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MedCLIVAR

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Editorial

MedCLIVAR: Mediterranean CLImate VARiability

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1. Scope

MedCLIVAR aims to coordinate and promote research on the Mediterranean climate. The objectives of this project cover a comprehensive set of issues: the reconstruction of climate past evolution, the description of patterns and mechanisms characterizing its space-time variability, the study of the occurrence of extreme events, the identification of trends in observational records and of the forcing parameters responsible for the observed changes, the simulation of climate change under future emission scenarios, and of climate change impacts (Lionello et al 2006a,c).

The idea of MedCLIVAR has been proposed during the ESF-LESC Exploratory Workshop on "Mediterranean Climate Variability and Predictability" held in Rome, may 17-19 2004. Subsequently MedCLIVAR has been endorsed by CLIVAR in January 2005 and approved as program by the ESF-LESC committee in August 2005. Several countries and institutions have already expressed their support to MedCLIVAR ESF program so that its official launch should be expected for spring 2006.

2. The Mediterranean climate

The Mediterranean regions has peculiar characteristics because of its location and morphology (Lionello et al. 2006a).

The Mediterranean Sea is located in a transitional zone, where mid-latitude and tropical variability are both important and compete. The southern part of the region is mostly under the influence of the descending branch of the Hadley cell, while the Northern part is more linked to the mid-latitude variability, characterized by the NAO (North Atlantic Oscillation) and other mid latitude teleconnections patterns. An important consequence is that the analysis of the Mediterranean Climate could be used to identify changes in the intensity and extension of global scale climate patterns.

The region is, obviously, characterized by Mediterranean Sea itself, a marginal and semi-enclosed sea on the western side of a large continental area connected to the Atlantic Ocean through the narrow Gibraltar strait. This relatively large mass of water is a heat reservoir and a source of moisture for the surrounding land areas, mainly those around the eastern part of the basin.

A specific characteristic of the Mediterranean region is its complicated morphology. The high mountain ridges surrounding the Mediterranean Sea, the distinct basins gulfs, islands and peninsulas of various sizes, produce much sharper climatic features than expected without their existence and determine many sub-regional and mesoscale structures on both atmospheric and sea circulation. The regional weather regimes, with energetic meso-scale features and several cyclogenesis areas (Lionello et al, 2006b), and the major thermohaline cells (Tsimplis et al 2006), characterizing the atmospheric and sea circulation, respectively are important consequences. One cell connects the eastern to the western Mediterranean and is associated with the inflow of Atlantic Water at the Gibraltar strait in the surface layer and the outflow of Levantine Intermediate Water (LIW) in the intermediate layer below. Two others cells are confined to the eastern and western Mediterranean basins and are driven by localized deep convective events, which occur in the Northern Mediterranean areas and are determined by intense air-sea interaction.

Several planetary scale patterns exert an important role on the climate of the Mediterranean region, though the time and space behaviour of the regional features associated with such large scale forcing is complex, because of the characteristics of the Mediterranean region (Trigo et al. 2006, Alpert et al 2006). The large-scale mid-latitude atmospheric circulation (mainly via the NAO, North Atlantic Oscillation) exerts a strong influence on the cold season precipitation over the Mediterranean, though the strength of the relation varies across the region and depends on the considered period. The role of the Mediterranean Sea itself as source of moisture and the subsequent eastward advection by the atmospheric circulation implies a more complex picture for the Eastern Mediterranean. ENSO has been found to play a role on winter rainfall in the eastern Mediterranean and is has a significant positive correlation with the western Mediterranean-autumn averaged rainfall. Also a correlation with western Mediterranean spring rainfall has been found, but it has undergone strong interdecadal variability during the 20th century.

In summer, when the advection of moisture from the Atlantic is weaker and the Hadley cell moves northward and its strength diminishes, there are evidences of connections (stronger in the eastern Mediterranean and at the North African coast) with the Asian and the African monsoons.

It is important to investigate the possible active role of the Mediterranean on the global climate as the role of its sea surface temperature on the climate of other regions (Li et al. 2006). Moreover, the Mediterranean outflow across the Gibraltar strait determines the presence of a tongue of very salty water in the entire Northern Atlantic at intermediate depths. This important signature in the salinity field has a role in preconditioning the surface water column of the convective cells and increases the stability of the Atlantic Meridional Overturning Circulation (Artale et al. 2006). The interaction of the Mediterranean outflow with the thermohaline circulation of the North Atlantic raises the possibility for feedback mechanisms, eventually active both at decadal and millennial time scales, involving the North Atlantic, the Mediterranean and the overlying atmosphere, which have potentially important climatic implications.

3 Climate trends and future scenarios

The large amount of long instrumental series, documentary proxy evidence and natural proxies allow the reconstruction of spatio-temporal highly resolved Mediterranean temperature and precipitation fields covering the last few centuries, their comparison with model simulation runs, and the analysis of the change of atmospheric influence on the Mediterranean climate on centennial time scales (Luterbacher et al. 2006). Significant warming (0.75°C in one hundred years) and decline of precipitation have been observed in the Mediterranean region during the 20th century. Trends are largest in winter: the recent winter decades (end of twentieth, beginning of the twenty first century) were the warmest and driest in the last 500 years. However, the structure of climate series can differ considerably across regions showing variability at a range of scales. In particular for precipitation, sub-regional variability is high and trends in many regions are not statistically significant in view of the large variability.

Reduction of precipitation is consistent with the reduction of cyclone frequency. At the same time an increase of the relative frequency of intense precipitation is suggested for parts of the western Mediterranean

Important changes of the Mediterranean Sea circulation and sea level have been observed in the last decades. Sea level has followed the mean estimated global increase (1.8mm/year) till the 1960s, but it has subsequently dropped by 2-3 cm and since beginning of the 1990s has increased 10 times faster than on global scale (Tsimplis et al. 2006). Warming trends have been observed both in deep and intermediate water. The closed internal thermohaline cell of the eastern Mediterranean experienced between 1987 and 1990 a major change, called EMT (Eastern Mediterranean Transient), when the Aegean Sea temporarily replaced the Adriatic Sea as the source of the eastern Mediterranean bottom water.

The analysis of the climate change signal at regional scale has produced interesting results, but presents important open issues (Ulbrich et al. 2006). The simulation of the future Mediterranean climate requires high resolution models and most as global model do not resolve adequately the basins and the mountains ridges in region, whose characteristic features can be identified only if the grid cell size is smaller than 50km. Regionalization is achieved with nested Regional climate models or with global model adopting a variable grid resolution such as ARPEGE. However, global simulations tend to agree predicting in the Mediterranean region a temperature increase larger than the global average, a large precipitation decrease in summer and controversial in winter, as it depend critically on the shift and intensification of the mid-latitude storm track over Europe. Regionalization studies substantially confirm these conclusions and the uncertainty on the future evolution of winter precipitation. Recent simulation of the Mediterranean sea circulation suggest temperature and salinity increase and an overall stronger stratification corresponding to a weaker and shallower thermohaline circulation.

4. Vulnerability to climate change

Water availability would probably be the most critical issue in the Mediterranean region, because water shortages could affect a significant fraction of the population and agriculture, which is a major economic activity (Lionello et al. 2006). Problems are related not only to a decline of precipitation, but also to its highly variable space and time variability. Water resources are unevenly distributed with 71, 20 and 9% present in the northern, eastern and southern countries, respectively. In general the impact of temperature and precipitation on crops depends on changes of the annual cycle, so that severe water deficit can occur during the growing season even if there is a sufficient annual precipitation. Moreover, the Mediterranean coast is already densely populated with about 145 million inhabitants at the end of the 20th century. Present GDP per capita is from 3 to 6 times higher in the north-western countries compared to the southern ones, where moreover demographic growth is high, so that North African and Middle East countries are expected to double their population by mid 21st century. This situation points to the higher vulnerability of African and Middle East countries to irregular or diminished future availability of water. However, the hot and dry summer 2003, produced 30000 casualties and financial losses up to 13 billion Euros to agriculture in western Europe, affecting Mediterranean countries such as France, Spain, and Italy. Finally the high social and economic impact of adverse weather events, especially heavy rainfall and floods, poses the issue of changes of the weather extremes in the future climate.

5. MedCLIVAR Activities

The tasks promoted by MedCLIVAR include collection, quality control and analysis of observations plus proxies data (documentary and natural), development and application of models for describing and understanding the physical processes responsible for the Mediterranean climate variability and predictability at seasonal, inter-annual, decadal, centennial time-scales, the occurrence of extremes embedded in these variations, and impacts of climate change. The activities of MedCLIVAR can be organized in five groups:

1. Analysis of past climate: construction of quality-controlled paleo-climatic and instrumental data sets in order to extend the record of past Mediterranean climate variability over the time-scales of interest and their comparison with paleo simulations including natural and anthropogenic forcing
2. Systematic observations of the present climate: construction of homogeneous sets of data for regional climate analysis and comparison with model simulations; analysis of the observed climate record, detection and attribution of the anthropogenic climate signals at regional climate scale.
3. Understanding climate processes at regional scale: diagnostic use of oceanic and atmospheric models for the purpose of understanding the processes responsible for the past and present Mediterranean climate variability.
4. Simulation of future climate scenarios: production and analysis of model simulations aiming at identifying the climate response of the Mediterranean regions to future emission scenarios, providing sets of data that could be used for performing regional simulations, creation of an archive of model simulations relevant to the Mediterranean region, and assessing the impact of the projected climate changes
5. Dissemination of MedCLIVAR objectives and results: A main task of MedCLIVAR is to make available scientific information on regional climate variability, trends

With reference to this last point, a major result of MedCLIVAR has been the publication of the book "Mediterranean Climate Variability", whose content is extensively referred to in this paper. The book, published by Elsevier, is expected to be distributed in spring 2006. A series of annual MedCLIVAR workshops will be initiated with "Reconstruction of past Mediterranean climate: Unexplored sources of high resolution data in historic time" to be held in Spain, fall 2006. Finally, MedCLIVAR supports the session "Mediterranean Climate Variability", inserted since 2003 in the program of the EGU General Assembly. Information on structure, activities and results of MedCLIVAR are available at the webpage http://clima.casaccia.enea.it/medclivar/ hosted by ENEA (Rome, Italy).

6. References

All following papers are published in "Mediterranean Climate Variability", P. Lionello, P. Malanotte-Rizzoli & R. Boscolo (eds), Amsterdam: Elsevier. The reader is referred to this book for a more complete bibliography.

Alpert P. et al. (2006). Relations between climate variability in the Mediterranean region and the tropics: ENSO, South Asian and African Monsoons, hurricanes and Saharan dust, pp. 149-177.

Artale V. et al. (2006). The Atlantic and Mediterranean Sea as connected systems, pp. 283-323.

Li L. et al. (2006). Regional atmospheric, marine processes and climate modelling, pp. 373-397.

Lionello P. et al. (2006a). The Mediterranean climate: an overview of the main characteristics and issues, pp. 1-26.

Lionello P. et al. (2006b). Cyclones in the Mediterranean region: climatology and effects on the environment, pp. 324-372.

Lionello, P. et al. (2006c). MEDCLIVAR: Mediterranean CLImate VARiability and predictability project. In PAGES News/CLIVAR Exchanges. Joint Edition of the IGBP Past Global Changes Project (PAGES) News and the WCRP Climate Variability and Predictability Project (CLIVAR) Exchanges. Vol 13 (3), page 23.

Luterbacher J. et al. (2006). Mediterranean climate variability over the last centuries: a review, pp. 27-148.

Trigo R. et al. (2006). Relations between variability in the Mediterranean region and mid-latitude variability, pp. 179-226.

Tsimplis M. et al. (2006). Changes in the oceanography of the Mediterranean Sea and their link to climate variability, pp. 227-282.

Ulbrich U. et al. (2006). The Mediterranean climate change under global warming, pp. 398-415.

Mediterranean past climate variability

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The reconstruction and interpretation of spatial and temporal patterns of climate change in earlier centuries is a necessary task for assessing the degree to which the instrumental period is unusual against the background of pre-industrial climate variability. Recently, a number of temperature reconstructions at the global and northern hemispheric scale were presented (see Jones and Mann 2004 and references therein). Hemispheric temperature reconstructions, however, do not provide information about regional-scale climate variations. Several sources point to differing courses of temperature change in Europe and sub-regions and generally greater amplitudes of variation than recorded for the Northern Hemisphere (e.g., Luterbacher et al., 2004; Xoplaki et al. 2005; Brázdil et al., 2005; Casty et al. 2005; Guiot et al., 2005). While the anomalous nature of recent trends and variability in global or hemispheric averages are often highlighted in climate change discussions, changes and extremes at continental or regional scale have much greater environmental, socio-economic and health impacts as e.g. the hot European summer of 2003 which was much larger in amplitude compared to usual extremes at hemispheric scales (e.g. Schär and Jendritzky, 2004).

One of the main goals of MedCLIVAR (Mediterranean CLImate VARiability and predictability project, http://clima.casaccia.enea.it/medclivar; see also Lionello et al. 2006) is the reconstruction of Mediterranean past climate variability and extremes and the description of patterns and mechanisms characterizing its space-time variability. The Mediterranean area offers a high quantity and quality of long instrumental station series, a wide range of documentary evidence (i.e. reports from chronicles, daily weather reports, ship logbooks, the time of freezing and opening up of waterways, religious ceremonies, etc., see Brázdil et al., 2005 for a review) as well as high and low spatio-temporal resolved natural proxies (tree-rings, tropical and non-tropical corals, speleothems, lake sediments, vermetid reefs, etc.; see Luterbacher et al. 2006 for an extended review). This large body of multi-proxy climate information makes the Mediterranean area ideal for climate reconstructions at different time and spatial scales, as well as the analysis of changes in climate extremes and socio-economic impacts prior to the instrumental period. This Exchange contribution is a short summary of the review of Luterbacher et al. (2006) who describe and discusses the regional coverage and the possibilities/limitations of these proxies (Figure 1 page 17) and presents yet unexplored archives (marine and from land) and their potential for past reconstructions of different climate parameters (temperature, precipitation, drought, sea surface temperature). In their review, Luterbacher et al. (2006) also address the question on the importance of documentary and natural proxies for Mediterranean precipitation and temperature reconstructions for boreal winter and summer. It turned out, that different proxy types have their specific response region, which suggests using region-specific multi-proxy sets in seasonal climate reconstructions. Results indicate, that documentary based precipitation indices and tree ring data are the most important proxies for the reconstruction of boreal winter and summer precipitation in large areas around the Mediterranean.

Other proxies such as corals, speleothems and ice cores are relevant for smaller restricted areas. It was also found, that not only the proxy type determines the results but also its initial number and location.

Numerous seasonally resolved documentary proxy data and information gathered from natural archives discussed in Luterbacher et al. (2006) have been used to reconstruct winter Mediterranean temperature (Figure 2 page 17) and precipitation fields and averaged time series back to AD 1500. Associated uncertainties, trends and extremes have been discussed as well. The Mediterranean area experienced several cold relapses and warm periods as well as dry and wet intervals on decadal timescales, on which shorter-period quasi-oscillatory behavior was superimposed. Substantial winter warming started at the end of the nineteenth century. In the context of the last half millennium, the last winter decades of the twentieth/twenty first century were the warmest (Figure 2) and driest, in agreement with recent findings from Europe and the Northern Hemisphere.

Cold conditions have been experienced during the Late Maunder Minimum (1675-1715) and the last decades of the nineteenth century. The analysis of anomalously wet and warm winters has revealed that in the regional-averaged time series of the Mediterranean no statistically significant changes with respect to the frequency and intensity of extreme winters have occurred since 1500.

The relationship between large-scale atmospheric circulation patterns and Mediterranean winter climate anomalies during the last 500 years revealed that warm and dry winters are linked with a positive North Atlantic Oscillation (NAO) mode, whereas cold and wet Mediterranean winters are connected with Scandinavian blocking. However, Mediterranean sub-regions might react differently in terms of temperature and precipitation anomalies to different circulation modes. Cold and dry winters are related to different anticyclonic regimes, whereas warm and wet winters are connected with different cyclonic regimes.

Running correlation analyses between the leading atmospheric circulation modes and the regional averaged Mediterranean temperature and precipitation indicates, that the NAO (East Atlantic/Western Russia pattern) has a robust signal on Mediterranean mean land precipitation (temperature), whereas the influence on Mediterranean mean land temperature (precipitation) is fluctuating and depends on the time window. Results also indicate that sub-regional processes provide different signals which can cancel (i.e. non-significant connection between atmospheric circulation and climate over the last centuries).

A final aspect of the review of Luterbacher et al. (2006) deals with the comparison between the empirical temperature and precipitation reconstructions and the ECHO-G and HadCM3 simulations over the 1500-1990 period. It is shown that the range of variability reproduced by the climate models is only slightly larger than that of the reconstructions. In the case of temperature, the HadCM3 simulation trends are comparable to those in the statistical reconstructions and slightly smaller than those in the ECHO-G simulations. This is a reasonable feature, as the latter does not include aerosol (and land use change) forcing. As for the case of Mediterranean precipitation, no trends are reconstructed nor simulated. Both assessments reveal the need for a more thorough study that takes into consideration the behavior of the atmospheric circulation in climate reconstructions and model simulations. Finally, this chapter ends with scientific challenges for future research on past climate over the Mediterranean area. For instance, despite the fact that there are many proxy data available from the larger Mediterranean area (Figure 1), the uncertainties of the climate reconstruction (Luterbacher et al. 2006; Figure 2) increase back in time. In order to improve reconstruction skill both in time and space and expand climate estimates further back in time, one main aim is therefore to enlarge the spatio-temporal coverage of high resolution, accurately dated, natural and documentary proxy evidence from all countries around the Mediterranean Sea, with special emphasis on regions with scarce information (North African coastal regions, sea information, Figure 1) and those being sensitivity to climate change. Archives of the Islamic world, yet unexplored, are believed to provide a large body of documentary evidence on past weather and climate. Attention should be also paid to ship logbooks of which many thousands have now been located, as a major and reliable data source pointing to a more comprehensive review of climatic variation in the region than has hitherto been the case. New high-resolution marine archives and application of isotopic and geochemical proxies will be of much relevance for past sea surface temperature, salinity, near surface air temperature and precipitation reconstructions. The use of multiproxy data with a high spatio-temporal coverage, together with sophisticated reconstruction methodologies (bearing in mind the extreme character of some of the data, linear and non-linear approaches) will provide a broader picture of past Mediterranean climate variability, not only averaged over the entire area but for specific sub-regions including the Mediterranean Sea. Analyses concerning circulation-climate-relationships will have to consider additional seasons and specific sub-regions of the Mediterranean area. The combination of highly resolved climate reconstructions and model climate simulations offer extended scientific understanding on the climate response to external forcing (e.g. the direct radiative and the poorly investigated dynamical response to tropical eruptions over the Mediterranean).

Future work involving climate reconstructions and model simulations can benefit our understanding of Mediterranean climate variability at several levels (Luterbacher et al. 2006). Regional climate modeling and statistical downscaling are useful tools in understanding the variability at smaller spatial scales and the processes involved. Model studies investigating the role of processes, such as the stratospheric ozone chemical response to solar variability or the ocean circulation response to solar or volcanic perturbations, can help to determine how regional patterns are setup and why model results differ at regional scales. Further, assessment of the changes in the dynamics associated to extreme climate episodes through the last millennium both in climate simulations and in statistical reconstructions will help better understand the mechanisms involved in extremes and related impacts.

References

Brázdil, R., C. Pfister, H. Wanner, H. von Storch, and J. Luterbacher, 2005: Historical climatology in Europe – The State of the Art. *Climatic Change*, **70**, 363-430.

Casty, C., H. Wanner, J. Luterbacher, J. Esper, and R. Böhm, 2005: Temperature and precipitation variability in the European Alps since 1500. *Int. J. Climatol.*, **25**, 1855-1880.

Guiot, J., A. Nicault, C. Rathgeber, J. Edouard, F. Guibal, G. Pichard, and C. Till, 2005: Last-millennium summer-temperature variations in western Europe based on proxy data. *Holocene*, **15**, 489–500.

Hansen, J., R. Ruedy, M. Sato, M. Imhoff, W. Lawrence, D. Easterling, T. Peterson, and T. Karl, 2001: A closer look at United States and global surface temperature change. *J. Geophys. Res.*, **106**, 23947-23963.

Jones, P.D., and M.E. Mann, 2004: Climate Over Past Millennia, *Reviews of Geophysics*, **42**, RG2002.

Lionello, P., and 16 coauthors, 2006: MEDCLIVAR: Mediterranean CLImate VARiability and predictability project. In *PAGES News/CLIVAR Exchanges*. Joint Edition of the IGBP Past Global Changes Project (PAGES) News and the WCRP Climate Variability and Predictability Project (CLIVAR) Exchanges. **Vol 13 (3)**, page 23.

Luterbacher, J., Dietrich, D., Xoplaki, E., Grosjean, M., and H. Wanner, 2004: European seasonal and annual temperature variability, trends and extremes since 1500, *Science*, **303**, 1499-1503.

Luterbacher, J. et al. (2006) Mediterranean climate variability over the last centuries: a review. In: P. Lionello, P. Malanotte-Rizzoli & R. Boscolo (Eds), Mediterranean Climate Variability, Amsterdam: Elsevier, pp. 27—148.

Mitchell, T., and P.D. Jones, 2005: An improved method of constructing a database of monthly climate observations and associated high-resolution grids. *Int. J. Climatol.*, **25**, 693–712.

Pauling, A., J. Luterbacher, C. Casty, and H. Wanner, 2005: 500 years of gridded high-resolution precipitation reconstructions over Europe and the connection to large-scale circulation, *Clim. Dynam.*, DOI 10.1007/s00382-005-0090-8.

Schär, C., and G. Jendritzky, 2004: Hot news from summer 2003, *Nature*, **432**, 559–560.

Xoplaki, E., J. Luterbacher, H. Paeth, D. Dietrich, D., N. Steiner, M. Grosjean, and H. Wanner, 2005: European spring and autumn temperature variability and change of extremes over the last half millennium, *Geophys. Res. Lett.*, **32**, L15713.

What is triggering the outstanding March precipitation decline in Iberia?

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1. Introduction

The Iberian Peninsula is characterized by a strong inter-annual variability of precipitation, particularly during the winter months (Oct-Mar), when the majority of the precipitation occurs. As a consequence, very wet and dry years occur with some frequency, strongly affecting the hydrological cycle. Recent studies indicate a general decline in winter precipitation in the northern Mediterranean Basin (Zhang et al. 1997; Trigo and DaCamara 2000). These negative trends are likely to be associated with the decrease in storm frequency for that area (e.g. Trigo I. F. et al. 2000; Alpert et al. 2002). Over Iberia and the western Mediterranean sector the most prominent trend of precipitation occurs during early spring, particularly during the month of March. In contrast to Iberia, other western European regions have shown positive trends of March precipitation in recent decades. In particular, positive and significant trends have been detected for Ireland (Hoppe and Kiely 1999) and Scotland (Smith 1995). This evidence supports the idea of a changing precipitation scenario in March for parts of the western European continent.

2. Data

Daily precipitation data series between 1941 and 1997 were obtained from 55 stations across the Iberian Peninsula. The European precipitation trends between 1960 and 2000 are computed using the Climatic Research Unit (CRU) high resolution (0.5o latitude by 0.5o longitude) dataset of monthly precipitation (New et al. 1999) derived from a worldwide network of observations, particularly dense over Europe. Finally the storm detection and tracking scheme is performed using 6-hourly geopotential height at 1000 hPa, available from the European Centre for Medium-Range Weather Forecasts 40-year reanalyses (ERA 40) on a 1.125o x 1.125o grid (Trigo 2005). The data cover a wide area (30oN to 80oN and 60oW to 70oE), enclosing Europe and most of the North Atlantic sector, for the period 1958-2000.

3. Precipitation trends

Trends of monthly-accumulated precipitation for the month of March were computed between 1941 and 1997 (Fig. 1), and their statistical significance was assessed with a Mann-Kendall non-parametric test; any trend is considered to be significant at $p<0.1$. It is clear that there is a large homogeneous region (28 contiguous stations), covering most of the central and western Iberia, that present highly significant decreases of March precipitation (Fig.1). These trends correspond to decreases of more than 50% in relative precipitation since 1941 and are in agreement with previous works dealing with monthly precipitation for March over Portugal (Zhang et al. 1997; Trigo and DaCamara 2000) and for the whole Iberia (Serrano et al. 1999). It is worth noticing that most of eastern and northern stations of Iberia, however, do not show significant trends.

Averages in space and time were computed for each month over the contiguous region with stations presenting significant negative trends in March, for both periods of 1941-1970 and 1971-1997. Absolute (mm) and relative (%) precipitation changes were computed,

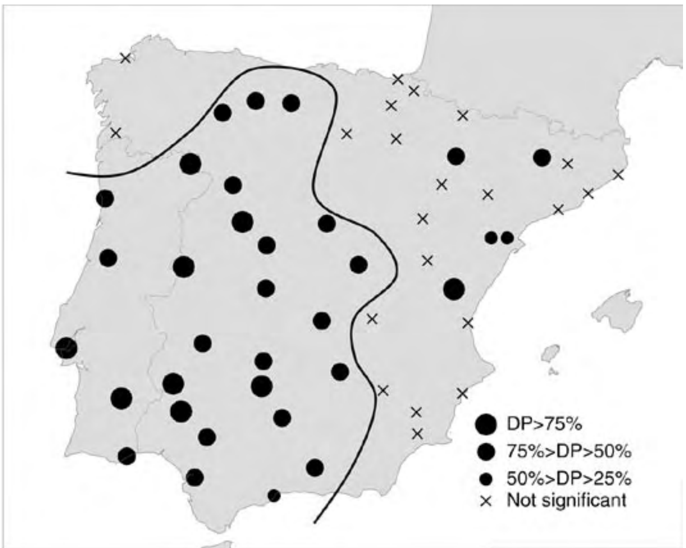

Figure 1. Decreasing Precipitation (DP) trends in March for the period 1941-1997. The different sizes of black dots depict the relative change in precipitation for the complete period after fitting March time series to a linear model. "Crosses" correspond to non-significant or positive trends, while the dots represent stations with declining precipitation at less than the 10% level (Mann-Kendall test).

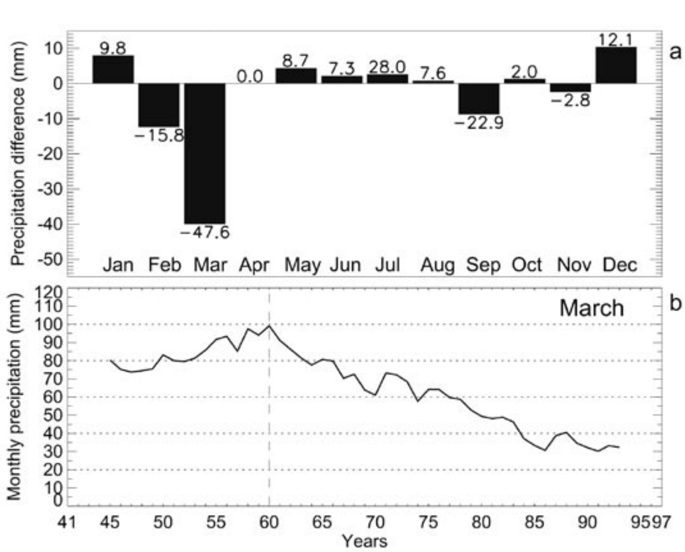

Figure 2. a) Absolute precip. change (mm) between the 1941-1970 and the 1971-1997 normal periods. The corresponding relative change (%) is also indicated over (or below) each column. b) 9-year moving average of spatially averaged precipitation in March. The vertical axis indicates the approximate location of the changing point for the trend.

showing the monthly differences in Fig. 2. It is clear that March presents the highest variation in precipitation of all months, with an absolute decrease of roughly 40 mm, representing a decline of nearly 50% during the studied period (Paredes et al. 2006).

There is evidence of increasing precipitation in Northern Europe since the 1970's (Smith 1995) while other researches have proved the existence of increasing annual average and spring precipitation over Northern Norway (Hassen-Bauer and Forland 1998). These results suggest that the Iberian trends might be associated to a wider scale phenomenon. Nevertheless, within the present scope, the most important results correspond to those works that have found significant positive trends of March precipitation for Ireland (Hoppe and Kiely 1999) and Scotland (Smith 1995). It is natural to suggest that these changes may be related to those detected for Southern Europe, supporting the idea of a changing precipitation scenario in March for a large sector of the western European continent. To examine this point we have computed trends for March, using the high-resolution precipitation data from CRU (New et al. 1999). Results are shown in Fig. 3, where the immediately striking result is the appearance of two contrasting areas displaying positive (northern Europe) and negative trends (southern Europe). To the sake of simplicity, results are only displayed when the corresponding precipitation trends (positive or negative) are significant at least at the 10% significance level, although large areas of significant trends at the 2% level are also found. As expected, the (Western) Mediterranean basin is affected by the largest continuous negative trend. In particular, the Iberian Peninsula presents a large and homogeneous region affected by such changes in March, perfectly compatible with the pattern previously shown (Fig. 1). On the contrary, the northern European territory is affected by significant positive trends, which extend from Ireland and Scotland to the Scandinavian Peninsula.

4. Physical mechanisms associated

The detection and tracking of North Atlantic cyclones applied here is based on the algorithm first developed for the Mediterranean region by Trigo I.F. et al. (1999) and recently adapted to the entire north Atlantic area (Trigo 2005). Cyclones are identified as minima in geopotential height fields at 1000 hPa, fulfilling a set of conditions regarding the central pressure and the geopotential gradient. The tracking is based on a nearest neighbour search in consecutive charts, assuming that the speed of individual storms is less than 50 km/h in the westward direction, and 110 km/h in any other.

Long-term averages for the number of cyclones detected in March between 1960 and 2000 were computed (Fig. 4a page 17). The corresponding decadal trend (% relative to the mean over the study period) of the average number of cyclones detected in March can be see in Fig. 4b, page 17. The negative trend extending from the Azores archipelago, in the mid Atlantic Ocean, to the west of Iberia is significant at least at 10%. The average decline per decade reaches values over 20% (of the mean cyclone count) at the northwest of Iberia, representing a decrease of over 60% of cyclonic centres between the first and last decades on record (relative to the first decade). On the contrary, the area between Scotland, Iceland and Scandinavia reveals a strong increase (significant at 10%) of more than 15% per decade at its maximum (relative to the period's average), which corresponds to an increment of roughly 50% between the first and last decades.

The combined analysis of cyclone trends and large-scale precipitation over land gives a very useful and complementary perspective: a) negative trends in densities of cyclones centres extend from northern Azores to Iberia, while equally significant (positive) trends dominate the synoptic picture over the North Sea; b) changes in the location of cyclones are obviously related with contemporaneous changes in precipitation averages for those areas immediately under their influence (Fig. 3).

It is now accepted that the NAO index has a major impact on Western Europe precipitation, particularly over the western Mediterranean basin (Hurrell 1995; Trigo et al. 2002). The Pearson's correlation coefficient between the spatially averaged precipitation series for the homogeneous region of the Iberian Peninsula previously described (Fig 1) and the normalized NAO index, in the period 1960-1997, is –0.60 ($p<0.01$). This means that the NAO is responsible of 36% of the precipitation variance in March. Moreover, the spatial distribution of the correlation coefficient values below –0.5 over the Iberian Peninsula is highly coincident with those regions described by the first EOF (Paredes et al., 2006) and the region affected by the downward precipitation trends (Fig.1).

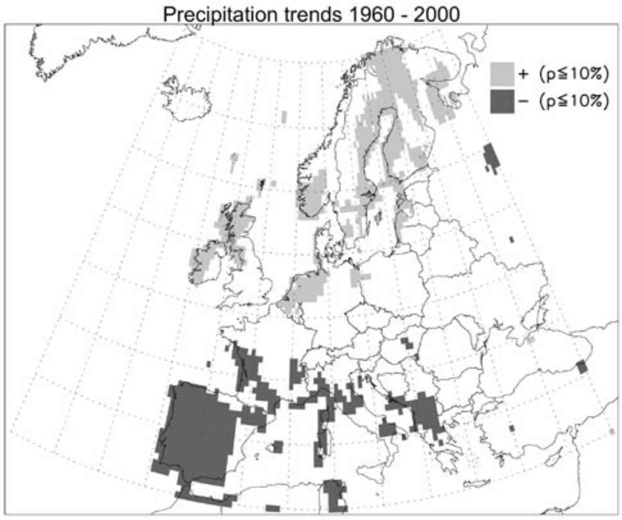

Figure 3. Significance (%) of precipitation trends in March over Europe for the period 1960-2000, computed from the CRU monthly precipitation dataset. The trends are assessed using the Mann-Kendall test; only values significant at less than 10% are shown. Dark (light) grey cells correspond to negative (positive) tendencies.

5. References

Alpert, P., and Co-authors, 2002: The paradoxical increase of Mediterranean extreme daily rainfall in spite of decrease in total values. *Geophys. Res. Lett*., **29** (11), doi:10.1029/2001GL013554.

Hanssen-Bauer, I., and E. J. Forland, 1998: Long-term trends in precipitation and temperature in the Norwegian Arctic: can they be explained by changes in atmospheric circulation patterns?. *Climate Res.*, **10**, 143-153.

Hoppe, H., and G. Kiely, 1999: Precipitation over Ireland – Observed change since 1940. *Phys. Chem. Earth*, **24**, 91-96.

Hurrell, J. W., 1995: Decadal trends in the north Atlantic oscillation: regional temperatures and precipitation. *Science*, **269**, 676-679.

New, M. G., M. Hulme, and P. D. Jones, 1999: Representing twentieth-century space-time climate variability. Part I: Development of a 1961-90 mean monthly terrestrial climatology. *J. Climate*, **12,** 829-856.

Paredes D., Trigo, R.M., Garcia-Herrera R., Trigo, I.F. (2006) "Understanding precipitation changes in Iberia in early Spring: weather typing and storm-tracking approaches", *Journal of Hidrometeorology*, in press.

Serrano, A., V. L. Mateos, and J. A. García, 1999: Trend analysis of monthly precipitation over the Iberian Peninsula for the period 1921-1995. *Phys. Chem. Earth*, **24,** 85-90.

Smith, K., 1995: Precipitation over Scotland, 1757-1992: Some aspects of temporal variability. *Int. J. Climatol*., **15**, 543-556.

Trigo, I. F., T. D. Davies, and G. R. Bigg, 1999: Objective climatology of cyclones in the Mediterranean region. *J. Climate*, **12**, 1685-1696.

Trigo, I. F., T. D. Davies, and G. R. Bigg, 2000: Decline in Mediterranean rainfall caused by weakening of Mediterranean cyclones. *Geophys. Res. Lett*., **27**, 2913-2916.

Trigo, I. F. 2005: Climatology and Interannual Variability of Storm-Tracks in the Euro-Atlantic sector: a comparison between ERA-40 and NCEP/NCAR Reanalyses. *Clim. Dyn*., in press.

Trigo, R. M., and C. C. DaCamara, 2000: Circulation Weather Types and their impact on the precipitation regime in Portugal. *Int. J. Climatol*., **20**, 1559-1581.

Trigo, R. M., T. J. Osborn, and J. Corte-Real, 2002: The North Atlantic Oscillation influence on Europe: climate impacts and associated physical mechanisms. *Climate Res*., **20,** 9-17.

Zhang, X., X. L. Wang, and J. Corte-Real, 1997: On the relationships between daily circulation patterns and precipitation in Portugal. *J. Geophys. Res*., **102**, 13495-13507.

Developments in sea level research and observations in the Mediterranean Sea

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1. Trends

Sea level trends for the three longer stations in the Mediterranean Sea over the 20-th century are in the range of 1.1-1.3 mm/yr. This is at the low range of the estimated global value for sea level rise which is in the range of 1-2 mm/yr (Church et al., 2001). However, during the last 40-50 years sea level trends within the Mediterranean basin differ significantly from those of the nearby Atlantic Ocean (Tsimplis and Baker, 2000). While up to the 1960s sea levels at these tide gauges in the Mediterranean Sea had trends equivalent to those at the open ocean stations between 1960 and the beginning of the 1990s sea level in the Mediterranean Sea was either not changing or decreasing (Tsimplis and Baker, 2000), mainly due to atmospheric pressure changes during the winter period (Tsimplis and Josey, 2002; Tsimplis et al., 2005) as well as temperature (T) reduction and salinity (S) changes linked to the NAO (Tsimplis and Rixen 2002). After 1992 analyses of the TOPEX/POSEIDON dataset (Cazenave et al., 2001; Fenoglio-Marc, 2002) reveal a picture much more complicated than that of a coherently varying basin. During this period fast sea level rise was observed at the Eastern Mediterranean Sea (Cazenave et al., 2001; Fenoglio-Marc, 2002) and was linked with changes in observed sea surface temperature (Cazenave et al., 2001). Sea level rise in the period 1993-2001 in the eastern basin was confirmed from tide gauge studies to have rates of 5-10 mm/yr probably related to the Eastern Mediterranean Transient (EMT) (Tsimplis et al., 2005). Recently an abrupt reduction of sea level rise rates as well as negative trends in parts of the eastern Mediterranean Sea after 1999 have been confirmed (Fenoglio-Marc, 2002 Vigo et al., 2005). These changes, which appear consistent with sea surface temperature changes, are probably a consequence of the restoration of the Adriatic Sea as the main source of deep water in the eastern basin following the EMT (Vigo et al., 2005). The cause of the sea level changes in the Eastern Mediterranean during the 1990s have been shown to be linked with steric changes at least in the Adriatic and the Aegean Seas. (Tsimplis and Rixen, 2002). During the same period of time a reduction in the sea level gradient across the Strait of Gibraltar has been observed and varied hydraulic conditions in the Strait have been suggested as cause (Ross et al., 2000). Although the contribution of the various processes causing sea level change is not yet fully clarified, it appears that local or regional forcing is significantly contributing to the observed trends. The large spatial and temporal variability of the decadal trends indicates that the forcing processes are characterized by an oscillatory nature and therefore difficult to project into the future. Moreover, if a mechanism of mass addition to the ocean by melting ice is assumed as the primary cause of sea level rise (Miller and Douglas, 2004) and provided that such a mechanism is enhanced with time (Church et al., 2001), it is likely that the decadal and interdecadal oscillations in trend observed in the 20-th century will be masked by a general trend dominated by the global process.

2. Seasonal Cycles

Seasonal cycles are primarily controlled by thermal heating and cooling while direct meteorological forcing, that is atmospheric pressure and wind changes as well as oceanic circulation also contribute. The contribution of the heating and cooling in the Mediterranean Sea dominates the annual frequency while the direct atmospheric forcing dominates the semi-annual frequency (Tsimplis et al., 2005). Significant changes in the Mediterranean seasonal cycle have been known to exist (Zerbini et al., 1996; Papadopoulos et al, 2006). Such changes must be included in any impact assessment of climate change: for the same mean sea level rise, the increase in coastal risk would be different depending on whether the sea level rise is uniform or mainly expressed in the winter season.

3. Extreme sea levels

Changes in extreme sea levels when coupled with increasing mean sea levels pose significant risks to coastal regions. Within the Mediterranean Sea very few studies on extreme sea levels have been conducted and even fewer are concerned with changes in extremes with time. Moreover, the published studies are not basin-wide but rather regional and limited in scope. Lionello (2005) has analysed the trends of extremes storm surges on the basis of the records in Venice and found no significant trend since 1940 apart from that produced by the combination of sea level rise and local ground subsidence. Raicich (2003) has investigated sea level extremes in Trieste for the periods 1939-2001 and found a decreasing trend in strong positive surges in spite of increases in southerly winds due to increased atmospheric pressure (Raicich, 2003; see also Pirazzoli and Tomasin, 2002; Trigo and Davies, 2002). Tsimplis and Blackman (1997) have documented the sea level extremes for the Aegean Sea for a period of eight years (1982-1989) but no information on trends of extremes could have been derived with these short time series. However, Tsimplis and Blackman (1997) suggest that the observed extremes are in most cases common in the whole of the Aegean Basin and are consistent with a linear addition of the extreme pressure and wind effects. This implies that knowledge of these fields would suffice for estimating changes in the sea level extremes at least within the Aegean Sea.

4. Developments in observational networks and data management

In addition to the Permanent Service for Mean Sea Level (Woodworth and Player, 2003) which collects mean monthly sea level data around the globe, MedGLOSS (Figure 1 page 18) and the European Sea Level Service (ESEAS) are the two major regional initiatives in developing, improving and standardising the tide-gauge network. The MedGLOSS programme of sea level monitoring network in the Mediterranean and Black seas was established jointly by CIESM and IOC/UNESCO in 1997 (http://medgloss.ocean.org.il/new/). The ESEAS (http://www.eseas.org) covers the whole European coasts and includes in its aims the development of parallel continuous GPS measurements to provide observations of vertical land motion at tide gauges (Figure 2 page 18). Twenty three European countries managing in excess of 200 tide gauges are presently included in the ESEA which is developing into a major research infrastructure for all aspects related to sea-level, be it in the field of climate change research, natural hazards or marine research.

5. Concluding comments

The Mediterranean Sea includes several particular characteristics in respect to oceanic circulation and sea level variability. Continuing efforts have resolved and explained partly the observed behaviour, however there are outstanding issues which need further work. The ESEAS and MedGloss initiatives in the Mediterranean region are promising a continuous improvement in the amount, quality and accessibility of in situ sea level data in the region. However, there are important gaps in the tide-gauge network at the North African coasts upon which efforts must be focused. Such efforts should be developed in parallel with the necessary transfer of knowledge and technology to the North African countries. The MedClivar initiatives and its new European Science Foundation project aims amongst others at the transfer of knowledge in all climate related respects to these countries.

References

Cazenave A., C. Cabanes, K. Dominh and S. Mangiarotti (2001). Recent sea level changes in the Mediterranean Sea revealed by TOPEX/POSEIDON satellite altimetry. *Geophys. Res. Let.*, **28**(8), 1607-1610.

Church J.A., J.M. Gregory, P. Huybrechts, M. Kuhn, K. Lambeck, M.T. Nhuan, D. Qin and P.L. Woodworth (2001). Changes in sea level. Chapter 11 of the Intergovernmental Panel on Climate Change Third Assessment Report, Cambridge University Press.

Fenoglio-Marc L. (2002). Long-term sea level change in the Mediterranean Sea from multi-satelitte altimetry and tide gauges. *Physics and Chemistry of the Earth*, **27**, 1419-1431.

Lionello P. (2005). Extreme surges in the Gulf of Venice. Present and Future Climate "Venice and its lagoon, State of Knowledge" C.Fletcher and T.Spencer Eds., Cambridge University Press, Cambridge UK, 59-65.

Painter, S. C. and Tsimplis, M. N. (2003). Temperature and salinity trends in the upper waters of the Mediterranean Sea as determined from the MEDATLAS dataset. *Continental Shelf Research*, **23**, 1507–1522.

Pirazzoli P.A. and A. Tomasin (2003). Recent evolution of surge-related events in the northern-Adriatic Sea, *J. Coast. Res*. **18**(3) 537-554.

Raicich F. (2003). Recent evolution of sea-level extremes at Trieste (Northern Adriatic), *Continental Shelf Research*, **23**, 225-235.

Ross., T., C. Garrett and P.-Y. Le Traon (2000). Western Mediterranean sea-level rise: changing exchange flow through the Strait of Gibraltar, *Geophys. Res. Let*., **27**, 2949-2952.

Tsimplis M.N. and D. Blackman (1997). Extreme sea level distribution and return periods in the Aegean and Ionian Seas. *Estuarine Coastal and Shelf Science*, **44,** 79-89.

Tsimplis M.N and N.E.Spencer (1997). Collection and analysis of monthly mean sea level data in the Mediterranean and Black Sea. *Journal of Coastal Research,* **13**(2), 534-544.

Tsimplis, M. N., Baker, T. F. (2000). Sea level drop in the Mediterranean Sea:An indicator of deep water salinity and temperature changes? *Geophysical Research Letters*, **27**, 12, 1731– 1734.

Tsimplis M.N. and S.A. Josey (2001). Forcing of the Mediterranean Sea by atmospheric oscillations over the North Atlantic. *Geophys. Res. Let*., **28**(5) 803-806.

Tsimplis M.N. and M. Rixen (2002). Sea level in the Mediterranean Sea: The contribution of temperature and salinity changes. *Geophys. Res. Let.* **29**(3) art. no. 2136.

Tsimplis M.N., E. Álvarez-Fanjul, D. Gomis, L. Fenoglio-Marc and B. Pérez 2005. Mediterranean Sea level trends: Atmospheric pressure and wind contribution. Geophysical Research Letters, Vol. 32, L20602, doi:10.1029/2005GL023867

Trigo I.F. and Davies T.D. (2002). Meteorological conditions associated with sea surges in Venice: A 40 year climatology, *Int. J. Climatology*,**22** (7): 787-803.

Vigo I., D. García, and B. F. Chao (2006). Change of Sea Level Trend in Mediterranean and Black Seas, *Journal of Marine Research* (in press).

Woodworth, P.L. and R. Player (2003). The Permanent Service for Mean Sea Level: an update to the 21st century. *Journal of Coastal Research* **19** (2): 287-295.

Zerbini S., Plag H.-P., Baker T., Becker M., Billiris H., Burki B., Kahle H.-G., Marson I., Pezzoli L., Richter B., Romagnoli C., Sztobryn M., Tomasi P., Tsimplis M., Veis G. and G.Verrone (1996). Sea Level in the Mediterranean: a first step towards separating crustal movements and absolute sea-level variations. *Global and Planetary Change*,**14,** 1-42.

Climatology of cyclones in the Mediterranean: present trends and future scenarios

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1. Mediterranean cyclones

Cyclones in the Mediterranean area often result in extreme and adverse weather events producing floods, landslides, winds, storm surge and high ocean waves. Moreover, the high variability of cyclone frequency and intensity, within the Mediterranean region is associated with contrasting climate conditions, ranging from the southern arid areas to the greatest annual precipitations totals in Europe, in the Dinaric Alps (e.g. Trigo et al., 2002). It is therefore important to study mechanisms responsible for generation and evolution of cyclones, to understand their effects on the environment, and to describe their variability in relation with global climate patterns, to detect trends and understand the climate change signal in scenario simulations.

A fundamental role in the formation and evolution of the of the cyclones in the Mediterranean area is played by the interaction between large scale flow and the small scale morphological features. The former advects potential vorticity at high atmospheric levels, while the latter (the mountain ridges around the basin and the complicated land-sea distribution) produce low level disturbances. Most intense cyclogenetic areas are located in the western Mediterranean Sea: mainly the Gulf of Genoa, but also the Palos-Algerian sea, the Catalonian- Balearic sea and the gulf of Lyon. Other cyclogenetic areas are the Adriatic and Ionian Seas, the Cyprus area, the Aegean Sea, the Black Sea, the southern side of the Atlas mountains, the Iberian peninsula in summer. Consequently, many categories of cyclones can be identified, according to their seasonality, area, and mechanisms of formation. Beside the cyclones entering from the Atlantic, there are lee-cyclones, thermal lows, African cyclones, small-scale hurricane-like cyclones, and middle east cyclones (Lionello et al. 2006).

Mediterranean cyclones are generally characterized by shorter life-cycles and smaller spatial scales than the extra-tropical cyclones developed in the Atlantic. Their radius is generally within the subsynoptic scale, lower than 500km, and the mean duration is about one day or little longer. The overall synoptic activity over the entire basin has a well defined annual cycle, being more intense in the period from November to March. Winter cyclogenesis occurs essentially along the northern coast in three major areas characterized by strong baroclinicity: the lee of the Alps, the Aegean and Black Seas. In spring, the strengthening of the meridional temperature gradient along the northern African coast favours the development of Saharan depressions, which tend to occur on the lee side of the Atlas mountains (Trigo et al., 2002). The link between NAO and the position and strength of the storm track in the central Atlantic implies a link between NAO and the frequency of orographic cyclogenesis which is triggered by the passage of Atlantic cyclones. 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 eastern Atlantic.

2. Present trends

A climatology of cyclone activity has been created using a newly compiled dataset of the North Atlantic - European region from 1850 to 2003 (Bhend, 2005), which was developed in the European and North Atlantic daily to multi-decadal climate variability project (EMULATE). These data consist of gridded daily mean sea level pressure fields, which are based on land and island stations and have been elaborated using Reduced Space Optimal Interpolation (RSOI) on a 5°x5° degree grid. Seasonally averaged statistics of the cyclones have been computed with an objective locating and tracking procedure. From 1881-2003 cyclone density decreases over most parts of the Mediterranean. However, trends are not uniform and interdecadal variability is high. Figure 1 shows a counting of cyclone centres in winter for two areas, one in the western and another in the eastern Mediterranean. Significant findings are a marked decrease (about 5%) in winter (DJF) cyclone density over most of the western Mediterranean. The situation in the eastern Mediterranean, is less clear, as trends differ considerably from grid point to grid point. Different characteristics of western and eastern Mediterranean and high interdecadal variability are presumably source of some disagreement with other studies, which support a positive trend of the winter density during the second half of the 20th century (Maheras et. al. , 2001,) or no actually significant trend (J.G. Pinto, pers. comm..).

The trends in the Mediterranean region have been analyzed as part of a study of interannual variability of storm-tracks in the Euro-Atlantic Region, derived from ERA-40 and NCEP/NCAR reanalyses, for the December–to–March season, between December 1958 and March 2000 (Trigo, 2005). Figure 2 page 18 shows the decadal relative trends of cyclone numbers aggregated within 9° long x 9° lat cells for the ERA-40, and within 10° long x 10° lat cells for the NCEP/NCAR dataset. The major features (common to ERA-40 and NCEP/NCAR reanalyses) include two zonal bands, one exhibiting an overall increase of storms, ranging from the Labrador Sea to Scandinavia, and a second band, dominated by decreasing cyclone counts, which ranges from the Azores to Central Europe and the Mediterranean. Such pattern, suggesting a northward shift of storm-tracks, mirrors the fluctuations observed during the last 40-years of the main mode of atmospheric variability in the Euro-Atlantic sector – the NAO.

The impact of such trends on the local weather of the Mediterranean and Middle East regions is likely to be extremely high. There are several studies indicating a general decline in winter precipitation, particularly in the northern Mediterranean Basin (e.g. Trigo et al. 2000; Alpert et al. 2002; Xoplaki et al. 2004), likely to be associated with the decrease in storm frequency for that area. An overall decreasing trend of cyclones in the Mediterranean is also confirmed by a significant decrease of the winter average wave height (Lionello and Sanna, 2005).

3. Future scenarios

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 CO_2 scenarios

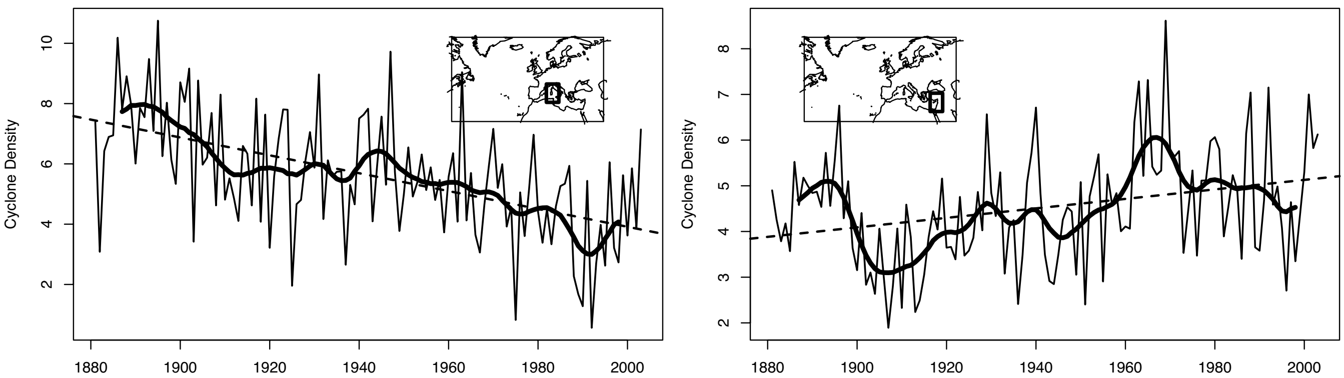

Figure 1. Time series of average cyclone density (in units of percentage of systems/25 degree latitude squared) in winter (DJF) at boxes including nine grid points in the western Mediterranean centred at 10°W 40°N (western Mediterranean, left panel) and in the eastern Mediterranean centred at 35°W 35°N (eastern Levantine basin, right panel). The dashed lines denote the respective linear trends, in bold, a smoothed curve is plotted using a Gaussian filter with a standard deviation of 3 years (after Bhend, 2005).

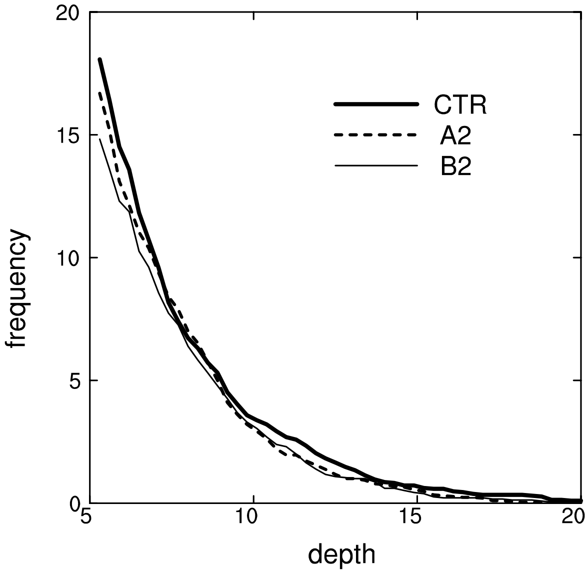

Figure 3. frequency (number of cyclones per month, y-axis) exceeding a given threshold (hPa, x-axis) in January for the CTR, A2 and B2 simulations. The counting include cyclones with duration longer than half day and is restricted to the area shown in the following figure 4

(Lionello et al 2002). The present climate is characterized by a slight, but statistically significant, higher overall number of cyclones. The doubled CO_2 simulation is characterized by more extreme weather events, but the difference between the two scenarios is hardly significant. No variation of the regions of formation of the cyclones has been clearly identified in this study. This is likely to depend on the fundamental role which orographic features and land-sea distribution play in the formation and evolution of cyclones in the Mediterranean region (Lionello et al, 2005) .

This analysis has been repeated for the A2 and B2 emission scenarios for the period 2071-2100 using the results of a regional model (ReGCM Model at ICTP, Italy, with a 50Km resolution in rotated coordinates). The CTR simulation carried out for comparison was based on observed GHG concentration for the period 1961-1990. Boundary condition have been extracted from the HadAMH model results at the Hadley Center with a 1.25x1.875 lat-lon resolution. The analysis (Lionello and Boldrin, 2006) is applied to the band pass filtered SLP fields (Sea Level Pressure; 12 hours and 7 days lower and upper cut off periods, respectively). The results confirms a reduction of the overall number of cyclones in winter (figure 3 shows the frequency of cyclones as function of their depth in January), but also suggest a complex situation with seasonally and spatially varying trends. Figure 4 , page 19 shows the difference of the SLP, standard deviation between CTR and scenario simulations, which shows small changes over large part of the Mediterranean are, with a transition from a significant increase in the upper left corner to a decrease in the lower left corner.

However a decrease in the number of cyclones appears to be the dominant signal in future climate simulations. In a transient simulation with the ECHAM4-OPYC3 model covering the period 1860-2100 and adopting a IS92a scenario, a 15% decrease of the overall number of cyclones was found. Reduction is larger for cyclones with high vorticity, where a 44% decrease is observed (Pinto et al. 2006).

4. Conclusions

The analysis of cyclone climatology in the Mediterranean region shows trends and a moderate response to future emission scenarios. The main signal is associated to a decrease of cyclone frequency during winter in the western Mediterranean region, presumably associated with a northward shift of the storm track and persistent high phase of NAO. Such decline of cyclone frequency is suggested to continue as green house gas concentration increases, as shown by scenario simulations (Ulbrich and Christoph 1999). However, cyclone activity present large seasonal and spatial variability, with large differences from western to eastern Mediterranean and between cold and warm season. This complex situation leaves many important issues open and requires further studies

5. References

Bhend, J. (2005). North Atlantic and European Cyclones: their variability and change from 1881 to 2003. Masters Thesis, University of Bern available at at http://www.giub.unibe.ch/klimet/publications.html .

Lionello P, F. Dalan, E. Elvini (2002). Cyclones in the Mediterranean Region: the present and the doubled CO2 climate scenarios, *Clim. Res.*, **22,** 147-159

Lionello P. and A. Sanna (2005) Mediterranean wave climate variability and its links with NAO and Indian Monsoon *Clim.Dyn.* , **25**, 611-623

Lionello P. et al. (2006). Cyclones in the Mediterranean region: climatology and effects on the environment, In: P. Lionello, P. Malanotte-Rizzoli & R. Boscolo (Eds), Mediterranean Climate Variability, Amsterdam: Elsevier, pp. 324-372

Lionello P. and U.Boldrin (2006) Analysis of cyclones in a regional climate simulation over Europe (in preparation)

Maheras P., H. Flocas, I. Patrikas and Ch. Anagnostopoulou, 2001: A 40 year objective climatology of surface cyclones in the Mediterranean region: Spatial and temporal distribution', *Int. J. Climatol*. **21**, 109-130

Pinto J.G., T. Spangehl, U.Ulbrich and P.Speth (2006): Assessment of winter cyclone activity in a transient ECHAM4-OPYC3 GHG experiment. Meteorol. Zeitschrift, in press

Trigo, I.F, G.R.Bigg and T.D.Davies 2002: Climatology of cyclogenesys mechanisms in the Mediterranean, *Mon.Wea. Rev.*, **130,** 549-649

Trigo IF, Davies TD, Bigg GR (2000) Decline in Mediterranean rainfall caused by weakening of Mediterranean cyclones. *Geophys Res Lett* **27**: 2913-2916

Trigo, I F (2005) Climatology and interannual variability of storm-tracks in the Euro-Atlantic sector: a comparison between ERA-40 and NCEP/NCAR reanalyses. *Clim Dyn* DOI 10.1007/s00382-005-0065-9

Ulbrich U, Christoph M (1999) A shift of the NAO and increasing storm track activity over Europe due to anthropogenic greenhouse gas forcing. *Clim Dyn* **15**: 551-559

Xoplaki E, González-Rouco JF, Luterbacher J, Wanner H (2004) Wet season Mediterranean precipitation variability: influence of large-scale dynamics and trends. *Clim Dyn* **23:** 63-78. DOI 10.1007/s00382-004-0422-0

Climatic trends over the Eastern Mediterranean: past and future projections

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1. Introduction:
We recently analyzed model outputs on temperature and rainfall changes over the Eastern Mediterranean for 2071-2100 compared to 1961-1990. These data are based on Regional Climate Modeling (RCM) simulations performed for the EU PRUDENCE project with RegCM model nested with the global atmospheric model HadAMH (Deque et al. 2005) at the International Centre for Theoretical Physics (ICTP) (Giorgi et al. 2004a,b). The data are analyzed for IPCC scenarios A2 and B2, and preliminary results are presented and discussed in view of recent observed climatic trends calculated for 1948-2000 based on NNRP reanalysis as well as CRU (Climatic Research Unit) data archives.

2. Observed and projected temperature changes:
Figure 1 (from Saaroni et al., 2003) shows significant warming of summer (JJA) for 850hPa temperatures over the Mediterranean. Trend values of 1.5-4°C/100y, based on NNRP reanalysis for 1948-2000, cover the whole Mediterranean with maxima over the Western Mediterranean and North Egypt. These outstanding heating trends values are about 3-4 times larger than global trends for the last 100 years. Somewhat smaller heating trend has been determined by Giorgi (2002) based on the data archive for terrestrial regions produced by CRU of the University of East Anglia, and described by New et al. (1999, 2000).

The surface temperature differences from 2071-2100 compared to 1961-1990 based on ICTP regional climate modeling for two IPCC emission scenarios A2 and B2 IPCC were analyzed by Giorgi et al. (2004a,b, IPCC 2001).

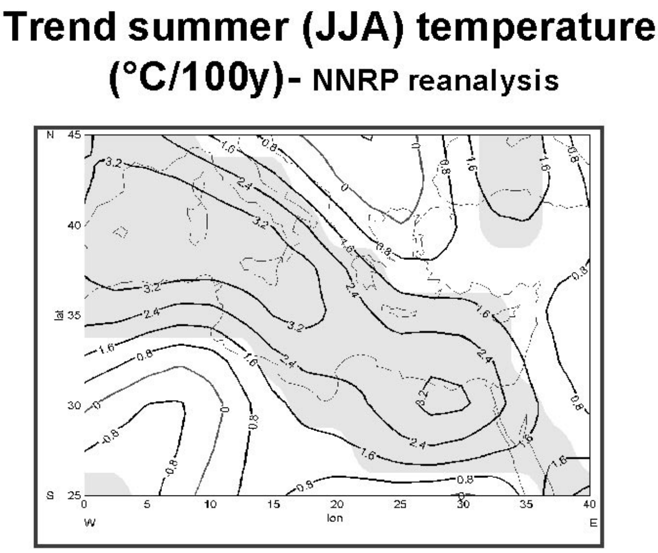

Fig. 1: Summer temperature (JJA) trend for 850 hPa (oC/100y) based on NNRP reanalysis for 1948-2000.

Results show that for A2 scenario, the changes over the Eastern Mediterranean are about 3-5°C, while for B2 scenario the differences are only about 2.5-3.5°C.

It is interesting to note that the surface heating trends projections over the sea are lower than over the surrounding land, which is just the opposite case for the observed temperature trends. In the observations (Fig. 1) the trends over the land are only about 0-0.8°C/100y, and in some regions (Algeria, Balkan) even negative trends are seen.

Since the warming over the Mediterranean Sea is of the same magnitude, can we conclude that the warming over land is also going to accelerate in the 21st Century? Or, that the models are not doing a good job? Or maybe there are significant variations from 850 hPa to the surface? The answer is not yet clear.

3. Observed and projected rainfall changes:
The precipitation trends over nearly the whole Mediterranean are dominantly negative during 1948-2000 (Alpert et al., 2004 based on NNRP reanalysis as well as numerous observational raingauge-based studies e. g. Alpert et al., 2002, IPCC, 2001). The results may be compared with those by Giorgi 2002. The RegCM-ICTP runs for 2071-2100 compared to 1961-1990 show large differences between scenarios A2 and B2 (Fig. 2). In A2, most of the Eastern Mediterranean shows rainfall reduction of about 15-75 mm for DJF, which is equivalent to drop of about 10-30%. The DJF period covers most of the annual rain in the Eastern Mediterranean, and realistically reflects the annual rainfall changes. In scenario B2, however, (Fig. 2) reductions are significantly lower and are of about 0-5% in total rainfall, while over most of Turkey significant rainfall increases are noticed.

4. Summary:
We point out two interesting features of 21st century climatic trends:

1. In temperature: the observations as deduced from reanalysis for 1948-2000 indicate maximum warming over the Mediterranean Sea. On the contrary, maximum warming from the current to future climate conditions is found over the continental areas in the RCM output. This different behavior could be the result of modeling or reanalysis errors or may be a true feature since significantly lower heating values are obtained based on the CRU data for terrestrial areas. The issue should be further investigated.

2. In rainfall: over the EM the scenarios A2 and B2 show very different results, i.e. A2 shows significant 10-30% overall reduction, while B2 shows mixed trends.

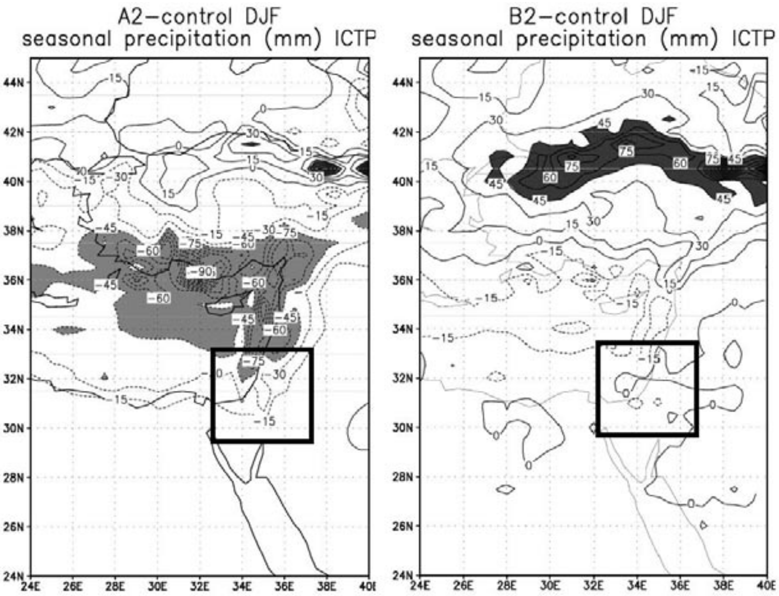

Fig. 2: Average seasonal (DJF) precipitation change (mm) from ICTP. On the left, A2 vs. control, and on the right B2 vs. control. Inside the square – the region of the Eastern Mediterranean

The results indicate a high sensitivity of the Eastern Mediterranean climate to the changes in the global emission scenarios.

Acknowledgement

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References

Alpert, P., T., Ben-Gai, A., Baharad, Y., Benjamini, D., Yekutieli, M., Colacino, L., Diodato, C., Ramis, V., Homar, R., Romero, S., Michaelides and A., Manes, 2002: The paradoxical increase of Mediterranean extreme daily rainfall in spite of decrease in total values. *Geophys. Res. Lett.*, **29**, 11, 31-1 – 31-4, (June issue).

Alpert, P., 2004: The water crisis in the E. Mediterranean-and relation to global warming? in Water in the Middle-East and N. Africa (Eds. F. Zereini & W. Jaeschke), Springer, 55-61.

Deque,M., R. G. Jones, M. Wild, F. Giorgi, J. H. Christensen, D. C. Hassell, P. L. Vidale, B. Rockel , D. Jacob, E. Kjellstro, m, M. de. Castro, F. Kucharski, B. van den Hurk, 2005: Global high resolution versus Limited Area Model climate change projections over Europe: quantifying confidence level from PRUDENCE results. *Clim. Dyn.*, **25,** 653–670.

Giorgi, F. 2002: Variability and trends of sub-continental scale surface climate in the twentieth century. Part I: observations, *Clim. Dyn.*, **18**: 675–691.

Giorgi, F., X. Bi and J. Pal, 2004: Means, trends and interannual variability in a regional climate change experiment over Europe. Part I: Present day climate (1961-1990). *Clim. Dyn.*, **22**(6-7), 733-756.

Giorgi, F., X. Bi and J. Pal, 2004: Means, trends and interannual variability in a regional climate change experiment over Europe. Part II: Future climate scenarios. *Clim. Dyn.*, **23**(7-8), 839-858.

IPCC, Climate Change, 2001: The Scientific Basis, Contribution of WG I to the Third Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge Univ. Press.

New M. G., M. Hulme and P. D. Jones, 1999: Representing twentieth century space time climate variability. Part I: development of a 1961–1990 mean monthly terrestrial climatology. *J. Clim.*, **12**, 829–856.

New M. G., M. Hulme and P. D. Jones, 2000: Representing twentieth century space time climate .elds. Part II: development of a 1901–1996 mean monthly terrestrial climatology. *J. Clim.*, **13,** 2217–2238.

Saaroni, H., B., Ziv and P., Alpert, 2003: Long-term variations in summer temperatures over the eastern Mediterranean. *Geoph. Res. Lett.*, **Vol. 30**, N0. 18, 1946, doi:10.1029/2003GL017742.

From Luterbacher et al page 6: Mediterranean past climate variability

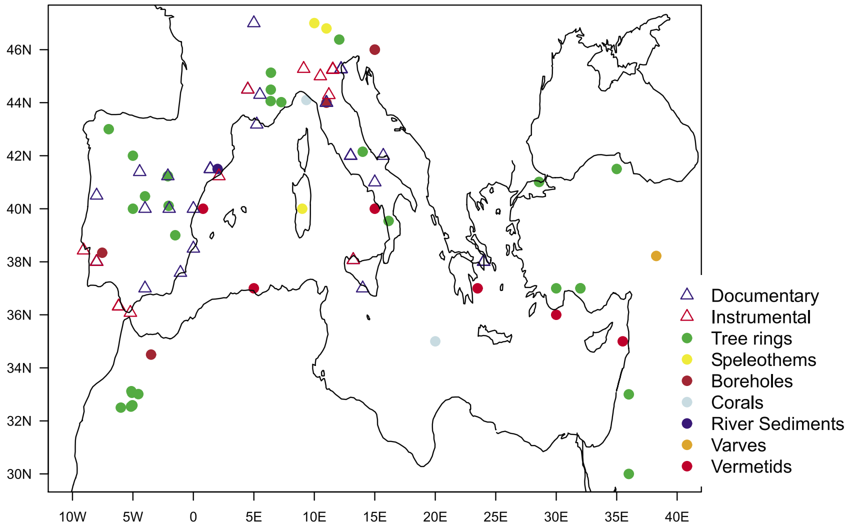

Figure 1: Compilation of long homogenized early-instrumental data, documentary proxy evidence and of "high temporal resolved" natural proxies from the larger Mediterranean area covering the last few centuries. Note, that the length of the different proxies varies and that the proxies may record climate conditions at different times of the year and provide information either on temperature, sea surface temperature, precipitation, drought or circulation. Proxies resolving only multidecadal-to-century time scale resolution have not been included (see Luterbacher et al. 2006 for details).

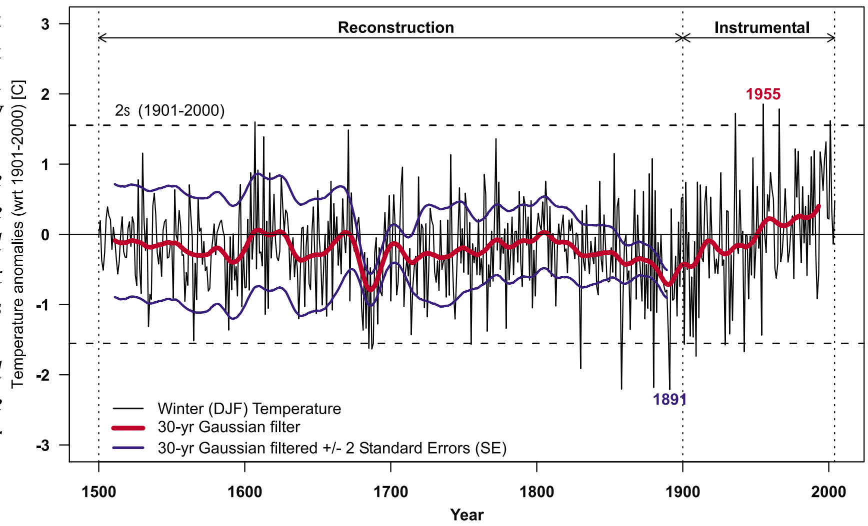

Figure 2: Winter (DJF) averaged-mean Mediterranean temperature anomalies (with respect to 1901 to 2000) from 1500 to 2005, defined as the average over the land area 10°W to 40°E and 35°N to 47°N (thin black line). The values for the period 1500 to 1900 are reconstructions, data from 1901 to 2005 are derived from Mitchell and Jones (2005) and Hansen et al. (2001), respectively. The thick red line is a 30-year smooth. Blue lines: ±2SEs of 30-yr Gaussian filtered reconstructions. The dashed horizontal lines are the 2 standard deviations of the period 1901-2000. The warmest and the coldest Mediterranean winter are denoted.

From Trigo et al page 5: What is triggering the outstanding March precipitation decline in Iberia?

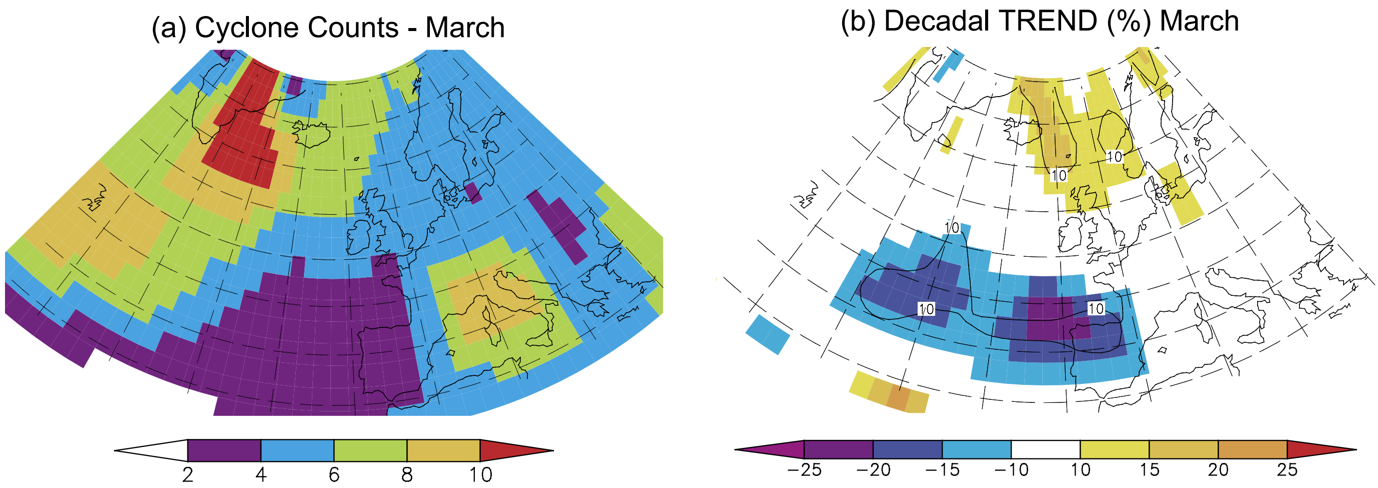

Figure 4. (a) March climatology of cyclone counts, and (b) decadal trends (% relative to the mean over the study period) of the average number of cyclones detected in March. The solid line indicates the grid cells with significant trends at least at the 10% level. Both graphics were computed on cell boxes with 9º longitude by 9º latitude for the period 1960-2000.

From Tsimplis et al page 10: Developments in sea level research and observations in the Mediterranean Sea

Figure 1. The MedGloss tide-gauge network. Proposed stations in the western part of North African coasts are in green.

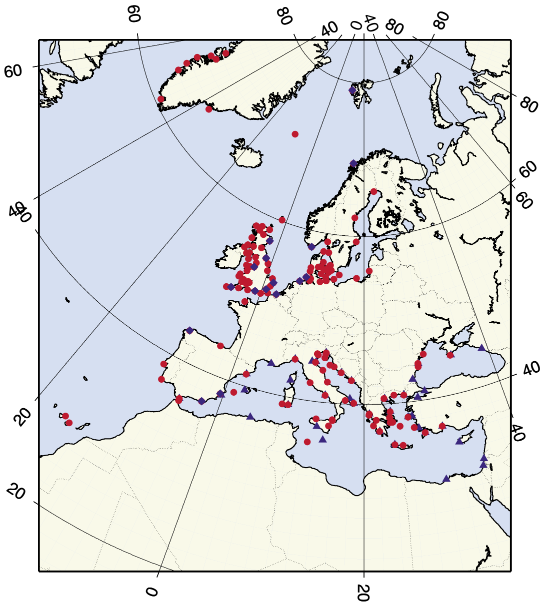

Fig.2 The European Sea Level Service Network. Red dots are tide gauges. Blue diamonds are tide gauges with co-located CGPS.Blue triangles are designated MedGLOSS sites which are available to ESEAS through coordination with MedGLOSS. The North African coasts do not have a sufficient network. Plans to update them are in progress (Fig.1).

From Lionello et al, page 12: Climatology of cyclones in the Mediterranena: present trends and future scenarios

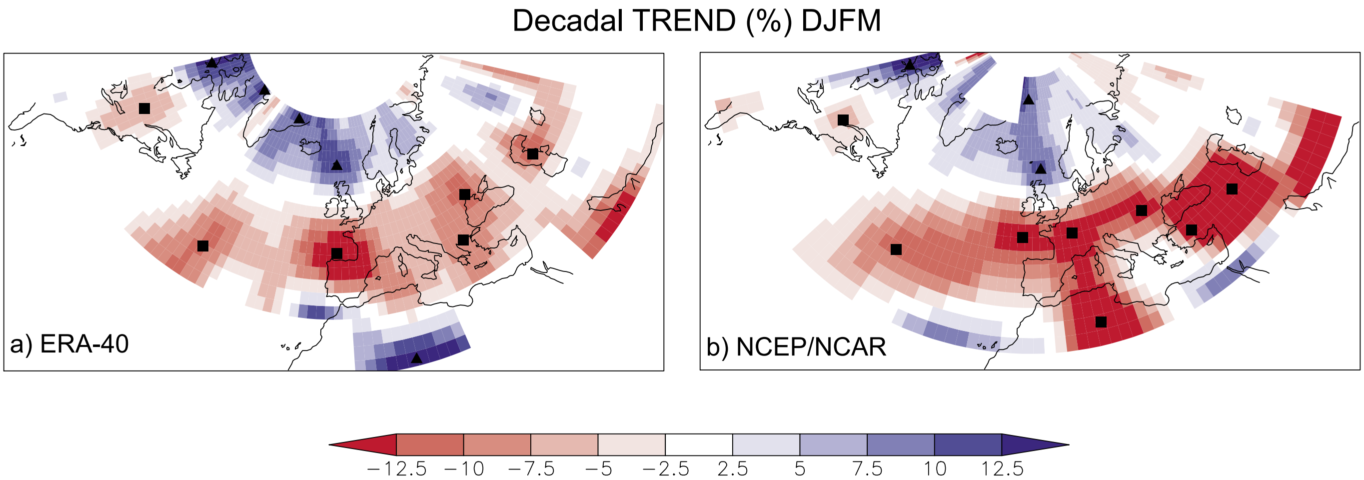

Figure 2. Decadal relative changes in DJFM cyclone numbers, aggregated within 9ox9o, and 10ox10o grid boxes, for (a) ERA-40, and (b) NCEP/NCAR data, respectively. The blue (red) shades encircle areas with increasing (decreasing) storm numbers, during the 1959-2000 period. Shades with significant trends, at less than the 10% level, are marked with solid triangles for positive, and with solid squares, for negative trends. [from Trigo, 2005]

From Lionello et al, page 12: Climatology of cyclones in the Mediterranena: present trends and future scenarios

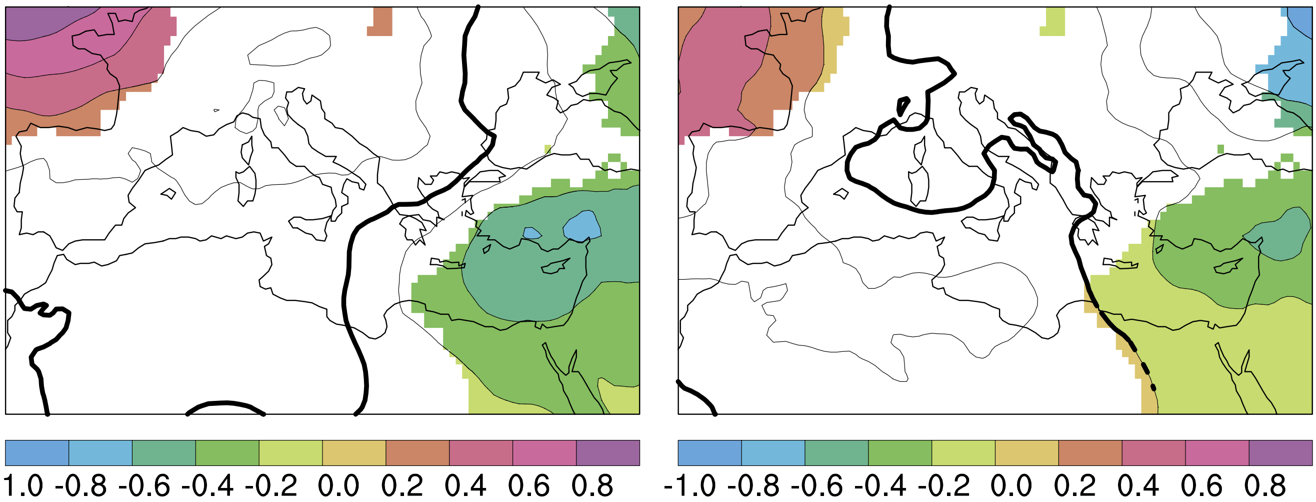

Figure 4. Standard deviation (hPa) of the band pass filtered SLP fields. The right panel shows the difference between A2 and CTR, the left panel between B2 and CTR. Contour lines every 0.2 hPa. In the colour filled areas the difference is statistically significant at the 90% confidence level (according to the Mann-Whitney test

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From Theocharis et al page 21: Dense water formation in the Mediterranean Sea

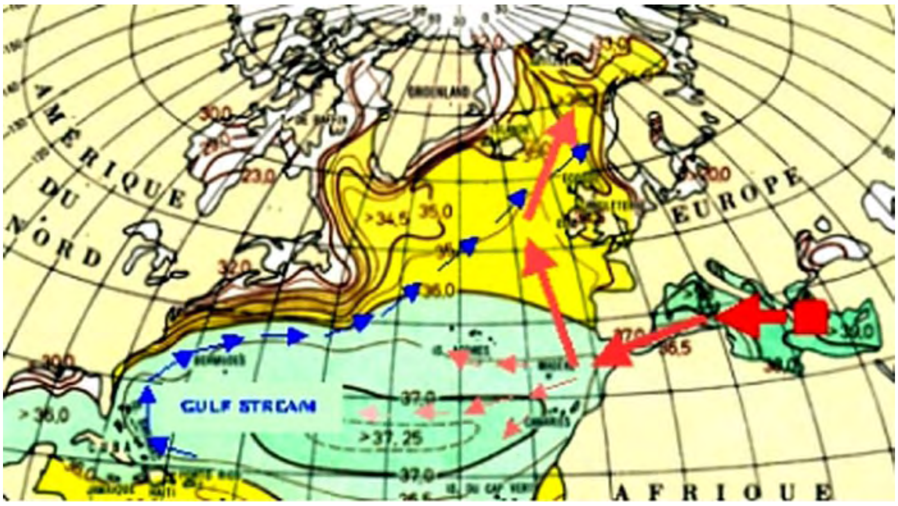

Figure 4. The salty Mediterranean Water in the Atlantic Ocean

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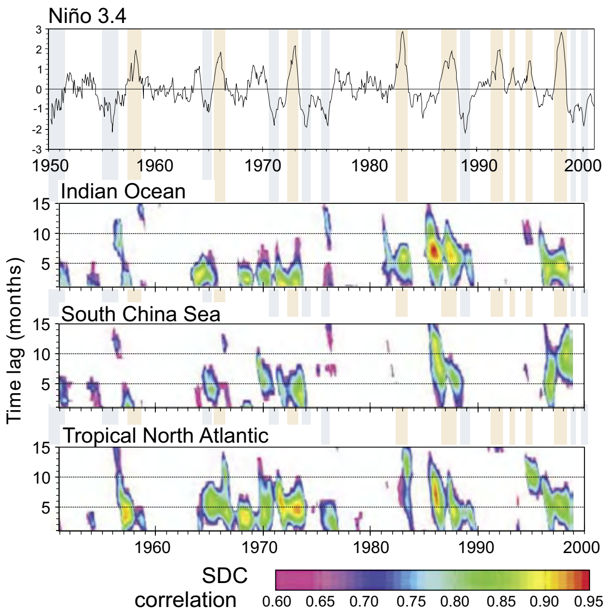
From Rodo et al, page 27: The role of ENSO in fostering teleconnection p atterns between the tropical north Atlantic and the western Mediterranean Basin

Fig. 1. Short-term positive correlations of SDC analysis larger than 0.6 and with a delay between 1 and 15 months. Computation was done between el Niño3.4 index and the SSTa in the Indian Ocean, South China Sea and TNA. In the background, the most intense ENSO events during the period are shown in light red for El Niño and in light blue for La Niña (redrawn from Rodó and Rodríguez-Arias, 2006).



From Rodo et al, page 27: The role of ENSO in fostering teleconnection p atterns between the tropical north Atlantic and the western Mediterranean Basin

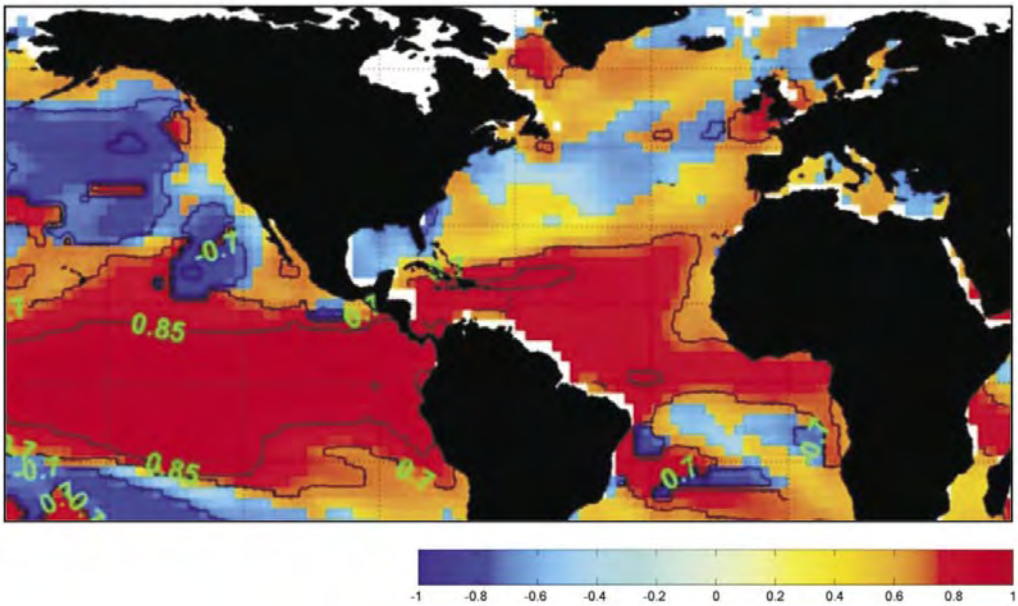


Fig. 2. Short-term correlation maxima between SST time-series and the Niño3.4 index during El Niño 1987 episode (Rodó et al., unpublished results)

Dense Water Formation in the Mediterranean Sea

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The Mediterranean Sea (area: 2.26 x 10^6 km^2, volume 3.2 x 10^6 km^3, average depth 1.45 km, max. depth 5.5 km) is an elongated, semi-enclosed almost isolated midlatitude (30-45°N) basin bounded by the European, North-African and west Asian coasts (Fig. 1). It communicates with the Atlantic Ocean through the narrow (15km) and shallow (~250m) Strait of Gibraltar. It is composed by two major interacting sub-basins, the western and eastern Mediterranean, connected by the Straits of Sicily with sill depth ~1000m. In each sub-basin there exist smaller basins and seas; the Alboran, the Balearic, the Ligurian and Tyrrhenian in the west and the Ionian, Levantine, Adriatic and Aegean in the east. To the northeast the Mediterranean communicates with the Black Sea through the Strait of Dardanelles.

In the largest scales of interest, i.e. interannual and basin-wide scales, the circulation of the Mediterranean is determined by its exchanges of water and heat with the atmosphere through the sea surface and the water and salt with the adjacent seas through the Straits. The thermohaline circulation of the Mediterranean, which reflects the largest scale motion, is forced by the buoyancy exchanges and is driven by its negative heat and freshwater budgets. The Mediterranean is a "concentration" basin, where evaporation exceeds precipitation and river runoff, with high-density water production. It receives light waters from the Atlantic Ocean and to a lesser extent from the Black Sea at the surface layers and exports dense and saline waters by underwater currents. This type of circulation is called "lagoonal". Therefore, equilibrium is reached by which the salinity remains constant.

The deep layers of the Mediterranean Sea are renewed through deep vertical mixing in winter. This process is effective in exchanging properties (i.e. heat, salt, oxygen, nutrients, etc) between the euphotic zone and the abyssal depths. On the contrary, the neighboring Black Sea is an example of "dilution" basin, where precipitation and river runoff exceed evaporation and establish the "estuarine" type of circulation, a less saline water outflow at surface and more saline water inflow at depth. In this case, the strong pycnocline prevents vertical mixing and therefore the deep and bottom layers remain isolated from the atmosphere and consequently have very low oxygen content.

Therefore, two kinds of thermohaline cells result. The first, the upper open conveyor belt, is consisted by (i) the non-return flow of low salinity Atlantic Water (AW), entering from the Gibraltar Strait, to the easternmost end of the Levantine Basin in the upper 150-200m and (ii) the formation and westward spreading of the warm and saline (S~39.00-39.1 at the source area) Levantine Intermediate Water (LIW), at depths 200-400m, to the Gibraltar, where it enters the Atlantic Ocean. Secondly, there exist internal thermohaline cells or closed conveyor belts in each of the Mediterranean sub-basins driven by deep water formation processes (Theocharis et al., 1998) (Fig. 2a). Intermediate and deep water formation occurs in the Mediterranean by both open-ocean and shelf processes during winter storm events.

In particular, in winter, over the entire Mediterranean, surface cooling increases the density of the surface waters that sink and produces a homogenized upper layer, the maximum thickness of which is about ~100m. At very well defined areas, called "water mass formation sites", where specific atmospheric (very low temperatures, strong and dry northerlies, increased evaporation) and oceanic (cyclonic circulation) conditions prevail, the winter cooling is episodically violent and the vertical mixing, namely "convection", reaches greater depths and even down to the bottom (Fig. 3). There are one main source of intermediate water and two of deep waters in the Mediterranean. The northwest Levantine Basin is the main source of the Levantine Intermediate Water (LIW), while the Gulf of Lions and the Adriatic Sea are the basic sites of the Western Mediterranean Deep Water (WMDW) and the Eastern Mediterranean Deep Water (EMDW) respectively. Additionally, there are other minor and sporadic sources in other parts of the Basin. Such important sites exist e.g. in the North and South Aegean Sea, which under the synergy of extreme meteorological and favorable hydrological conditions become more effective and may considerably influence the thermohaline circulation in medium or longer term.

LIW is considered the most important component of the large scale circulation and dynamics because it spreads throughout most of the Basin and affects the background stratification at the other major deep water formation areas (Adriatic and Aegean). It is also the main constituent (80%) of the high-salinity Mediterranean Water that is exported to the Atlantic Ocean (Lascaratos et al., 1999). Another loop connects the Mediterranean with the Black Sea. In this case, the Aegean Sea acts as an intermediate machine that modifies the received LIW and exports it to the Black Sea via the Marmara Sea.

Of particular importance is also the role of the Mediterranean to the global circulation (Fig. 4). The Mediterranean water injected into the Atlantic is entered into the North Atlantic thermohaline circulation. The North Atlantic Deep Water (NADW) is formed in the Iceland-Greenland and Labrador Seas and then is

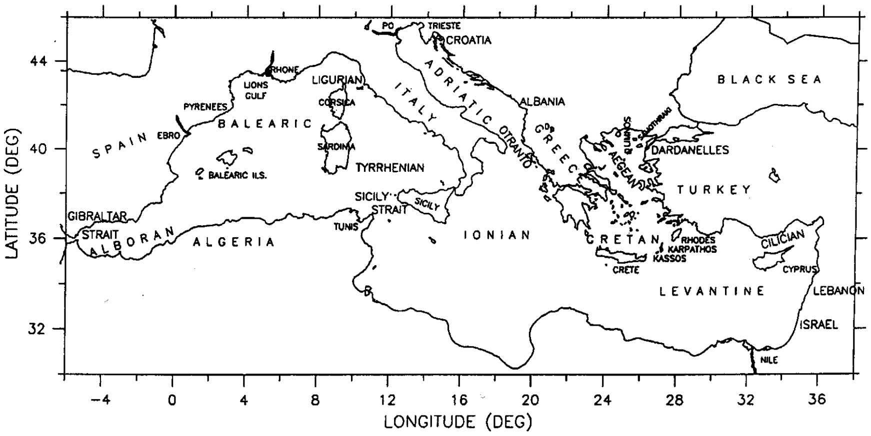

Figure 1. Map of the Mediterranean Sea

spread through the global thermohaline cell into the Atlantic, Southern, Indian and Pacific Oceans. Any significant changes in the hydrological properties of the Mediterranean out-flowing water may have influence in the deep-water formation processes in the North Atlantic.

The deep waters of the Mediterranean are confined in the deep and bottom layers of the respective sub-basins because of the existence of the sills at the Sicily and Gibraltar. On average, the deep-water annual production rate reaches 0.3 Sv at each sub-basin, while the intermediate 1-1.5 Sv (Lascaratos 1993). The renewal of the deep waters is of the order of 80-100 years. Open-ocean convection in the Gulf of Lions is the mechanism responsible for the formation of the WMDW. The favorable local cyclonic circulation leads to an uplifting of the isotherms, isohalines and isopycnals within the dome, where the LIW salinity maximum is brought to shallow enough depths into the mixed layer. In early winter, strong, cold and dry winds blowing either from the Rhone valley or out of the Pyrenees, called Mistral and Tramontane, respectively, combine to prepare the water column for a subsequent deep convection. Three important scales are related with the convection regime (MEDOC group, 1970; Schott and Leaman, 1991, Jones and Marshall, 1993). One is the mixed deep patch itself, known as chimney, having a width 30-40 km. The second is the scale of the instability eddies present along the front separating the chimney from the stratified surrounding waters that have the scale of the Rossby radius (~5km for the stratified regime). The third is that of small-scale plumes only a few hundred meters wide observed within the chimney during cooling periods, the integral effect of which is that of a mixing agent rather than carrying water downward in a mean motion. The boundary current removes about 50% of the total volume of the dense water formed by the convection (Send et al., 1996).

The EMDW originates primarily in the Adriatic Sea from the Adriatic Deep Water (ADW). During winter the waters subjected to intense cooling become dense and sink towards the deep layers of the Ionian. The open-ocean convection mechanism is also evident in the South Adriatic Pit (Ovchinnikov et al., 1985). Complete vertical overturning occurs with typical horizontal scales of the vertical mixing on the order of a few tens of miles and time scales of a few days. The prevailing cyclonic topographically controlled circulation, with the typical isopycnal doming brings towards the surface heavier colder water. Vigorous convection occurs during winter outbreaks of cold and dry Bora winds. The surface cooling processes during Bora events are more efficient than evaporation in determining the vertical stratification due to the fact that the bottom salinity is lower than the salinity at intermediate layers. Apart from the above mechanism, there are shelf processes contributing to the bottom water formation in the south Adriatic that take place (i) in the large shallow continental shelf of the North Adriatic, where air-sea thermal and evaporative fluxes are strong enough to mix the water column down to the bottom and give rise to bottom density-driven current along the Italian coast flowing southwards (Artegiani and Salusti, 1987; Zoccolotti and Salusti, 1987) and (ii) in the wide shelf and the continental slope along the eastern shore, where relatively salty surface water is mixed with the underlying LIW during upwelling events (Artegiani et al., 1989).

Apart from the above mentioned main sources, there were sporadic events of deep water formation in the Levantine Basin during 1986, 1990, 1992 and 1995, when newly formed deep water, namely Levantine Deep Water (LDW), with density near the one of the EMDW, occurred within the Rhodes cyclonic gyre at depths reaching ~1000m in 1990 and 1995 and exceeding 1000m in 1986 and 2000m in 1992 (Kontoyiannis et al., 1999). The lateral scales of the newly formed water masses in cyclonic structures appear roughly proportional to the penetration depth of the convection, so that a large lateral scale indicating a massive production would be associated with a deep rather than an intermediate formation.

The Aegean Sea has also been reported as a sporadic secondary source of dense waters (Nielsen, 1912; Miller, 1963). However, the amounts produced have never been enough to drastically influence the thermohaline structure of the eastern Mediterranean. In late 80s-early 90s, abrupt significant consecutive changes, increase in salinity (1987-1992) and drop in temperature (1992-1994), caused continuous increase of density and massive deep water formation in the south Aegean (Malanotte-Rizzoli et al., 1999; Theocharis et al., 1999) that alter the thermohaline circulation of the eastern Mediterranean

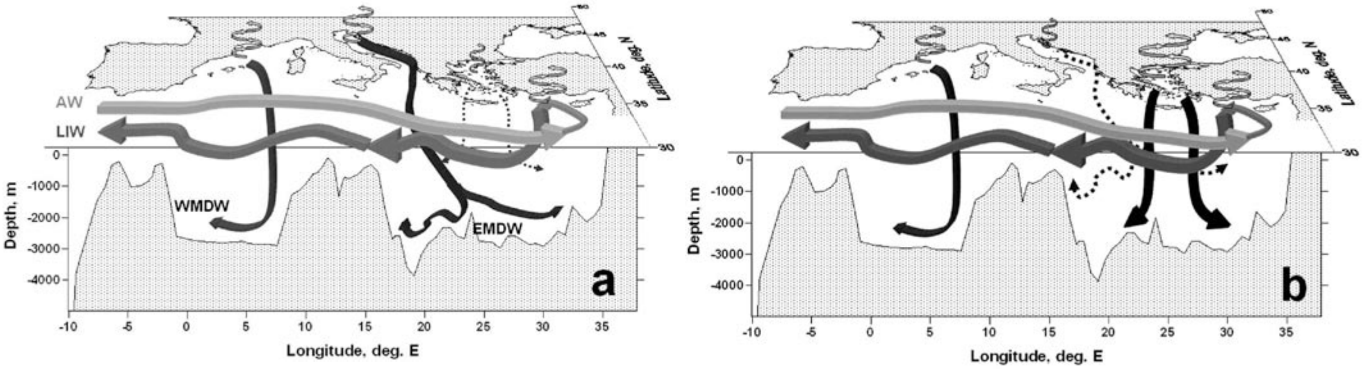

Figure 2. The thermohaline cells of the Mediterranean Sea before the EMT (a) and after the EMT (b) (From Tsimplis et al., 2006)

(Fig. 2a, 2b) (Robinson et al., 2001; Roether et al., 1996) with consequences also in the distribution of other environmental parameters (Klein et al., 1999). This major event, unique in the oceanography of the Mediterranean since the beginning of the 20th century, evolved within the last 18 years and was called the "Eastern Mediterranean Transient" (EMT). The engine of the conveyor belt was up to 1987 the convective cell of the Southern Adriatic, while in early 90s the active convection region has shifted to the Aegean. The new source has become more effective since the production rate reached 1Sv instead of 0.3Sv. During the EMT period, both open-ocean and shelf processes were the responsible mechanisms for the deep-water formation in the Aegean. The signal of this change has passed the Sicily Strait and has been felt in the western Basin. The event has gradually decayed since 1995 indicating its transitional nature (Theocharis et al., 2002). This abrupt change has been mainly attributed to important meteorological anomalies (extended reduced rainfalls, change in wind patterns, exceptionally consecutive cold winters) in the eastern Mediterranean and to changes of circulation patterns (routes of the AW and LIW) and to the reduced Black Sea Water outflow (Malanotte-Rizzoli et al., 1999; Theocharis et al., 1999; Zervakis et al., 2004). The relationship between the heat loss and large scale atmospheric patterns (e.g. NAO) is also investigated. These episodic changes have been superimposed to the long-term trends observed in the Mediterranean (Boscolo and Bryden 2001). It is worth to mention that palaeoceanographic information has certified the large sensitivity of the Aegean Sea to climatic variability.

In conclusion, the Mediterranean is not in a steady state and is potentially very sensitive to changes in atmospheric forcing (Tsimplis et al., in press). How the Mediterranean will eventually respond in the future to the different proposed scenarios is an important issue that must be addressed.

References

Artegiani A. and E. Salusti, 1987. Field observations of the flow of dense water on the bottom of the Adriatic Sea during the winter 1981. *Oceanol. Acta*, **10**(4), 387-391.

Artegiani A., R. Azzolini and E. Salusti, 1989. On the dense water in the Adriatic Sea. *Oceanol. Acta*, **12**(2), 151-160.

Boscolo R. and H. Bryden, 2001. Causes of long-term changes in the Aegean Sea deep water. *Oceanologica Acta*, **24**, 519-527.

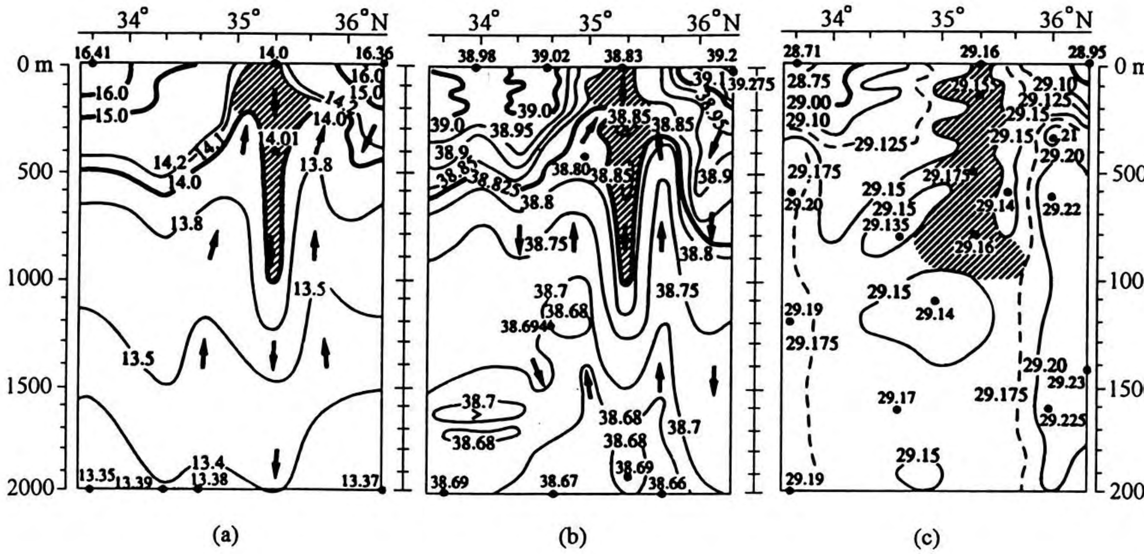

Figure 3. Potential temperature (a), salinity (b) and □□ (c) on the meridional section along 280 40' across the middle of the Rhodes cyclonic gyre (Febr. 1990) (From Gertman et al., 1994)

Gertman I. F., I. M. Ovchinnikov and Yu. I. Popov, 1994. Deep convection in the eastern basin of the Mediterranean Sea. *Oceanology*, **34** (1), 19-25.

Jones H. and J. Marshall, 1993. Convection with rotation in a neutral ocean: a study of open ocean deep convection. *J. Phys. Oceanogr.*, **23**, 1009-1039.

Klein B., W. Roether, B. B. Manca, D. Bregant, V. Beitzel, V. Kovacevic and A. Luchetta, 1999. The large deep water transient in the Eastern Mediterranean. *Deep-Sea Res. I*, **46**, 371414.

Kontoyiannis H., A. Theocharis and K. Nittis, 1999. Structures and characteristics of newly formed water masses in the NW Levantine during 1986, 1992, 1995. In: NATO Science Series, Environmental Security: The Eastern Mediterranean as a Laboratory for the Assessment of contrasting Ecosystems. Malanotte-Rizzoli, P., Eremeev, VN. (Eds.). 51(2) Kluwer Academic Publishing, The Netherlands, 453-464.

Lascaratos A., 1993. Estimation of deep and intermediate water mass formation rates in the Mediterranean Sea. *Deep-Sea Res., II*, **40**, 1327-1332.

Lascaratos A., W. Roether, K. Nittis and B. Klein, 1999. Recent changes in deep water formation and spreading in the eastern Mediterranean Sea: A review. *Prog. Oceanog.*, **44** (1-3), 5-36.

Malanotte-Rizzoli P., B. Manca, M. Ribera d' Alcala, A. Theocharis, S. Brenner, G. Budillon and E. Ozsoy, 1999. The Eastern Mediterranean in the '80s and in the '90s: the big transition in the intermediate and deep circulation. *Dyn. Atmos. Oceans.*, **29**, 365-395.

MEDOC group, 1970. Observation of formation of deep water in the Mediterranean Sea, 1969. *Nature*, **227**, 1037-1040.

Ovchinnikov M., V. I. Zats, V. G. Krivosheya and A. I. Udodov, 1985. A forming of deep eastern Mediterranean water in the Adriatic Sea. *Okeanologia*, **25**(6), 911-917.

Robinson A. R., A. Theocharis, A. Lascaratos and W. Lesley, 2001. Ocean Currents: Mediterranean Sea Circulation . In: Encyclopaedia of Ocean Sciences. London: Academic Press Ltd., 1689-1706.

Schott F. and K. D. Leaman, 1991. Observatios with moored acoustic Doppler current profilers in the convection regime in Golfed du Lion. *J. Phys. Oceanogr.*, **21**, 558-574.

Send U., J. Font and C. Mertens, 1996. Recent observations indicate convection' s role in deep water circulation. *EOS, Trans. American Geophys. Union*, **77**(7), 61-65.

Theocharis A., M. Gacic and H. Kontoyiannis, 1998. Physical and Dynamical processes in the coastal and shelf areas of the Mediterranean. *The Sea*, **11** (chapter 30), 863-887.

Theocharis A., K. Nittis, H. Kontoyiannis, E. Papageorgiou and E. Balopoulos , 1999. Climatic changes in the Aegean Sea influence the Eastern Mediterranean thermohaline circulation (1986-1997) *Geophys. Res. Letters* **26**(11), 1617-1620.

Theocharis A., B. Klein , K. Nittis and W. Roether, 2002. Evolution and Status of the Eastern Mediterranean Transient (1997-1999). *J. Mar. Sys.*, **33-34**, 91-116.

Tsimplis, M.N. et al. (2006) Changes in the oceanography of the Mediterranean Sea and their link to climate variability. In: P. Lionello, P. Malanotte-Rizzoli & R. Boscolo (Eds), Mediterranean Climate Variability, Amsterdam: Elsevier, pp. 227—282.

Zervakis V., D. Georgopoulos, A. P. Karageorgis and A. Theocharis, 2004. On the response of the Aegean Sea to climatic variability: A review. *Int. J. Climatol*. **24**, 1845-1858.

Modelling regional-scale climate change of the Mediterranean

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1. Regionally-oriented climate scenarios

Regional climate changes under global warming context are the most important motivations for the Mediterranean regional climate modelling. It is generally agreed that the Mediterranean region is one of the 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.

In terms of global mean surface air temperature, the Globe has experienced a general warming of 0.6°C over the last century. IPCC estimated changes of the global temperature to be between 2 to 5°C at the end of the 21st century. The global mean temperature is only a mean indicator and changes at regional scales can be much larger. Many global and regional models tend to simulate a warming of several degrees (from 3 to 7°C) 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 a mean precipitation decrease for the region (especially in Summer), due mainly to the northward extension of the descending branch of the subtropical Hadley circulation.

In the framework of the French national programme GICC-MedWater, two regionally-oriented atmospheric models, LMDZ-Med (developed in IPSL in Paris) and ARPEGE-Med (developed in Meteo-France in Toulouse), were used to study the Mediterranean climate change for the end of the 21st century. Both models are global atmospheric GCMs, but with stretched grid and increased spatial resolution over the Mediterranean. Unlike limited-area models, LMDZ-Med and ARPEGE-Med need only the SST and greenhouse gas concentration from global climate models to perform regionally-oriented climate change scenario simulations. We used only one emission scenario - IPCC SRES A2, but three global climate scenarios provided by three institutions (IPSL, CNRM

Simulation	period	Conditions
LMDZ/CTRL	1970/1999	Control simulation
ARPEGE/CTRL	1970/1999	Control simulation
LMDZ/IPSL	2070/2099	Emission SRES-A2 Global climate IPSL
LMDZ/CNRM	2070/2099	Emission SRES-A2 Global climate CNRM
LMDZ/GFDL	2070/2099	Emission SRES-A2 Global climate GFDL
ARPEGE/CNRM	2070/2099	Emission SRES-A2 Global climate CNRM

Table 1: Different simulations with the corresponding time periods and boundary conditions

and GFDL) running global ocean-atmosphere coupled models. Both LMDZ-Med and ARPEGE-Med were firstly run for the period 1970/1999 to produce their respective control simulations. LMDZ-Med was run furthermore for the three future scenarios for the period 2070/2099. ARPEGE-Med was run for the future scenario provided by CNRM. Table 1 summarizes the simulations used in the project GICC-MedWater.

The hydrological cycle is an important component of the Mediterranean regional climate. For the four future scenario runs, Table 2 gives the annual-mean values for changes in E, P and E-minus-P. All the future climate simulations show a decrease of precipitation rate. Evaporation increases for LMDZ/IPSL, LMDZ/CNRM and ARPEGE/CNRM, but there is a very weak, insignificant decrease for LMDZ/GFDL. The net water deficit thus increases in all the four scenarios. The last column of Table 1 shows the gain of total heat flux at the sea surface for the three scenarios compared to the control simulation. We can see that the Mediterranean Sea gains (or loses less) energy from the atmosphere for future climate scenarios. The net gain of heat flux varies from 3.6 to 11.9 W/m2 for different runs.

2. Sensitivity of the Mediterranean thermohaline circulation to anthropogenic global warming

The Mediterranean Sea is a concentration basin with an evaporation rate much larger than the rainfall rate and river runoff, leading to increase in salt content. It is also a heating source to the atmosphere with annual decrease of temperature for water masses. The Mediterranean Sea is similar to a thermodynamic engine which transforms the inflowing light Atlantic water into dense deep Mediterranean waters through air-sea coupling. This water transformation process generates thermohaline forcing which drives, in a large proportion, the Mediterranean marine general circulation. Convection can thus be observed in several places of the Mediterranean Sea, particularly, in the Gulf of Lions, Adriatic Sea, Aegean Sea and Levantine basin.

Simulation	E	P	E-P	H
LMDZ/IPSL	39	-57	96	3.6
LMDZ/CNRM	57	-74	131	5.8
LMDZ/GFDL	-7	-20	13	11.9
ARPEGE/CNRM	120	-60	180	4.9

Table 2: Annual-mean changes of evaporation (E: mm/yr), precipitation (P: mm/yr), water deficit (E-P: mm/yr) and gain of heat flux (H: W/m2) for the whole Mediterranean Sea and for the four scenarios respectively.

Here we investigate the sensitivity of the Mediterranean thermohaline circulation to global warming. As indicated in Table 2, the simultaneous increase of both surface temperature and water deficit could counteract each other in the possible evolution of the Mediterranean Sea thermohaline circulation (MTHC). A weakening or strengthening of the MTHC due to climate change could have an impact on the Mediterranean sea surface temperature and consequently on the climate of the surrounding areas. Through the Mediterranean Outflow Waters, changes of MTHC can furthermore influence the Atlantic Ocean and then the Atlantic and global thermohaline circulation. The Mediterranean marine ecosystems are also expected to be strongly influenced by the variation of marine circulation.

By using the regionally-oriented climate scenarios, as described in Table 1, Somot (2005) and Bozec (2006) studied the impact of global warming on the Mediterranean Sea thermohaline circulation. The Mediterranean Sea general circulation model is MED8, derived from the OPA oceanic model, with the horizontal resolution at 1/8 degree. Results on water mass properties are reported in Table 3. The increase of temperature and salinity is observed in the whole Mediterranean. In the case of LMDZ-Med, the increase of salinity is quite weak, due to an irrealistic restoring of the salinity to current climate values for the control and scenario runs.

Since the Gibraltar Strait is the only connection of the Mediterranean Sea with the global ocean, the water mass transport and the associated properties can give an integrated indication of climate variation and changes in the Mediterranean basin. Table 4 gives the mass transport, temperature and salinity in the Gibraltar Strait simulated by MED8 using atmospheric forcings from LMDZ-Med and ARPEGE-Med for the control runs and scenario runs. We can see that the water mass transport is diminished when the climate is warmed. This diminution is also larger when the warming is stronger. In the case of LMDZ-Med, the proprieties of incoming water do not change very much, since the buffer zone in the Atlantic was not allowed to change. For the Mediterranean outflow on the bottom, both temperature and salinity are increased. This conclusion is confirmed in the ARPEGE/CNRM scenario, with the outflow slower, saltier and warmer for the end of the 21st century. Some recent observation-based studies revealed also a warmer and saltier trend for the Mediterranean deep water masses (Bethoux et al. 1990; Potter and Lozier 2004; Rixen et al.

	temperature (°C)			salinity (PSU)		
	total	upper	lower	total	upper	lower
LMDZ/CTRL	13.91	15.33	13.79	38.59	38.43	38.66
ARPEGE/CTRL	13.2	14.2	13.1	38.61	38.27	38.66
LMDZ/IPSL	0.31	1.25	0.15	0.02	0.08	0.00
LMDZ/CNRM	0.43	1.81	0.20	0.02	0.09	0.00
LMDZ/GFDL	0.49	2.13	0.22	0.02	0.07	0.00
ARPEGE/CNRM	1.0	2.0	0.8	0.18	0.31	0.16

Table 3: Temperature (°C) and salinity (PSU) for the control simulations LMDZ/CTRL and ARPEGE/CTRL, and their changes for the four scenario runs (LMDZ/IPSL, LMDZ/CNRM, LMDZ/GFDL and ARPEGE/CNRM). "total" indicates the whole Mediterranean. "upper" indicates from 0 to 250 m. "lower" indicates from 250 m to the bottom.

2005), which is probably the manifestation of the ongoing anthropogenic global warming.

3. Perspectives and Outlooks

By using a sequential and one-way approach, we show here that, under the global warming context, the Mediterranean Sea will have an increased water deficit and will enter into a stage with a weaker overturning circulation. This may further impact the marine ecosystem. Our study is only a first step toward an integrated study on the Mediterranean climate change and impact. Two important pathways can be foreseen for the Mediterranean regional climate modelling in the next few years.

3.1 Toward high-resolution Mediterranean climate modelling

The spatial resolution of future modelling systems will be further increased. It is expected to have regional atmospheric models with resolution around 10 to 20 kilometres 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. 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. For the Mediterranean region, high resolution is particularly important, since there is a very complex terrain surrounding the Mediterranean Sea, responsible for intense wind events, such as Mistral and Bora which contribute largely to oceanic convection in the Mediterranean (Gulf of Lions, Adriatic Sea, and Aegean Sea).

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 always be necessary to provide appropriate solutions for climate change impact studies.

3.2 Development and validation 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 items, the Mediterranean Sea general circulation, basin-scale hydrology, dynamic 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 derived from 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 utilisation in the Mediterranean climate studies.

It is also necessary to emphasize the perspectives of multi-model ensemble approach for future Mediterranean

Table 4: Mass transport (Tr: Sv), temperature (T: °C) and salinity (S: psu) in the Gibraltar Strait for the control simulations LMDZ/CTRL and ARPEGE/CTRL, and their changes for the four scenario runs (LMDZ/IPSL, LMDZ/CNRM, LMDZ/GFDL and ARPEGE/CNRM). Surface inflow and bottom outflow are presented seperately.

	surface inflow			bottom outflow		
	Tr	T	S	Tr	T	S
LMDZ/CTRL	0.656	16.44	36.45	0.656	13.53	38.26
ARPEGE/CTRL	1.18	15.69	36.35	1.18	12.43	38.28
LMDZ/IPSL	-0.070	0.02	0.00	-0.070	1.15	0.15
LMDZ/CNRM	-0.013	0.16	0.00	-0.013	1.57	0.13
LMDZ/GFDL	-0.150	0.25	0.00	-0.150	1.84	0.09
ARPEGE/CNRM	-0.09	1.40	0.19	-0.09	2.01	0.44

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 close cooperation with computer industry is thus necessary in the future to accomplish this task.

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References

Bethoux, J.P., B. Gentili, J. Raunet, and D. Tailliez, 1990: Warming trend in the Western Mediterranean deep water, *Nature*, **347**, 660-662.

Bozec, A., 2006: La circulation thermohaline de la Mer Méditerranée sous des climats présent et futur. Ph.D thesis, LOCEAN, University of Paris, France.

Somot, S., 2005: Modélisation climatique du bassin méditerranéen : variabilité et scénarios de changement climatique. Ph.D thesis, Meteo-France, University of Toulouse, France.

Somot, S., et al. 2006: Is the Mediterranean Sea Thermohaline Circulation Stable in a Climate Change Scenario? *Climate Dynamics*, in revision.

Li, L. et al. (2006) Regional atmospheric, marine processes and climate modelling. In: P. Lionello, P. Malanotte-Rizzoli & R. Boscolo (Eds), Mediterranean Climate Variability, Amsterdam: Elsevier, pp. 373—397

Potter, R. A., and M. S. Lozier, 2004: On the warming and salinification of the Mediterranean outflow waters in the North Atlantic. *Geophys. Res. Let.*, **31**, 1, L01202, doi: 10.1029/2003GL018161.

Rixen, M., et al., 2005: The Western Mediterranean Deep Water: A proxy for climate change. *Geophys. Res. Lett.*, **32**: L12608, doi:10.1029/2005GL022702.

Ulbrich, U. et al. (2006) The Mediterranean climate change under global warming. In: P. Lionello, P. Malanotte-Rizzoli & R. Boscolo (Eds), Mediterranean Climate Variability, Amsterdam: Elsevier, pp. 398—415.

The role of ENSO in fostering teleconnection patterns between the tropical north Atlantic and the western Mediterranean Basin

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Mediterranean basin teleconnections: hypothesis and observations

Global ENSO impacts have been documented in the literature since the end of the 80's, among which, those in the Mediterranean Area (MA) too (e.g, Ropelewski and Halpert 1987). In the MA, two areas were long ago identified, namely NAS (Northern Africa – Southern Europe) and MME (Mediterranean – Middle East). Early simulations of ENSO responses in the North Atlantic European (NAE) region traditionally proved elusive, the same as for the MA. Despite of this difficulty, regional and local observational studies identified ENSO responses ranging from weak, in some atmospheric parameters, to strong magnitudes, but only during selected intervals. These 'temporal' associations showed up in the MA as well, following strong to very strong ENSO events. It was found a variable delay in the responses ranging from 1 to 2 seasons, attributed to nonlinear couplings taking place in remote oceans and originating in the tropical Pacific (Figure. 1, page 19). The Tropical North Atlantic (TNA) and the North Atlantic regions can act as intermediate basins, with either an amplifying or damping effect. A clear link between SSTa in the equatorial Pacific Ocean and the TNA has been well recognized, both through observations and modeling studies (Lau and Nath 2001). Among the teleconnection mechanisms suggested, lagged responses might involve a PNA response to El Niño that by means of interactions with climatological stationary waves, could induce changes in areas of the North Atlantic (Trenberth et al. 1998). Alternatively, a tropical atmospheric bridge between the equatorial Pacific and the TNA region has been suggested as a plausible mechanism linking the two oceans and as predictor of SSTa there (Lau and Nath 1996). Alteration of the local Atlantic Hadley cell or the southward drift of the North Atlantic low pressure systems in the winter season during El Niño were also postulated as plausible ways by which Mediterranean climate might be affected.

Several observational and diagnostic studies have been devoted to shed light on the ENSO's role for potential predictability, also for the western MA, and from seasonal (Oldenborgh et al. 1999, Mariotti et al. 2002, 2005) to interannual (Rodó et al. 1997, Rodó 2001) and longer timescales. These studies enabled the identification of specific atmospheric structures coherent with the postulated teleconnections (Mariotti et al. 2002).

Contrary to what originally thought, ENSO teleconnections are not confined to the winter season, autumn and spring stand as well as sensitive seasons. The far-field component of ENSO teleconnection is generated from several processes, including interactions with the Atlantic storm track system and the MA orography. Often, the poor simulation of ENSO reflects the incomplete representation of these interactions in models (Joseph and Nigam 2006). ENSO winter teleconnections to tropical precipitation and extratropical circulation were found by Nigam (2003) in 250 hPa GPHa, even to affect the southern Mediterranean countries. This alteration of the branch of the local Hadley circulation over the NAE region can be traced in large-scale atmospheric air movements (Rodó 2001). However, the confirmation of this linkage is sometimes inconclusive, as it appears to be episode-dependent, and lie in the domain of nonlinear processes, i.e. it is not easily traceable by means of customary statistical techniques. The lack of a full understanding of the dynamical mechanism responsible for such signals and how it operates through different ocean basins, further complicates this picture. The difficulty to reproduce observed patterns with general circulation models (GCMs) reveals the complex interplay of tropical and subtropical dynamics and the highly dynamical atmosphere at midlatitudes. In fact, the analysis in the IPCC AR4 simulations of 20th century climate also reveal that climate models are improving but are still unable to simulate many features of ENSO variability and its circulation and hydroclimate teleconnections (Joseph and Nigam 2006).

New diagnostic attempts

Approaches to constrain the role of local transitory couplings in modifying responses far from the source have been recently addressed with the aid of new tools (Rodó and Rodríguez-Arias 2006). These approaches allow addressing more clearly atmosphere-ocean couplings, whatever their temporal duration and strength. In the case of ENSO and the MA, this relationship was highlighted in Rodó (2001) and the importance of regions, such as the TNA, has been later confirmed by other diagnostic and modelling studies (e.g., Rodríguez-Fonseca et al. 2006). Figure 2, page 20 shows short-term correlation maxima between SST time-series and the Niño3.4 index during El Niño 1987 episode. Regional maxima in correlations with extensive areas in the TNA regions show couplings accounting for over 60% of total variability. This result points out to the existence of a strong and discontinuous coupling. Recently a differential warming or cooling in the western Mediterranean basin has been detected in association to other ENSO events.

Modeling Mediterranean teleconnections

Several studies attempted to reproduce remote ENSO forcings simulating the hypothesized teleconnection mechanisms. There is still a limited capacity to reproduce far distance temporary ENSO forcings due to a narrow southern extent representation of the associated pattern and the more intense wind trades as a result of a low grid resolution. In addition, errors generated in one simulated component are often transmitted to the coupled component in a kind of positive feedback loop that increases uncertainty and may severely affect predictability (Chen et al. 2004). In order to study whether the underepresentation of this ENSO alteration on surface heat fluxes in the TNA region, might translate later on, in the form of a subsequent weakening of the ENSO response in the MA region, a regionally coupled model (RCM) was used. RCMs are an alternative approach to the more common atmosphere-only general circulation models (AGCMs) and coupled general circulation models (CGCMs). In this approach, SSTs are prescribed in a limited region only, whereas an ocean model acts outside this area. This approach resulted in a significant improvement in the representation of the Indian monsoon compared to models with fully specified SSTs (Wu and Kirtman 2004). An example of this modelling approach (the ECBilt-Clio v.3.0, Opsteegh et al. 1998) produced encouraging preliminary results. ECBilt-Clio v.3.0 has a T21 resolution in the atmospheric component and a 3x3 horizontal resolution in the ocean with 20 unevenly spaced vertical levels, while still provides a realistic

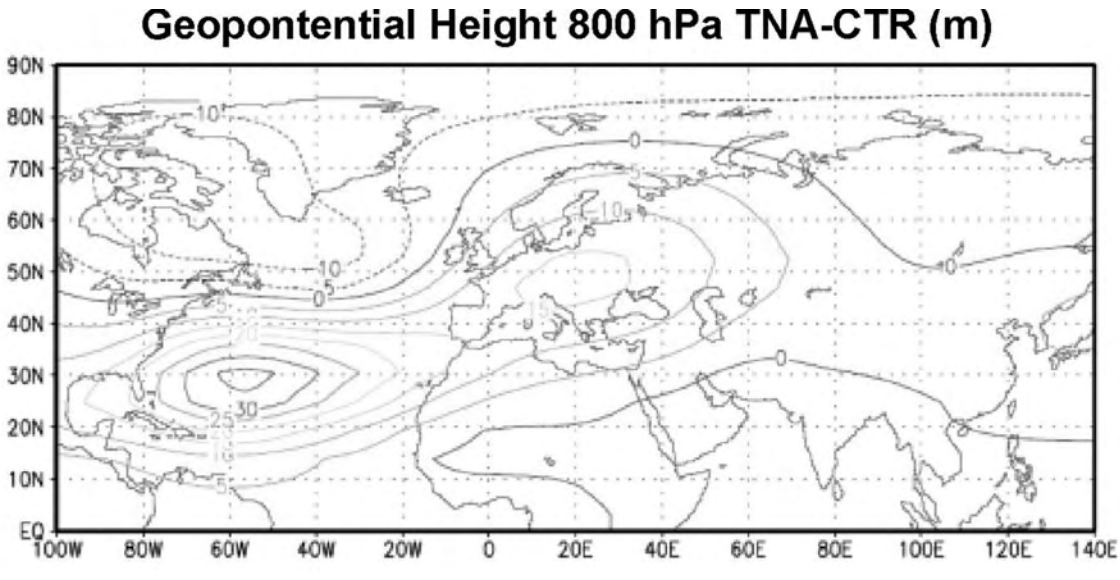

Fig. 3. GPHa at 800hPas response to a TNA prescribed forcing in EcBILT-Clio v. 3.0. Notice the change in location of the maxima in anomalies and the elongated band to cover the western MA (Rodó et al., unpublished results).

representation of large-scale dynamics. However, its atmospheric response has shown to be underestimated by a factor of two. Due to this fact, SSTs were prescribed in the center of the TNA region identified in Figure 2, with value of 3°C (an anomaly that doubles the maxima isolated of 1.7 °C) to force a more realistic atmospheric response. Figure 3 shows the extent of the GPH responses at 800hPa with regard to the control run. At equilibrium a change in location to a more northward extension is evident in the response. Also, an elongation of the resulting GPH was found to cover most of western MA with maxima found over northern Italy and the Balkans.

Conclusions

Generating realistic ENSO variability remains yet challenging for most climate models, mostly in terms of representing duration, timing and constraining location. This is particularly difficult when reproducing ENSO response at midlatitudes, as for instance the amplitude ridge over the MA is not captured in most IPCC's XXth Century Climate simulations (Joseph and Nigam 2006). New areas for exploration in ENSO teleconnections possibly yielding a potential increase in predictability of Mediterranean climate should include a better understanding of the role of the atmospheric forcing in generating dynamical responses in regions far from the tropical oceans. A clear example may be the TNA region and its role during ENSO events in modulating climate in the MA. An increase in our capacity to highlight regional couplings between distant oceans by means of new diagnostic tools may enhance our understanding and help to better simulate teleconnection responses. Increasing the horizontal resolution to obtain more reliable responses may also account for some of the discrepancies occurring between observed and simulated results. Preliminary exploration of such regions and couplings by means of an intermediate-complexity model has proven useful in generating far distance responses in the MA to tropical forcings. The use of full complexity AGCMs and a dynamical ocean in a transitorily interacting environment may strongly help in such a search.

References

Chen D, Cane MA, Kaplan A, Zebiak SE, Huang D (2004) Predictability of El Niño over the past 148 years. *Nat*, 733-736.

Joseph, R and S Nigam (2006) ENSO evolution and teleconnections in IPCC's 20th climate simulations: Realistic representation. *J. Climate*, in press.

Lau, NC and MJ Nath (1996) The role of the "Atmospheric bridge" in linking tropical Pacific ENSO events to extratropical SST anomalies. *J. Clim*. **9** (9): 2036-2057.

Lau, NC and MJ Nath (2001) Impact of ENSO on SST Variability in the North Pacific and North Atlantic: Seasonal Dependence and Role of Extratropical Sea–Air Coupling. *J. Clim*, **14**:2846-2866

Mariotti A, Zeng N, Lau KM (2002) Euro-Mediterranean rainfall and ENSO – a seasonally varying relationship. *Geophysical Research Letters*, **29**, 10.1029/2001GL014248.

Mariotti A, Ballabrera-Poy J, Zeng N (2005) Tropical influence on Euro-Asian autumn rainfall variability. *Clim Dyn*, **24**, 511-521.

Nigam, S. (2003) Teleconnections. Encyclopedia of Atmospheric Sciences; Editors: J.R. Holton, J.A. Pyle & J.A. Curry; Academic Press, Elsevier Science, London, 2243-2269

Oldenborgh GJ, G Burgers, AK Tank (1999) On the El Niño teleconnection to Spring precipitation in Europe, available at http://www.knmi.nl/~oldenbor/publ/oldenbor03.html

Opsteegh, JD, RJ Haarsma, FM Selten and A Kattenberg (1998). ECBilt, a dynamic alternative to mixed boundary conditions in ocean models. *Tellus*, **50A**, 348-367.

Rodó X (2001) Reversal of three global atmospheric fields linking changes in SST anomalies in the Pacific, Atlantic and Indian oceans at tropical latitudes and midlatitudes. *Clim Dyn*, **18**:203-217.

Rodo X, E Baert and F Comin (1997) Variations in seasonal rainfall in Southern Europe during the present century: relationships with the NAO and the ENSO. *Clim Dyn*, **13**: 275-284.

Rodó, X and MA Rodríguez-Arias (2006) A new method to detect transitory signatures and local time/space variability structures in the climate system: the Scale-Dependent Correlation (SDC) analysis. *Clim Dyn*, in press.

Rodríguez-Fonseca B, Polo I, Serrano E, Castro M (2006) Evaluation of the North Atlantic SST forcing on the European and Northern African Winter Climate. *Int J Clim*, **26**, 179-191

Ropelewski CF and MS Halpert (1987) Global and regional patterns associated with the ENSO. *Mon Wea Rev*, **115**:1606-1626.

Trenberth KE, GW Branstator, D Karoly, A Kumar, NC Lau, C Ropelewski (1998) Progress during TOGA in understanding and modeling global teleconnections associated with tropical sea surface temperatures. *J Geophys Res – Oceans*, **103**(C7): 14291-14324

Wu, R, and BP Kirtman (2004). Impacts of the Indian Ocean on the Indian summer monsoon-ENSO relationship. *J. Climate*, **17**, 3037-3054.

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