000 m but the forcing of these changes remains unresolved. The relationship of the water mass characteristics with the circulation changes is in most cases speculative.

3.1.4 Straits

The exchange of water at the Strait of Gibraltar is hydraulically controlled both at the Camarinall Sill and at the Tarifa Narrows (Farmer and Armi, 1986). Because of the difficulties of obtaining continuous measurements at the Strait no documented influence of the NAO or other climatic parameter on the exchange has been documented. Nevertheless it would be surprising if there is no influence. Ross et al. (2000) suggest that the Mediterranean sea level rise between 1994-1997 causes reduction in the inflow of Atlantic water at the Strait. Other straits within the Mediterranean basin show variability which in some case related to NAO and sometimes not. For example the transport in the Corsica Channel (1985-today) shows a significant seasonal and interannual variability significantly correlated with the NAO Index. In contrast, the data available since 1993 for the Sicily Strait, indicate that the variability of the water flux is less accentuated and independent from the NAO Index (Astraldi *et al*., 1999; Vignudelli et al., 1999).

3.1.5 Sea Level

Probably the most dramatic of all the changes as far as impacts on society are concerned are the changes in the Mediterranean sea level. . Since 1992 sea level change is monitored by satellite altimetry, that provides a dense and complete coverage of the sea, while previously only few tide gauge data were available, providing a discrete data coverage over several years (Woodworth, 2003). Before 1960 sea level in the Mediterranean has been increasing in line with the estimated global value of 1.8 mm/yr (Church et all, 2001), between 1960 and the beginning of the 1990s sea level in the Mediterranean Sea has dropped by 2-3 cm (Tsimplis and Baker, 2001) in spite of the general atmospheric warming. Part of this reduction was due to direct atmospheric pressure increases linked with the North Atlantic Oscillation (Tsimplis and Josey, 2001) while cooling of the upper waters also played a part in the Aegean and the Adriatic Seas (Tsimplis and Rixen, 2002). Notably after 1993 sea level in the Eastern Mediterranean increased rapidly with rates 10 times that of global sea level rise (Fenoglio-Marc, 2002; Cazenave et al., 2001). These increases appear temperature related, as it corresponds to an increase of the observed sea surface temperature (Fenoglio-Marc 2001), and connected with the reduction of transport of Atlantic Water to the Eastern Mediterranean as it has been diverted northwards in the Ionian by changes in the wind stress (do you have a reference here?). Which part of this long-term sea level change is due to steric effect has still to be quantified. Coherence analysis between mean sea level and atmospheric pressure shows a significant departure from a standard inverse barometric, that confirms the role of the Strait of Gibraltar and Sicily in limiting the water exchange (Le Traon and Gauzelin 1997). Venice and the Nile delta are two of the most vulnerable areas of the Mediterranean to sea level changes. The impact of the NAO has so far being to reduce the damage of rising sea levels especially during the winter where most storms occur. Nevertheless the recent fast sea level rise indicates that the recent decades have been exceptional and it is therefore essential to monitor and understand these changes in order to assess future projections of sea level in the region.

3.1.6 Modelling

Significant efforts have been made in the past years to model the circulation of the Mediterranean Sea (Malanotte-Rizzoli et al., 1991; Pinardi and Masetti 2000) and to explore the forcing of, particularly the EMT (See for a review Lascaratos *et al*., 1999; Meyers *et al*., 1999; Samuel et al., 1999) and the generation of the LIW (Nittis and Lascaratos, 1998). Nevertheless in the absence of measurements of LIW formation rates and a comprehension of the full mechanism of the initiation of the EMT these studies are largely exploratory and depend on the tuning of the model. The models show a large amplitude interannual variability of the circulation and water mass structure associated with the anomalies of atmospheric forces over the basin (Pinardi et al 1997, Demirov and Pinardi 2002). Nevertheless these models are the only consistent way of looking at the water formation, water transport and surface forcing rates simultaneously and thus they are useful in linking the different parts of the puzzle of the Mediterranean circulation and its variability.

3.2 Outlook and Future Challenges

- Investigation and identification of the main modes of temporal and spatial variability of circulation in the Mediterranean and their response to different modes of atmospheric variability.
- Analyse the relationship between changes in the Mediterranean circulation and regional climate variability especially intermediate and deep water formation as well as paths of transport of the water masses.
- Identify the links between climate variability in each part of the Mediterranean area and global scale climate patterns (NAO, Monsoon, ENSO)
- Identify the links between changes in water mass parameters (e.g. temperature and salinity) with circulation variability.
- Identify previous shifts in the circulation of the Mediterranean Sea from historical hydrographic and climatic records.
- Identify sub-basin scale variability and link it with basin scale variability. In particular quantification of exchange of particular water masses between sub-basins are needed.
- Quantify the freshwater contribution to the Mediterranean and its time variability and explore its contribution to the water budget of the Mediterranean.

- Identify climate change related variability in the surface forcing parameters (wind stress, temperature, precipitation etc.) and river runoff and its impact on circulation changes. Seasonal cycles, extremes and changes in the distribution of parameters should be explored.
- Assessments of future changes in Mediterranean circulation due to enhanced man-made greenhouse forcing, including dynamical as well as statistical downscaling techniques, referring to particular regions and to the whole Mediterranean area as well.
- Resolve the contribution of forcing parameters on sea level variability. In particular, for long-term changes: quantify steric and non-steric long-term sea level change using for example the existing Atlas (WOA98 and Medar/Medatlas).> Explore the links between sea level and sub-basin scale circulation change.
- Produce future sea level changes under scenarios of global change
- Use the available models describing the Mediterranean circulation for climate variability related research.

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4. Evaluation of the Regional Variability in Connection with Weather Patterns

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4.1 Climatology of Cyclones in the Mediterranean

4.1.1 The Role of the Atlantic Storm Track and of the North Atlantic Oscillation

In recent years, two distinct approaches have been used to study the storm activity over the North Atlantic and Europe: storm track algorithms and analysis of synoptic variability. Usually, storm track algorithms are sophisticated methods that can detect the regions of storm development (cyclogenesis) and decay (cyclolysis) as well as the specific paths of each individual storm (Murray and Simmonds, 1991; Serreze et al., 1997; Trigo et al., 1999; Trigo et al., 2002, Lionello et al 2002). Analysis of synoptic variability is a simpler approach which corresponds to the identification of the synoptic variability using a band-pass filter that retains mainly variability on the 2-8 day period range of SLP or 500 hPa geopotential. This second approach has been more widely applied to quantify the synoptic activity associated with high and low NAO index (e.g. Rogers, 1997; Ulbrich and Christoph, 1999; Trigo R. et al., 2002). However the first technique has also been used to show the areas of significant difference in storm activity between winters with high and low NAO index (Serreze et al. 1997). Both approaches show that the major cyclone variability mode is strongly associated with NAO (North Atlantic Oscillation), with centres of action over the Denmark Strait (positive NAO) and over the Bay of Biscay (negative NAO).

The Mediterranean region is only partially affected by the North Atlantic Storm track, whose main path crosses the Northern Atlantic towards Northern Europe. Consequently, the main mode of the North Atlantic Storm track variability, which describes its north-south shift and intensification over the Atlantic, is only marginally related to the frequency and intensity of the cyclones in the Mediterranean region. In fact, a clear signal of NAO storm-track dependence over the Mediterranean has not been detected in all studies., though Trigo et al. (2000) have clearly demonstrated that an association exists and that it depends on the cyclone structural characteristics. The parallel analysis of the low frequency SLP (Sea Level Pressure) variability patterns and of the frequency of cyclones in the Mediterranean region shows that this is associated also with teleconnection patterns other than NAO. High level of SLP synoptic scale variability is associated with the positive phases of the SENA pattern (Southern Europe Northern Atlantic) and, to a minor degree, to the SCAN (SCANdinavian) and EATL (Eastern ATLantic) [Rogers 1990] and a similar East Atlantic/Western Russia (EAWR) [Krichak et al. 2000, 2002] patterns. While NAO is linked to the latitudinal variability of the Storm-track in the central Atlantic, instead the bulk of the variability over Central and Southern Europe and over the Mediterranean region is linked to low frequency patterns, whose centres of actions are localized over Europe and North-eastern Atlantic. However, such large-scale analysis is generally based on coarse resolution fields where the sub-synoptic and meso-scale characteristics of the cyclones in the Mediterranean region are poorly reproduced. Moreover, usually, these teleconections are defined on a monthly scale. Naturally, sub-monthly large scale features such as the well known, and relatively frequent, euro-Atlantic blocking episodes (Tibaldi et al, 1997) can influence the trajectory of storm tracks and their associated precipitation fields (Trigo R., 2004).

Note that Mediterranean features are well distinct in the global storm track structure, though their amplitude is smaller than that of the Atlantic and Pacific centres of activity. In fact, the Northern Hemisphere storm track presents a separate branch crossing the Mediterranean region, with areas of cyclogenesis in the western Mediterranean and of prevalent cyclolisis in the Central and Eastern Mediterranean (Hoskins and Hodges, 2002).

4.1.2 Sub-Areas of Cyclogenesis, Seasonality and Generation Mechanisms

The analysis of the ERA-15 (ECMWF ReAnalysis) at T106 resolution shows that the characteristic space and time scales of cyclones in the Mediterranean region are smaller than in the Atlantic (Trigo et al.1999). Over 65% of cyclones have a maximum radius less than 550 km, compared to the 1000-2000 km of the Atlantic synoptic systems. If the shortest living cyclones (with duration lower than 12h) are excluded, the average life of cyclones in the Mediterranean region is about 28 hours, compared to 3 – 3.5 days in the Atlantic. Radius and maximum gradient tend to scale with the minimum pressure. In general cyclones are deeper and have a larger radius in the western than in the Eastern Mediterranean. A recent evaluation (restricted to the western Mediterranean region, Picornell et al.2001), based on higher resolution fields (computed by HIRLAM at 0.5° resolution), and including also short living cyclones, produced smaller space and time scale values. In this data-set the radius of most cyclones is in the range from 150 to 350km (the mean value is 255km) and the most frequent lifetime of intense cyclones is about 18-24hours. Positive deepening values are mostly lower than 2hPa $(6h)^{-1}$, though value as high as 10hPa$(6h)^{-1}$ can be observed. Therefore, also deepening rates are smaller than in the Atlantic. Moreover, many cyclones in the Mediterranean region have null or even negative deepening rate, meaning that they are originated in neighbouring regions and cross the Mediterranean during their attenuation phase.

The cyclogenesis within the Mediterranean region is characterized by a rich mesoscale structure, with many different generation areas (tab.1), cyclones types, generation mechanisms and seasonal variability (Alpert et al 1990a, Alpert et al 1990b, Trigo et al 1999, Maheras et al 2001, Picornell et al.2001).

AREA	SEASONALITY	RADIUS (km)
Sahara	Spring , Summer	530-590
Gulf of Genoa	Whole Year	530-380
Southern Italy	Winter	520
Cyprus	Spring, Summer	330-460
Middle East	Spring, Summer	320-460
Aegean Sea	Winter, Spring	500
Black Sea	Whole year	380-400
Iberian Peninsula	Summer	410

Table 1. Cyclogenetic region in the Mediterranean area (after Trigo et al. 1999). Values represent average values in selected months (January, April, August)

Cyclogenesis occurs in the Gulf of Genoa, Spain, Southern Italy, Northern Africa, Aegean Sea, Black Sea, Cyprus, Middle East (Figure 8). Despite the use of different methodologies, selection criteria and data sets, these studies agree on the spatial location of cyclone generation (but for the Aegean Sea, which is present only in Trigo et al.1999). Unfortunately, the use of so many different pre-requisites undermines the possibility of comparing results between these papers. Recent studies, based on automated database methods (Campins et al 2000), have identified even smaller meso-scale structures and identified in the western Mediterranean 7 types of cyclones, on the basis of shape and intensity of the associated circulation.

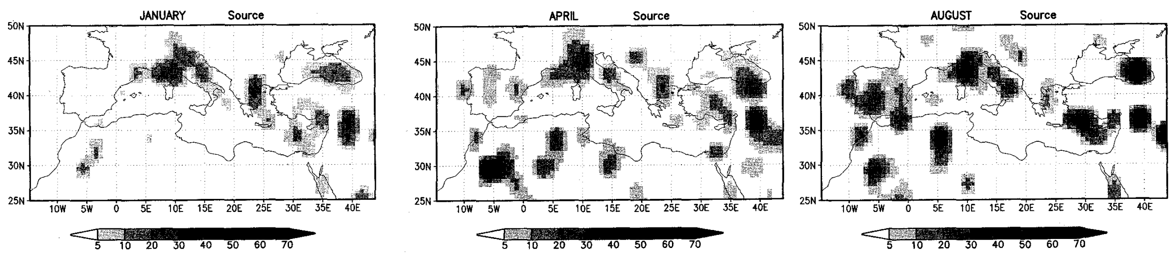

Figure 8. Number of cyclogenesis events detected per 2.25° X 2.25° in January, April, and August from 1979 to 1996 in ECMWF re-analyses (from Trigo et al. 1999)

The analysis of the monthly fields favours the definition of three seasons: winter, spring and summer, while autumn appears as a transitional period with large inter-annual variability, whose months could be characterized as late summer or early winter. However, seasonal characterization is not fully adequate, because of large inter-monthly variability (Alpert et al 1990a).

The role of orographic cyclogenesis (Buzzi and Tibaldi 1978) is fundamental in the Gulf of Genoa, in the North-western Mediterranean Sea, and in the Aegean Sea. In general areas with high concentration of cyclones are located near mountain ranges (mostly south of the Pyrenees, the Apennines and the Alps). Cyclones that develop over the three most active areas in winter are essentially subsynoptic lows, which may occur consecutively, being triggered by passage of a major system over northern Europe, whose path is a main factor determining their generation (Trigo et al. 2002). Thermal lows are characteristic of the Iberian Peninsula, and of most of the Mediterranean basin during summer (Picornell et al, 2001, Maheras et al.2001), when the number of low-pressure systems presents a large dependence on the daily cycle. The intensity of the cyclogenetic activity in the south-eastern Mediterranean region is to a large extent controlled by the large-scale synoptic processes over Europe and especially by those characterized by mid- and upper-tropospheric southward air-mass intrusions and tropopause folding effects (Krichak and Alpert, 2003). The processes are often associated with the formation of three-dimensional potential vorticity structures, jet streaks and low level jets conditions over the region to the south of Alps (Buzzi and Foschini, 2001; Liniger and Davies, 2003). Finally, Mediterranean cyclones with hurricane-like structure, whose intensity depends critically of the latent heat release at the sea surface have been identified, but their frequency and space-time distribution has not been investigated, yet (Pytharoulis et al 1999).

4.1.3 Present Trends and Future Scenarios

A counting of cyclone centres (without any differentiation on intensity), based on the NCEP re-analysis, shows a reduction of the number of cyclones in western Mediterranean and an increase in the East (Maheras et al., 2001). Linear fit to the data implies a 10% increase/decrease. Changes are not seasonally homogeneous. If only the rainy period (October to March) is considered, a reduction of the number of cyclones is present also in the Eastern Mediterranean. Other studies suggest a distinction between the increasing trend of weak cyclones and a decreasing trend of strong cyclones in the Western Mediterranean Sea (Trigo et al. 2000). It results that the positive trend identified in the Northern Hemisphere Storm track for the last decade of the 20th century (Chang and Fu, 2002) is not valid in the Mediterranean region.

It is difficult to analyze Mediterranean cyclones in scenario simulations because of their intrinsic small scale. However, the differences in cyclonic activity have been estimated for two 30-year long slice experiments, carried out with the ECHAM-4 model at T106 resolution, simulating the present and the doubled CO2 scenarios (Lionello et al 2001). The present climate is characterized by a slightly, but statistically significant, higher overall number of cyclones (fig.2, left panel). The doubled CO2 simulation is characterized by more extreme weather events, but the difference between the two scenarios is hardly significant (fig.2, right panel). No variation of the regions of formation of the cyclones has been clearly identified in this study.

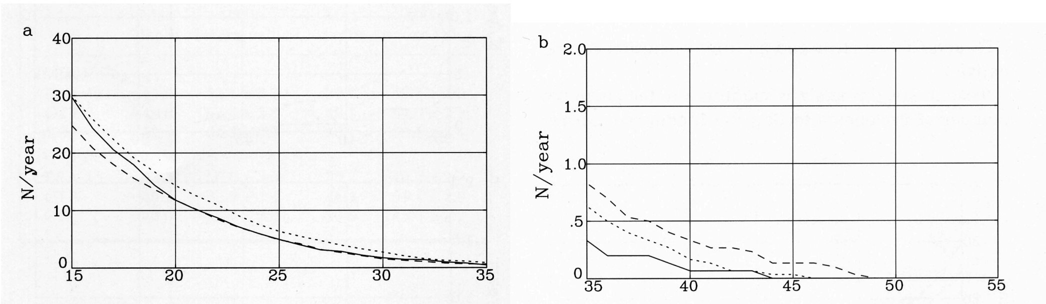

Fig. 2 Left panel: cumulated distribution, that is the average number of cyclones per year (y-axis) exceeding a given threshold (x-axis) for the present scenario (dotted line), doubled CO2 (dashed line), and ERA-15 (solid line) scenarios. Right panels: the tails of the cumulated distributions, that is cyclones with depth exceeding 35 hPa.(from Lionello et al.2001)

4.2 Weather Patterns and Mediterranean Environment

Obviously weather patterns have a deep influence on important environmental variables and, particularly, on the timing and magnitude of extreme values. Cyclones are associated with rain, wind waves and surges in shallow water areas (namely in the Gulf of Venice). Intensity of the cyclogenetic activity in the region to a large extent is controlled by the large-scale synoptic processes over Europe and especially by those characterized by mid- and upper-tropospheric southward air-mass intrusions and tropopause folding effects [Krichak and Alpert, 2003]. The processes are often associated with the formation of three-dimensional PV structures (PV streamers), jet streaks and low level jets conditions over the region to the south of Alps [Buzzi and Foschini, 2001; Liniger and Davies, 2003]. The conditions tend to stimulate development of the mesoscale convective complexes and Mediterranean cyclones. Intensity, location, duration and orientation of the systems as well as their inter-decadal trends in association of those of the main European teleconnection patterns appear to be important elements of the eastern Mediterranean weather and climate trends.

4.2.1 Precipitation

Cyclones play an important role in establishing the precipitation patterns and their variability, as synoptic scale disturbances have been found responsible for most of the floods both in the Northern Mediterranean and in the Middle East. Only a minority of local flush floods has been associated to intense small convective cells, whose presence in not clear in the standard meteorological analysis. A study carried out for the Negev Desert identified 4 classes of synoptic disturbances responsible for most of the floods, the two more important denoted as Syrian Low and Red Sea Trough (Kahana et al 2002). During the cool season, precipitation in the southern part of the eastern Mediterranean (EM) region is mainly associated with cyclonic systems of the Mediterranean origin. Major floods over Northern Italy have been mostly associated to well developed cyclones. It is likely that this holds also for other regions.

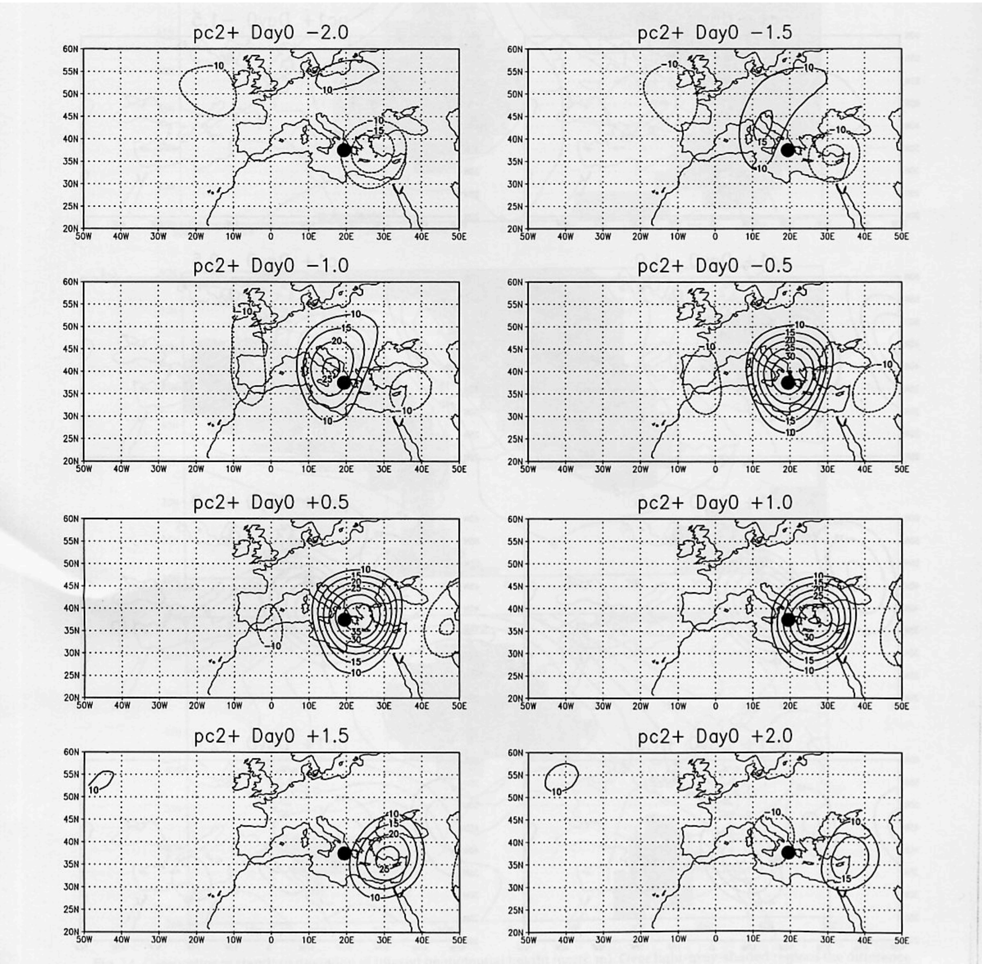

Figure 10. Maps of the lagged correlation with the value in the point indicated by the dot for the 500hpa synoptic scale filtered geopotential height. This point is selected as a maximum of explained variance of the precipitation field associated to the EOF describing a moisture transport from western to eastern Mediterranean areas. The maps are meant to describe of the evolution of the cyclonic disturbances associated with such transport (From Fernandez et al. 2002)

Cyclones have been found to play a key role in the internal redistribution of moisture in the Mediterranean region (Fernandez et al. 2003). A main mode of variability describes the transport of moisture from the Western to the Eastern Mediterranean and it corresponds to the generation (or intensification) of cyclones in the western Mediterranean and their following eastward motion (fig.3). Air sea interaction and a large latent heat flux are likely to play an important role in this process.

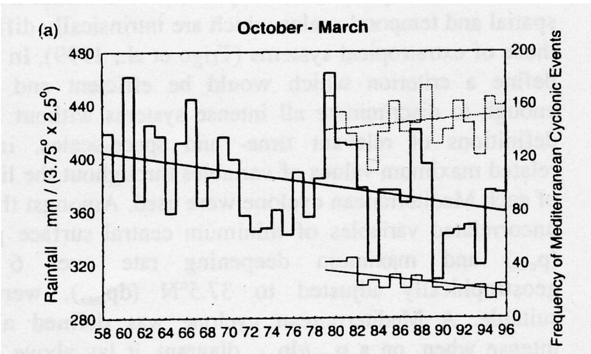

Figure 11. Time series, and respective linear trends, of the total amount of precipitation in the Northern Mediterranean Basin (bold curve, left axis), the total occurrence of intense Mediterranean cyclones (light curve, right axis), and of non intense cyclones (dotted curve, right axis) for the October to March period (from Trigo and Davies 2000).

The decrease of total precipitation during the wet season in the Northern Mediterranean has been associated with the reduction of intense cyclones (fig.4) and the Northward shift of the storm track over Europe in the period from the 1979 onwards (Trigo et al.2000). However, the analysis of precipitation shows different trends depending on the intensity of the events (Alpert et al.2002). The torrential rainfall in Italy exceeding 128 mm/day has increased percentage-wise by a factor of 4 during 1951–1995. In Spain, extreme categories at both tails of the distribution (light: 0-4 mm/d and heavy/torrential: 64 mm/d and up) increased significantly. No significant trends were found in Israel and Cyprus. The consequent redistribution of the daily rainfall categories-torrential/heavy against the moderate/light intensities - is of utmost interest particularly in the semi-arid sub-tropical regions for purposes of water management, soil erosion and flash floods impacts. Specific isolated regions exhibit an increase of extreme rainfall in spite of the reduction of the total precipitation.

4.2.2 Waves and Surges

The surface wind, which is associated to a cyclone, produces ocean waves and, in shallow water, storm surges. The variability of the cyclones regime has, therefore, an impact on wave field and surge level, which can both, in turn, be considered a “proxy” of the cyclones characteristics.

The surge in the Northern Adriatic, and the consequent floods of Venice, is associated with intense cyclones in the Northwestern Mediterranean. The increase of the local relative sea level is the main cause for the increased frequency of floods. The residual variability is mainly associated to that of the meteorological forcing. There is an indication that the frequency of moderate surges is increasing (Pirazzoli and Tomasin, 1999) and at the same time major independent surge events do not show any large variation (Trigo and Davies, 2002). A weak decreasing trend has been identified in the value of extremes levels in Trieste (Raicich, 2003). This behaviour has been shown to be consistent with the variation of the meteorological forcing in the Northern Adriatic area, that is with more frequent moderate storms and less frequent intense storms. Scenario evaluations have been carried out applying a downscaling procedure to T106 global simulation (Lionello et al 2002). The comparison between the present and future climate simulations shows no statistically significant change in the extreme surge level. Unfortunately, though greatly compensating for the coarse resolution of the global forcing fields, this study still presents a systematic under-evaluation of the surge extremes, which could affect the results of the comparison.

Little is known about wind waves as present climate variability and trends are concerned. The same downscaling procedure used for the surge in the Adriatic Sea has been applied also to the wave fields in the Adriatic Sea, and results show a reduction of the extreme wave height in a doubled CO_2 climate scenario (Lionello et al 2002).

4.3 Outlook: Crucial Topics for Ongoing Research

Though many interesting research lines have been carried out and they provide a well-established understanding of many aspects of the Mediterranean meteorology, further research is recommended for reconsidering these phenomena from a climate perspective.

The investigation has to assess whether the present archives provide an adequate database for the analysis and to identify the actions required to fill gaps. On the centennial time scales it appears that there is an unbalance between regions and phenomena that are well documented (e.g. the surge of Venice, Camuffo 1993) and other where data are scarce and reconstruction necessarily indirect (e.g. precipitation patterns and extremes on the whole African coast). Moreover, for the recent decades, when meteorological observations are worldwide available and model re-analysis have been carried out (e.g. NCEP and ERA-40 re-analysis), it has to be fully investigated whether the sub-synoptic and mesoscale characteristics of cyclones in the Mediterranean region are well represented in the available data archives. On this respect the development of extensive, high-resolution sets of data appears extremely important for addressing unresolved scientific issues.

4.3.1 Identification of Generation Mechanisms and Relevant Processes

The available classifications of the cyclones often lack an analysis of the generation mechanisms, whose identification might help predicting future scenarios and the change in the frequency and intensity of some specific cyclone types (e.g. the so-called Mediterranean lows). The availability of regional high-resolution re-analysis, where cyclone structures are well reproduced, might be crucial for this task. Moreover, it is important to identify the deficiencies in the models that account for inadequacies in simulating the cyclones in the Mediterranean region and evaluating their variability.

4.3.2 Connection to Large Scale Patterns

Though there is an extensive description of the mesoscale distribution of the cyclogenesis areas and of the cyclone tracks characteristics, including their seasonality and trends, the connection between the climate of the cyclones in the Mediterranean region and the low frequency large-scale variability is poorly understood. Intensity, location, duration and orientation of the systems as well as their inter-decadal trends should be analyzed in association of those of the main European teleconnection patterns. The importance of regional scale processes (e.g. latent heat release over the sea) and of their variability with respect to forcing from large-scale patterns (e.g. the meridional shift and/or intensification of the storm track over northern Europe) has not been precisely quantified.

4.3.3 Analysis of Weather Regimes in Future Climate

The analysis of Mediterranean cyclones in future climate scenario is still preliminary and it is undermined by the lack of adequate resolution of most simulations and the consequent doubt that the mesoscale structure responsible for the cyclones behaviour are properly represented. Therefore, the assessment of the role of resolution is crucial. The prediction of future scenario would greatly benefits from an improved understanding of the teleconnection to large scale patterns, whose behaviour in future climate has already been investigated and that are likely to be more adequately described in global climate simulations. There is, possibly to a larger extent than in other areas of the globe, the need to restrict uncertainty of future scenarios, and to reach a resolution to describe mesoscale storms. It is important to understand if the absence of large trends, resulting from the available studies, is real or it is the result of poor description of sub-synoptic and mesoscale structures.

4.3.4 Impact of Variations of Weather Regimes on Precipitation Patterns, Surges, Waves

It may be suggested that the variations observed during the last decade of the precipitation over the Mediterranean region were associated with relatively small variations in the characteristics of the air mass and transport. Such changes might be small and not always easily detectable, however, their impact on local climate and climate variability is likely to be large. These variations could have serious consequences for the rain intensities in many Mediterranean areas. The danger is twofold. There are, on one hand, areas already under stress because of recurrent water shortage during summer, and, on the other hand, areas where torrential rains have produced large damages to properties and also human casualties. It is important to identify the factors responsible for the increased of rainfall extremes and the reduction of total precipitation. It is also important to understand the relation between intensity of precipitation and that of the cyclones, represented by the depth of the low-pressure system or the vorticity in the area surrounding its centre.

The Mediterranean Sea is characterized by complicated coastline, with highly vulnerable areas (e.g. the Nile's delta and the Gulf of Venice). Though the main danger for these areas is due to the increased coastal erosion and land losses that would be produced by sea level rise, the change in storminess is also potentially critical. Variations of the frequency or intensity of sea storms could further increase risks and damages. The analysis of changing wind waves and surge regimes requires detailed impact studies carried out on the basis of sufficiently precise forcing fields, that is it relies on accurate surface wind fields or adequate downscaling techniques.

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5. Role of the Mediterranean Salty Water Tongue Outflowing from Gibraltar on the North Atlantic Deep Water Cell and on the Transitions from Glacial to Inter-Glacial Scenarios

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Substantial uncertainties exist, concerning the quantitative and qualitative characterization of the main pathways for the spreading of the Mediterranean salinity anomaly in the North Atlantic. Advances in the knowledge of the Mediterranean Outflow in the major climatic transitions are expected from:

- investigation of large scale phenomena connected with water mass formation processes in the North Atlantic, by means of simplified (low-dimensional) models;
- direct (lagrangian) observation of the spreading of the Mediterranean outflow;
- better representation of the exchange at the Strait of Gibraltar in large scale climatic models (A/OGCM's).

5.1 Introduction

The Mediterranean Sea is considered an exceptional marginal basin because all of the fundamental oceanic processes occur in it. The interactions between the water masses originate about 1 Sverdrup of relatively warm and saline water, flowing out of the Strait of Gibraltar. The same contribution to the average salinity of the world ocean would be achieved by distributing over the North Atlantic (north of 20°S) the net evaporation observed over the Mediterranean Sea. This is equivalent to a negative contribution of about 50 mm/y to the estimated 250 mm/y fresh-water input in the North Atlantic (Wijfels et al. 1992). Then, the contribution of the Mediterranean Outflow Water (MOW) amounts to about 20% of the total freshwater budget over the North Atlantic (Gerdes et al., 1999).

5.2 State of the Art

The MOW is neutrally buoyant in the North Atlantic at about 1000m depth. Two main paths are observed for the spreading of MOW in the North Atlantic at intermediate depth.

One is the Westward Tongue (WT), extending from the Gulf of Cadiz towards the central North Atlantic at mid-latitudes. This path is characterized by the presence of stable subsurface eddies containing Mediterranean water, so called meddies, that are advected by the large scale wind driven circulation (Nof, 1982; Hogg and Stommel, 1990) and play the role of heat and salt sources in the Mid-North Atlantic.

Another path is the Northward Undercurrent (NU), off the Iberian Peninsula, driven by geostrophic balance of the ocean interior and mixing with the surrounding water masses (Spall, 1999).

A quantitative description of the two branches of flow is given by Sparrow et al. (2002) who analysed recent float data and found, north of 36°N, a background northward flow, with average velocity of 1.8±0.6 cm/s, and peaks of 10.1±3.7 cm/s off the coast of Portugal. South of 36°N they found a weaker background flow (about 0.12 cm/s), and a strong mesoscale activity with peak energy as high as 89 cm^2/s.

5.2.1 The Signature of the Mediterranean Outflow Water (MOW) in the North Atlantic

Early documentation of the westward propagation of the Mediterranean Outflow can be found in Wüst (1935), while Needler and Heath (1975) used the spreading of the salinity anomaly to estimate the vertical and horizontal diffusion coefficients in the ocean. Although the strong mesoscale activity of the WT has been investigated in great details (McDowell and Rossby, 1978; Armi and Zenk, 1984; Bower et al., 1997), very different estimates of the role and relative contribution of meddies to the total westward transport of salt exist. Richardson et al. (1989) suggest a contribution of about 25% of the total transport of MOW based on a statistics of observed meddies; Arhan et al. (1994) estimates 55% contribution of meddies; Mazè at al. (1997) attribute to the detachment of meddies from the slope undercurrent almost all of the westward advection of the salinity anomaly.

The NU path has also been the object of much attention in the past but is still very uncertain. Two similar cruises, Bord-Est 2 and Bord-Est 3, conducted in 1988 and 1989, analysed by Mazè al. (1997) and Arhan at al. (1998), produced quite different pictures of the Eastern North Atlantic. In the first case (Bord-Est 2), a southward surface flow of 2-3 Sv off the coasts of Portugal was inferred from hydrographical sections. Similar results are reported by Krauss and Käse (1984), Roether and Fuchs (1988) and Paillet & Mercer (1997). In the second case (Bord-Est 3) a total northward transport of 9-12 Sv was observed, with a well defined maximum in the MOW layer. A northward flow off the coast of Portugal was also observed by Haynes and Barton (1990) and by Rios at al. (1992).

Many different factors, such as the interactions with regional topographic features, the superposition of water masses, the strong mesoscale activity and even the seasonality of the Azores High may seriously affect all indirect measurements of both the WT and NU paths in this region.

Further north, the MOW can be clearly tracked at 46° N in the central Bay of Biscay (van Aken, 2000) and some authors (Reid, 1979) claim a direct contribution of the Mediterranean Sea outflow to the Greenland-Iceland-Norwegian (GIN) Sea. Iorga and Lozier (1999) also support the so called deep source hypothesis, in whereby a substantial northward transport of MOW, way through the Rockall Channel, may affect directly the preconditioning in the GIN Sea.

More recently, this possibility has been severely criticized on the base of different hydrographical observations by McCartney and Mauritzen (2001) who strongly support the alternative shallow-source hypothesis. In this case the warm, salty inflow in the Nordic Sea is attributed to the northward branching of the North Atlantic Current.

Bower et al. (2002) have recently attempted a direct measurement of the mid-depth circulation of the eastern North Atlantic. They shed new light on the NU pathway in the North Atlantic observing that the MOW is diverted into the ocean interior from the Bay of Biscay and 'probably penetrates north of 52°N by mixing with the North Atlantic Current in the complex area southwest of the Porcupine Bank'. In this new scenario, relatively little water of Mediterranean origin is found inside the Rockall Through either at the surface or at depth. Rather, almost all of the North Atlantic Current crosses the ridge and flows into the Icelandic Sea.

To summarize, different pictures of the spreading of MOW in the North Atlantic have been constructed from the observations and no definitive agreement has been reached yet about any of them. Most importantly, very little is known about the variability of these pathways.

5.2.2 Modelling of MOW

Much effort as been devoted to the understanding of the mechanisms that contribute to the shaping of the Mediterranean Outflow. Motivated by the observations of Arhan (1987), Tziperman (1987) used a multi-layered geostrophic model to investigate the mechanism for the northward spreading and narrowing of the Mediterranean outflow, which is attributed to the westward propagation of Rossby waves. Spall (1994) analyses the linear instability of the meridional flow in the eastern North Atlantic, and found that baroclinic instability could be responsible for a significant fraction of the westward transport.

The role of ventilation has been considered by Stephens and Marshall (1999) who stressed the crucial role of the wind forcing in shaping the salinity tongue in the central Atlantic, while meddies were described as a distributed source of salt in the interior of the ocean.
One of the most serious limitations to the description of the dynamics of the MOW in ocean models is the existence of a shallow and narrow communication between the North Atlantic and the Mediterranean Sea at the Strait of Gibraltar. A common approach to overcome this limitation is to restore values of temperature and salinity at the eastern boundary to climatology (Stanev, 1992; Hecht et al., 1998; Rahmstorf, 1998; New at al. 2001).
However Gerdes et al. (1999) found that realistic WT and NU can be obtained only by the imposition of an actual inflow at the eastern boundary.
Furthermore, recent numerical simulations (Sannino et al., 2002; Sannino et al., 2004) have shown that tides contribute up to 30% of the total exchange at the strait. They also showed that the depth of the outflow is substantially affected by changes in its salt content, thereby suggesting that the dynamics of the Strait of Gibraltar deserves a careful treatment especially in the case of large scale climatic models where the resolution is usually coarse.

5.2.3 MOW and Climate

Since the Atlantic Ocean contributes for a substantial part of the poleward heat transport from the tropics, all major climatic shifts on all ranges of time scales have been related to major changes in the overturning circulation of the North Atlantic. On centennial time scales, the onset of different convective regimes in the North Atlantic have been observed and related to the effect of atmospheric activity (Root et al. 1999), although no coupling mechanism has been proposed yet.

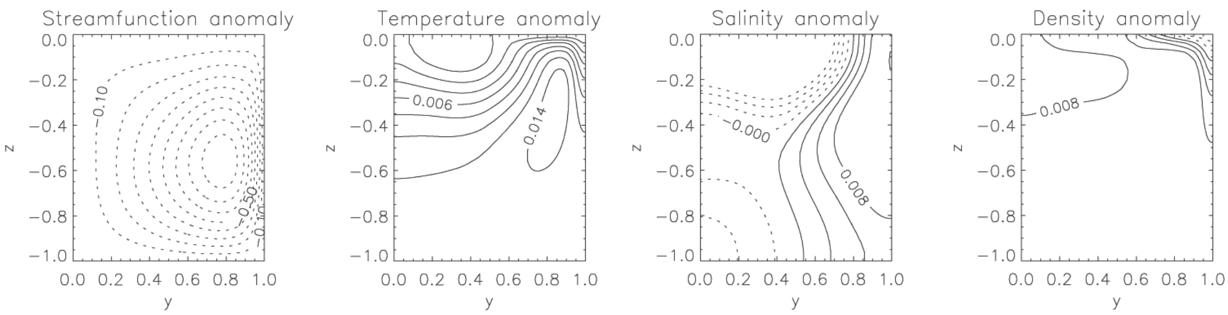

Figure 12. Enhancement of the advective feedback in a simplified model of the thermohaline circulation. The panels show the differences between two similar overturning regimes, which differ by the presence of an intermediate depth anomaly. Mixed boundary conditions are employed. The formation of strong temperature gradients at the surface and the advection of the salinity front, help destabilizing the water column in the deep-water formation region, thereby enhancing the circulation (from Artale et al., 2002).

On palaeoclimatic time scales, both observational and modelling evidences exist, supporting the hypothesis that the transition from the Last Glacial Maximum (LGM) to the Holocene has been related to a major reorganization of the overturning circulation of the North Atlantic (Boyle et al., 1987; Sarnthein et al., 1994; Seidov et al., 1997).
Moreover, modelling studies suggest that under glacial conditions the meridional overturning circulation may be characterized by different stability properties than under present day conditions (Ganopolski et al., 1999).

Usually, two fundamental processes, which are also opposed to each other, are called for a leading role in the instability and in the rapid transitions between different modes of operation of the overturning circulation, namely the *advective* and *convective* feedbacks (Rahmstorf et al., 1996). The former is related to the lateral advection of warm and salty waters towards areas of deep-water formation. The excess of heat is rapidly lost through enhanced exchanges with the atmosphere while the salt content is retained. This way, the instability of the water column is enhanced and, by mass continuity, a positive feedback on the circulation is created. The convective feedback relies on similar exchange mechanism but operates in the vertical during the onset of deep-convection, and is related the localization of convective sites (Lenderink and Haarsma, 1994). Tziperman (2000) illustrates how this two mechanisms may interact and generate the instability of a given circulation regime and the formation of a new equilibrium.

Surprisingly, although the Mediterranean Outflow gives a substantial contribution to the thermohaline forcing of the North Atlantic and thereby to the efficiency of such mechanisms, it is usually neglected in the formulation of palaeoclimatic variability scenarios.
Nevertheless an impact of the MOW on the strength of the overturning circulation of the North Atlantic was observed by Rahmstorf (1998). Hecht et al. (1997) achieved a stable overturning circulation only when a realistic MOW was present. Recently Artale et al. (2002) found a substantial impact of intermediate depth salinity anomalies on the processes affecting the stability of meridional circulation patterns (figure 12). Furthermore, palaeoclimatic data show that the Mediterranean Outflow was deeper (1600-2000 m), saltier (2 psu) and colder (5°C) during the Last Glacial Maximum (Schoenfeld and Zahn, 2000). If such an outflow would have a different impact on the stability of the MOC is still poorly understood.

5.3 Scientific Challenges

Very little is known about the role of the Mediterranean salty water tongue on the transitions from glacial to inter-glacial scenarios. To this aim, substantial efforts must be undertaken for a systematic investigation of the role of MOW on the stability and variability of the North Atlantic overturning circulation.

5.3.1 Fundamentals

Important contributions to a better definition of the role of MOW on the efficiency of fundamental processes such as the advective-convective feedback may come from the analysis of simplified models, from box-models to GCM's with idealized geometry, which have proven to be invaluable tools for the identification of large scale oceanic processes observed in nature.

However, an unavoidable step is a deeper comprehension of the role of MOW in present day's climate. Important uncertainties have been stressed here, concerning the knowledge of the main pathways for the spreading of MOW.

5.3.2 Paths of MOW

As to the WT path, one of the most challenging tasks in climate modelling on very long time scale is to account for the role of meddies. It appears that the only possibility is to impose them as an additional source of salt for the interior North Atlantic. However, their quantitative contribution is still very uncertain. Therefore, a deeper understanding and modelling of the processes of meddy formation as function of the characteristics of the Mediterranean Outflow is required. Possibly, this leads to the construction of meddy statistics to be used in climate models.

From the experimental point of view the observation of meddies from combined satellite and in-situ measurements (Oliveira, 2000) appears to be a promising technique for the assessment of their role in the westward transport.

Furthermore, a robust picture of the NU path in the North Atlantic, and most importantly of its variability, has not been established yet. This task can be achieved only by the coordination and integration of observational and modelling activities. In particular, direct current measurement employing float data is to be strongly supported.

It is worth noting that the modelling of the NU appears to rely on a proper description of the outflow in large scale ocean models, which appears to be still further to come. In this context, important information may also come from the detailed modelling of the functioning of the Strait of Gibraltar under different climatic conditions.

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6. Modelling of the Mediterranean regional climate

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6.1 Scientific background

It is generally agreed that global coupled ocean-atmosphere general circulation models (CGCMs) are the best tools to predict climate variations at seasonal and interannual scales, and to estimate climate changes at longer time scales, especially those related to the anthropogenic modification of the atmospheric composition. Outputs from such models cannot, however, be directly used in many impact oriented applications because of their relatively coarse spatial scale (typically several hundreds of kilometers) and associated uncertainties. Furthermore, while particular coarse-resolution CGCM may be capable of capturing the mean climate behavior, they are not usually successful in reproducing higher-order statistics and extreme values. Regional climate modelling plays thus an important role to fill the gap between the global climate models and the growing demand of climate predictions and scenarios on shorter spatial-temporal scales.

The most important regional climate forcing in the Mediterranean region is associated with the complex orography characterized in many coastal regions by step mountain slopes and the large land-sea contrast. This provides a very good testbed but also a big challenge for regional climate modelling. Determination of the Mediterranean regional climate is currently undertaken through several different approaches. The most popular one is the use of (usually atmospheric only) regional climate models (RCM) or limited area models (LAM) (Giorgi and Mearns 1999). Spatial resolution of such models varies from a few kilometers to several tenths of kilometers, upon the assumption or not of the hydrostatic approximation. Regional climate models (for example, those used in Christensen et al. 1997; Jones et al. 1995; Giorgi and Mearns 1999, and many others) need to be nested into coarser-resolution global models in order to get the necessary driving information through the frontiers of the domain. This approach allows implementation of much-detailed physical parameterizations in RCM to ensure a better simulation of local weather and climate events. Another existing approach is based on the use of variable grid (zoomed) general circulation models (GCM) with closer resolution for the Mediterranean basin (for example, Déqué and Piedelievre 1995, Li and Conil 2003). This ensures a best downscaling of information from large scales to regional scale, but the resolution limit is currently thought to be around the 50 kilometers, due to either computing capacity or physical parameterizations implemented in such GCMs. Third approach for high-resolution determination of climate parameters over the Mediterranean region is associated with the application of statistical methods for the downscaling of results issued from climate modelling in large-scale GCMs. Combination of dynamical and statistical approaches are also possible and have been reported (Krichak et al. 2000).

6.2 Current Status

Numerical modelling, both global and regional, is an important tool to understand physical mechanisms controlling climate change and variability at different spatial-temporal scales. It also provides the unique possibility to construct physically-based and comprehensive future climate scenarios, the starting point for many socio-economical impact considerations. Few studies dedicated to the Mediterranean regional climate modelling are reported as so far. Most of the existing research programmes, such as Mice, Prudence and Stardex (http://www.cru.uea.ac.uk/projects/mps), on climate variability and change over Europe include only partially the Mediterranean basin as the southmost part of their considered domain. Due to the marginal effects, simulated climates over the Mediterranean basin are often biased by the prescription of the boundary conditions. This decreases largely the validity of such studies on the Mediterranean climate. The bias of present climate simulations in the Mediterranean basin is in the range from -1K to 5K for temperature and from -30% to 20% for precipitation, according a study reported by Giorgi and Francisco (2000 a,b) with different GCMs.

Regional climate changes under global warming context (Jones et al. 1997, Machenhauer et al. 1998, Frei et al. 2002, Gibelin and Déqué 2003) are the most important motivations for the Mediterranean regional climate modelling. It is generally agreed that the Mediterranean region is one of the most sensitive areas on Earth in the context of global climate change, due to its position at the border of the climatologically determined Hadley cell and the consequent transition character between two very different climate regimes in the North and in the South.

Many global and regional models tend to simulate a warming of several degrees (from 3 to 7 K) on the Mediterranean for the end of the 21st century and the warming in Summer is larger than the global average. There is also a general trend of mean precipitation decrease for the region (especially in Summer), due to mainly the northward extension of the descending branch of the subtropical Hadley circulation. Even when a decrease of total mean precipitation is simulated, the precipitation amounts in the intensive events may increase in many places (Christensen and Christensen, 2003). A plausible explanation of more intense extreme events around the Mediterranean is that a warmer climate contains more water which serves as an additional potential for latent heat release during the build-up of low-pressure systems.

Another major anthropogenic modification of the Mediterranean natural environment concerns the land use of the region. There are indications that the albedo change due to the progressive deforestation in the Mediterranean region since the Roman classical has significantly altered the atmospheric circulation over northern Africa and the Mediterranean and consequently, the regional precipitation patterns (Reale and Shukla, 1998).

Besides the important changes which Mediterranean climate may be on the verge of experiencing, modelling is also a crucial resource to understanding current climate fluctuations, many of which still need to be satisfactorily explored. For instance, the decadal changes which have characterized Mediterranean winter precipitation in the last 50 yrs (Hurrell, 1995; Mariotti et al. 2002) and the related impacts on the Mediterranean environment. On interannual timescales, the so-called heat waves, which during summertime have been so heavily affecting the quality of life in the Mediterranean region (Schar et al. 2004). The increasing evidence that the global-scale fluctuations in tropical sea surface temperature, mostly associated to ENSO, influence Mediterranean climate, still remains unexplained (Hoerling and Kumar 2003).

6.3 Outlook and Future Challenges

Three important issues are foreseen for the Mediterranean regional climate modelling in the next few years.

6.3.1 High-Resolution Mediterranean Climate Modelling Systems

The spatial resolution of future modelling systems will be further increased. It is expected to have models with resolution around 10 to 20 kilometers in the next few years. Experience with numerical weather forecasting shows that higher spatial resolution usually leads to better prediction, mainly due to improvements in the representation of atmospheric instability which is crucially dependent on the model's spatial resolution. In climate modelling, higher spatial resolution may lead to improvements in some aspects and degradation in others (Leung et al. 2003, May and Roeckner 2001). Climate is in fact more related to the sources and sinks of energy, moisture and momentum.

Mechanisms controlling their budgets and evolution at different spatial-temporal scales are thus crucial for climate. In general higher spatial resolution models can provide a more comfortable background to incorporate sophisticated physics and the latter will improve the performance of regional climate models.

The overall studies reported in the current scientific literature seem to show improved model performance with higher spatial resolution, especially in reproducing extreme events, such as strong precipitation episodes and cyclogenesis often related to the specific surface orography. But there is indeed a need to further evaluate and quantify the impacts of spatial resolution on regional climate simulation. Even in the most advanced high-resolution regional climate models, it will be difficult, in some cases, to determine dynamically the hydrological variables, such as run-off. Application of statistical methods will be always necessary to provide appropriate solutions.

In the next few years, high-resolution Mediterranean climate modelling systems are expected to be used to produce consistent data for the Mediterranean basin during the last 40 years, which can not be achieved by global re-analysis done in weather prediction centres (such as NCEP and ERA40) due to the too coarse spatial resolution and the deficiency in the hydrological cycle. By performing a special calibration through the regional atmospheric/land-surface climate models covering a quite large domain around the Mediterranean, it is in principle possible to reduce the hydrological bias of the re-analysis products. Such simulations of the Mediterranean climate over the last 40 years will be very useful to study the dynamical and physical processes controlling the climate in the Mediterranean region. They are also useful for climate trend detection for the last 40 years.

6.3.2 Development of Integrated Regional Modelling Systems

Other components controlling the regional climate will enter interactively into the regional modelling system. They include, through the most important, the Mediterranean Sea general circulation, basin-scale hydrology, dynamical surface vegetation, land use, atmospheric chemistry, air pollution and man-made or desert-originated aerosols, marine and land-surface ecosystems. It is expected that new climate feedbacks and modes yielded through the complex interaction among different components of the Mediterranean climate system might be discovered and quantified. Especially the regional atmosphere and Mediterranean sea coupled models should receive high priority for their development and utilization in the Mediterranean climate studies. From studies currently undertaken in several European institutes, the high resolution of atmospheric models is quite crucial to correctly simulate the convection in the Mediterranean sea.

With increasing complexity of numerical modelling systems, validation against appropriate observational data is becoming an important issue. This will require however a significant improvement of the currently existing data bases for the region and an increasing capacity to obtain and analyze new measurements with different geophysical characteristics of the region like soil moisture, soil types, vegetation coverage, dust sources and transport (Tsidulko et al. 2002, Alpert et al. 2002, Krichak et al. 2002), etc. The current observational network around the Mediterranean basin is still scarce and accuracy of measured geophysical parameters in this region is also significantly lower than that over more developed areas like Europe.

Putting the numerical systems in the configuration of paleoclimate will be an interesting exercise to test the robustness of the numerical models because it is the only way to test the sensitivity of our complex models to documented climate changes. Paleoclimate simulations will allow to test the ability of models to simulate the correct amplitude but also geographical pattern of climate changes thanks to a large number of dated samples all around the Mediterranean basin.

6.3.3 Multi-Model Ensemble Regional Climate Simulations

It is also necessary to emphasize the perspectives of ensemble approach for future Mediterranean regional climate modelling activities. This is the only way to assess the uncertainties of numerical modelling for climate variation and probabilistic estimates for changes at long terms. Any climate impact considerations should take into account this aspect of probability.

In terms of global mean surface air temperature, it is generally agreed that the changes of the global temperature will be between 2 to 5 degrees at the end of the present century. In broad terms, the current thinking attributes about half of this range of uncertainty to uncertainties in the emission scenarios and half to uncertainties in the construction and use of global climate models. The use of regional climate models will further increase the uncertainty range. We need thus to use a hierarchy of global and regional models and to run ensemble simulations. This is just at the limit of our current computing capacity. A more close cooperation with computer industry is thus necessary in the future to accomplish this task.

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7. Aspects of Climate Dynamics Due to the Sun

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Climate variability is due to several causes – internal atmospheric dynamics, variations in external forcing and the ocean-atmosphere coupling. To understand the relative importance of these factors we need to understand the role played by each. Some studies based on observational data, suggest that the upper tropical troposphere is warmer and moister at solar maximum than at solar minimum. Other studies indicate a broadening and weakening of the Hadley cell at solar maximum resulting in a poleward displacement of the mid-latitude storm tracks. The MED region might be particularly vulnerable to this shift due to its dependence on extratropical cyclone activity in winter for water supply.
The mechanisms that link solar variability to climate processes should be studied in order to explain these observations. The study should include both data-analysis building on recent advances in detecting and characterising solar signals (Gleisner & Thejll 2003, Thejll et al. 2003), and model-studies focusing on amplifying processes, for instance the role played by ozone (Haigh 1994), vertical dynamical coupling [Christiansen, 2001], clouds and the hydrological cycle (Kristjánsson et al. 2003). Simplified GCM models should be used as diagnostic tools to understand feed-back mechanisms during radiative heating (Haigh 1996, 1999, 2001, 2003, Labitzke et al. 2002) in particular with respect to the reported solar signal in low clouds (Kristjansson et al. 2002) and SSTs (White et al. 1997).

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