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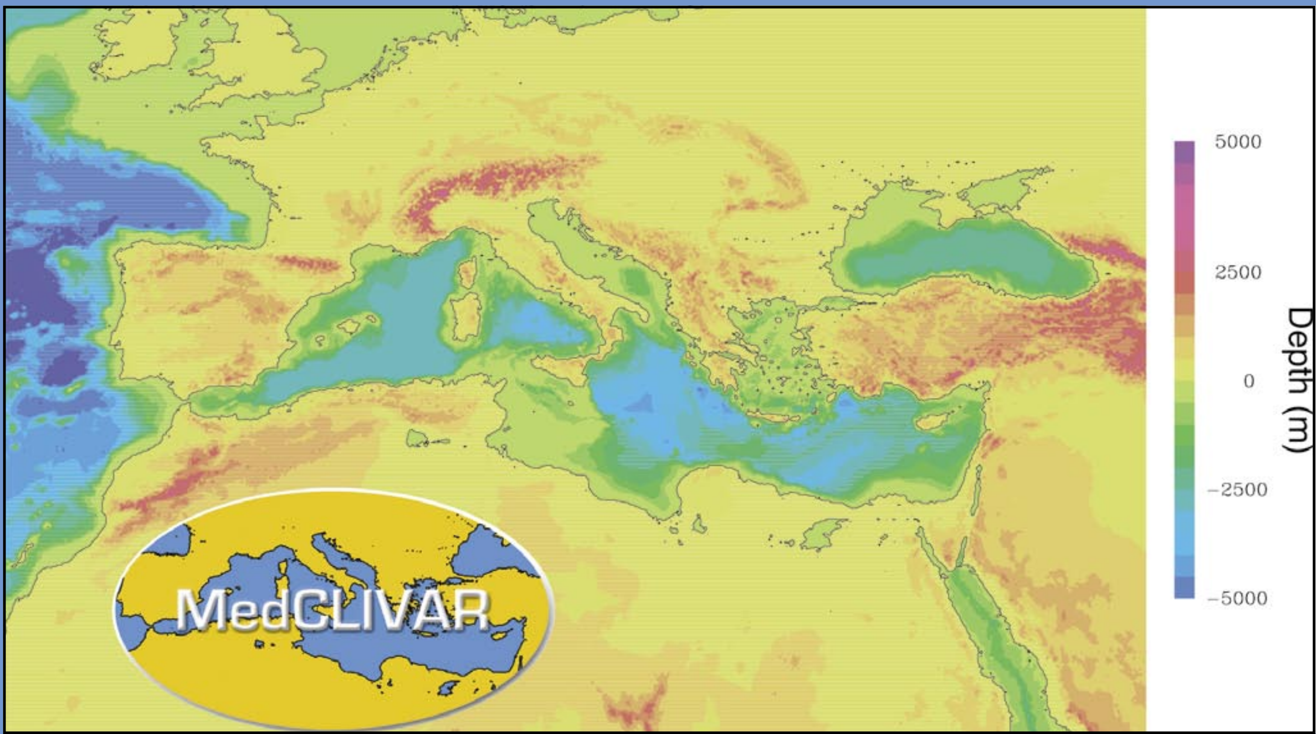
MedCLIVAR



CLIVAR is an international research programme dealing with climate variability and predictability on time-scales from months to centuries.

CLIVAR is a component of the World Climate Research Programme (WCRP). WCRP is sponsored by the World Meteorological Organization, the International Council for Science and the Intergovernmental Oceanographic Commission of UNESCO.

CLIVAR has a new website, with a new look and feel. It can be seen at the same location (http://www.clivar.org)

Please send any comments you have on the new website to ICPO (icpo@noc.soton.ac.uk). We would particularly welcome any feedback related to the way the website is loaded by different platforms and operational systems.

Call for Contributions

We would like to invite the CLIVAR community to submit CLIVAR related papers to CLIVAR Exchanges for the next issue. The deadline for submission is **21st May 2006**

Guidelines for the submission of papers for CLIVAR Exchanges can be found under: http//www.clivar.org/publications/exchanges/guidel.php

Editorial

As you will see, this edition of Exchanges is devoted to aspects of Mediterranean climate variability, study of which will be much enhanced by the status of MedCLIVAR as an ESF Research Networking Programme, as outlined in Roberta Boscolo's editorial below and in the paper by Piero Lionello et al. opposite. Progress with CLIVAR overall was reviewed earlier this month when the Joint Scientific Committee (JSC) for WCRP met in Pune, India from 6-11 March. The CLIVAR presentation, given by Tim Palmer (CLIVAR SSG co-chair) and well received by the JSC, reviewed CLIVAR's role within the framework of the WCRP's Strategic Framework for 2005-2015, its contributions to the JSC cross-cutting topics of monsoons, anthropogenic climate change and extreme events and highlights of progress with CLIVAR more generally. In response to a request from the JSC, a set of metrics against which to assess progress with CLIVAR were developed and presented by the SSG co-chairs. These will be discussed further when the CLIVAR SSG meets in Buenos Aires in April.

Part of the JSC meeting was devoted to a joint session with the Scienctific Steering Committee for the International Geosphere Biosphere Programme (IGBP). Key CLIVAR links to IGBP are with Past Global Changes (PAGES) through the CLIVAR/PAGES Intersection (see the last edition of Exchanges, No 36), IGBP IMBER (Integrated Marine Biogeochemistry and Ecosystem Research) and GLOBEC needs for information on climate variability. The JSC session with IGBP included review of the projects carried out under the Earth System Science Partnership (ESSP - www.essp.org). The partnership, a joint initiative of the 4 global change programmes DIVERSITAS, IGBP, IHDP and WCRP, is organising a major Global Environmental Change Open Science Conference in Beijing, China later this year (9-12 November 2006). CLIVAR will be present at this major conference, further details of which can be found at www.essp.org/ESSP2006/.

As noted above, the CLIVAR SSG meets in April. The primary focus of the meeting will be an assessment of progress in and further development of the major CLIVAR theme areas of (i) ENSO and other models of tropical variability, (ii) monsoons, (iii) decadal variability and the thermohaline circulation and (iv) anthropogenic climate change with emphasis on CLIVAR's key mission in understanding the role of the oceans in climate. Other topics will include consideration of the roadmap for CLIVAR and associated metrics, data management and information and outreach issues. We will report on outcomes in the next edition of Exchanges.

Howard Cattle

MedCLIVAR Editorial

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This issue of CLIVAR Exchanges celebrates the achievements MedCLIVAR has made over the last few years. I have been involved in developing the MedCLIVAR concept since its very beginning when, in 2001, I started discussing this idea with John Gould (former ICPO director), and Harry Bryden (Professor at NOCS, UK). However, MedCLIVAR would have been only a word if this idea didn't also meet the enthusiasm of Paola Malanotte-Rizzoli (Professor at MIT, USA) and Piero Lionello (Professor at the University of Lecce, Italy). We began proposing MedCLIVAR to the scientific community through the special session on "Mediterranean Climate Variability" which has been part of the EGS/EGU annual assembly programme since 2003. In the same year we started to produce a white paper on state-of-the-art of the research on Mediterranean Climate Variability and Predictability and future challenges with the help of several scientists actively involved in different aspects of the study of the Mediterranean Climate. The white paper was discussed at an ESF/LESC funded workshop held in Rome in May 2004 and successively presented to the CLIVAR SSG in June 2004. MedCLIVAR has been a CLIVAR endorsed project since January 2005.

Currently, a book entitled "Mediterranean Climate Variability", Eds: P. Lionello, P. Malanotte-Rizzoli and R. Boscolo, and published by Elsevier, will be available in April 2006. The book builds on the material presented in the white paper and has the same contributing authors; several of them also feature in this Newsletter issue.

In August 2005 MedCLIVAR also received the approval of the ESF-LESC Committee to become an ESF Research Networking Programme. The ESF MedCLIVAR programme has already received the support of several European Institutions and will be officially launched as a 5-year programme in summer 2006 with a budget of about 1M euros.

Among the activities that MedCLIVAR has planned through the ESF programme are:

1) Annual workshops; the first one will be held in Seville, Spain in fall 2006 with the topic on reconstruction of past Mediterranean climate. Further workshops will cover topics such as the connections between Mediterranean and global climate variability, Mediterranean Sea circulation and sea level trends, possible feedbacks of the Mediterranean dynamics in the global climate system and Mediterranean climate predictability

2) Two summer schools on "trends and the occurrence of extreme events" and "teleconnections and climate change at the regional scale"

3) Young scientists' exchange programme; about 8 grants per year will be assigned to young scientists to spend a period of several months in a host institution.

Being the project coordinator of MedCLIVAR, I will keep the CLIVAR community informed on activities and progress; meanwhile you can also visit the MedCLIVAR webpage for up-to-date information: http://clima.casaccia.enea.it/medclivar/

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's 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 was proposed during the ESF-LESC Exploratory Workshop on "Mediterranean Climate Variability and Predictability" held in Rome, 17-19 May 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 the MedCLIVAR ESF program so that its official launch can be expected in spring 2006.

2. The Mediterranean climate

The Mediterranean region 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 teleconnection 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 the 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 and the distinct basins, gulfs, islands and peninsulas of various sizes, produce much sharper climatic features than might be expected without their existence and determine many sub-regional and mesoscale structures in both the circulation of the atmosphere over the region and the sea. 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 respectively the circulationof the atmosphere and sea, are important consequences. One thermohaline 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 other 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) 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 a 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 is evidence 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 through 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 of feedback mechanisms, eventually active both at decadal and millennial time scales, involving the

North Atlantic, the Mediterranean and the overlying atmosphere, and which have potentially important climatic implications.

3 Climate trends and future scenarios

The large amount of long instrumental time series, documentary proxy evidence and natural proxies allow the reconstruction of highly resolved spatio-temporal Mediterranean temperature and precipitation fields covering the last few centuries. These may be compared with model simulation runs and used for 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 time 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.

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 in the Mediterranean Sea circulation and sea level have been observed in the last decades. Sea level followed the mean estimated global increase (1.8mm/year) till the 1960s, 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 a major change between 1987 and 1990, called the EMT (Eastern Mediterranean Transient), when the Aegean Sea temporarily replaced the Adriatic Sea as the source of the eastern Mediterranean bottom water.

Analysis of the climate change signal at the 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. However most global models do not resolve adequately the topography of the 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 in predicting for the Mediterranean region a temperature increase larger than the global average and a large precipitation decrease in summer. Predicted changes are more controversial in winter, as they 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 simulations of the Mediterranean sea circulation suggest temperature and salinity increases and an overall stronger stratification corresponding to a weaker and shallower thermohaline circulation.

4. Vulnerability to climate change

Water availability are 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. 2006a). 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 in 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 30,000 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 in weather extremes in the future climate.

5. MedCLIVAR Activities

The tasks promoted by MedCLIVAR include collection, quality control and analysis of observations plus proxy data (documentary and natural), development and application of models for describing and understanding the physical processes responsible for 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 are 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 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 and 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 except Lionello et al (2006c) 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. and 16 co-authors. (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*. **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.

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 (0.5° latitude by 0.5° longitude) dataset of monthly precipitation (New et al. 1999) derived from a worldwide network of observations, particularly dense over Europe. A storm detection and tracking scheme has been run on 6-hourly geopotential height at 1000 hPa, available from the European Centre for Medium-Range Weather Forecasts 40-year reanalyses (ERA 40) on a 1.125° x 1.125° grid (Trigo 2005). The data cover a wide area (30°N to 80°N and 60°W to 70°E), 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, page 6), 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 of Iberia (Serrano et al. 1999). It is worth noticing that most of eastern and northern stations of Iberia, however, do not show significant trends.

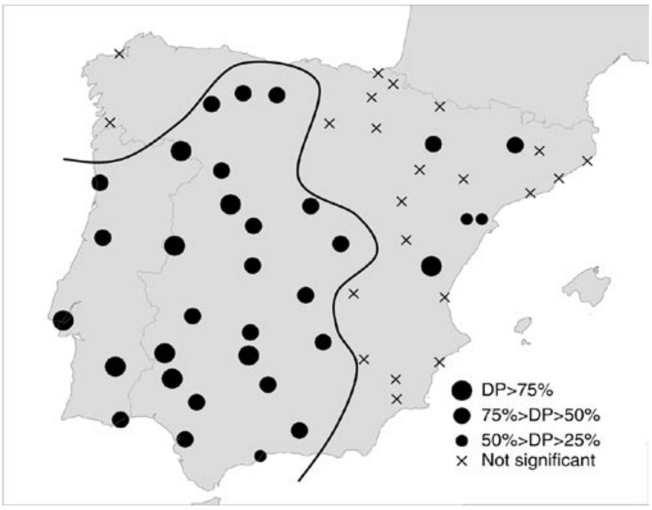

Figure 1. Decreasing Precipitation (DP) trends in March for the period 1941-1997. The different sizes of black dots depict the relative change in precipitation for the complete period after fitting March time series to a linear model. "Crosses" correspond to non-significant or positive trends, while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

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

The detection and tracking of North Atlantic cyclones applied here is based on the algorithm first developed for the Mediterranean region by Trigo 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 15). 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 15. 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),

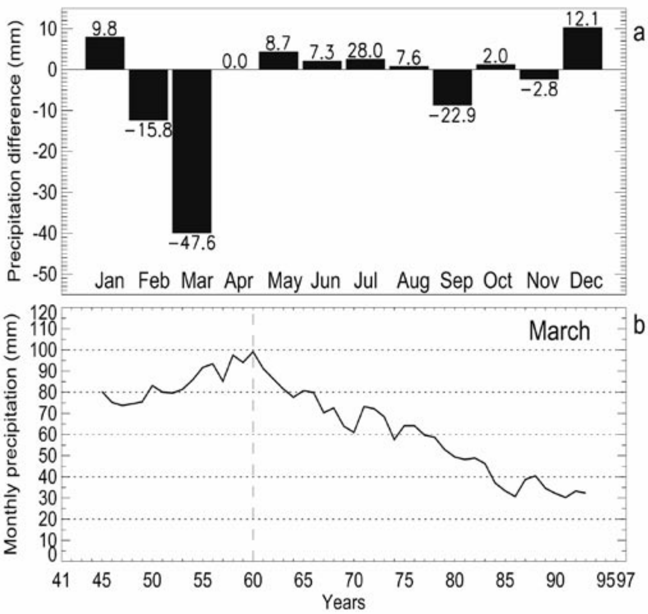

Figure 2. a) Absolute precip. change (mm) between the 1941-1970 and the 1971-1997 normal periods. The corresponding relative change (%) is also indicated over (or below) each column. b) 9-year moving average of spatially averaged precipitation in March. The vertical dashed line indicates the approximate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

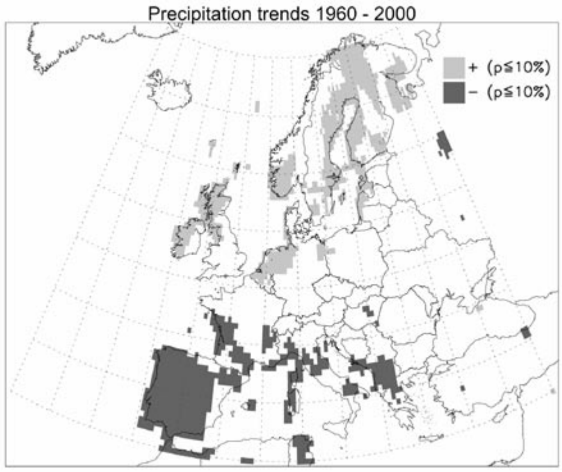

Figure 3. Significance (%) of precipitation trends in March over Europe for the period 1960-2000, computed from the CRU monthly precipitation dataset. The trends are assessed using the Mann-Kendall test; only values significant at less than 10% are shown. Dark (light) grey cells correspond to negative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

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 the 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).

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*, **7**, 101-113.

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 20th century are in the range of 1.1-1.3 mm/yr. This is at the low end of the 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, 2001; Tsimplis et al., 2005) as well as temperature (T) reduction and salinity (S) changes linked to the North Atlantic Oscillation (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 16) 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 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 of the 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 16). 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 of oceanic circulation and sea level variability. Continuing efforts have resolved and partly explained 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 initiative 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.

Miller L., B.C. Douglas.: Mass and volume contributions to twentieth-century global sea level rise. *Nature* **428** (6981): 406-409

Papadopoulos, A., S. Mertikas, M.N. Tsimplis (2006). Changes in extreme sea levels and the seasonal sea level cycle in the Southern Aegean Sea. *Int. J. Clim* (in press)

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., 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*, **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 surges 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 the mechanisms responsible for generation and evolution of cyclones, to understand their effects on the environment, and to describe their variability in relation to 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. The 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 over the Adriatic and Ionian Seas, the Cyprus area, the Aegean Sea, the Black Sea, the southern side of the Atlas mountains and 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 and 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 the 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 to 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. The different characteristics

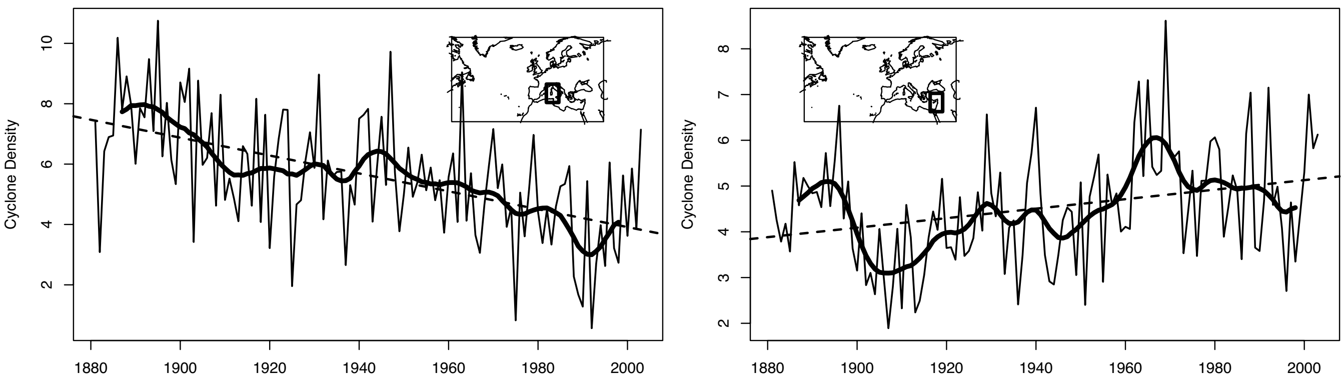

Figure 1. Time series of average cyclone density (in units of percentage of systems/25 degree latitude squared) in winter (DJF) at boxes including nine grid points in the western Mediterranean centred at 10°W 40°N (western Mediterranean, left panel) and in the eastern Mediterranean centred at 35°W 35°N (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).

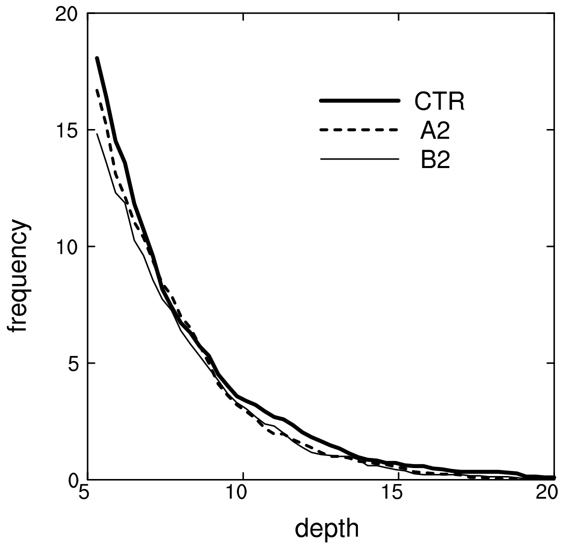

Figure 3. frequency (number of cyclones per month, y-axis) exceeding a given threshold (hPa, x-axis) in January for the CTR, A2 and B2 simulations. The counting include cyclones with duration longer than half day and is restricted to the area shown in the figure 4, page 17.

of the western and eastern Mediterranean and high interdecadal variability are presumably the source of some disagreement. In fact, other studies suggest no actually significant trend (J.G.Pinto, pers.comm), an increase

of weak cyclones in the western Mediterranean in the period 1978-1994 (Trigo et al 2000), a positive trend in the eastern Mediterranean, though not in the rainy season (Maheras et al., 2001).

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 16) 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 a 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 (Lionello et al 2002). The present climate is characterized by a slight, but statistically significant, higher overall number of cyclones than the future A2 and B2 scenario. 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 conditions have been extracted from the HadAMH model results at the Hadley Center with a 1.25x1.875 lat-long resolution. The analysis (Lionello and Boldrin, 2006) is applied to the band pass filtered SLP fields (Sea Level Pressure; 1 day and 7 days lower and upper cut off periods, respectively). The results confirm 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 17) shows the difference of the SLP, standard deviation between CTR and scenario simulations. It shows only small changes over large part of the Mediterranean are, with a significant increase only in the upper left corner and a decrease in the lower left corner.

However a decrease in the number of cyclones appears to be the dominant signal in other 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, Lionello et al, 2002). 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

Alpert P., Ben-Gai T., Baharad A., Benjamini Y., Yekutieli D., Colacino, M., Diodato L., Ramis C., Homar V., Romero R., Michaelides S. and Manes, 2003: The paradoxical increase of Mediterranean extreme daily rainfall in spite of decrease in total values". *Geophys. Res. Lett*., **29**, 11, 31-1 - 31-4.

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 CO_2 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*, **14**, 823-838

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 the 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 in summer (JJA) in the 850hPa temperature trends 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. A 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). Results show that for the A2 scenario, the changes over the Eastern Mediterranean are about 3-5°C, while for the B2 scenario the differences are only about 2.5-3.5°C.

It is interesting to note that the surface heating trend 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, Balkans) 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.

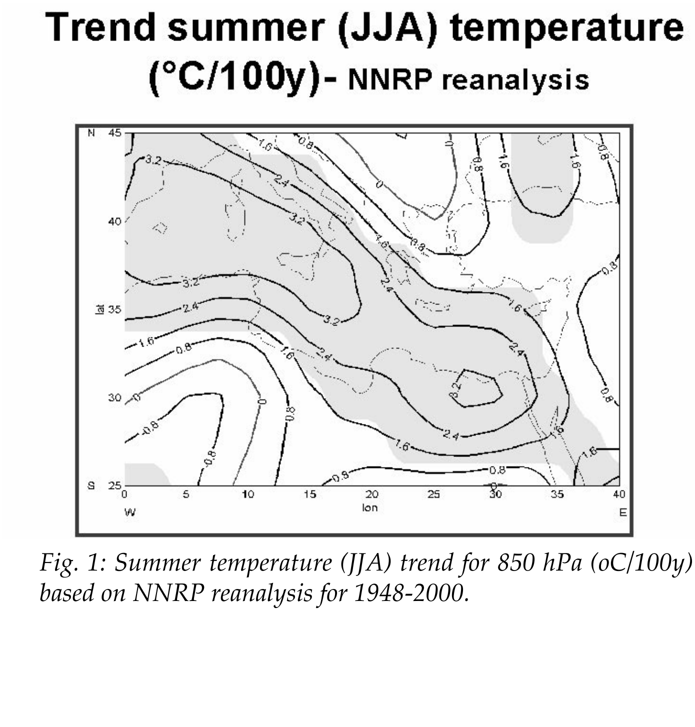

Fig. 1: Summer temperature (JJA) trend for 850 hPa (oC/100y) based on NNRP reanalysis for 1948-2000.

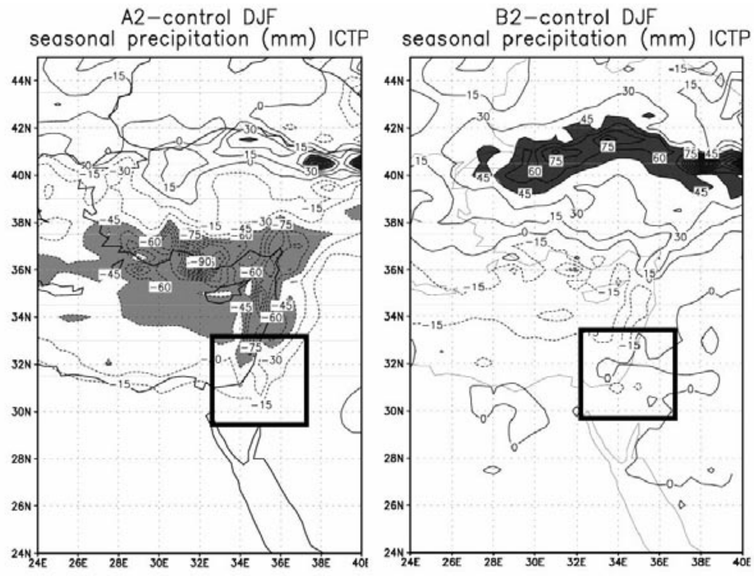

Fig. 2: Average seasonal (DJF) precipitation change (mm) from ICTP. On the left, A2 vs. control, and on the right B2 vs. control. Inside the square – the region of the Eastern Mediterranean

3. Observed and projected rainfall changes:

The precipitation trends over nearly the whole Mediterranean were 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 scenariooutput. 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 Eastern Mediterreanen the scenarios A2 and B2 show very different results, i.e. A2 shows significant 10-30% overall reduction, while B2 shows mixed trends. The results indicate a high sensitivity of the Eastern Mediterranean climate to the changes in the global emission scenarios.

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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. Kjellstrom, 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, 2004a: 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, 2004b: 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.*, **30**, 18, 1946, doi:10.1029/2003GL017742.

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., Mann et al., 2000; 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 (e.g. Schär and Jendritzky, 2004) which was much larger in amplitude compared to usual extremes at hemispheric scales.

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 Exchanges contribution is a short summary of the review of Luterbacher et al. (2006) who describe and discuss the regional coverage and the possibilities/limitations of these proxies (Figure 1, opposite) and present 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 of the importance of documentary and natural proxies for Mediterranean precipitation and temperature reconstructions for boreal winter and summer. It turns 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) 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 indicate 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

From Luterbacher et al (opposite): Mediterranean past climate variability

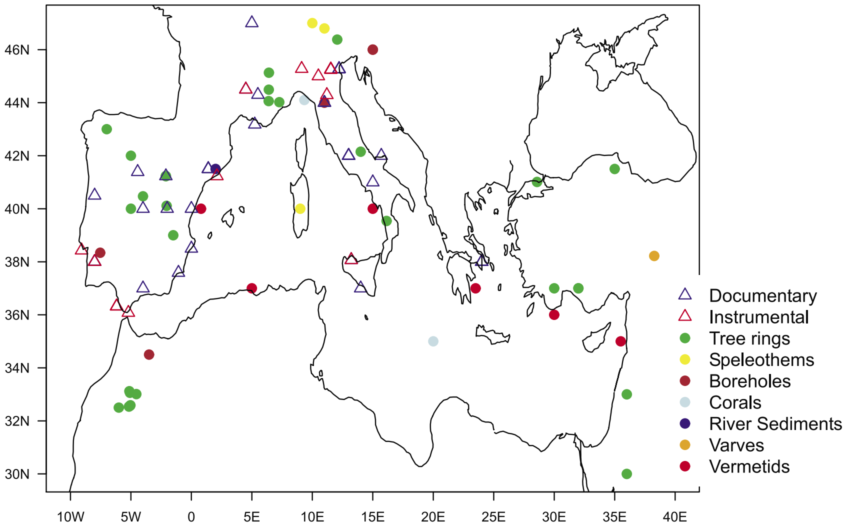

Figure 1: Compilation of long homogenized early-instrumental data, documentary proxy evidence and of ''high temporal resolved'' natural proxies from the larger Mediterranean area covering the last few centuries. Note, that the length of the different proxies varies and that the proxies may record climate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

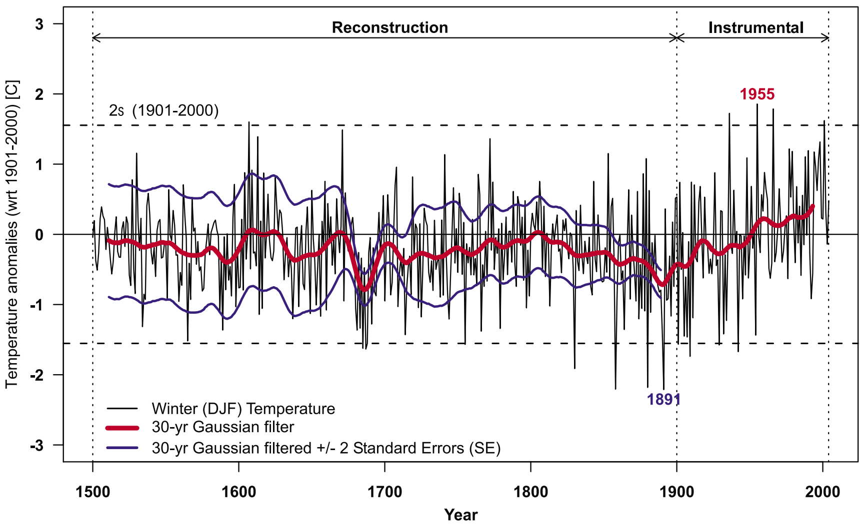

Figure 2: Winter (DJF) averaged-mean Mediterranean temperature anomalies (with respect to 1901 to 2000) from 1500 to 2005, defined as the average over the land area 10°W to 40°E and 35°N to 47°N (thin black line). The values for the period 1500 to 1900 are reconstructions, data from 1901 to 2005 are derived from Mitchell and Jones (2005) and Hansen et al. (2001), respectively. The thick red line is a 30-year smoothings. 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?

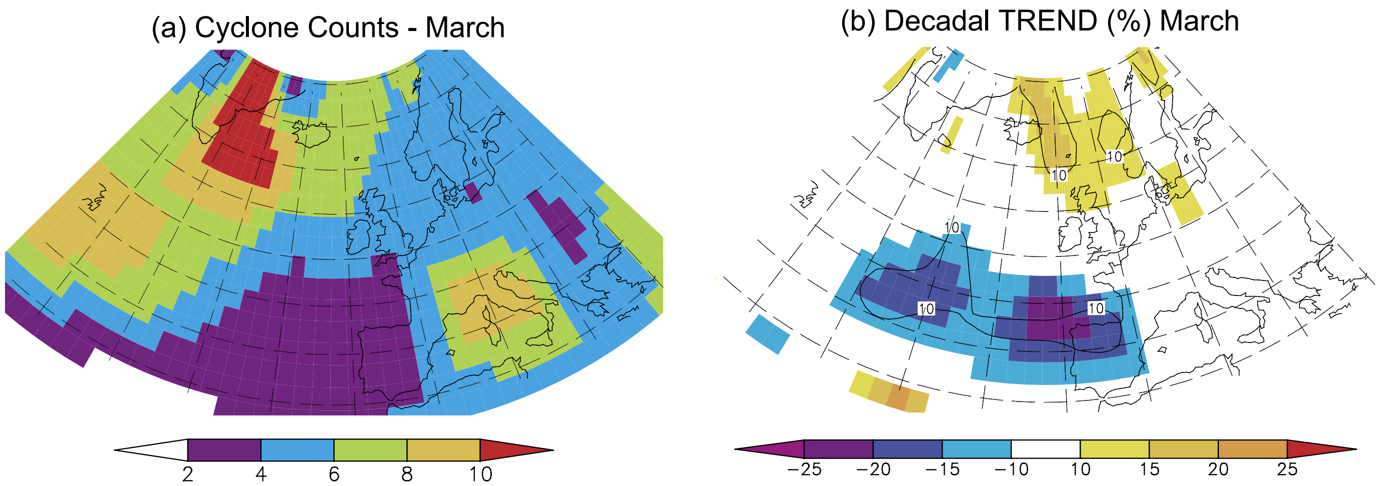

Figure 4. (a) March climatology of cyclone counts, and (b) decadal trends (% relative to the mean over the study period) of the average number of cyclones detected in March. The solid line indicates the grid cells with significant trends at least at the 10% level. Both graphics were computed on cell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

From Tsimplis et al page 8: 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.

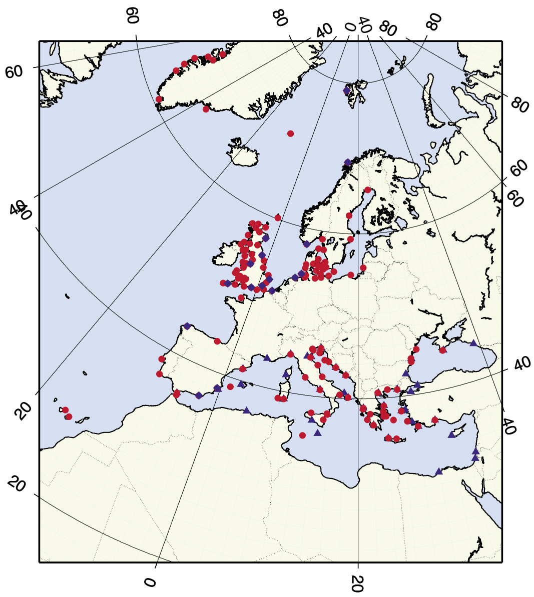

Fig.2 The European Sea Level Service Network. Red dots are tide gauges. Blue diamonds are tide gauges with co-located CGPS.Blue triangles are designated MedGLOSS sites which are available to ESEAS through coordination with MedGLOSS. The North African coasts do not have a sufficient network. Plans to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

From Lionello et al, page 10: Climatology of cyclones in the Mediterranena: present trends and future scenarios

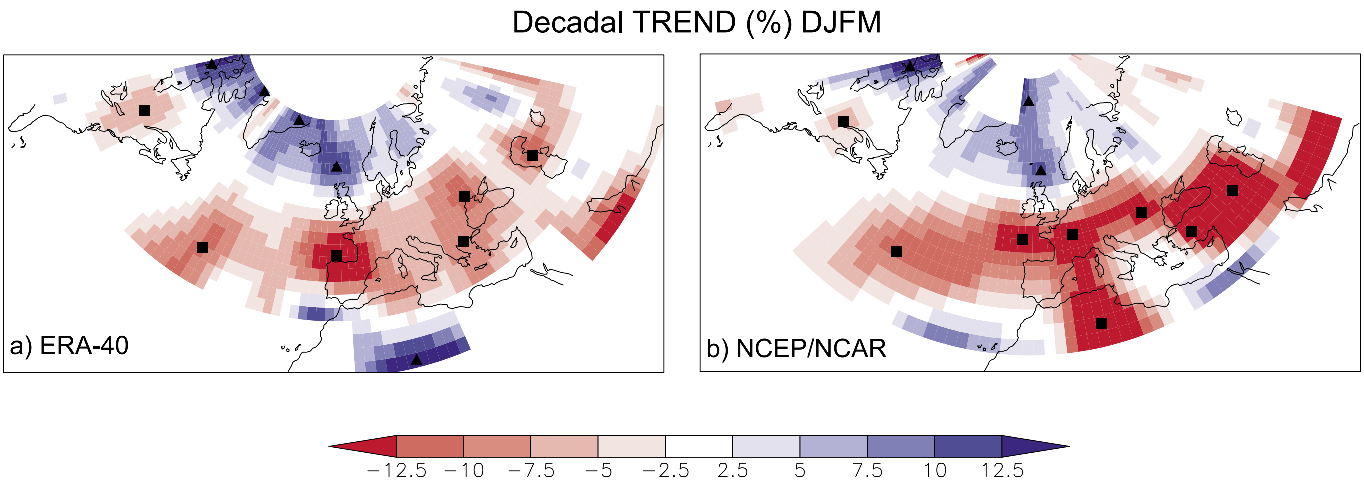

Figure 2. Decadal relative changes in DJFM cyclone numbers, aggregated within 9ox9o, and 10ox10o grid boxes, for (a) ERA-40, and (b) NCEP/NCAR data, respectively. The blue (red) shades encircle areas with increasing (decreasing) storm numbers, during the 1959-2000 period. Shades with significant trends, 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 10: Climatology of cyclones in the Mediterranena: present trends and future scenarios

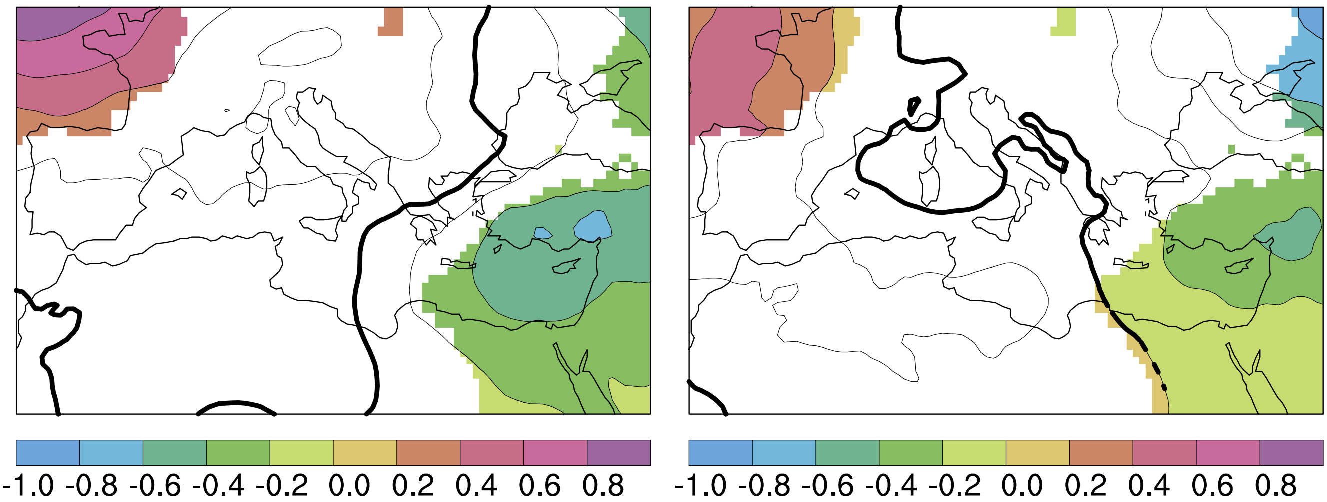

Figure 4. Standard deviation (hPa) of the band pass filtered SLP fields. The right panel shows the difference between A2 and CTR, the left panel between B2 and CTR. Contour lines every 0.2 hPa. In the colour filled areas the difference is statistically significant at the 90% confidence level (according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

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From Theocharis et al page 20: Dense water formation in the Mediterranean Sea

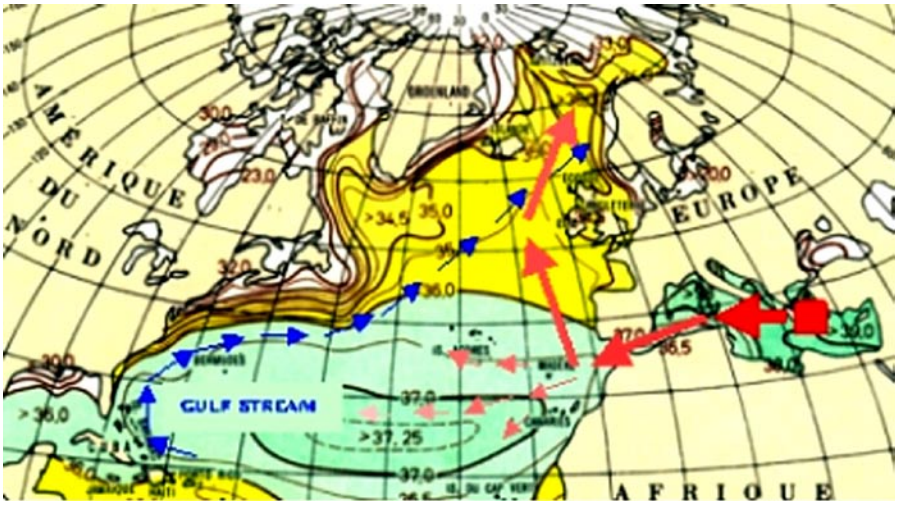

Figure 4. The salty Mediterranean Water in the Atlantic Ocean

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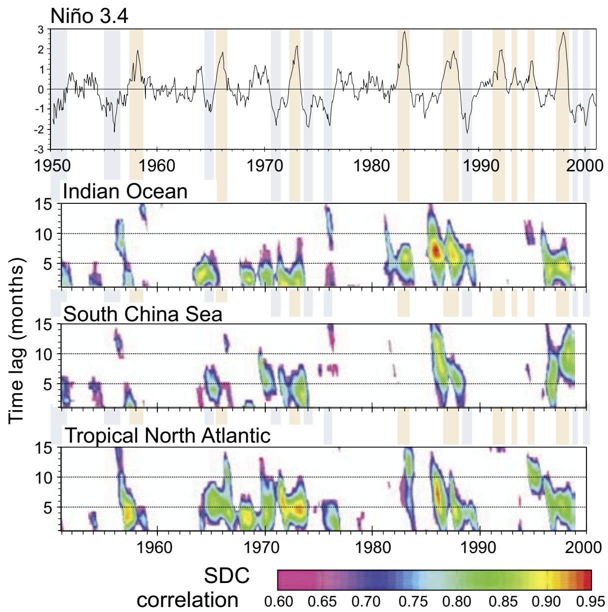
From Rodo et al, page 26: The role of ENSO in fostering teleconnection p atterns between the tropical north Atlantic and the western Mediterranean Basin

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 26: The role of ENSO in fostering teleconnection p atterns between the tropical north Atlantic and the western Mediterranean Basin

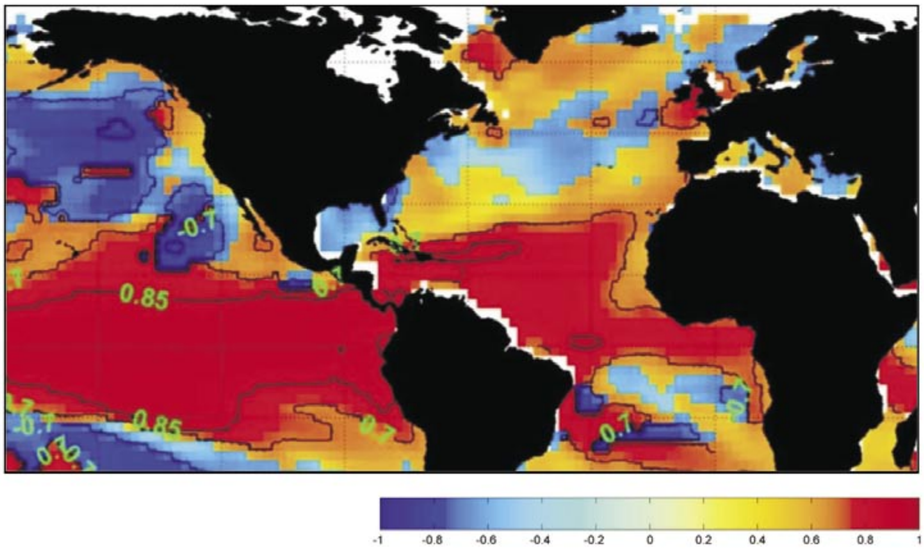


Fig. 2. Short-term correlation maxima between SST time-series and the Niño3.4 index during El Niño 1987 episode (Rodó et al., unpublished results)

From CLIVAR Announcement of new dataset, HadCRUT3, page 31

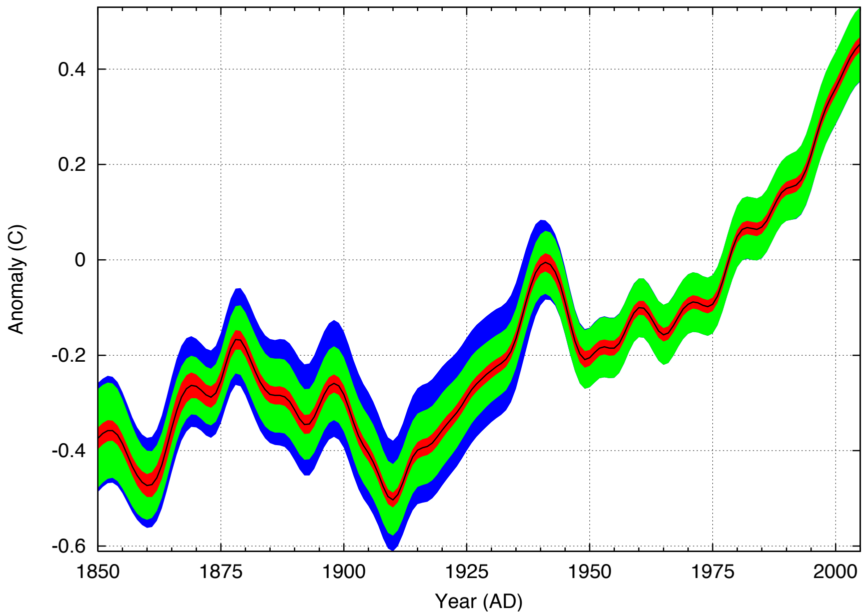


Figure 1. Global annual blended land surface air temperature and sea surface temperature anomalies from HadCRUT3, smoothed with a 21-point binomial filter. The solid black line is the best estimate value. The red band gives the 95% uncertainty range caused by station, sampling and measurement errors, the green band adds the 95% error range due to limitations of observational coverage, and the blue band adds the 95% error range arising from uncertainties in removing biases.

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. Luterbacher et al (2006) identify a number of 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 having 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 ships 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 with 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.

Acknowledgements

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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., et al, 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.

Mann, M.E., Gille, E., Bradley, R.S., Hughes, M.K., Overpeck, J.T., Keimig, F.T., Gross, W. 2000: Global Temperature Patterns in Past Centuries: An interactive presentation, *Earth Interactions*, **4-4**, 1-29.

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.

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.

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.

On 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 Strait of 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 produced 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 page 22). There is one main source of intermediate water and there are 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

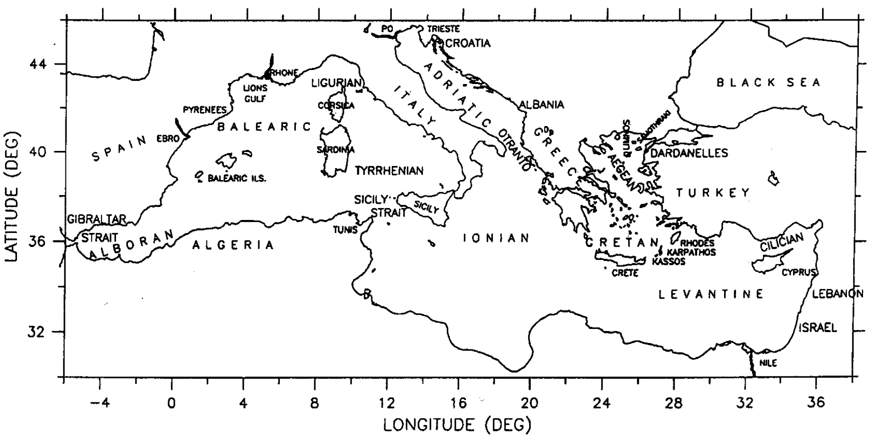

Figure 1. Map of the Mediterranean Sea

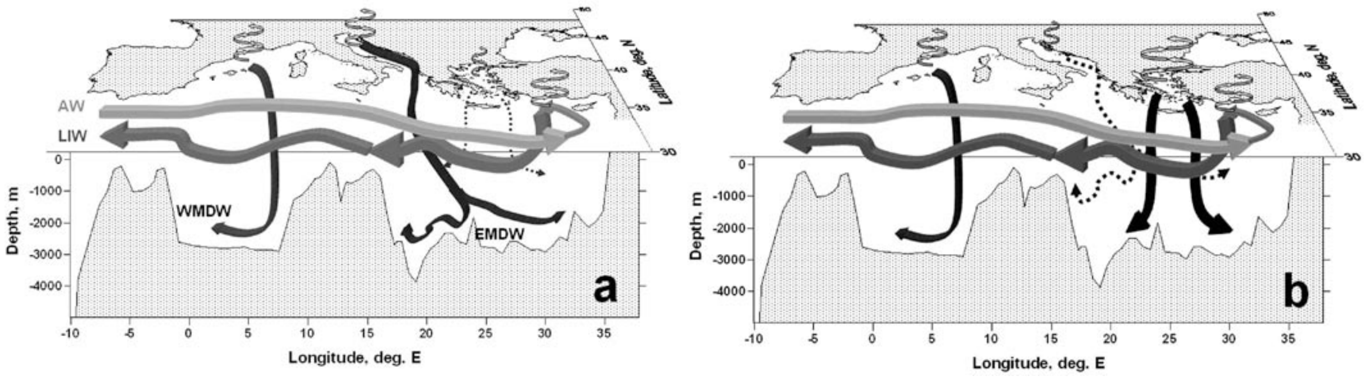

Figure 2. The thermohaline cells of the Mediterranean Sea before the EMT (a) and after the EMT (b) (From Tsimplis et al., 2006)

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 page 17). 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 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 Sicily and Gibraltar Straits. On average, the deep-water annual production rate reaches 0.3 Sv at each sub-basin, while the intermediate water production rate is 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 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 Sea. 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 altered the thermohaline circulation of the eastern Mediterranean (Fig. 2a, 2b) (Robinson et al., 2001; Roether et al., 1996) with consequences also for 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 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) was also investigated. These episodic changes have been superimposed onto the long-term trends observed in the Mediterranean (Boscolo and Bryden 2001). It is worth mentioning 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., 2006). 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.

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.

Miller, A., R., 1963. Physical Oceanography of the Mediterranean Sea: A Discourse. *Rapp. Comm. Int. Mer Medit.*, **17**(3), 857-871.

Nielsen, J. N., 1912. Hydrography of the Mediterranean and Adjacent Waters, in Report of the Danish Oceanographic Expedition 1908-1910 to the

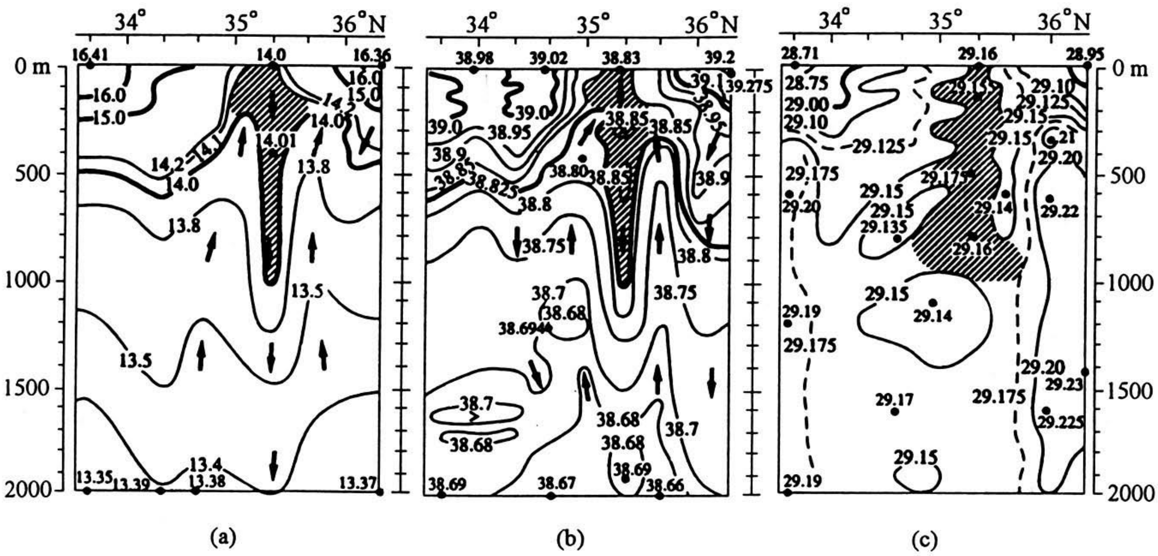

Figure 3. Potential temperature (a), salinity (b) and σθ (c) on the meridional section along 280 40' across the middle of the Rhodes cyclonic gyre (Febr. 1990) (From Gertman et al., 1994)

Mediterranean and Adjacent Waters, 1, 72-191.
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.
Zoccoloti,L. and E. Salusti, 1987. Observations of a vein of very dense marine water in the southern Adriatic Sea. *Cont. Shelf Res*., **7**, 535-551.

Modelling regional-scale climate change of the Mediterranean

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1. Regionally-oriented climate scenarios

Regional climate changes in a global warming context are the most important motivations for 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 by the end of the 21st century lie between 2 to 5°C. 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) over the Mediterranean for the end of the 21st century with the warming in summer 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 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 used three global climate scenarios provided by three institutions (IPSL, CNRM 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 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

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

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.

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 unrealistic 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 have revealed also a warmer and saltier trend for the Mediterranean deep water masses (Bethoux et al. 1990; Potter and Lozier 2004; Rixen et al. 2005), which is probably the manifestation of the ongoing anthropogenic global warming.

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.

3. Perspectives and Outlooks

By using a sequential and one-way approach, we have shown 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 the hydrological variables, such as run-off dynamically. Application of statistical methods will always

	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.

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 Mediterranean climate studies.

It is also necessary to emphasize the perspectives of a multi-model ensemble approach for future Mediterranean regional climate modelling activities. This is the only way to assess the uncertainties of numerical modelling for climate variation and probabilistic estimates for long term changes. 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.

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

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, including in the Mediterranean Area (MA) (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, as they did for the MA. Despite 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. A variable delay was found 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 17). 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 sea surface temperature anomalies (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 shedding light on the ENSO's role for potential predictability for the western MA also, 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 was originally thought, ENSO teleconnections are not confined to the winter season, autumn and spring stand as sensitive seasons as well. 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 to 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 they operate through different ocean basins, further complicates this picture. The difficulty in reproducing 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 atmosphere-ocean couplings to be addressed more clearly, 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 18 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 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.

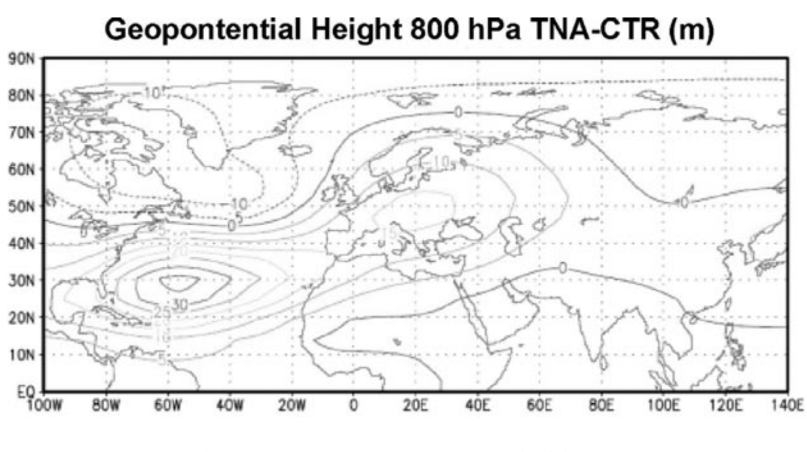

Fig. 3. GPHa at 800hPas response to a TNA prescribed forcing in EcBILT-Clio v. 3.0. Notice the change in location of the maxima in anomalies and the elongated band to cover the western MA (Rodó et al., unpublished results).

Modeling Mediterranean teleconnections

Several studies have 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 of surface heat fluxes in the TNA region might translate later on to 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 3°x3° horizontal resolution in the ocean with 20 unevenly spaced vertical levels, but still provides a realistic 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 twice that observed) 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. At equilibrium a northeastwards extension of the response relative to the position of the SST anomaly is evident, with the elongation of the resulting GPH anomaly found to cover most of the western MA and with a secondary maximum 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 and timing and constraining location. This is particularly difficult when reproducing ENSO response at midlatitudes; for instance the amplitude ridge over the MA is not captured in most IPCC 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.

Obituary: Sergey Sergeyevich Lappo

Sergey Sergeyevich Lappo died on 5 January 2006. He was 67. Since 1995 he was Director of the P.P. Shirshov Institute of Oceanology of Russian Academy of Sciences in Moscow and Oceanography Professor at Moscow State University, Russia. Before he was Director of the State Oceanographic Institution of the Russian (until 1991 Soviet) Hydrometeorological Service. At that time he joined the international community that drew up and participated in the World Ocean Circulation Experiment WOCE. In those late Soviet times, with his enthusiasm for and vision of the role of the ocean in the climate system and his premonition of political changes yet to happen, he sent many of his "young people" into WOCE working groups, primarily to learn about how western scientists worked, argued and persevered. In the 1990s Sergey Sergeyevich was vice-president of SCOR and member of the JSC for WCRP. He enthusiastically promoted the ocean´s role in the climate system in many programmes developed under the umbrella of the WCRP, in CLIVAR in particular.

To acknowledge his contribution to global oceanography we have translated an article he published in Russian in 1984 arguing what since has been established as the global thermohaline circulation and the causes of its variability.

Sergey Gulev and Peter Koltermann

On the origins of the northward cross–equatorial heat advectiuon in the Atlantic Ocean

Sergey S. Lappo

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Meridional heat transport in the ocean is one of the key-mechanisms for the re-distribution of heat resulting from solar energy in the climate system and from climate variability. There were several authors, who estimated the meridional heat transport in the North Atlantic. The recent review of Koprov [2] reports that starting from the first computation of Budyko in 1956 to the values reported by computations of the early 1980s, the estimate of the heat advection to the North in the Atlantic increased by 5 times. In 1980 Hastenrath [6] published the results of the computation of meridional heat transports at different latitudes in the Atlantic, Indian and Pacific Oceans. A remarkable feature of his picture of the global heat advection is the primarily southward direction of the advection in the Pacific and Indian Oceans and the northward advection of heat in the Atlantic.

This is in agreement with the global distribution of the surface temperature anomalies in different oceans computed with respect to the global ocean zonal means. Thus, north of 40°N in the Atlantic such an anomaly is remarkably positive, being about 9°C at the latitudes of the United Kingdom and Greenland. Moreover, similar estimates for the air temperature anomalies at these latitudes give positive values of about 20°C. Ugriumov[1] in his recent study noted that the averaged tropospheric temperature over the Atlantic north of 20°N is significantly higher than over the Pacific at the same latitudes.

Mintz [7], using the results of Budyko[1] and Oort[1] and Von der Haar[1], gives the quantitative estimate of the components of the heat balance in the northern part of the Atlantic, including the Norwegian and Greenland Seas. His estimate of the sources is 25×10^{21} J/year (0.78 PW – SG&PK). The sinks of heat from the North Atlantic estimated by Mintz [7] altogether give about 29×10^{21} J/year (0.93 PW – SG&PK). Thus, the heat loss is approximately 4×10^{21} J/year higher than the heat gain in the Atlantic and it is unclear where the deficit of heat is compensated from and by which mechanisms. This estimate of the heat deficit in the North Atlantic would become even higher, if we account for the additional long-wave emission from the North Atlantic surface due to its anomalously higher temperature, that was not accounted for by Mintz. Assuming that on average a 5°C anomaly (with respect to the zonal mean) is observed over the area of 6×10^6 km^2, we will obtain an additional emission of about 8×10^{21} J/year. Thus, the actual imbalance is about 12×10^{21} J/year (0.38 PW). In other words, the anomality of the North Atlantic is definitely a global climate feature and its origins should lie in the global processes.

We think, that the anomalous temperature characteristics of the North Atlantic are associated with the global ocean circulation between the Atlantic and the Pacific. This circulation can be tentatively described as consisting of two layers. In the lower limb, the dense waters of the Atlantic move southward to Antarctica and then, joining the cold Antarctic waters, flow northward in the Pacific. Alternatively, the warm-sphere surface waters of the North Pacific move to the southwest to the Indian Ocean, and, rounding Africa with the Agulhas Current come to the Atlantic, providing further heat transport to the North. Such a scheme of the global inter-ocean circulation agrees with the comparison of the mean property characteristics of the Atlantic and Pacific Oceans given in Table 1 (page 30). Thus, the SiO_2 concentrations increase from the Atlantic

[1]***Comment:*** *At that time there were limitations of the number of references per article page in Soviet research publications. This is why Sergey Lappo sometimes does not give the correct or full citation, but just mentions the name of the author (this was the known trick of the Soviet authors).*

Photo: Sergey Lappo in his office on 23 December 2005 gives an interview to the First Channel of National TV.

(30 μmol/l) to the Indian Ocean (60 μmol/l) and further to the Pacific Ocean (90 μmol/l). The concentrations of PO_4 demonstrate a similar tendency with the domain-averaged values of 1.8, 2.2 and 2.5 μmol/l respectively in the Atlantic, Indian and Pacific Oceans. The oxygen concentrations alternatively decrease from the Atlantic to Pacific from 0.47 to 0.33 μmol/l. Finally, the age of the deep waters increases from the Atlantic to Pacific. This was also pointed out by Bruevich [4, p.335], "The World Ocean demonstrates a very interesting peculiarity: the concentrations of the biogenic elements grow from the smallest values in the North Atlantic to Antarctica and further from the South Pacific to its northern part near the Aleutian islands". This is also in agreement with Stepanov's [3] chart of the propagation of the deep waters in the global ocean.

The surface dynamical topography according to Burkov [1, p. 77] reveals about 100 cm higher sea levels in the North Pacific mid latitudes in comparison with the North Atlantic. In the southern parts of both oceans, the dynamical topography heights are approximately equal. Comparisons of the domain-averaged densities reveal differences in the sea level between the Pacific and Atlantic of about 80 cm. It is very natural to expect the slow upper layer flow in the direction of the sea level slope. For a very rough estimate of the velocities we can employ the hypothesis about a stabilized 2-layer density circulation. According to the theory, the surface velocity is approximately 1.5 times higher than the maximum velocity in the deep layer. Given the estimate of the maximum deep layer velocity of 0.8 cm/s [3], we obtain 1.2 cm/s for the upper layer flow. Now, we can try to estimate the additional cross-equatorial advection of heat by this mechanism in the Atlantic. Assuming the length of the equator in the Atlantic to be 5000 km and the temperature of the upper 100 meters to be 20°C, with a velocity of 1 cm/s, we obtain exactly 12×10^{21} J/year. Thus, the mechanism of the density-driven large-scale circulation can effectively explain the thermal anomality of the North Atlantic. With the assumed velocity estimates, a typical time of the particle-overturning in such a circulation is 200-300 years.

From a climate perspective, let me note here that the Atlantic and Pacific have very different fresh water budgets. In the Pacific, precipitation dominates over evaporation, while in the Atlantic (and Indian Ocean) the evaporation is higher than precipitation. Using the terminology of Lacombe[1], the Pacific is the basin of the dissolving of properties, while the Atlantic can be considered as the basin of the concentration of properties. In the Atlantic, the domination of evaporation over precipitation results in the salinification of the upper waters and in relatively (with respect to the Pacific) higher vertical mixing. As a consequence of this, we have higher mean salinities and temperatures in the Atlantic with, however, somewhat lower surface temperatures (16.53°C in the Atlantic and 19.37°C in the Pacific) [3].

Let me now consider the difference in the heat content of the relatively "warm" (30°S-30°N) and relatively "cold" (30°S-60°S and 30°N-60°N) waters in the Atlantic and Pacific. The volumes of these waters are approximately equal to each other for both oceans. For the Pacific the difference between the heat content of these waters is 3.4×10^{24} J, while in the Atlantic it is just 0.5×10^{24} J. Thus, the meridional heat contrast in the Pacific is 6 times stronger than in the Atlantic. This implies that the Pacific Ocean plays the major role in the maintenance of the meridional gradients in the atmosphere and, thus, the trade winds, exchanging water between the oceans and continents in the tropics. In the pair Pacific-Atlantic, the Atlantic role is similar to the role of Mediterranean sea in the pair Atlantic-Mediterranean.

Let me add two more comments on the global inter-ocean circulation. First, it would not be right to consider the deep water formation near Greenland and in the Weddell Sea to be the only mechanisms driving the global inter-ocean circulation. The role of anticyclonic gyres and wind forcing is also important. Second, such a 2-layer system should necessarily have eigen-frequencies, associated with the oscillations of the kind of internal waves. Such oscillations may be simply a consequence of the distortion of the equilibrium between the density field and the sea level field. Let's take $\Delta\rho = 7x10^{-4}gm/cm^3$ between the upper layer and the deep layer. Assuming the upper layer to be 400 meters, the eigen-frequency will be about 2 years. If we take an exotic upper layer thickness of 1 meter, we will obtain the period of oscillations of 20 years. The actual typical periods of the interannual variations of the global inter-ocean circulation should lie somewhere in this range. Thus, of special importance will be an accurate analysis of the eigen-oscillations of such a system.

References

1 Burkov, V. A. General circulation of the World ocean. Hydrometeoizdat, Leningrad, 1980, 253 pp.

2 Koprov, B. M. On the estimates of meridional energy transports by the atmosphere and ocean. Izvestia USSR Academy of Science, Atmospheric and Oceanic Physics, 18, no. 1, 1982, 30-37.

3 Stepanov, V. N. The World Ocean. Znanie, Moscow, 1974, 256 pp.

4 Bruevich, S. V., edt. Chemistry of the Pacific Ocean. Nauka, Moscow, 1966, 359 pp.

5 Horn, P. Marine chemistry. – Mir, Moscow, 1972, 399 pp.

6 Hastenrath, S. Heat budget of tropical ocean and atmosphere. J. Phys. Oceanogr., 10, 1980, 159-170.

7 Mintz, Y. Simulation of the oceanic general circulation. Report of the AOC Study Conference on Climate. GARP Publication series, 2, no. 22, 1979, 607-687.

Table 1. Comparison of the basic characteristics of the Pacific and Atlantic oceans.

Characteristic	**Pacific Ocean**	**Atlantic Ocean**	**World Ocean**	**Comments**
Area, 10^6 km^2	179	92	361	Ocean Atlas, 1974, 1977
Volume, 10^6 km^3	0.71	0.33	1.37	Ocean Atlas, 1974, 1977
Mean temperature, C	3.7	4.0	3.8	Krummel, 1907
Mean potential temperature, C	3.36	3.73	3.52	Montgomery, 1958[1]
Mean temperature of the upper layer, C	19.37	16.53	17.54	Stepanov [3]
Mean temperature at 4000 m, C	1.5	1.9	1.5	Stepanov [3]
Mean salinity, %	34.62	34.90	34.72	Montgomery, 1958
Mean density, g/sm^3	1.02753	1.02773	1.02760	Stepanov [3]
Mean concentration of SiO_2, $\mu mol/l$	90	30	60	Ivanenko, Sapozhnikov, 1978[1]
Mean concentration of PO_4, $\mu mol/l$	0.33	0.47		Ivanenko, Sapozhnikov, 1978[1]
The age of deep waters	1300	600	1300	Horn [5]
"Evaporation minus precipitation", 10^3 $km^3/year$	-6	24		Stepanov [3]

CLIVAR Announcement of new dataset, HadCRUT3

HadCRUT3 (Brohan et al., 2006) is a new monthly global analysis of combined land surface air temperature and sea surface temperature anomalies, relative to 1961-1990, for the period 1850 to the present. HadCRUT3 improves on its predecessor in several ways:

HadCRUT3 incorporates an expanded sea surface temperature data base, ICOADS, with improved bias adjustments (Rayner et al. (2006)). The quality-control techniques make better use of marine data in sparsely-observed areas.

HadCRUT3 also includes additional or improved land surface air temperature data.

Error estimates are made for each gridded value and include uncertainties in the bias-adjustments as well as measurement and sampling error.

In grid cells containing both land and ocean, the land and ocean data are blended with weightings inversely proportional to their assigned errors.

HadCRUT3 is available at a range of grid resolutions.

HadCRUT3 is not interpolated across data voids; it is not designed for forcing atmospheric general circulation models.

HadCRUT3 is replacing HadCRUT2v as the basis for the Hadley Centre / Climatic Research Unit global and hemispheric surface temperature series in the forthcoming 4th Assessment report for the Intergovernmental Panel on Climate Change. Figure 1 page 18 shows a smoothed global surface temperature series from HadCRUT3 with associated uncertainties.

Along with other major climate datasets, HadCRUT3 is available from http://www.hadobs.org and from http://www.cru.uea.ac.uk/ along with separate files of its land component CRUTEM3 and its ocean component HadSST2. Also available are datasets with homogenised local variance. as described by Brohan et al. (2006): HadCRUT3v, CRUTEM3v and HadSST2v. These versions are designed for local and regional analysis.

References

Brohan, P., Kennedy, J., Harris, I., Tett, S.F.B., and Jones, P.D. 2006: Uncertainty Estimates in Regional and Global Observed Temperature Changes. *J. Geophys. Res.* (Atmospheres), in press.

Rayner., N.A., Brohan, P., Parker, D.E, Folland, C.K., Kennedy, J.J., Vanicek, M., Ansell, T. and Tett, S.F.B., 2006: Improved analyses of changes and uncertainties in sea surface temperature measured in situ since the mid-nineteenth century: the HadSST2 data set. *J. Climate*, in press.

CLIVAR CALENDAR

10 - 12 April	The Shelf Seas: Present Understanding and Future Challenges	Bangor, Wales, United Kingdom	http://www.sos.bangor.ac.uk/coastal2006
19-22 April	CLIVAR SSG 14	Buenos Aires, Argentina	
22-23 April	9th VAMOS Panel Meeting	Foz do Iguacu, Brazil	
24-28 April	8th International Conference on Southern Hemisphere Meteorology and Oceanography	Foz do Iguacu, Brazil	http://www.cptec.inpe.br/SH_Conference/index.shtml
8-10 May	U.S. CLIVAR Salinity Workshop	Woods Hole, Massachusettes, U.S.A.	http://www.usclivar.org/Organization/Salinity_WG/Salinity2006.html
16-20 May	OOPC-11	Tokyo, Japan	
5-8 June	Time Series of the Northeat Pacific: A symposium to mark the 50th Anniversary of Line-P	Victoria, Canada	http://www.pices.int/meetings/international_symposia/2006_symposia/Line-P/Background.aspx
6-9 June	Understanding Sea-level Rise and Variability	Paris, France	http://copes.ipsl.jussieu.fr/Workshops/SeaLevel/index.html
7-10 June	PAGES/CLIVAR Workshop	Wengen, Switzerland	
24-29 June	ESF-JSPS Science Conference on Climate Change	Nynashamn, Sweden	http://www.esf.org/
28 May - 1 June	ASOF Scientific Conference	Torshavn, Faroe Islands	http://asof.npolar.no/NEWS/ASOF_conf.html

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