1. INTRODUCTION AND BACKGROUND

The workshop was held in Monaco from 22 to 24 April 2002, at the Headquarters of IHO (International Hydrographic Organization). As many as 31 researchers and hydrographers, originating from twelve countries, did attend at the invitation of CIESM.

The participants were greeted by RAdm Giuseppe Angrisano, IHO President, who outlined the essential missions of his Organization before noting his keen personal interest, from the start, in this CIESM initiative. He recalled in particular that as soon as he had been approached by the Direction of CIESM, he had sent a letter to the Directors of the National Hydrographic Services of Mediterranean and Black Sea countries, encouraging their future collaboration, either by direct participation in the workshop or through concrete involvement in the future monitoring operations at sea.

In his welcoming remarks, the Director General of CIESM, Pr Frédéric Briand, expressed his kind appreciation, on behalf of all participants, to RAdm Angrisano for both his hospitality and for his personal commitment to the success of this operation. Frédéric Briand underlined the originality of the potential collaboration between the two organisations, particularly in allowing ship access, over a long-term horizon, to monitoring stations in key Mediterranean areas that are not within easy reach for most researchers, for instance in southern waters where data sets are practically non-existent.

He went on stressing that a modern, reliable and well-positioned monitoring network was a realistic expectation considering the substantial “cards” at hand. Such an observing system could be efficiently run, at relatively little cost, if one could (a) tap and develop North-South scientific synergies, building upon the solid contacts and trust established on all Mediterranean shores within the large CIESM community of researchers, (b) apply recent technological development to the deployment of cheaper, autonomous, user-friendly, yet accurate instrumentation to key locations of the Mediterranean, not forgetting southern waters and southern scientists in the process and (c) rely on the lasting and very promising support of relevant National Hydrographic Services.

He then warmly introduced the coordinator and main initiator of the workshop, Dr Claude Millot, former Chair of the CIESM Committee on Physical Oceanography, who recalled the conceptual genesis of this meeting : a few months previously a round-table held during the 36th CIESM Congress (Monte Carlo, September 2001) had concluded that existing data sets on hydrological variations were too limited to provide useful insights on this issue and that more adequate data sets could be fairly easily collected. In the immediate aftermath, and with the active support and involvement of Pr Alex Lascaratos, present Chair of the Committee on Physics and Climate of the Ocean, the CIESM Direction agreed to organise a three-day research workshop to examine this issue in depth, with the participation of relevant physical oceanographers and if possible interested hydrographers. As noted above, contacts initiated with IHO proved very encouraging in this regard. In addition, fruitful links were also initiated with CLIVAR, the global programme on climate variability, thanks to the efforts of Pr Paola Malanotte-Rizzoli and Dr Mario Astraldi. The workshop would allow time for a presentation of relevant CLIVAR activities and for reviewing various options of possible interactions with the CIESM project.

Claude Millot reminded everyone that the main objective of the workshop was to elaborate a realistic scientific monitoring strategy, to be backed up by a circum-Mediterranean observational network, so as to better assess and describe long-term hydrological variations in the Mediterranean Sea. The idea was to deal not only with data collection but also with theoretical analyses, as reflected in the List of invited participants (see Chapter IV). He emphasised that most current data sets are provided by ship-handled CTDs (instruments that measure Conductivity, Temperature, Depth/pressure) that are operated in a few places and on a weekly – at best – to six-monthly basis. Although such data sets do allow the computation of trends (as inferred from a linear regression) over decades, they are not adequate to estimate data significance or to compute covariance between different data sets. The basic proposal, therefore, of the workshop coordinator was to take advantage of the availability on the market of new, quite inexpensive autonomous instruments, which display impressive performance in terms of accuracy, resolution, stability, memory and energy consumption, to constitute a network of autonomous oceanographic stations with a broad cover over the Mediterranean Sea. The CTD time series provided through such a network would be essential links between the ship-handled CTD casts that need to be regularly collected to provide information on the vertical structure of the water column.

2. EXISTING DATA SETS AND ANALYSES

The first day was devoted to brief oral presentations (see extended abstracts, this volume) and discussions of existing data sets and analyses. The data, available mostly since the 1960s, attest to the existence of important inter-annual and decadal variability, often correlated with large-scale meteorological parameters, in most – if not the whole – of the Mediterranean Sea. Presenting a comprehensive analysis of the available data sets is obviously beyond the scope of this summary, but a few points deserve to be emphasised.

One is that a large variability has been observed at all depths in the *eastern* basin. In the deeper layers, this variability has been expressed by the Eastern Mediterranean Transient – i.e., the dramatic shift, in the late 1980s / early 1990s, of the deep-water formation site of the eastern basin from its classical location in the Adriatic to a new location in the Cretan Sea, which drastically changed the deep water characteristics in the area (see full presentation of this event in CIESM Workshop Series n°10, 2000). It is now speculated that events broadly similar to the Transient may have occurred earlier, some forty years ago. At sub-surface (Atlantic Water) and intermediate layers (Levantine Intermediate Water), important variability has been observed as well, with, as its dominant characteristic, a significant decrease of temperature from 1955 to 1995.

In the *western* basin, significant increases of a few10^{-1}-10^{-2} in °C and salinity units per decade have been noted since the 1960s in waters deeper than ~2000 m, and since 1975 from the surface down to ~200 m at the few places which have been investigated. This is an important point since it signals the possibility to evidence more detailed decadal changes in the surface layer, regardless of the noise generated by seasonal and interannual variabilities. The fact that significant changes have been registered, among other places, in Spanish coastal waters is particularly interesting when one considers that the surface water characteristics there do not have any direct link with the intermediate and denser waters formed in the eastern basin. This precludes explaining Sea-wide long-term changes on the basis of phenomena having occurred in the eastern basin only.

Another point worth noting is that recent data collected in the Mediterranean *outflow* from 1995 to present (2002), relatively far away from Gibraltar in the Bay of Biscay, point to a general increase in temperature and salinity as well, but with a markedly higher slope than what recorded in the western basin. These data, which likely represent an integrator of the characteristics of both intermediate and deeper waters that outflow at Gibraltar, raise an intriguing question: should they be comforted by further analyses, how much confidence can we have overall in our current representation, based on data available so far, of trends in the Western Mediterranean ?

During the general discussion high interest was expressed for a better understanding of long-term changes. This will require an information richer than that now available which allows little more than a statistical fit of linear trend lines. At the very least, on-going experiments and programmes based on ship surveys must be continued, new analyses must be performed and new data sets must be collected through dedicated process studies and by means of sustained observations with autonomous instrumentation.

By concluding the first day discussions, the workshop coordinator remarked that hypotheses published so far assume the water of Atlantic origin flowing through Gibraltar to have stable characteristics. Yet the variations evidenced within the Mediterranean Sea could result from variations, possibly even larger, in this incoming Atlantic water itself. This underlined, if necessary, the need to monitor, as accurately as possible, the characteristics not only of the outflow but also of the *inflow* at Gibraltar

3. THEMATIC AXES / PRIORITIES IDENTIFIED

The morning session of the second day was devoted to presentations of on-going global and regional programmes, and to proposals for an efficient monitoring strategy (see extended abstracts, this volume). Following elaborate discussions, four themes were recognised as worthy of detailed consideration for possible articulation and integration within the overall monitoring strategy considered:

i) the relationships between the Mediterranean Sea and both the world ocean and the atmosphere;

ii) the long-term variability of the thermohaline circulation and the water masses characteristics;

iii) hydrological cycles;

iv) key processes in poorly-known sectors of the Mediterranean Sea.

Participants distributed themselves into four sub-groups accordingly. The conclusions and recommendations that emerged from these groups were further consolidated in the direct aftermath of the workshop. They are presented below.

3.1. The Mediterranean Sea relationship with the global ocean-atmosphere and its response to local forcing

Group: R. Boscolo, G.P. Gasparini, A. Lascaratos and P. Malanotte-Rizzoli

Rationale

- There is evidence of interaction between the sea and the global ocean-atmosphere. Indeed, it has recently been demonstrated that the total heat flux from the sea, and meteorological parameters as well, are strongly correlated with NAO (North Atlantic Oscillation) in winter in the western basin, and with the Indian monsoon in summer in the eastern basin.
- It has been established that rainfall in both the western and the eastern basins is highly correlated with ENSO (El Niño-Southern Oscillation).
- Past and recent studies indicate that Mediterranean water spreading from Gibraltar across the Atlantic Ocean plays an important role in affecting the intensity of the Atlantic thermohaline circulation and the NADW (North Atlantic Deep Water) formation.
- Because of its small dimensions, the sea response to local forcing is very rapid. Hence, the Mediterranean Sea can be used as a test bed for climate studies.
- Conversely, the characteristics of the incoming Atlantic water strongly modulate the circulation inside the sea and the dense water formation processes.

Priority studies

- Existing oceanographic, meteorological and satellite Mediterranean data sets should be further analysed to investigate their correlations with global meteorological parameters (NAO, ENSO and the Indian monsoon), particularly in terms of time scales and phase lags, so as to better understand the interaction mechanisms.
- In this perspective, air-sea fluxes should be directly measured at sea along north-south sections in the western, central and eastern basins, and along an east-west section across the whole sea. On a long-term basis, meteorological buoys to be deployed in the Ligurian, Southern Adriatic and Cretan sub-basins should be used as reference measurement points. The spatial variability of the fluxes parameterization will thus be correctly appreciated.
- The flow and hydrographic properties of the Atlantic water at Gibraltar should be monitored on a continuous basis. Then, the pathway of this water should be monitored by a number of hydrographic transects regularly repeated along the whole African slope.

- Dense water formation sites should be monitored in order to assess i) the response of water masses formation and convection to the atmospheric forcing and ii) the consequences on the circulation of all water masses.
- For all these studies, both process-oriented numerical models and ocean general circulation models would prove helpful as a tool for hypotheses testing and for a better understanding of the mechanisms involved.

3.2. Monitoring long-term variability of the thermohaline circulation, water masses properties, biogeochemical contents and transports in the whole Mediterranean Sea

Group: M. Astraldi, G. Civitarese, G. Fusco, M. Gacic, I. Gertman, B. Manca, L. Prieur, J. Salat and A. Theocharis

Rationale

- The Mediterranean Sea is known to be very sensitive to atmospheric forcing and far from a stationary state.
- Long-term variations of water masses characteristics have been documented in the last decades throughout the whole Mediterranean Sea.
- Recent studies based on observations and simulations have shown that sudden modifications in dynamics, mostly related to changes in atmospheric forcing, may change the circulation patterns in the surface, intermediate and deep layers. Such changes are also evident in the nutrient supply to the euphotic zone and in the deep ecosystem, affecting the organic matter produced and exported.
- In the long term, physical and biogeochemical systems are linked, both being subjected to natural forcing and anthropogenic influences.
- Systematic assessments of hydrological variability in relation to climate (see theme 1), to changes in biogeochemical processes and in biodiversity, are crucial to understand the mode of response/ functioning of the marine ecosystem.

Objectives

- To assess the interannual variability of the thermohaline circulation, water masses properties, transports and biochemical contents.
- To better understand the dynamic response to natural forcing and anthropogenic influence, as well as main changes in biodiversity at interannual to decadal scales.
- To perform basic hydrographic measurements along north-south and west-east sections at basin scale, assessing the biotic component response to large-scale variability observed in the main thermohaline circulation and in the water masses properties.
- To achieve a composite monitoring programme, linking hydrographic observations and transports, working closely with on-going operational programmes.
- To provide a framework for co-ordination and co-operation in collecting and analysing basic oceanographic data sets in a large integrated project and/or in clusters with on-going projects.

Monitoring outlines

The observational programme would include:

1) hydrographic sections connecting the major sites of dense water formation with the basin interior. These will be monitored once a year for the thermohaline structures, the water masses properties and biogeochemical content. Moreover, other sections should connect the deep sub-basins where the water masses are stored for a while, yielding major differences in long-term changes due to sub-basin scale phenomena. As process studies of dense water formation will be conducted with platforms moored in areas identified by complementary observational programmes (see theme 1), the sections should be scheduled after the convection period and before thermal re-stratification occurs. The measured parameters will include T, S, O_2, nutrients, tracers and some representative biological parameters. To obtain information on the circulation processes time scales and water masses age, emphasis should be given to the joint collection of hydrographic, biochemical and transient tracers data.

2) continuous monitoring of the straits and channels where exchanges between basins and sub-basins can be estimated. Current time series, complemented with hydrological data along sections close to the moorings, are crucial to understand the water masses structure, the associated biogeochemical properties and transports.

3) sub-basin scale surveys to specify the long-term variability of hydrographic properties and of the trophic status at the primary and secondary levels, and to investigate the deep sea fauna. Quantification of the circulation time scales and of the changes in water properties will provide a coherent description of the system evolution. Biodiversity changes in the deep sub-basins should be estimated every two or three years. Information on biodiversity and on ecological processes will be interpreted in the light of ecosystem modelling studies to be run in parallel.

Priority studies

Signals indicative of specific processes driving the whole system should be tracked down in the following key locations:

- The straits and channels, which are integrators of most of the processes occurring in the basins and sub-basins. Long-term current time series, possibly using bottom ADCPs, have to be collected within the main waters cores, and hydrological sections have to be performed close to the moorings as often as possible.
- The zones of dense water formation, where at least one mooring with ADCPs and CTDs would have to be maintained.
- Specific meridian and zonal sections, where multidisciplinary hydrographic surveys have to be repeated, at least on a yearly basis, to monitor the variability of the water masses structure, properties and transports, as well as their biochemical contents.
- The deep sub-basins parts, as long as they do not strongly interact with coastal areas, which have to be surveyed on a two-three-year basis to investigate changes in living communities and their reactions to hydrological changes.
- Sectors known to be sensitive to climatic effects where single CTD casts should be collected.
- Coastal zones where “simple” (classical thermometers and bottle samples) measurements could be regularly performed.

3.3. Hydrological cycles

Group: D. Georgopoulos, E. Kontar, J-L. Lopez-Jurado, S. Papaevangelou, N. Pinardi, P. Povinec and I. Vilibic

Rationale

- The Mediterranean domain, i.e., the sea itself and the surrounding catchment area, is characterised by the vulnerability of its water resources to natural forcing and to anthropogenic influences.
- The sensitivity of its energy and water cycles to atmospheric conditions, locally and through connections with NAO, ENSO or the Indian monsoon, is exacerbated by exploitation of groundwater resources.
- It is thus necessary to study the overall water cycle and its components over the whole Mediterranean domain through comprehensive modelling at regional scale.

Priority studies

- Evaporation:
  - new bulk formulas should be established from more adequate measurements;
  - existing data sets should be re-analysed;
  - new methods using stable isotopes should be used.
- Precipitation:
  - water vapour content, cloudiness and water able to precipitate should be monitored using satellite sensors;
  - atmospheric models should be developed and used;
  - sea and ground truth data sets should be collected.

- River run-off:
  - national actions should be encouraged to create adequate data bases (water level, temperature, …);
  - anthropogenic impact should be better estimated.
- Groundwaters (discharge, intrusion):
  - a set of three typical regions should be selected;
  - numerical modelling of groundwaters processes should be developed.

3.4. Filling geographical gaps on key processes in the Mediterranean Sea

Group: A. Abdulfattah, J. Font, D. Jourdan, C. Maillard, G. Manzella, C. Millot, M. Snoussi, M. Tber and M. Vargas

Rationale

- Due to historical and logistic difficulties several Mediterranean areas, particularly the southern sector of the western basin and, more significantly, the southern sector of the eastern basin, are very poor in hydrological data sets and current time series.
- Furthermore, the circulation in southern sectors is characterised by intense mesoscale variability induced by the unstability of the Atlantic water flow. This variability prevents from easily estimating the transports, and will make any monitoring difficult.
- These southern sectors are of primary importance since surface water undergoes there most of its preconditioning before reaching the northern sectors.

Objectives

- To better characterise the evolution, in both time and space, of the inflowing water of Atlantic origin.
- To share a common monitoring network, since processes occurring from the far west to the far east in the southern sectors of the sea are very similar, if not identical.
- To involve all coastal countries in order to promote scientific knowledge and understanding, and evidence the benefits to be derived for human activities such as fishing and pollution control.
- To optimise scientific potential and synergies by involving research institutes historically linked with CIESM and by seeking new collaborations with National Hydrographic Services across the Mediterranean Sea.

Priority studies

- Hydrographic sections in the southern sectors should be monitored, at least on a seasonal basis.
- On-going international programmes (such as MFSTEP, Mediterranean ocean Forecasting System: Toward Environmental Predictions) and relevant national or local initiatives must be vigorously pursued.
- Major results are expected from the Mediterranean-wide action detailed below, especially since key locations such as the Strait of Gibraltar and the Channel of Sicily are in the southern sectors of interest.
- Real time data acquisition could be usefully initiated in some countries, taking advantage of current international programmes such as MAMA (Mediterranean network to Assess and upgrade the Monitoring and forecasting Activity).

4. CIESM INITIATIVE – NEXT STEPS

It is expected that many of the priority axes identified by the thematic groups will form the starting point of future multi-lateral research projects, once proper funding is set in place by the relevant international and national agencies. In this respect alone the workshop was viewed as a “watershed” meeting.

The participants considered the proposed monitoring network as an essential methodological tool that would be precious for all four themes. Thanks to its rich links with the scientific community on Mediterranean shores, and to the unique co-operation which it can establish through IHO with relevant National Hydrographic Services CIESM will provide much more than a welcome umbrella in this respect. The Mediterranean-wide monitoring network to be developed under the aegis of CIESM would clearly represent an original and quite substantial achievement.

Recommended Action: Establish a monitoring network to better describe long-term change of the hydrological characteristics in the whole Mediterranean Sea

Rationale

- Long-term variations of temperature and salinity can be evidenced (see this volume) with *in situ* measurements everywhere in the whole Mediterranean Sea, from the upper layer of Atlantic Water down to the deepest layers, and even in the Atlantic Ocean within the outflow of Mediterranean water.
- Most of the data sets now available have been collected with ship-handled CTDs in specific places and on a weekly (at best) to six-monthly (and even more) basis. While this strategy is the only one able to regularly monitor variations in the whole water column over decades, it requires investments that are beyond the reach of many institutes, in terms of ship time and persons x months, to correctly resolve the scales of major importance. In any case, continuous Eulerian time series should be collected as well in order to draw significant comparisons.
- A better understanding of long-term changes will require not only complex experiments and numerical models, but also the launch of an effective permanent monitoring, as emphasised in the recommendations of the four sub-groups.
- The scientific aim of this action is thus to build a sea-wide monitoring network, i.e., a network of autonomous oceanographical stations that would be the marine counterpart of the network of meteorological stations for the atmosphere.
- Another explicit aim of this initiative is to gather strongly committed participants from as many coastal states as possible in the monitoring network, providing them in return with an equal access to the database.

Monitoring outlines

- The monitoring must be maintained over the long term, that is, at least for decades, which underlines the benefit to be derived from the collaboration of established structures such as the National Hydrographic Services of coastal countries.
- It must focus on temporal variations with an adequate sampling interval. To avoid the noise generated by spatial variations, instruments will have to be maintained as much as possible at the same location.
- It must be as cheap and simple as possible so as:
    - to be easily maintained on the long term;
    - to allow an efficient and similar participation from both specialised and less-specialised teams from all coastal surrounding countries;
    - to require a minimum amount of non-necessarily-oceanographic ship time;
    - to be supported essentially with national/regional/local funds.

Monitoring strategy

- Building the monitoring network can efficiently start with autonomous CTDs, which fulfil the necessary requirements in terms of accuracy, resolution, stability, memory and energy consumption, set on simple near-bottom moorings for periods of up-to-two years before being re-calibrated.
- Moorings have to be located over the whole Mediterranean Sea:
    - in key locations: first of all the Gibraltar Strait in order to monitor the inflowing Atlantic water as well as the outflowing Mediterranean water; in all other straits and channels; and in the zones of dense water formation;
    - in “opportunistic” locations: where dedicated initiatives already exist; where ongoing programmes have a relevant focus; and/or in the vicinity of logistic facilities.
- CTD time series collected in this way will have to be complemented by CTD casts performed close to the moorings and along specific sections as often as possible.

Data collection and management

- To be considered as a product of the monitoring network, data will have to be collected with instruments calibrated and operated according to a series of specific procedures.
- To avoid interrupting the time series during calibration of the instruments and maintenance of the equipments, and to reduce both ship time and persons x months, shared instruments and equipments will be made available to all participants in the monitoring network. Recovery and redeployment of the instruments will thus require a few hours only.
- Before being integrated in the database, new time series will be checked by a data manager, considering the previous time series and the posterior calibration.
- Each participant in the monitoring system will have access to, and be allowed to analyse, all time series produced by the network.

Toward the establishment of the monitoring network

This phase can be considered to have already started. Certain local, regional and international sponsors have already expressed an interest in supporting the cost of basic monitoring stations (a CTD, an acoustic release, floats, fittings) in several key locations. It is expected that participants will submit proposals in their own country to obtain funding from relevant national agencies.

To ensure the efficient and normalised running of the monitoring network, a meeting of its main actors will be organised by CIESM in the not-distant-future at a convenient time and place. It will review the efficiency of the initial operations and train those participants less specialised with mooring operations.

Understanding climate changes in Mediterranean water masses

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INTRODUCTION

The Mediterranean Sea appears to be getting saltier. It is reasonably well known that the salinity of western Mediterranean deep water formed in late winter in the Gulf of Lions is increasing at a rate of 0.007·per decade (Lacombe *et al.*, 1984; Leaman and Schott, 1991; Rohling and Bryden, 1992). There is some evidence that Levantine Intermediate Water is also increasing in salinity (Rohling and Bryden, 1992). Most dramatically, new deep water has been observed to form in the Aegean Sea between 1987 and 1995 with a salinity 0.12 higher than previous deep water salinities observed in the eastern Mediterranean during this century (Roether *et al.*, 1996; Klein *et al.*, 1999). Nof (1979) argued that increasing Mediterranean salinity should be expected as result of the change in the water budget for the Mediterranean basin following the diversion of the Nile and Russian rivers for irrigation. Our interest in Mediterranean monitoring is to understand the way in which salinity and temperature change as a result of anthropogenic modifications to the water and heat budgets of the Mediterranean basin.

BACKGROUND

The completion of the Aswan Dam on the Nile River in 1964 effectively ended the historic Nile River discharge of 90 km^3 yr^{-1} into the Mediterranean Sea (Nof, 1979). Construction of dams on Russian rivers feeding into the Black Sea and ultimately into the Mediterranean beginning in 1947 has reduced the flow of freshwater into the Mediterranean by 50 to 70 km^3 yr^{-1} (Tolmazin, 1985). Overall the reduction in freshwater input amounts to 140 km^3 yr^{-1}, which is about 10% of the overall net evaporation over the Mediterranean basin estimated from measurements of the fluxes through the Strait of Gibraltar. Thus the river diversion projects since the 1940's have effectively increased the net evaporation over the Mediterranean basin by about 10%.

Hydraulic control models of the two-layer exchange between the Atlantic and Mediterranean through the Strait of Gibraltar argue that, if the maximum exchange possible through a narrow and shallow constriction is occurring through the Strait, then the salinity difference between the Atlantic and Mediterranean is determined by the physical configuration of the Strait and by the net evaporation over the Mediterranean basin (Bryden and Stommel, 1984). A maximal exchange solution for the physical dimensions of the Strait of Gibraltar suggest that the Mediterranean should be 1.8·saltier than the Atlantic for the estimated net evaporation of 1300 km^3 yr^{-1}, or

52 cm yr^{-1} average over the surface area of the Mediterranean (Bryden and Kinder, 1991; Bryden *et al.*, 1994). On the basis of such a maximal exchange model, Rohling and Bryden (1992) actually predicted that the Mediterranean salinity would increase by 0.13·as a result of a 10% change in the water budget.

QUESTIONS AND THE REQUIREMENT FOR OBSERVATIONS

It is of much interest to study the evolution of Mediterranean water masses in response to anthropogenic changes. Intuitively we might argue that the change in water budget should be locally felt first in the eastern Mediterranean close to the principal river diversions. But the first indications of change were identified in the western Mediterranean. Is this due to the lack of adequate measurements in the eastern Mediterranean or is it a real effect that we must understand?

Formation of new, higher salinity eastern Mediterranean deep water occurred in the Aegean Sea in the 1990's but why did it take 30 years after the initial major river diversion projects in the 1960's for new deep water to be formed ? Was there a gradual build-up in upper water salinities (Boscolo and Bryden, 2001) or was there a short burst of severe winters that led to a catastrophic formation of new deep waters (Wu *et al.*, 2000) ?

In recent years, it appears that no new deep waters are being formed while the large volume of recently formed dense, deep water continues to spill over the sills connecting the Aegean Sea to the eastern Mediterranean basin and to fill the deep eastern Mediterranean (Theocharis *et al.*, 1999a). Where and when will the next deep-water formation event occur and will the new deep waters be even saltier ? Will we have to wait 25 years before deep-water formation occurs again in the Aegean ?

Understanding the pattern of salinity and temperature changes over the Mediterranean requires a concerted observational programme to monitor water mass formation regions for the evolution of the water mass structure associated with anthropogenic changes to the freshwater and heat budgets. Observations are needed to answer the basic questions of where, when and how the water mass changes occur and to provide critical tests of numerical model predictions for anthropogenic climate change over the Mediterranean Sea.

Interannual variability of atmospheric parameters over the Mediterranean basin from 1945 to 1994

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In this paper we study the evolution of atmospheric parameters and the sea surface temperature over the Mediterranean basin for the fifty years period 1945-1994. Data are taken from the COADS (Comprehensive Atmosphere-Ocean Data Set) monthly data set with one-degree spatial resolution (da Silva *et al.*, 1994). Data are grouped into three sub-regional data sets namely, the Western Mediterranean, the Ionian and the Levantine Seas. Strong seasonal and QBO (Quasi-Biennual Oscillation) signals are evident in all data sets. This high frequency variability is subtracted with the use of a digital filter with a cut-off frequency at 24 months.

The low frequency time series of almost all parameters show important variability on various time scales, ranging from a few years to two decades. In some cases an underlying continuous trend is also evident. In the following lines we will discuss very briefly the most important features observed.

WIND FIELD

We first examine the evolution of the wind stress field over the Mediterranean. Wind stress shows important variability over the three sub-basins. The magnitude of the wind stress is characterized by a continuous increase during the 50 years period in the Levantine basin. A similar but weaker trend is also evident in the Ionian while in the Western Mediterranean no such signal is present. The examination of the zonal and meridional wind stress components indicates that the increase in the wind stress magnitude in the former two sub-basins is mainly due to an increase of its meridional component. This results in a shift of almost 20] of the wind stress direction for the Levantine from approximately 270° to 310° and for the Ionian from 310° to 330°.

Very interesting changes can also be seen in the wind stress curl time series. An increase (from 6 to $10e^{-8}$ Nt/m^3) is present in the Levantine basin, while in the Western Mediterranean it remains almost unchanged with a positive value close to $4e^{-8}$ Nt/m^3. The most interesting behavior regarding the wind stress curl is observed in the Ionian Sea where significant periodical shifts (with a time scale of 10-15 years) from positive to negative values are evident. An anomaly of this behavior is observed during the last 15 years : after a maximum positive value observed in 1982, the wind stress curl continuously decreased and reached a maximum negative value in 1990 after which, only a small increase is observed which is not enough to change the sign of the wind stress curl over the area. It has been evidenced both in data and in numerical models that the wind stress curl plays a very important role in the circulation of the southern Ionian (Korres *et al.*, 2000) which periodically shifts from cyclonic to anticyclonic. In the second case, Atlantic waters after passing the Sicily straits are bifurcated to the north along the eastern Sicily coasts towards the Adriatic and then shifted to the south. In this case the Atlantic waters entering the Levantine basin are more saline and lesser in volume.

WATER BUDGET COMPONENTS

A continuous increase from 0.45m/y to 0.65m/y in precipitation is evident in the Western Mediterranean and the Ionian from the mid-50’s to the early 80’s. A similar trend can be observed in the Levantine basin from the mid-70’s to the early 80’s. In all three sub-basins an abrupt decrease in precipitation is observed from the mid 80’s to the mid 90’s. Regarding the evaporation important interannual variability is also observed. The most interesting feature of this variability seems to be the continuous decrease of evaporation from the mid-70’s to the mid 80’s with an increasing gradient from west to east. These two factors result in the water budget (E-P) where an increase of the water deficit is evident in all three sub-basins from the mid 70’s to the mid 90’s. This increase is of the order 20% for the Western Med and 50% for the Ionian and the Levantine basins.

HEAT BUDGET COMPONENTS

The total heat flux Q_T undergoes important interannual variability (see also Garrett *et al.*, 1993) of the order of 15 W/m^2 in the Levantine and Ionian basins and 30 W/m^2 in the Western Mediterranean. In the latter, a very pronounced minimum (maximum heat loss) is observed in 1963 whereas a maximum in all three sub-basins is observed in 1975. Most of the variability observed in the heat budget is due to similar changes in the latent heat loss Q_E. Solar radiation Q_S has small variability.

SST AND AIR TEMPERATURE

SST and air-temperature time-series follow very closely each other. Maximum SST values are observed in all three sub-basins in 1963 and minimum values in 1975. During the 15-year period 1975-1990, a continuous increase in SST and air-temperature is observed in all three sub-basins with a decreasing tendency from west to east. In particular during that period an increase of 0.8°C, 0.5°C, and almost zero is observed in the three sub-basins respectively (see Fig. 1). The decreasing tendency from the WMED to the Levantine mentioned above might be indicative of an advective effect from west to east.

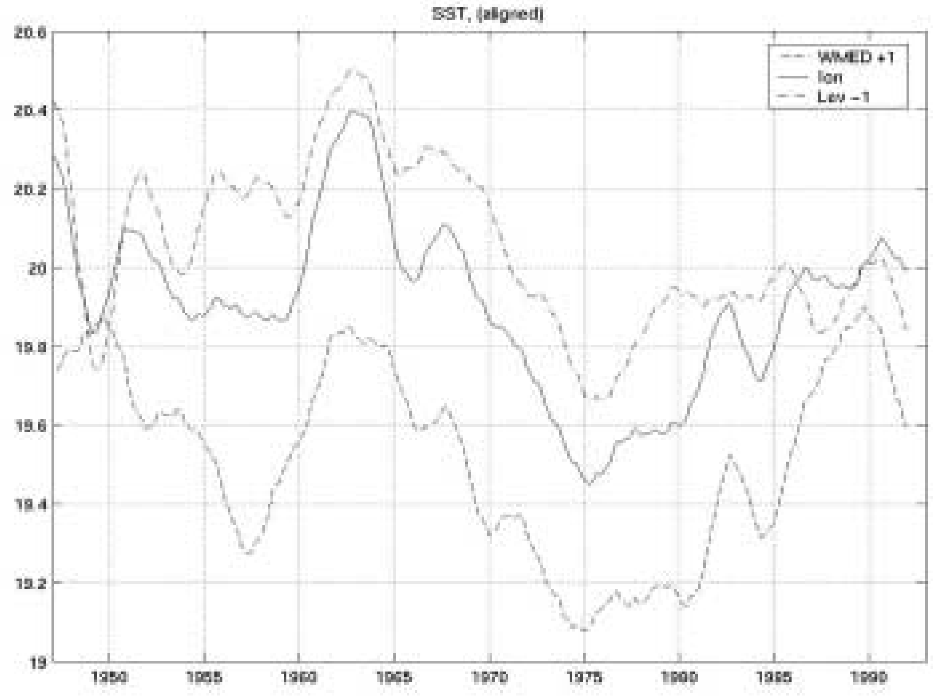

Figure 1.

During the period 1963 to 1975, when a decrease of SST is observed everywhere, it has been shown (Béthoux *et al.*, 1990) that the temperature of the deep waters in the western Mediterranean increased. This increase has been attributed by the same authors to global warming. We believe that if this interpretation is correct, such an increase should also be observed in the SST but this is not the case. We have also analyzed the winter SST values (January to March) and have observed no such signal of warming from1965 to 1975. We believe that our data strongly indicate that the observed increase in deep water temperatures is rather related to an increase in salinity by which surface waters reach high density values at higher temperatures (see also Rohling and Bryden, 1994).

TOTAL HEAT FLUX VS. SST

We conclude this brief presentation by examining the relation of the total heat flux (Q_T) and the SST of the Western Mediterranean. It is obvious that there are periods where the trends of the two variables have the same sign and periods with changes in opposite direction. In order to explain this, we divided the time series in five segments (see Fig. 2). In period 3, after reaching a maximum value in 1963, the SST decreases continuously until 1975, while Q_T shows the opposite, starting from a maximum heat loss and then decreases (becomes more positive). This behavior can be representative of a case where the SST's of a "static" ocean are controlling the air-sea fluxes. High SST values reflect strong heat-loss from the ocean; as the ocean is cooled the heat-loss becomes smaller.

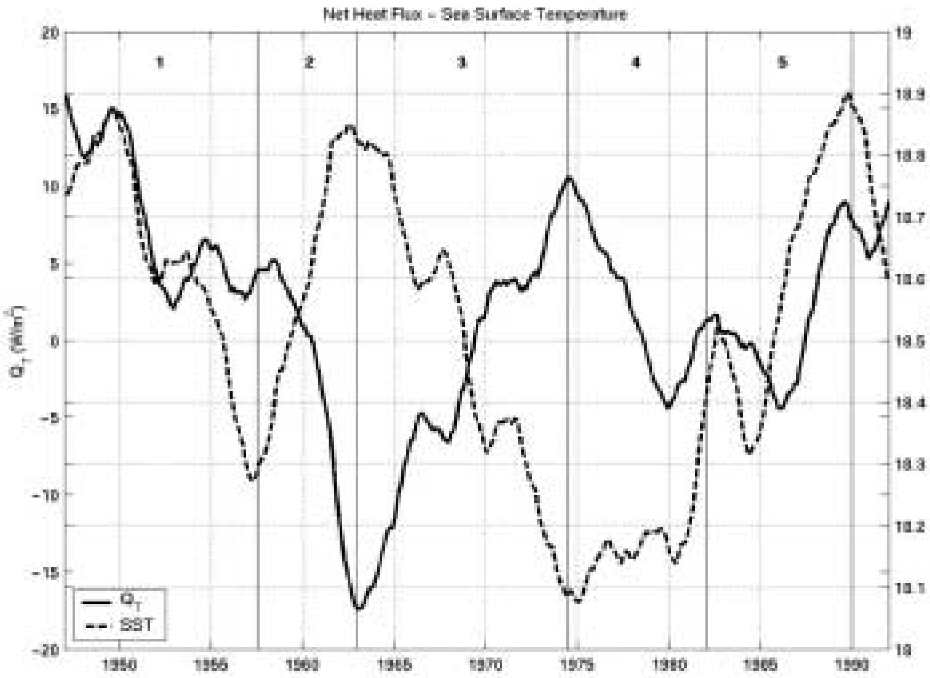

Figure 2.

During periods 1 and 5 Q_T and SST have similar trends (both increasing or decreasing). This behavior somehow indicates a "static" ocean again but now the atmospheric conditions (solar radiation, wind speed, air humidity) modulate the air-sea fluxes and control the SST.

Finally, during periods 2 and 4 we observe an increase in the heat-loss from the ocean while at the same time the SST is increasing, instead of decreasing. This behavior is not compatible with a static ocean, and other processes (such as oceanic advection) might come into play during those two periods.

Variability of the Mediterranean water around the Spanish coast: project RADIALES

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Since 1991, the Instituto Español de Oceanografía (IEO) has supported the project RADIALES. The aim of this project is to monitor different physical and bio-geo-chemical variables around the Spanish coast. In order to cover most of this geographical area, the RADIALES project is subdivided into several subprojects, each developed by a different laboratory. In the case of the Mediterranean Spanish coast, three labs (Málaga, Murcia and Baleares, Fig.1) carry out the three projects ECOMÁLAGA, ECOMURCIA and ECOBALEARES (EMA, EMU, EBA hereafter). There are some differences between these projects, but all of them participate of the same philosophy. A network of fixed stations, usually distributed along on-off shore transects, are visited periodically. The sampling in all of the stations includes water samples to evaluate nutrients and chlorophyll-a concentrations, dissolved oxygen and vertical profiles with a conductivity-temperature-depth/pressure (CTD) probe.

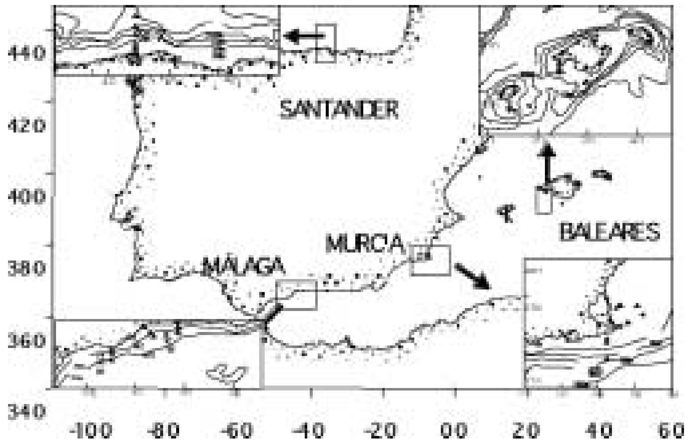


Figure 1.

Nevertheless there are differences between these projects. Each one includes some specific samplings such as sediment tramps, oblique trawls for icthyoplankton and/or zooplankton studies, etc. There are also differences in the starting date and in the sampling interval. EMA started in October 1992, EMU in July 1996 and EBA in January 1994. While EMA and EMU have a three month sampling interval, EBA was monthly visited from 1994 to January 2000, and every three months since.

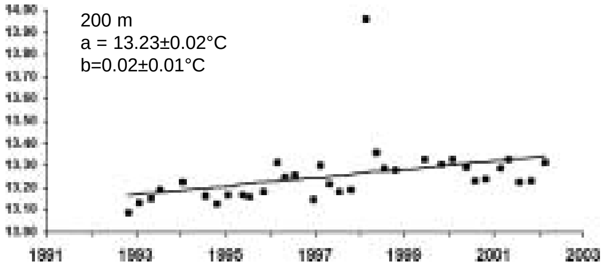
The network of stations is located over the continental shelf, the most offshore stations being on the shelf break, or the beginning of the continental slope. In order to investigate the evolution of temperature and salinity of waters around the Spanish Mediterranean shelf, we analysed time series from CTD profiles at the outermost stations in EMA and EMU at 200m depth. In the case of EBA and also in the offshore station temperature and salinity data from hydrographic bottles at 200m are used (see Fig.1 for station locations).

RADIALES project includes four more projects in the Atlantic Spanish shore. One of them is Santander transect (see Fig.1), which consists of seven stations, being the last one over a bottom depth of 1500m. This deep station started to be sampled in May 1995, and is visited monthly since then. Though most of the CTD casts do not reach the maximum depth, most of them have been lowered to depths ranging between 900 and 1000m, very close to the core of the Mediterranean Water (MW) vein that is detected in this area with 1-2 years delay after it gets out of the Strait of Gibraltar. For each of the casts analysed, we identify the core of this vein as the position of the maximum of salinity, and construct time series of temperature and salinity of this core.

THE MEDITERRANEAN SPANISH SHELF

The longest of our Mediterranean time series is that of EMA. In upper layers, temperature has a strong seasonal cycle which is not detectable below 50m, for this reason we fit to temperature and salinity time series at 200m the model, $a + bt + z$, with t the time in years, a the mean value and b the slope of the linear trend or mean annual increment. Z is considered as those deviations with respect to the expected value that are due to different causes, from instrument or position errors to subinertial variability that can not be resolved by the sampling frequency and is considered as a white noise superimposed to the trends analysed. 95% confidence intervals are included in all the estimations.

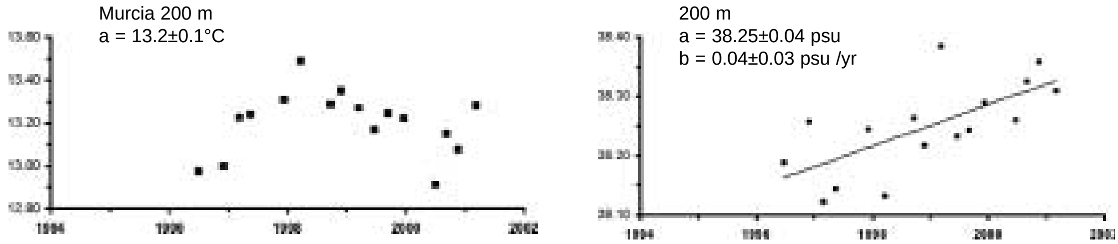
In EMA time series, salinity does not show any trend, while temperature has increased at a rate of 0.02ºC/yr (Fig.2). The initial data point, corresponding to October 92 is 13.0ºC. These data are the average of stations P3, M3 and V3 (Fig.1), but in the particular case of station M3, temperature at 200m was bellow 13ºC with salinity around 38.2. These are typical values found in the literature for the WIW in the Alboran Sea (Cano y Gil, 1977). Though found in the first survey in station M3, WIW has not been detected again in EMA surveys and could be responsible for, or at least have a great influence, on the warming commented above.



200 m
a = 13.23±0.02°C
b=0.02±0.01°C

Figure 2

In the case of EMU there is only one station over a bottom depth greater than 200m. This is marked as station E9 in Fig.1. We analyse temperature and salinity time series at 200m at this station fitting a linear trend as in the EMA case. Keeping the criterion that WIW is present if temperature is lower than 13ºC, we can identify it in the two first surveys of 1996. Then it disappeared until spring 2000. Fig.3 shows a temperature increment since 1996 to 1999 (both included) that is interrupted by the appearance of WIW in 2000. Estimations of the linear slope are not included as they are not significant. On the other hand there is a significant increase of salinity along the whole period analysed (Fig. 3b).


Murcia 200 m
a = 13.2±0.1°C

200 m
a = 38.25±0.04 psu
b = 0.04±0.03 psu /yr

Figure 3

In EBA there is also an increment of temperature throughout the 90s, with absence of cold WIW, that is again interrupted by the cold values of spring 2000. Figure 4 is temperature time series including the fit using years 1994 to 1999 (both included, solid line) and that using the complete time series. Along the year 2001 temperature is increasing again, but the time series is still too short to be conclusive. No main variations are observed for salinity.

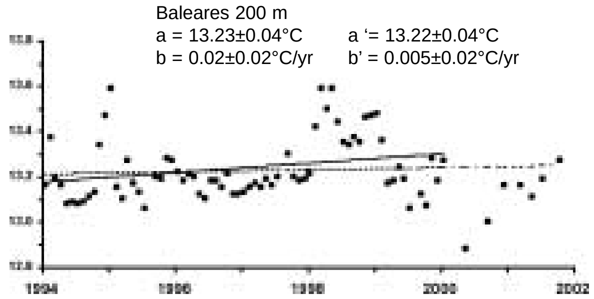
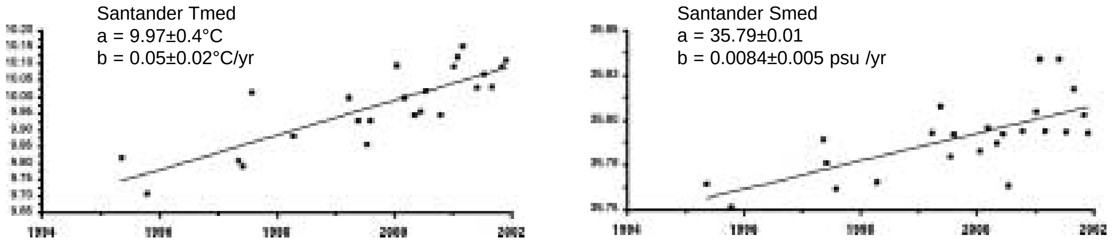

Baleares 200 m
a = 13.23±0.04°C
b = 0.02±0.02°C/yr
a '= 13.22±0.04°C
b' = 0.005±0.02°C/yr

Figure 4

THE MEDITERRANEAN WATER IN THE CANTABRIC SEA

The Mediterranean outflow spreads into the North Atlantic and can be identified clearly in TS diagrams. It is associated to an increase of temperature and salinity below the North Atlantic Central Water (NACW) with relative maximal between 900 and 1000m depth.

In Figure 5 we present the temperature and salinity of the salinity maximum since 1995. The trend in both variables is significant at the 95% confidence level.


Santander Tmed
a = 9.97±0.4°C
b = 0.05±0.02°C/yr

Santander Smed
a = 35.79±0.01
b = 0.0084±0.005 psu /yr

Figure 5

DISCUSSION

During the 90s there has been an increase of temperature at the continental shelf of the Spanish coast. Though local heating due to an increase of heat fluxes in continental shelf waters cannot be discarded with the data at hand, there seems to be a great influence of the WIW on these trends. The absence of this water mass since 1992 in Málaga Bay could indicate a diminishing of the volume formed of this water in the North Western Mediterranean. This weakening of the WIW signal during the 90s can be also observed in EMU and EBA. The presence of WIW in EMU in 1996 and its absence in EBA during the same year could be explained because the natural path of this water mass is the Ibiza channel and only when a very large volume of WIW is formed (in cold winters) it is felt in Mallorca channel. Pinot *et al.* (submitted) report an important decrease of WIW formation from 1996 to 1998. Though WIW formation must have increased in winter 2000 (EMU and EBA), it has not been enough to change the trend observed in EMA.

The increase of temperature and salinity in Santander also reflects changes in the Mediterranean water, but cannot be attributed to the same cause as that affecting our Mediterranean time series. The reason is that waters from continental shelf areas do not contribute in a significant way to the Mediterranean outflow through Gibraltar. This time series and the observed trends could be related to the LIW and WMDW reported in other papers (Béthoux *et al.*, 1998; Tsimplis and Baker, 2000).

The oceanographic and meteorological station at L'Estartit (NW Mediterranean)

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INTRODUCTION

L'Estartit is a small town located in the northern Catalan coast, near the Gulf of Lions (Fig.1). In 1969, J. Pascual started the weather observations and sporadic observations of sea surface temperatures. Since August 1973 up to now, a station located at 2.5 nautical miles offshore over a depth of 90 m has been regularly sampled at a frequency of 50-60 times per year (1612 visits between August 1973 and December 2001). In this station temperature and salinity has been measured at seven levels: surface, 5, 20, 35, 50, 65 and 80 m, providing nearly 30 years of weekly regular observations of the Mediterranean surface waters. In addition since January 1990 a continuous record of the sea level has been obtained at the harbour of l'Estartit. Some other points in the neighbourhood of the station have also been sampled with a small CTD since 1995. The data set is completed with visual observations: transparency, currents, clouds, birds, etc, at every visit of the station, and other complementary data like local river discharges, temperature of local sources of water, etc (Table 1). All the data collected in the station fulfill the standard procedures for atmospheric and oceanographic data. The sea level station has been georeferenced.

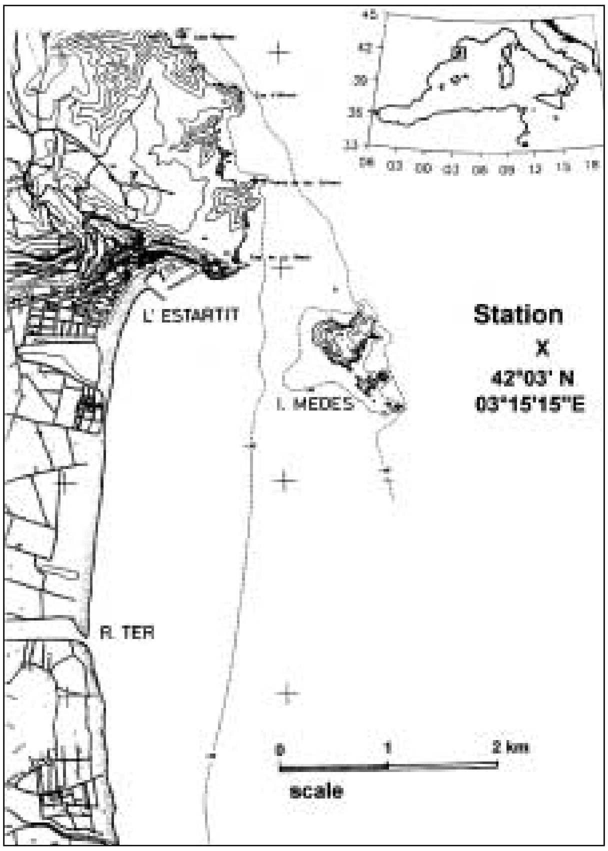

Fig. 1. Reference Map for the Station.

GENERAL CHARACTERISTICS

The coastal area off L'Estartit has been declared as a protected marine zone by the

Table 1. Summary of parameters observed in L'Estartit.

Parameter	location	Initial time	frequency	Observations
Precipitation	42°03'N 3°12'E	1969	daily	at sea level
Atmospheric pres.	42°03'N 3°12'E	1970	3/day	at sea level
Rel cloudiness	42°03'N 3°12'E	1970	daily	
Air temp.	42°03'N 3°12'E	1970	continuous	at sea level
Sea temp. and sal.: @ 0, 5, 20, 35, 50, 65 and 80 m	42°03'N 3°15'15''E	August 1973	50-60/year (~weekly)	2,5 miles offshore
Pot evapor.	42°03'N 3°12'E	1976	daily	at sea level
Rel. humidity	42°03'N 3°12'E	1982	daily	at sea level
Wind	42°03'35''N 3°11'E	1988	continuous	228m above sea level
Pot evapor.	42°03'35''N 3°11'E	1988	continuous	228m above sea level
Air temp.	42°03'35''N 3°11'E	1988	continuous	228m above sea level
Precipitation	42°03'35''N 3°11'E	1988	continuous	228m above sea level
Sea level	42°03'N 3°12'E	1990	continuous	
River Ter discharge		1993	monthly	6 km inland
River Ter wat. temp.		1993	monthly	6 km inland
Land sources wat. temp.		1993	monthly	
CTD surveys	various locations	1995	monthly	max offshore 7 miles

Government since 1990. The climatology of this region is characterised by northern winds (dry and cold) from the Gulf of Lions, more frequent in winter. The area can be affected by the river Ter inflow (2-30 m3/s) whose mouth is located 5 km southwestward off the main station (Fig. 1). The river outflow however is seasonal, with some peak in spring and autumn and very low during summer. Sea water is almost homogeneous during the period from early December to mid March with some periods of surface inversions of temperature due to the presence of low salinity waters, either due to local rain or to the Ter. During spring, when stratification of the water column is developing, the influence of the Rhône discharges (at the other side of the Gulf of Lions) can also reach this area producing a surface low salinity layer around 20 m deep.

The average annual cycle (Fig. 2) shows a temperature oscillation of nearly 12°C at the sea surface and around 4°C at 80 m.Wind episodes during the stratification period, mainly from late summer to the end of autumn contribute to vertical mixing over the intermediate levels in pulses. Only during the period from April to July, the mean air temperature is higher than the sea surface temperature. According to this situation the evaporation is higher during the rest of the year, when it is enhanced by the northerly winds which are stronger and more frequent during this period.

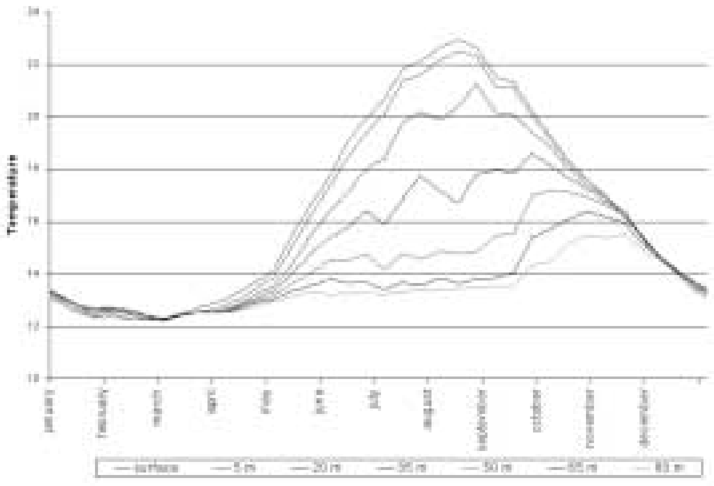

Fig. 2. Mean Annual cycle (1974-2001) of water temperature at the sampled levels.

In this area the interannual variability is high. Comparing the monthly averaged data, the mid depth layers sampled (35 and 50 m) present the maximum interannual variability in late summer and autumn due to vertical mixing episodes (more than 4°C). Winter and summer sea surface temperatures are more stable (less that 2°C of difference between the coldest and warmest years).

OCEANOGRAPHIC TRENDS

The availability of these sets of data can be very useful for climatological studies and oceanographic trends for surface waters. Let us give some examples of trends extracted from the data:

Air and Sea Temperatures

The air and sea temperatures show an upward trend in all levels, as can be seen in the time series (Figs. 3, 4 and 5). The linear tendency of the air temperature at the sea level shows an increase of 2.1°C in 30 years (0.07°C per year) while the linear tendency for sea surface temperature is of 1.1°C in 27 years (0.04°C per year), and at 80 m depth the tendency shows an increase of 0.7°C in 27 years (0.025°C per year). All these tendencies have been calculated with the anomalies, after removing the mean annual oscillation in the series. The significance level of the trends has been evaluated to be between 95 and 99%.

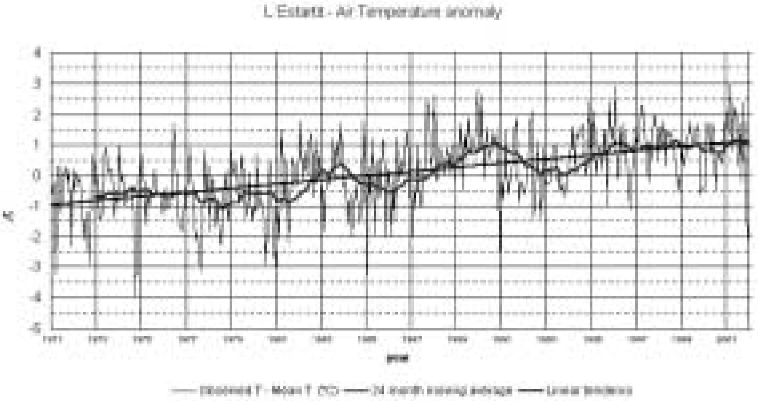

Fig. 3. Air Temperature anomaly (observed minus average) series (1971-2001) with tendencies: 24 month running average and linear.

Sea level

The sea level record and the atmospheric pressure have been used to estimate the interannual (12 month average) trend of the sea level compensated by the atmospheric pressure (Fig. 6). The linear trend obtained shows an increase of 3.3 cm in 11 years (0.3 cm per year). There are however strong variabilities which can bias this estimate (+5 cm between 1995 and 1997). Thus, while the test allows for a significance level of more than 95%, the data length is still too short to give robust estimates of general tendencies.

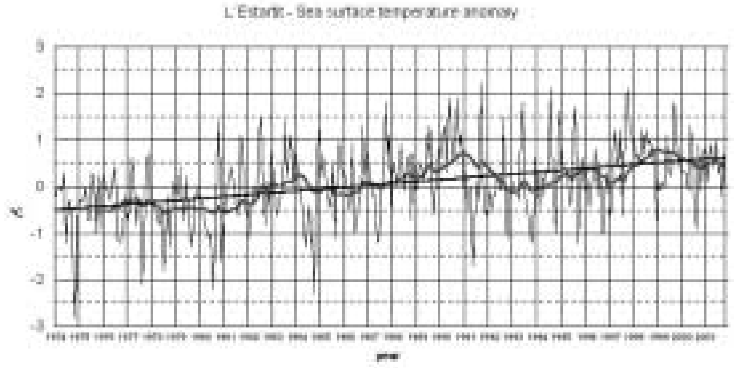

Fig. 4. Sea Surface Temperature anomaly series (1974-2001) with tendencies as in Fig. 3.

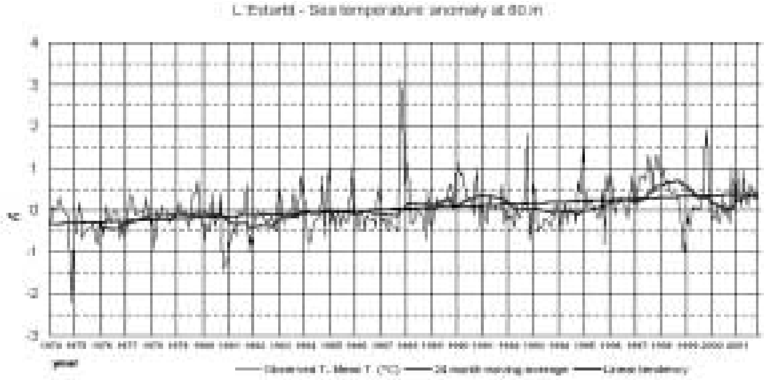

Fig. 5. Sea Water Temperature anomaly series at 80 m depth (1974-2001) with tendencies as in Fig. 3.

Other variables

Among other variables, we have been seeking for trends on the difference between sea and air temperatures, as an indicator of evaporation, and precipitation. No general trend was found in the annual data. However, when data are grouped by season, there appear significative (near 95%) negative trends in the spring data (around 0.04°C and 0.02 mm/day per year, respectively) and similar values in winter with lower significance level (around 90%).

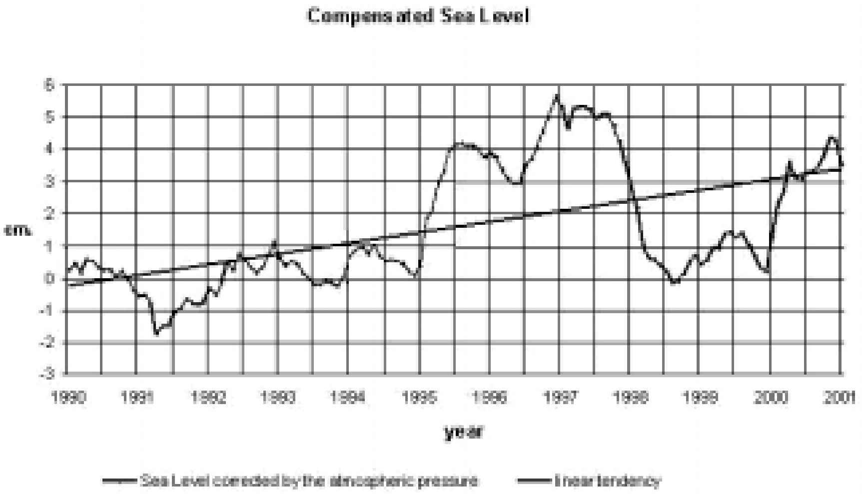

Fig. 6. Mean Sea Level series (1990-2001), compensated by atmospheric pressure, with linear tendency.

Interannual variability in waters of the Balearic Islands

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The Balearic Islands located in the middle of the Western Mediterranean basin are a crucial area for studying the variability of the hydrodynamic conditions and exchanges of water masses between the Algerian basin in the south and the Balearic sea in the north of their channels. Different projects have been developed from 1985 to now. The study of the data sets generated within these projects gives us an overview of the regional circulation of this zone and the different "trends" associated to it.

In a wide sense, the general circulation of the western Mediterranean follows a cyclonic pattern, with two well-known permanent currents: the Algerian current in the south and the Northern current in the north of the basin. The first one flows along the African coast, from the Alboran sea to the Sicily channel and drives waters of recent Atlantic origin (AW). The influence of these waters reaches the Islands from the instability of the Almeria-Oran front and from the mesoscale anticyclonic eddies detached by the Algerian current. The second one comes from the Ligurian sea carrying northern waters southward along the continental slope to the Ibiza channel. The surface waters of this current are Atlantic waters with a long time of residence in the Mediterranean (MW) and for this reason are saltier and colder than the surface southern waters.

The seasonal variability of this latter current is well known and is related to atmospheric forcing. Its transport decreases from 1-1.4 Sv in winter to less than 0.5 Sv in summer. This circumstance helps the northward progress of AW through the Ibiza and Mallorca channels. The Northern current also drives southward intermediate and deep waters and can generate eddies, helped by the topography of the zone. These eddies can reach different sizes, from a few tens to more than a hundred kilometers of diameter and affect from surface to more than one thousand meters of depth. These eddies will cross the Ibiza channel if their size and depth allow. Otherwise they will be trapped by topography in the Valencia gulf, to the north of Ibiza channel (Castellón *et al.*, 1990; Pinot *et al.*, 1995; Pinot and Ganachaud, 1999).

The regional circulation of this zone displays the following characteristics :

- The permanent mesoscale eddies entrain contain in their inner a large volume of Western Mediterranean Intermediate Water (WIW), which could form a layer of 400 meters of thickness.
- This water pushes the Levantine Intermediate Water (LIW) and the Deep Water (DW) down to greater depths.
- These eddies also disturb the southward circulation of the Northern current, deflecting it offshore. This current splits in two branches, one flowing toward the Ibiza channel and the other one forming the Balearic current. When it reaches the Mallorca channel, a part of this current pro-

ceeds southward crossing the channel and the remnant part flows to the northeast progressing along the islands slope.

• The seasonal relaxation and later deflection of the current facilitate the northward spreading of AW into the Ibiza channel.

• At the north of the Ibiza channel, the combined effect of these AW inflows and eddies can block the channel. In this case, the Northern current is deflected to the Mallorca channel, reinforcing the Balearic current. Oceanic fronts between AW and MW are observed in all the channels area.

• These circumstances extend along summer, disappearing by mixing and transport of WIW at the end of summer and by the re-intensification of the Northern current in the fall when atmospheric forcing increases the northern winds.

The interannual variability has shown that this situation of blocking has not been observed every year. In fact, the presence in this zone of more or less volume of WIW varies remarkably from one year to other. When there is little presence of WIW in the Ibiza channel, the Northern current progresses southward without problems, with only light disturbance caused by small eddies (temporary) and AW inflows. Then this current reaches the Ibiza channel and crosses it flowing southward along the continental slope. In this case, the Mallorca channel is the preferential path of AW in its progress to the north.

Some trends have been observed in relation to this interannual variability. The most remarkable trend happened during the period 1996-1998 and something similar happened during 1999-2001.

During 1996 WIW was observed in abundance in both channels. Later, a decrease of WIW volume associated with a progressive increase of the temperature (minimum) of the WIW core was observed from 1996 to 1998 (Fig. 1). At the same time, the northward transports of AW

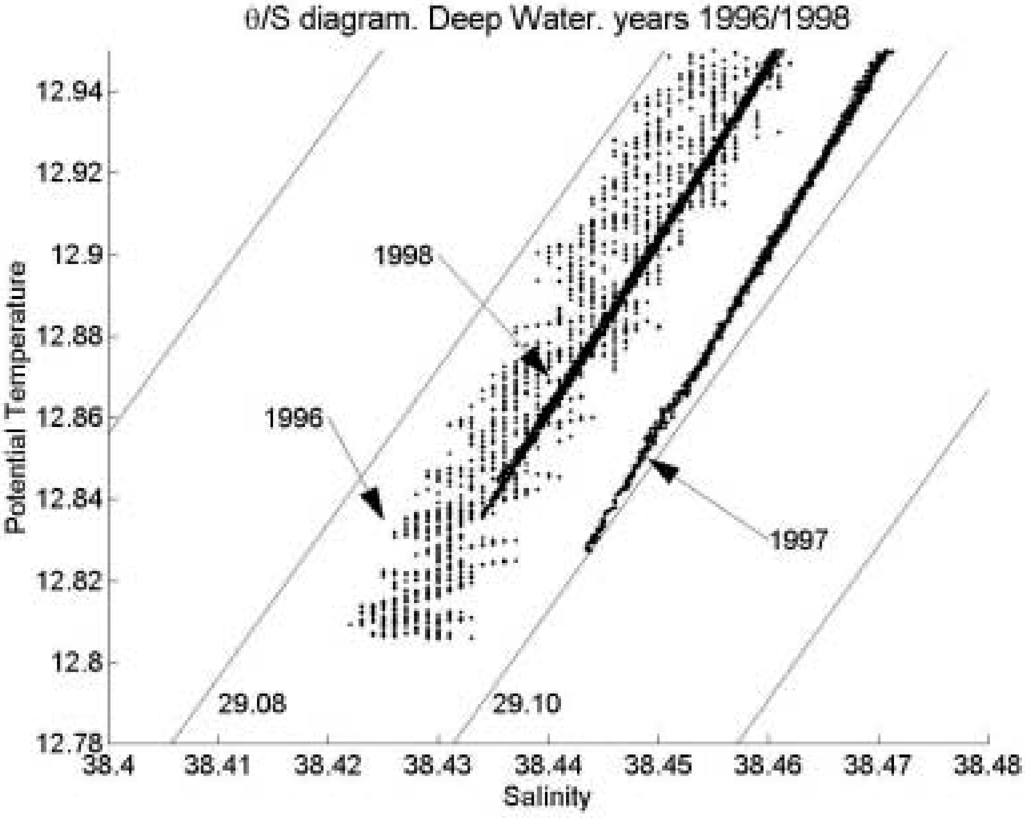

Fig.1. T-S diagrams from CTD stations in the channels area during May 1996, May 1997 and June of 1998.

through Mallorca channel have shown an increase from 1996 to 1998, which was not observed in Ibiza channel. It was followed by an increase of volume and decrease of temperature of WIW, from 1999 to 2000. During 2001 a very small presence of WIW was observed again, with values close to 13°C.

Other variability signals were also observed during these periods. Levantine Intermediate Water (LIW) was present with higher values of temperature and salinity than in 1996. Maximum values were recorded in 1998, probably enhanced by the lack of WIW. Concerning DW, extreme values closed to the isopycnal of 29.1 were recorded mainly during 1997, just one year after the presence of the largest amount of WIW sampled for the whole period (Fig 2). Probably the hard winter of 1996 induced formation of an important amount of DW with extreme values that reached Balearic deep areas within a year. Or it could be the result of mixing with LIW during 1996 caused by the pressure of WIW over them.

It seems that there is a closed connection between the climatological factors and dynamics of the Northern Mediterranean and the circulation regime in the Balearic channels. In the area of Balearic channels, severe winters are associated with large WIW volume and mild winters with small presence of this water. Consequently, WIW could be considered a valuable indicator of climatology and of Mediterranean interannual variability.

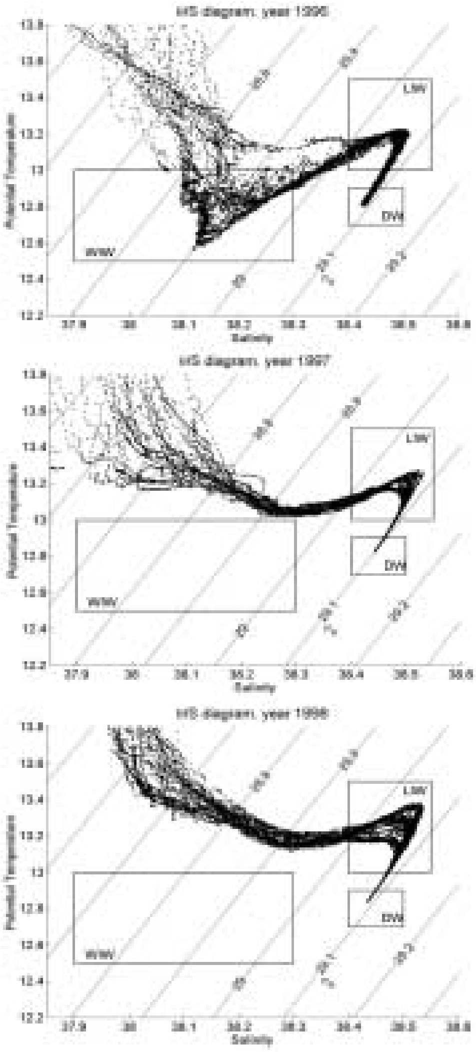

Figure 2 - T – S diagrams, DW details of the previous graphs.

The following list shows the WIW presence in recent years in the Balearic channel area and at lower latitudes in the Algerian basin:

1985	WIW was observed during survey BALEARES-0785 and 1085.
1986	WIW was observed in Algerian basin (Perkins H., and Pistek P., June 1986).
1987	WIW was observed during survey BALEARES-0387 and 0587.
1988	WIW was observed during survey BALEARES-0488 and 0688.
1989	??? no reference
1990	??? no reference
1991	WIW was observed during survey IBIZA-391, 0791
1992	WIW was observed during survey IBIZA-0692, 0792
1993	WIW was observed during survey IBIZA-0393, 0593, 0693
1994	??? no reference
1995	??? no reference
1996	WIW was observed during survey CANALES-0496, 0596, 0696, 0796
1997	no presence of WIW was observed
1998	no presence of WIW was observed
1999	WIW was observed during survey CANALES-0599
2000	WIW was observed during survey HERCULE-0500, CIRBAL-0900
2001	No presence of WIW was observed
2002	WIW was observed during survey CIRBAL-0302, just in a few stations into the Valencia gulf. We expect to find it later in the spring and summer into the channels.

In a wide sense, we could say that this period (1985-2002) is characterized by the presence of WIW, in spite of some lacks of data. Only critical years of 1997, 1998 and 2001 showed no presence of WIW.

During the last years, some studies were carried out in relation with the interannual variability of Deep Water formation. Mertens and Shott (1998) studied the period between 1968 to 1994. Our critical period (1996-1998) is out of this range, but there are good coincidences with our list, when WIW presence is associated with high losses of heat and the development of deeper mixed layer.

In a general sense, the interannual variability observed in the Balearic zone could cause changes in the trends of other parameters along the Spanish continental coast or hide these trends.

Physical historical data on the Ligurian Sea from the Villefranche-sur-mer Observatory

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The Oceanographic Observatory of Villefranche-sur mer (France) has a long expertise in monitoring the Ligurian Sea and the Bay of Villefranche in the field of physics and ecology. Weekly systematic series at standard depths were initiated in 1957 at a location, called Point B, at the mouth of the Bay of Villefranche, near Nice. Others followed since 1961, but less regularly, on the section Nice-Calvi. The majority of these series contain physical information about temperature and salinity, even if the objectives of the monitoring were often related to biological purposes. Certain analyses have been completed and are briefly reported here without exhaustive intention.

Béthoux *et al.* presented in 1980 a spectral analysis of temperature data at Point B. The study was performed on the 1957-1978 period, after substraction of the seasonal cycle which is dominant on the surface temperature. Several significant periods were found, mainly 2.5, 9 and 25 months, and a budget of the air-sea exchange in the Bay was presented. When the data base increased with time, a synthetic document was presented (Etienne *et al.*, 1991), with details on methodology and data. These data were interpreted using sophisticated statistical techniques by Ménard *et al.* (1994), Buecher *et al.* (1997), Buecher (1999) for example, to understand the annual changes of macroplankton abundance. Over the 27 years analysed (1966-1993), the years 1967 to 1984 were identified as a “cold period”. 1975 and 1980 were the coldest years in contrast with 1990, the warmest. The period 1985-1993 corresponded to a warm period. Salinity fluctuations showed similar trends. From 1967 to 1974 and from 1977 to 1979, salinities were generally below the mean values, whereas 1975 to 1976 and 1980 to 1983 were hypersaline periods.

The Ligurian Sea has been also investigated since 1961, but often irregularly. Water masses were first fully described by Gostan (1968) and Gostan and Nival (1967). The section Nice-Calvi was visited on a monthly basis, through the Hydrokor program (1969-1974), to describe the seasonal cycle. Nyffeler *et al.* (1980) published a document on the mean properties of water masses as indicated by bottle data obtained before 1980, while Béthoux and Prieur (1983) made a synthetic presentation of the hydrology of the Ligurian Sea. Studies were intensified after 1981, using CTD from the Observatory of Villefranche, mainly on the area between the coast and the central part of the Ligurian sea 25 miles offshore. These observations aimed to determine the fluctuation of the Ligurian current (Béthoux and Prieur, 1982, 1988; Sammari *et al.*, 1995; Alberola *et al.*,1995) and the hydrobiological processes in action near the geostrophical front associated with this important flow (Boucher *et al.*, 1987; Sournia *et al.*, 1990; Gorsky *et al.*, 1991; Andersen and Prieur, 2000). Systematic CTD measurements were pursued on the section after 1990 in association with biological sampling. By using some of these data and data from other parts of the Northwestern Mediterranean, Béthoux *et al.* (1998) found that deep water increased significantly in temperature and salinity and studied a possible link to the greenhouse effect.

These systematic observations initiated two new programmes supported by the French government agency INSU. One (DYFAMED) started in 1992 and concerns a monthly survey at a station 28 miles off Nice. The other concerns the weekly visit of Point B with a CTD. In this framework the data are put regularly on the observatory web site <www.oceane.obs-vlfr.fr> ("dyfamed" and "rade" services). Bibliography on related works will soon be found there.

In addition, under my responsibility, the INSU operates since 1998 a service consisting in the collection of ADCP (0-150 m) , surface temperature and salinity from the R.V. *Tethys II*. This database, mainly related to the French Mediterranean coast is also be briefly presented on web : <www.dt.insu.cnrs.fr/adcp/adcp. html>.

Recently, we undertook to harmonize all these physical (CTD) data in order to detect inter-annual variations, up to decadal, in connection with weather data and global change. Some unpublished preliminary results are shown as example. The 3597 CTD cast locations, available since 1981 are shown in Figure 1. Point B is situated near Nice at 80 m depth. The Dyfamed site is located 28 miles off Cap Ferrat. The section between Nice and Dyfamed was the most visited. Figure 2 (lower panel) shows the monthly mean air temperature from the Cap Ferrat meteorological station and the weekly mean sea surface temperature for the period 1966-2000 and 1957-2000 respectively. These climatic means were subtracted to

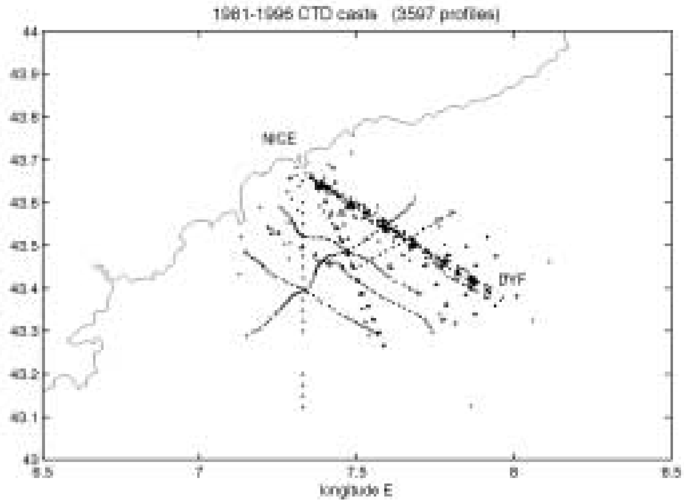

Fig. 1. Geographical location of the CTD casts available in the data base.

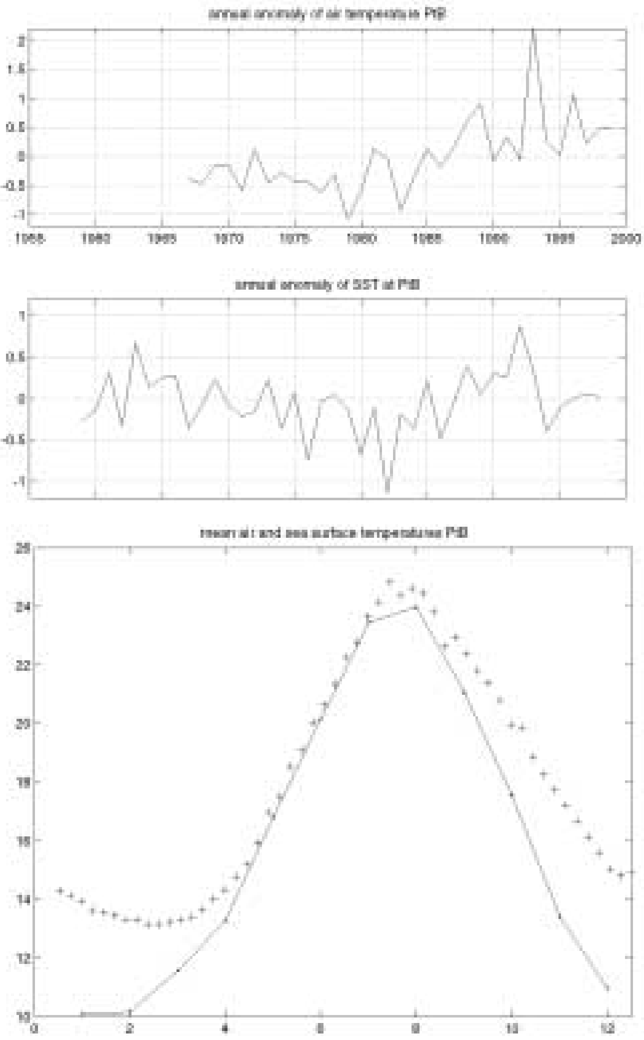

Fig. 2. Monthly mean temperature of air (line) and sea surface (+) at Point B for the period 1955-2000, lower panel. Upper and middle panels, annual mean of air and sea surface anomaly respectively.

the original data to constitute the so called temperature series anomalies. Then these anomalies were averaged each year and results are presented for air (upper panel) and sea surface temperature (middle panel). This simple data processing is sufficient to see the long term change of air and surface temperature at the mouth of Villefranche Bay. A more sophisticated processing, based on spectral analysis, gave similar results on long term tendency, where the cold period (1975-1985) is retrieved. The years after 1990 look like the hottest, but a certain tendency toward normal mean annual temperature can be seen. The same pattern, although less marked, is also found on the mean 0-10 m temperature layer in the central part of the Ligurian sea, where irregular sampling prevents simple spectral analysis (Fig. 3). When the anomalies were standardized by the monthly standard deviation, the similitude was more evident.

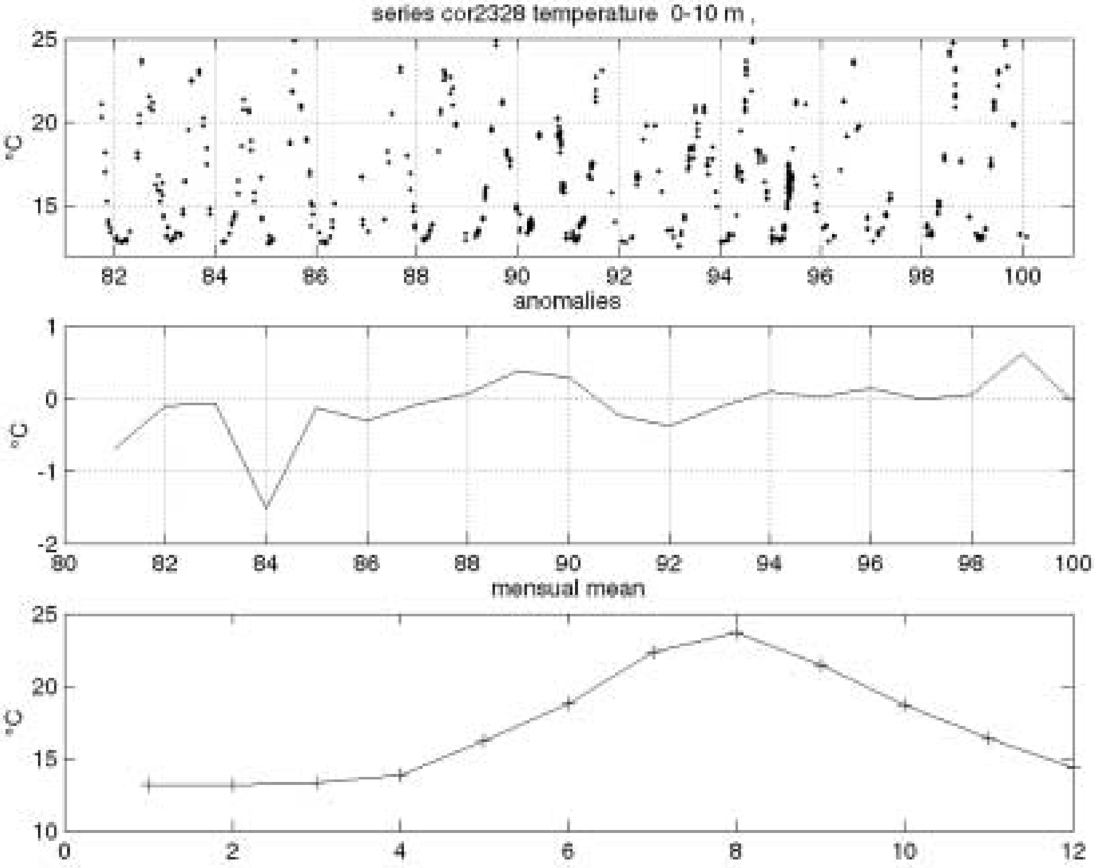

Fig. 3. Sea surface temperature in the central part of the Ligurian sea at 23 and 28 miles off the coastline. Upper panel: 0-10 m layer, averaged temperature for the period 1981-2000. Middle, annual mean anomaly The years are noted 81 to 100. Lower panel: monthly mean temperature for the same period..

Detection of annual trends can be dependent of the year period considered. As example the 0-75 m averaged temperature, weekly acquired at Point B is presented Figure 4. The smoothed curve corresponds to the 3 years Butterworth filtering of all data points, and the angular curve to the annual mean temperature of only first 3 months of each year. A near one degree increase is only detected when winter data are considered.

Interpretation of these results is yet in progress but will be discussed. These examples were chosen to show that long term, high frequency series, even close to shore, can bring information on the long term climatic change.

During the meeting, some questions were arose about the significance of small changes in temperature exhibited by trends when the surface temperature is yearly cycling on more than ten degrees. In addition to the classical spectral analysis, there are statistic techniques to evaluate the

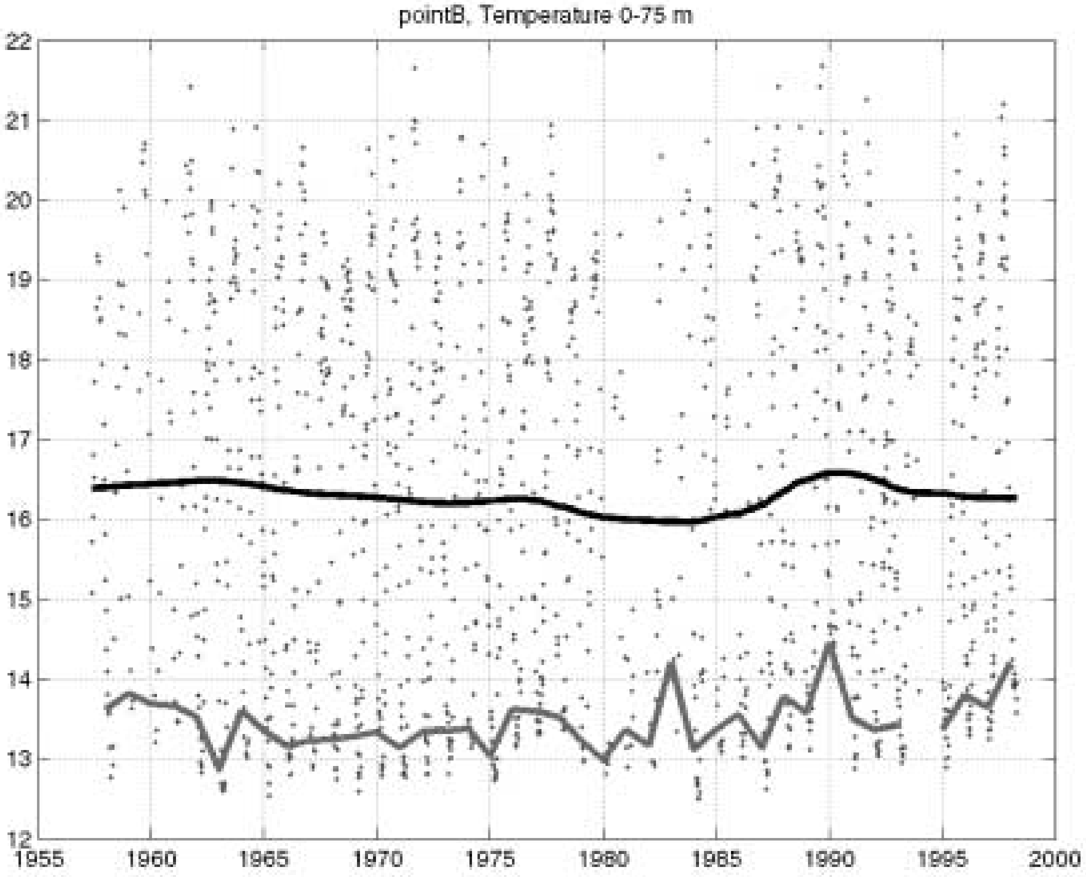

Fig. 4. 0-75 m depth averaged temperature at point B for the 1957-2000 period. Dots correspond to the weekly measured temperature. The two thick lines correspond to 3 years lowpass

significance of trends in such a case, as the bootstrap or jackknife methods (Emery and Thomson, 1997). I have not yet applied this techniques to the presented data. Overall, we cannot assimilated the huge variance of the sea surface temperature to a noise, then it is due to the annual cycle. The issue is not simple, because variance in winter period is not the same as during summer period, for example, and also variance is frequency dependent. It is the reason why I am thinking that the statistic significance of the trend through the cited methods could be tractable.

Overview on the marine monitoring programs in the Mediterranean coast of Morocco

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Historically, Moroccan marine activities have been focused on the Atlantic coast, but in the last few years, the Mediterranean coast has become a priority for economic development. This renewal of interest requires a better understanding of the hydrological functioning of the coastal waters.

In fact, there is no properly hydrological monitoring program. This is not only due to the lack of facilities and to the limited funds dedicated to marine *in situ* analysis, but also to the fact that the benefits of such activities are not immediately obvious for decision-makers.

The few existing studies on the Mediterranean coast were realized for specific issues (construction of ports or jetties, aquaculture, etc.) so data available are often scattered in time, and do not provide valuable information on potential trends.

Nevertheless, some marine monitoring programs which could be of interest to the workshop objectives are currently conducted by the following institutions.

1 – The National Institute for Fisheries (INRH)

The institute encompasses:

- three scientific departments at the main office in Casablanca:
  - Department of Living Resources
  - Department of Oceanography and Aquaculture
  - Department of Quality and Health of Marine Environment
- several laboratories around the Moroccan coast; three of them are on the Mediterranean shore: Nador, M’diq and Tangiers. Each of these laboratories has its own monitoring programme mainly focused on fisheries, but two of them assess the contamination levels in coastal waters, monitor the health of the ecosystems and serve as warning system in case of occurrence of red tides or toxic algal blooms.
- two research vessels equipped with CTD.

As member of the MEDAR-MEDATLAS project, the INRH has compiled and safeguarded existing data sets which will be published in the coming months on the MEDAR CDRom (Maillard, this volume).

2- The Royal Navy Hydrographic Service

The current mission of this service is to update the hydrography mainly in ports, and to edit the yearly tide table. Occasionally, for specific investigations, punctual oceanographic parameters are measured during the cruises.

3- The Administration in charge of the land cartography (ACFCC)

To update its leveling network, calibrate and get good zero references, ACFCC has set up 2 tide gauges, one in Casablanca (Atlantic) and the other in Al Hoceima (Mediterranean) in last September. The 2 gauges are now operational. Data are processed by ACFCC with SHOM softwares.

4- The Ports Directorate

Activity focuses on :

- port dredging;
- monitoring the quality of bathing waters; the microbiologic quality of 73 coastal Mediterranean stations is monitored yearly;
- improving coastal management tools.

5- The National Meteorology Directorate (NMD)

One of the NMD tasks consists in meteorological assistance to maritime activities. Two stations of observation and maritime information have been set up on the Mediterranean coast at Nador and Al Hoceima. The NMD plans to install other stations along the coast within the next decade. The following are some of recent and on-going projects:

- numerical forecast Development Project : started in 1991, the model is called ALADIN and is a product of multilateral cooperation between Morocco and some European countries;
- seasonal forecast : the objective is to perform a long range precipitation forecast mainly based on SST variability;
- Al Moubarak Project, which is based on the relationship between the precipitations and the North Atlantic Oscillation.

6- The Department of Environment

The main current project of this department, which is the Focal Point of the Mediterranean Action Plan (UNEP/MAP) is the monitoring of the pollution levels in the marine and coastal environments (MEDPOL Program), in order to develop sound management approaches and cleanup strategies. 72 stations are sampled seasonally and the monitored parameters are the chemical and biological pollutants in sewages, river and marine waters, sediments and organisms.

7- Universities and research institutes

Universities undertake education and research in marine biology, environmental and ecological studies, geological, chemical and physical oceanography, including numerical modelling, remote sensing and GIS. However, many of them suffer from a lack of facilities and skilled technicians. Apart the involvement of some scientists in EU or international (MEDPOL, MEDGOOS, etc.) projects, there is no hydrological monitoring activities conducted by the universities.

CONCLUSION

Even if there is no current hydrological monitoring program in Morocco, many elements are in place to initiate a concerted effort for studying the future trends by producing long time series of basic oceanographic observations like temperature, salinity, dissolved oxygen and nutrients.

Such an initiative should on one hand fill the gaps where data are lacking, by measuring seasonally hydrological parameters along on-off shore transects, and on the other hand, concentrate in the understanding of the role of the strait of Gibraltar by keeping a continuous monitoring of different fluxes (water, heat and salt) occurring through it, since it represents the only connection of the Mediterranean to the world ocean. Indeed, the published results of all experiments and studies have shown that straits are to be considered observationally and dynamically strategic, and as privileged places for the comparison/check for the general circulation models (Manalotte-Rizzoli, Millot, this volume). There is therefore a strong interest to join the Mediterranean network proposed in the framework of the Monitoring Hydrological Trends Project, under the CIESM umbrella.

In Morocco, such a research direction will require close collaboration between different national bodies, and specially between scientists and the Hydrographic Service of the Royal Navy. In addition to the scientific criterion, this could be an excellent opportunity to upgrade and strengthen the Moroccan capacities in marine hydrology, and to be fully involved in a Mediterranean scientific network.

Experimental evidence of the interannual variability of currents in two Mediterranean straits : the Strait of Sicily and the Corsica Channel

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INTRODUCTION

Starting from the '90s substantial progress has been made in the observation and understanding of the interannual variability in the Mediterranean Sea. All studies evidence that the Mediterranean is far from stationary and is very sensitive to large scale atmospheric changes, to which it responds very fast compared to the oceans.

Some experimental investigations described the interannual variability of the hydrographic characteristics at the basin and sub-basin scale (Roether *et al.*, 1995; Malanotte-Rizzoli *et al.*, 1999; Astraldi *et al.*, 2002a). However, the poor time series makes it difficult to follow the time evolution of the internal features and the reasons for their changes. Conversely, there are a few long-term observations of the Mediterranean currents, with a time sampling capable of providing a quantitative estimate of the interannual variability of the circulation pattern.

The Mediterranean is composed of several sub-basins separated by straits and channels that may become suitable observational places for the monitoring of the internal circulation (Astraldi *et al.*, 1999). Taking advantage of this structure, long term current observations were initiated in the Strait of Sicily and the Corsica Channel (Fig. 1). They have allowed the collection of significant information on the interannual variability of the water transport and its relationship with the large-scale atmospheric regime.

THE SICILY STRAIT

The two western sills of the Sicily Channel are monitored since November 1993 by two current meter moorings. Four instruments in each position permit to measure the surface current of MAW, directed toward

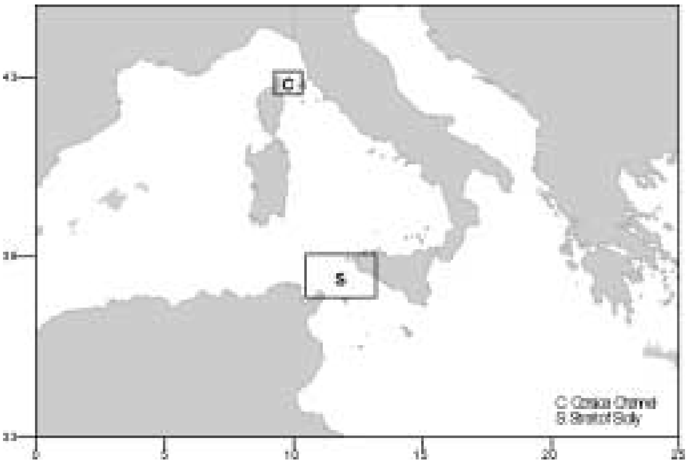
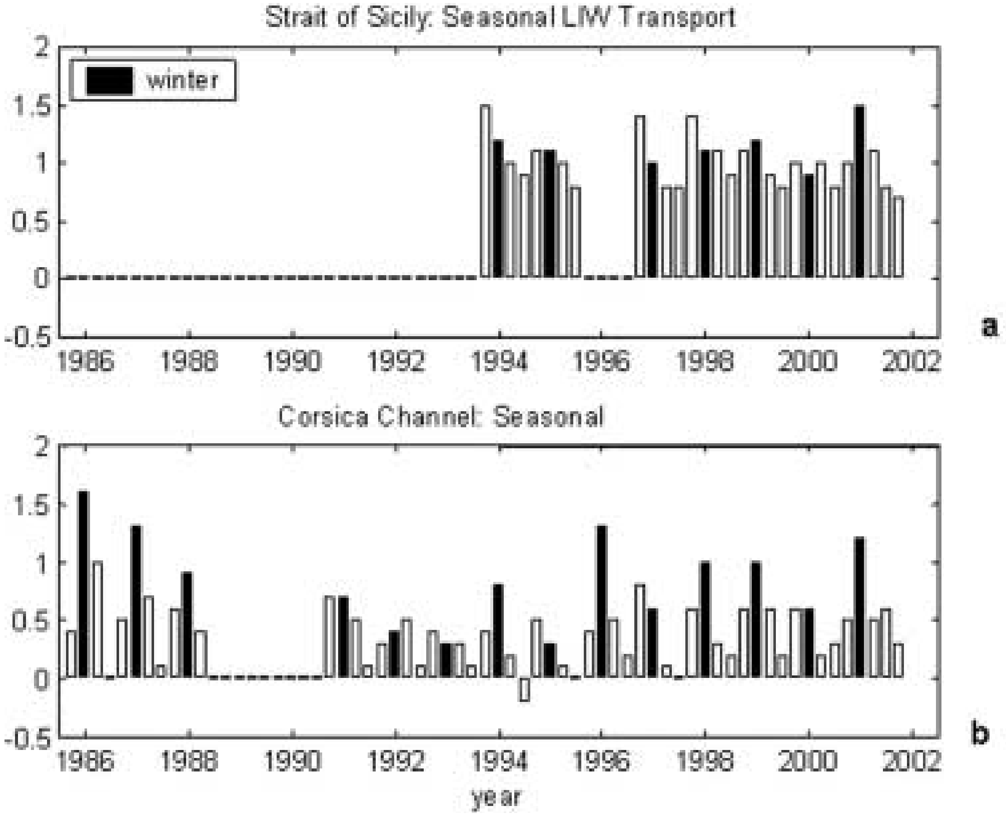


Fig. 1. Study area

the eastern basin, and the intermediate and bottom current directed toward the western. Due to the local topographic configuration, the flux of MAW spreads all over the Channel region, and this makes difficult a satisfactory computation of the surface transport. In contrast, we could retrieve a quite satisfactory estimation of the LIW transport, as the region involved with it is very narrow.

From the monthly evolution of LIW flux we have detected a mean transport of 1±0.25, thus evidencing that the mean value largely prevails on the seasonal and interannual variability (Fig. 2a). The annual cycle shows higher fluxes from November to February, while a minimum is observed in August. There is also a secondary minimum in May. A stable background flux of 0.7 Sv at least, can be observed year round.

Examining the interannual variability, the most intense winter flux is found in 1993-94, 1997-98 and mostly in 2000-2001. The weakest transport values occurred in 1999-2000. In terms of kinetic energy (KE), 94% is due to the mean flow, 3% to the annual cycle and 3% to the interannual variability.


Strait of Sicily: Seasonal LIW Transport

Corsica Channel: Seasonal

Fig. 2: Seasonal water fluxes

THE CORSICA CHANNEL

The flux in the Corsica Channel has been monitored since 1985. It controls the exchanges between the Tyrrhenian and the Ligurian seas and is especially sensible to the imbalance to the two basins during the cold season (Astraldi and Gasparini, 1992). The mean flux (0.49 Sv) and its variability (sd=0.42) are of the same magnitude (Fig. 2b). The current, quasi-permanently flowing from the Tyrrhenian to the Ligurian sea, has an evident seasonal cycle, with the highest values in winter and the lowest in summer. The seasonal cycle is a very stable feature and explains most of the flux variability. In terms of kinetic energy, the mean flux accounts for about 58%, while the annual cycle and the interannual variability are nearly of the same order (21%). The highest flux values were observed during the 1980s, while the lowest occurred in the first half of the 1990s.

THE WATER FLUXES AND THE NAO

While the influence of North Atlantic Oscillation (NAO) on Europe climate is well established, its effects on the Mediterranean Region are still mater of discussion. Recent studies have shown that the Mediterranean is subjected to different large-scale systems (Hurrel, 1995; Raicich *et al.*, 2001; Mariotti *et al.*, 2002) and the NAO seems to be mostly active in the northern part of it (Pozo-Vasquez *et al.*, 2001). Vignudelli *et al.* (1999) show that the influence on marine system is exerted through the intermediary of the atmospheric parameters, such as those determining the basin heat budget, whose variability modulates the interannual changes of marine circulation. A comparison of flux in the Corsica Channel and the NAO during the winter period shows that significant increases/decreases of flux from the Tyrrhenian to the Ligurian seas are connected with significant negative/positive values of the NAO index (Fig. 3).

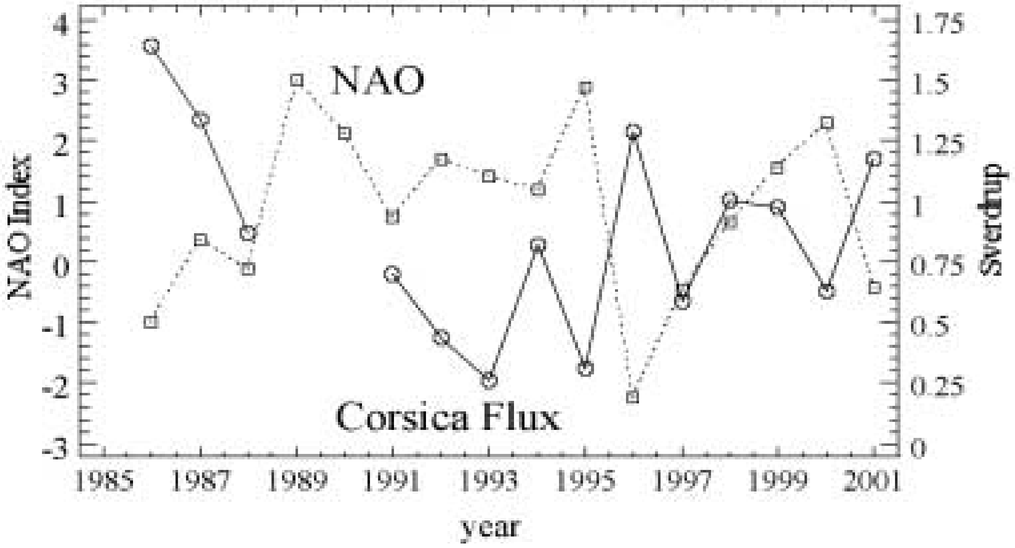


Fig. 3. Winter Mean values of Water Flux (continuous line) and NAO index (dashed line)

The relatively short length of flux time series prevents any further analysis of relationship between different levels assumed by NAO index and the corresponding flux. Yet, if one examines the winter interannual variability of the regional air temperature from 1865 to 1999, a non-linear relationship with the NAO index can be evidenced and we may expect a significant influence of the NAO when the monthly index is greater than 1.5 or lower than –1.5 (Fig. 4).

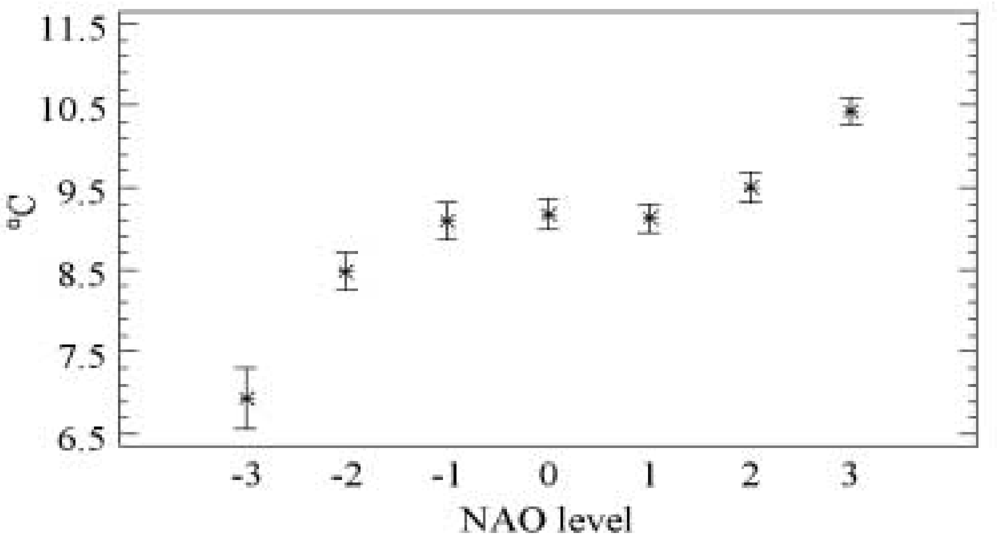


Fig. 4.Winter mean values and associated error bar for Genova air temperature, grouped considering 7 different levels of NAO index. The examined period is 1865-1999.

The existence of a relationship between NAO and the flux in the Sicily Strait is not so evident. This is certainly due to the shorter length of the time series existing there and from the reduced seasonal and interannual flux variability (Fig. 2), but it also depends from the largely unknown interaction between the eastern and western Mediterranean dynamics.

Acknowledgements. Genoa air temperature has been kindly provided by the Meteorological Observatory of University of Genoa.

Hydrographic and chemical time series in the central Mediterranean: a sensitivity test for long-term changes in the Mediterranean Sea

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A sequence of 11 oceanographic campaigns carried out from 1993 to 1999 in the Central Mediterranean (CM), between the Sardinia Channel (A), the Sicily Strait (B) and the wide passage between Sicily and Sardinia (C), allowed us to measure the basic physical and chemical parameters of water masses exchanged between the Eastern (EM) and the Western (WM) Mediterranean (Fig.1). The leading idea was that this may provide information on the processes affecting water masses in each basin and give, at the same time, appropriate elements for the comprehension of the effects generated by them in the adjacent one. An important role on this is played by local topography, in particular the different depths at the boundary sections. While in the Sardinia Channel the sill is at about 1900 m, allowing the free exchange of deep waters with

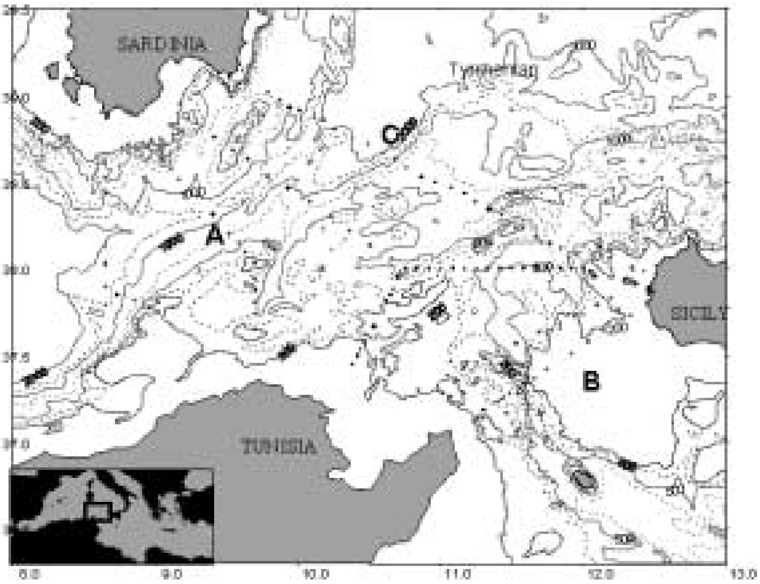

Fig. 1. The Central Mediterranean Region.

the WM, in the Sicily Strait the deeper sill is at about 430 m, thus posing strong constraints to the exchanges with the EM. Finally, in the Sicily-Sardinia section two main canyons are present, separated by an irregular plateau. The deeper canyon, in the central part, connects the Tyrrhenian with the Sardinia Channel and the WM, while the other, adjacent to the Sicilian slope, connects with an increasing depth, the Sicily Strait with the Tyrrhenian Sea.

The hydrographic data obtained from the different campaigns indicate a consistent pattern for water masses exchanged at depth between the EM and the WM (Astraldi *et al.*, 2002a). From the former basin, the well-known LIW and EOW – also known as tEMDW (Pollack, 1951) – flow into the CM. EOW is formed by the waters from the top part of the deeper layer in the Ionian that are sucked through the shallow sills of the Sicily Channel. Being denser than the local waters, EOW always flows at the bottom of the CM (Astraldi *et al.*, 2001). After passing the Sicily Strait, the LIW and EOW waters enter the Tyrrhenian following separate ways. While a part of LIW outflows again from this basin with a stream directed towards the WM in correspondence of the central canyon, EOW continues its sinking at the Tyrrhenian entry as far as a buoyancy equilibrium is reached at about 1500-1800m of depth. Below LIW, another stream leaves the Tyrrhenian, occupying most of the central canyon: this is the TDW, formed by the mixing of LIW and WMDW. A vein of WMDW heading the Tyrrhenian was actually observed at the bottom of the Sardinia Channel and the Sicily-Sardinia passage. It was superimposed, at intermediate depths, by another stream, whose depth and hydrographic properties are consistent with those of an old LIW coming from the WM. Both EOW and the old LIW then likely participate to the formation processes of TDW.

Table I reports the indicative reference values of the hydrographic and the chemical properties of the different water masses in the various positions of the CM (Astraldi *et al.*, 2002b). Besides the usual thermohaline properties, each of them can be defined on the basis of specific chemical parameters. It is worth noticing the minimum DO values of waters coming from the EM, in particular EOW. In contrast, the highest DO values are associated with WMDW. Finally, significantly higher values of silicate and nutrients affect water masses coming from the WM, in particular WMDW. In case of uncertainty, this may help for an easier identification of their origin.

Table I. Reference values or ranges for the hydrographic properties of different water masses in the CM.

Water mass	**θ (C)**	**S**	**γ_θ(kg m^{-3})**	**DO(μmol·dm^{-3})**	**NO_3 (μmol·dm^{-3})**	**SiO_2(μmol·dm^{-3})**
Old LIW	13.2-13.5	38.58-38.60	29.07-29.08	186-190	7.0-7.5	
LIW east	13.6-14.4	38.68-38.76	28.95-29.14	189-198	5.4 ±0.7	5.8 ± 1.1
LIW central	13.45-13.9	38.60-38.68	29.0-29.1	178-190	6.5 ± 0.9	6.6 ± 1.1
LIW west	13.6-13.9	38.55-38.68	29.02-29.10	186-190	6.3 ± 0.9	6.4 ± 1.0
EOW	13.6	<38.74	>29.14	<190	5.8 ± 0.3	7.4 ± 0.4
TDW	13.1313.15.15	38.50-38.56	29.10-29.11	<194	7.5 ±0.5	8.1 ± 1.3
WMDW	12.81	38.44	29.10-29.11	>194	7.9 ± 0.4	8.5 ± 0.2

Astraldi *et al.* (2002) showed that both temperature and salinity of the deep waters outflowing from the Sicily Strait decreased significantly, producing an increase of the water density. This tendency seems to subside in the final period, when both parameters approached again the original values. They concluded that these changes are consistent with the progressive uplifting induced by the transient in the deep waters of the Ionian Sea, and interpreted the final inversion as a possible relaxation of the structure responsible for this state.

To verify the impact caused by this oscillation in the Tyrrhenian Sea, the time evolution of water properties at three specific depth ranges in the central part of the Sicily-Sardinia section was considered: 400-500m (core of LIW), 1000-1500m (core of TDW) and 1900m (inflow of WMDW). From Fig. 2 we can see that, while the LIW properties show a decreasing tendency similar to the one in the Sicily Strait, T and S around the TDW core increased significantly throughout the whole period. The weak positive trend at the sea bottom is consistent with the one identified by Béthoux (1990) and other authors in the deep waters of the WM.

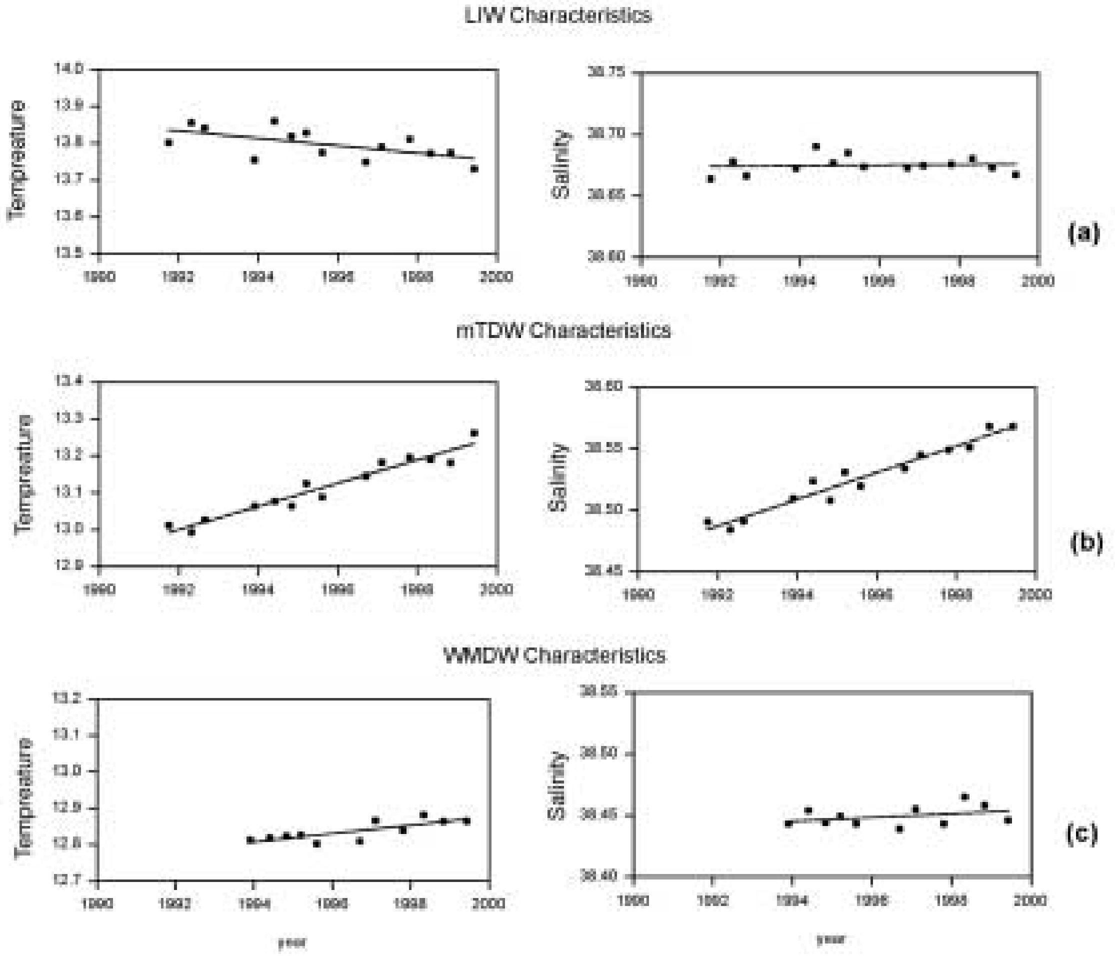

Fig. 2. Time evolution of T and S between 400-500m of depth (a), 1000-1500 m (b) and 2000 m in the central canyon of the Sicily-Sardinia section.

We explained the increasing trend at intermediate depths as the consequence of the sinking process undergone by EOW at the Tyrrhenian entry. This produces a continuous input of warmer and saltier waters as deep as about 1500 m which contributes to raise the heat and salt content of the water column. The largest effects then happen at the buoyancy equilibrium, where EOW is totally mixed with the resident waters. We can also presume that this mechanism may be enhanced in the presence of denser waters, like those observed during our measurements in the Sicily Strait, because of their tendency to deepen at major depths, where the local T and S are even lower. It is worth noticing, in this regard, that the density of EOW crossing the Sicily Strait increased from ~29.10 (Garzoli and Maillard, 1976) to ~29.16 (our data), due to the climatic transient.

Zodiatis and Gasparini (1996) observed the effects of this process in the stepped structure steadily present in the southern Tyrrhenian Sea. The historical data in that region associated with our data set (Fig. 3) show that, until 1992, a gradient of $5 \bullet 10^{-3}$ °C/y and $2 \bullet 10^{-3}$ psu/y affected the water layer between 1450 and 1500 m deep. It is interesting to observe that this trend is of the same order of the one observed in the WMDW by different authors (Béthoux *et al.*, 1990; Rohling and Bryden, 1992; Krahman and Schott, 1998). After that date, substantial modifications appear that can be connected with the arrival of the new denser waters associated with the transient. The new signal manifests itself with a sudden jump of T and S, whose gradients are now to $3 \bullet 10^{-2}$ °C and $1 \bullet 10^{-2}$ psu/y, respectively.

In conclusion, the hydrographic data set collected from 1993 to 1999 allows us to claim that the CM is crucial for the monitoring of water masses exchanged between the EM and the WM,

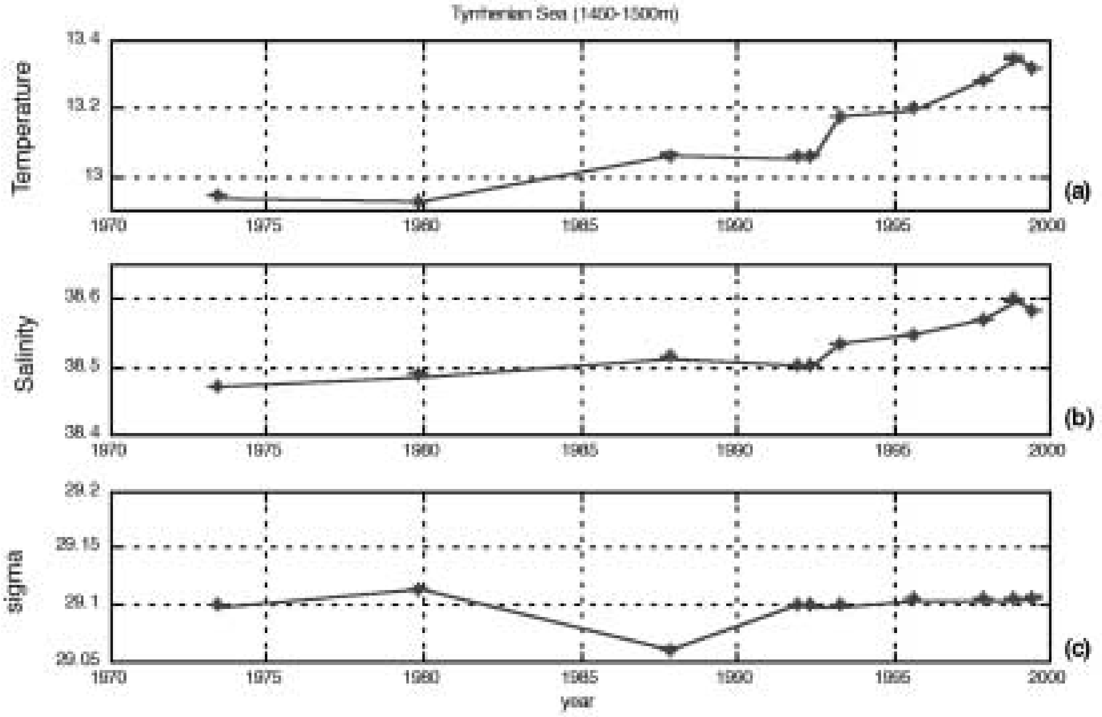

Fig. 3. Time evolution of Potential Temperature (a), Salinity (b) and density (c) in the southern Tyrrhenian Sea, between 1450 and 1500 m of depth.

from which one can achieve information on the variability of principal processes affecting the two basins. In particular, we could observe that the TDW leaving the Tyrrhenian Sea towards the WM, is affected by a trend in T and S of the same order of the one affecting the deep waters of this basin. It was connected with the internal mechanisms regulating the outflow of the Levantine water in this region. The intensity of this trend appears to be modulated by significant modifications of the internal structure of the EM, such as those produced by the climatic transient.

The monitoring of the hydrographic characteristics in the CM and in the Tyrrhenian Sea is continuing, while we are studying the effects produced by the different processes on the chemical properties of the involved water masses.

Warming and salting of the Tyrrhenian Deep Water

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This presentation is part of a work by Fuda J.L., G. Etiope, C. Millot, P. Favali, M. Calcara, G. Smriglio and E. Boschi. Warming, salting and origin of the Tyrrhenian Deep Water, Geophysical Research Letters, *in press.*

ABSTRACT

Data collected from 1996 to 2001 down to 3,500 m in the Tyrrhenian sub-basin with ship-handled and moored instruments show 5-year trends (warming ~$1.6\text{x}10^{-2}$ °C/yr, salting ~$0.8\text{x}10^{-2}$ psu/yr) that are, to our knowledge, the largest ever evidenced in Mediterranean deep waters.

INTRODUCTION

Warming and salting trends in deep Mediterranean waters have been reported in the last decade. At ~2,000 m, WMDW warming and salting were evaluated at 8.2 x 10^{-4} °C/yr | 3.0 x 10^{-4} psu/yr (1909-1955) and 1.6 x 10^{-3} °C/yr | 9.4 x 10^{-4} psu/yr (1955-1989) (Rohling and Bryden, 1992), at 3.5 x 10^{-3} °C/yr | 1.1 x 10^{-3} psu/yr (1959-1996) (Béthoux and Gentili, 1999), and at 1.6 x 10^{-3} °C/yr | 8.0 x 10^{-4} psu/yr (1960-1995) (Krahmann and Schott, 1998). Note that even though trend values should refer to a relatively long time-scale, /yr is used hereafter to be consistent with already published values. The accentuation of WMDW trends starting in the early 60s has been linked to climatic changes and/or anthropogenic environmental modifications (Béthoux *et al.*, 1990; Leaman and Schott, 1991; Rohling and Bryden, 1992; Krahmann and Schott, 1998; Béthoux and Gentili, 1999; Ross *et al.*, 2000; Boscolo and Bryden, 2001). In the Tyrrhenian sub-basin, increases of 1.9 x 10^{-2} °C/yr | 5.0 x 10^{-3} psu/yr (1973-1992) were reported for the 600-1,500 m layer (Zodiatis and Gasparini, 1996). At ~3,000 m, warming trends of 2.1 x 10^{-3} °C/yr and 1.2 x 10^{-3} °C/yr (1960-1991) were also evidenced (Tsimplis and Baker, 2000) in the deep Ionian and Levantine sub-basins, respectively.

Trends have been looked for at surface and intermediate levels. Data collected at a single station near 42°03'N-03°15'E from 1973 to 1994 by Pascual *et al.* (1995) evidence trends of 3.5 x 10^{-2} °C/yr at the surface and 2.0 x 10^{-2} °C/yr at 80 m. Trends for AW in the whole Liguro-Provençal sub-basin were evaluated at 4.3 x 10^{-3} psu/yr with no significant change in temperature (1960-1995) by Krahmann and Schott (1998). A major conclusion of these authors is the non-existence of significant trends at the LIW level (250-500 m) in the whole Western Mediterranean basin that, according to them, "*excludes eastern Mediterranean sources for the deep -western- trends as speculated by Rohling and Bryden (1992) and Leaman and Schott (1991)*". Also to be noticed is that the ~10-year old changes in the deep Eastern Mediterranean (known as "the Transient"; Roether *et al.*, 1996; Lascaratos *et al.*, 1999) have not altered markedly the T-S characteristics of the LIW (Roether *et al.*, 1998).

Since 1996, the abyssal surroundings of Ustica Island (southern Tyrrhenian Sea) are surveyed, as complementary investigations to the deployment of a long-term multiparametric deep-sea observatory, the European GEophysical and Oceanographic STation for Abyssal Research - GEOSTAR (Beranzoli *et al.*, 2000). In this work we report deep-sea data sets from CTD's and thermistors moored during several-month campaigns and from CTD casts performed at the same site during the last decade. These temperature and salinity records represent the first significant data set concerning a watermass, the Tyrrhenian Deep Water (TDW), which had not been extensively studied yet, and whose characteristics were previously inferred from various hypotheses (Hopkins, 1988; Millot, 1999) that have been reconsidered in the entire paper (Fuda *et al.*, 2002).

EVIDENCE FOR THE TDW WARMING AND SALTING

From June 1999 to February 2000, a Seabird SBE16 CTD (nominal accuracy-stability/month of 5 x 10^{-3}-2 x 10^{-4} °C | 5 x 10^{-4}-3 x 10^{-4} S/m, equipped with a pump and a quartz pressure sensor) was moored at 38°54'N-13°19'E, 10 m above seafloor about 25 km north-east of Ustica island (Fig. 1). Calibrations of temperature and conductivity sensors performed by the manufacturer in February 1996 and March 2000 indicate no significant drifts and guarantees the values accuracy. Both θ and S display some seasonal or interannual variability and unexpectedly large trends estimated to be, from a linear regression, 2.9 x 10^{-2} °C/yr ($r^2 = 0.91$) and 1.0 x 10^{-2} psu/yr ($r^2 = 0.82$) (Fig. 2a). The pressure sensor indicated a 3,504-dbar mean value with no drift (it also evidenced tidal signals having few-mm amplitude). A classical RCM8 Aanderaa current meter set ~15 metres above seafloor confirmed the temperature trend and indicated a current smoothly veering from east to south with an average speed of few cm/s.

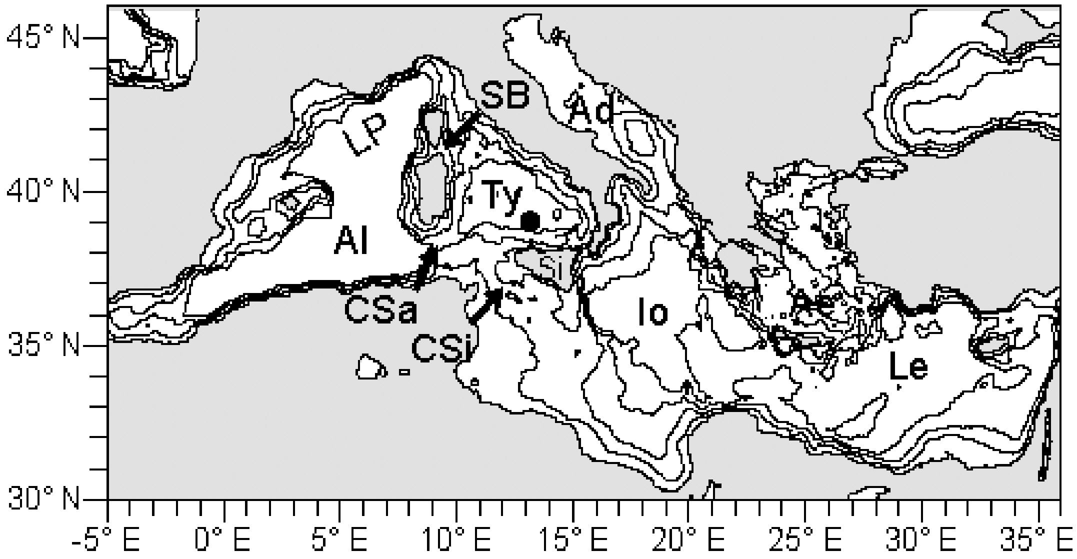

Fig. 1. Bathymetric map (isbaths 200, 1,000, 2,000 and 3,000). The position of the moored instruments and of the 1996/2000 CDT casts is indicated by the full circle.

From December 2000 to October 2001, a more complex mooring was set exactly at the same place. A RCM8 Aanderaa current meter modified, according to the manufacturer's specifications, to get a temperature resolution of 2 x 10^{-3} °C, was set at 10 m above seafloor (3504-dbar nominal pressure). A Seabird SBE37 CTD (nominal accuracy-stability/month of 2 x 10^{-3}-2 x 10^{-4} °C | 3 x 10^{-4}-3 x 10-4 S/m, both sensors calibrated by the manufacturer in November 2000; equipped with a pump) was set at a 3406-dbar nominal pressure. A Seabird SBE39 temperature recorder (accuracy-stability/month of 2x 10^{-3}-2 x 10^{-4} °C; calibrated by the manufacturer in November 2000) was set at a 3212-dbar nominal pressure. Another modified Aanderaa current meter was set at a 3115-dbar nominal pressure. All 4 instruments were inter-calibrated in the12-14°C range in our laboratory in December 2001. The almost perfect correlations between the SBE37 values and those from the three other instruments allow the definition of calibration curves having similar/

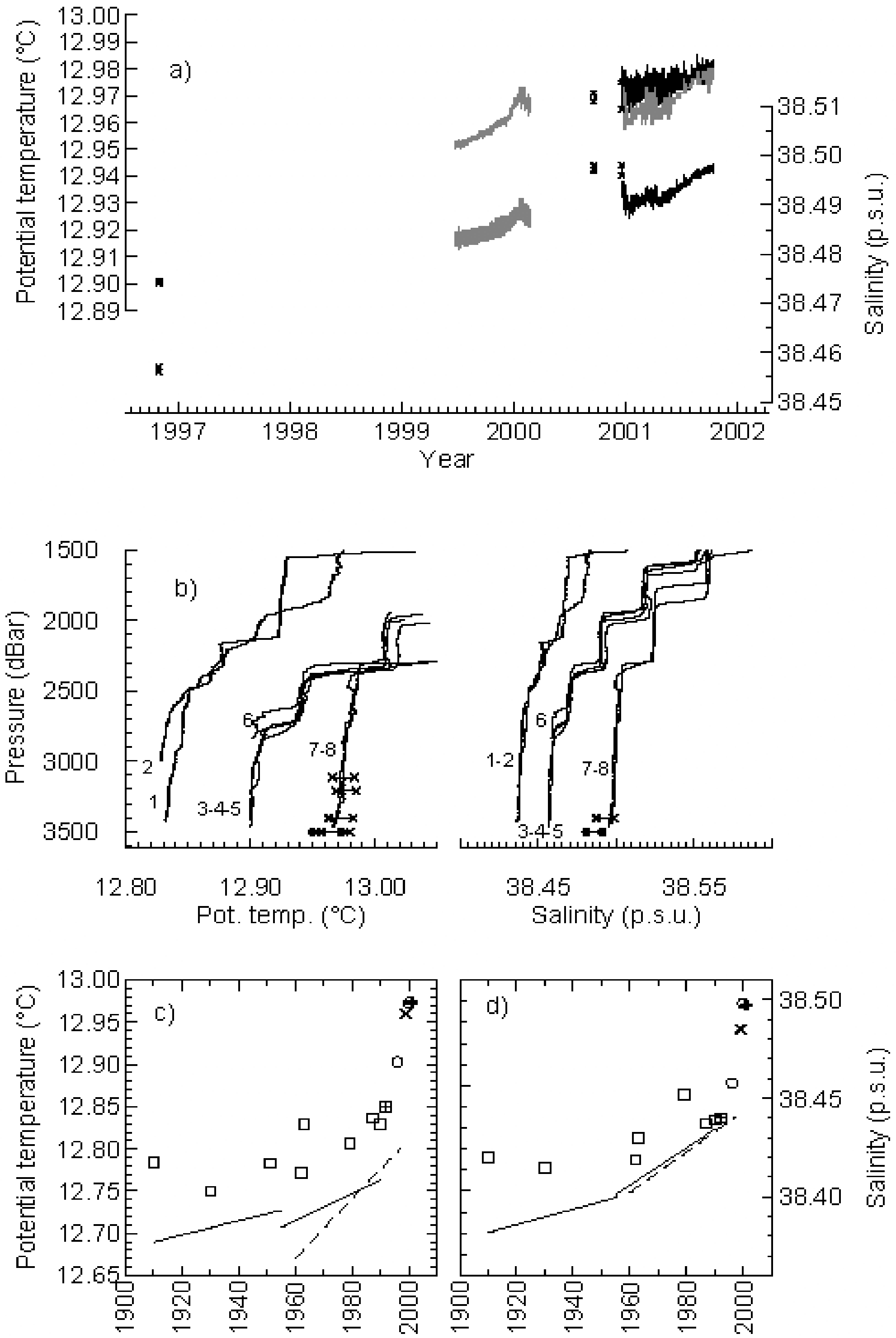

Fig. 2.(a) Time series of potential temperature (θ) and salinity (S) at 38°54'N-13°19'E: June 1999 to February 2000 from a SBE16 CTD moored at 3504 dbar; December 2000 to October 2001 from a RCM8 (3115 dbar), a SBE39 (3212 dbar), a SBE37 (3406 dbar) and a RCM8 (3504 dbar); time series at the same 3504 dbar level are in grey. θ and S intervals delimited by crosses represent the extreme values below 3115 dbar (the level of the uppermost time series) for the deepest October 1996 profile (down to 3470 dbar) and for the September 2000 (down to 3441 dbar) and December 2000 (down to 3470 dbar) profiles.

(b) θ and S profiles from the MEDATLAS data base at less than 20 nm from the moorings location in September 1987 (1) and March 1990 (2); profiles collected at less than 4 nm from the moorings location in October 1996 (3-6), September 2000 (7) and December 2000 (8).

(to continue)..../....

.../.... θ and S intervals delimited by full circles represent the extreme values of the June 1999-February 2000 time series whilst the intervals delimited by crosses represent the extreme values of the various December 2000-October 2001 time series (see Fig. 2a)
(c, d) Time evolution of the TDW characteristics. For a given year, θ and S values at depths $\geq$ 3,000 m within the Tyrrhenian sub-basin were averaged : MEDATLAS data (open squares), literature data for 1992 (crossed squares), data from October 1996 and September-December 2000 CTD casts (open circles). The "x" indicate average values of the June 1999-February 2000 times series. The "+" on **c)** indicates the average θ from all December 2000-October 2001 time series whilst the "+" on **d)** indicates the S average from the SBE37 time series only. Trends reported in the literature for WMDW in the Algero-Procençal sub-basin (i.e. Liguro-Provençal + Algerian) are represented by solid lines (Rohling and Bryden, 1992) and dashed lines (Béthoux and Gentili, 1999).

utmost accuracies. Even though the records in Fig.2a display significant seasonal/interannual variability (together with a varying temperature stratification), the trends previously evidenced are clearly confirmed (2.0 x 10^{-2} °C/yr (r^2 = 0.73) at 3504 dbar; 1.4 x 10^{-2} °C/yr (r^2=0.60) and 0.9 x 10^{-2} psu/yr (r^2 = 0.76) at 3406 dbar). The RCM8 set at ~10 m above seafloor indicated a current continuously veering from north-east to south and west while the one set at ~400 m above seafloor indicated an overall eastward current, both with average speeds of few cm/s.

A ship-handled Seabird SBE911+ CTD (temperature and conductivity sensors calibrated by the manufacturer in July 1996 and February 2000) was operated in the same area (less than 4 nautical miles from the moorings location) 4 years apart. The maximum and minimum values reported in Fig. 2a were measured below 3115 dbar (to provide information comparable to that from the moorings data) in October 1996 (considering the deepest – down to 3470 dbar – out of 4 profiles performed between the 19th and the 21st), in September 2000 (maximum pressure of 3441 dbar) and December 2000 (maximum pressure of 3470 dbar). The ship-handled CTD values are remarkably aligned with the moored CTD's and thermistors ones. From late 1996 to late 2001, the 5-year warming and salting can be estimated at 1.6 x 10^{-2} °C/yr and 0.8 x 10^{-2} psu/yr.

Complementary information about the temporal and spatial variations in the studied area is provided by Fig.2b. CTD profiles 1 (September 1987) and 2 (March 1990) are the sole recent ones in the MEDATLAS database (MEDATLAS Group, 1997) within 20 nautical miles from the moorings location. No trend (if any) can be evidenced over this 3-year period but deepest values are clearly <12.83 °C and <38.44 psu. Our four casts in October 1996 (profiles 3-6) evidence a clear homogeneity below ~2,800 m and deepest values near 12.900 °C and 38.455 psu whilst, in September-December 2000 (profiles 7-8), values deeper than ~2,400 m have increased near 12.970 °C and 38.495 psu. Minimum and maximum values from the instruments moored from June 1999 to February 2000 (full circles) and from December 2000 to October 2001 (crosses) are also plotted. Figure 2b provides evidence for trends that i) are significant at least since 1990 and ii) concern a relatively thick (more than ~1000 m) deep layer assumed to represent TDW.

Note that annual averages computed from the MEDATLAS database completed by 1992 data from Zodiatis and Gasparini (1996) reveal that the q and S of TDW at more than 3,000 m increased continuously during the 1960-1990 period, with relatively weak trends (1 x 10^{-3} °C/yr | 6 x 10^{-4} psu/yr), comparable to those already reported for WMDW (Fig. 2c-d). Our observations are thus consistent with the historical data and demonstrate that q and S have been increasing in the deep Tyrrhenian sub-basin for several decades, especially the latter, during which the θ-S trends appear one order of magnitude greater than before and than those already reported for the other deep Mediterranean sub-basins

CONCLUSION

Significant warming and salting was evidenced during the last decade with ship-handled and moored instruments at 2,500-3,500 m in the Tyrrhenian sub-basin. These trends, which are the largest for the Mediterranean deep waters, concern the water generally called TDW (Tyrrhenian Deep Water). Our analyses of the TDW characteristics and trends lead us to reconsider its origin, usually assumed to be the mixing of LIW and WMDW that are waters located at upper and different levels, whilst they are said to display lower trends. We hypothesise that TDW could be formed in another area of dense water formation, east of the Strait of Bonifacio.

Southern Adriatic and Otranto Strait - Key areas for climatic monitoring

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The Adriatic Sea is a very sensitive system, both as a physical and as a bio-geo-chemical environment. The physical component of the Adriatic Sea system depends on one hand on the buoyancy accumulated in the water column, and on the other hand it is conditioned by the air-sea buoyancy exchange and by the buoyancy input via riverine freshwater discharge. The Adriatic Sea has a peculiar property that it is characterized both by the estuarine circulation type and by an anti-estuarine circulation pattern in the Strait of Otranto. These two water exchange patterns are often in competition and one or another is prevalent in function of local climatic conditions (winter heat losses and precipitation).

The South Adriatic Pit is a portion of the Adriatic Sea where dense water formation takes place via an open-ocean convection. This is an oligotrophic area and a spring phytoplankton bloom is triggered by nutrient injections into the euphotic zone by the winter convection. Therefore to some extent, the spring primary production maximum should be associated to the intensity of the deep water formation processes.

The winter heat losses strongly change on interannual time-scale resulting in a variable convection depth which then determines the nutrient input into the euphotic zone and thus the new and export production. The vertical carbon flux data interpreted with remotely sensed algal biomass and in situ nutrient data suggest that the interannual variations of the Southern Adriatic open-sea spring bloom are indeed associated mainly to local winter climatic conditions. Correspondence of the high-chlorophyll content patch and the center of the cyclonic gyre confirms that the intermediate high-nutrient content water advected from the Eastern Mediterranean, is vertically mixed in the center of the Southern Adriatic by winter convection and dense water formation processes.

Sometimes, mild winter results in a complete absence of the vertical convection and, in these conditions the spring phytoplankton bloom in the open-sea area should be determined by other mechanisms such as the exchange with the nutrient-rich coastal waters and the large-scale vertical mixing. The new production estimated from the amount of nutrients made available to the phytoplankton by mixing over the convection depth is in a good agreement with the sediment trap data, confirming the predominant role of local winter climatic conditions in the Southern Adriatic biological pump.

It was also evidenced that the spring bloom undergoes high-frequency weekly time-scale variability as determined by strong heat loss events on the synoptic time-scale. In fact, the spring algal bloom maximum consists of a series of short-term high-production episodes associated with the calm weather periods which typically take place after the violent mixing events and transient nutrient injections into the euphotic zone. The total spring primary production, which is to a large extent a new production, represents then the sum of these single bloom events.

This high-frequency pulsating mode of the spring phytoplankton bloom in the Southern Adriatic requires the high-resolution biological sampling in order to resolve short time-scales associated with the open-sea convection and events in the local meteorological forcing function.

Interannual variations of the intensity of the vertical convection cause changes in the dense water volume formed. Dense water outflow measurements in the Strait of Otranto revealed interannual variations of the flow rate ranging from 0.1 to 0.4 Sv. which agreed perfectly with the winter climatic conditions : mild winters result in a weak outflow, while severe winters generate strong bottom water outflow in the Strait of Otranto.

These characteristics make the South Adriatic Pit and the Strait of Otranto key areas for the long-term monitoring of the variations of the sea response to interannual climatic variability. This monitoring should be interdisciplinary and should include some key biological and chemical parameters in addition to physical oceanography components.

Long-term changes in Adriatic thermohaline properties

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Systematic investigations of hydrographic properties were initiated rather early in the Adriatic Sea, by launching the expeditions Najade and Ciclope in the beginning of the 20th century. The data served as a basis for various studies. By examining these data together with the newer ones, Buljan (1953) reported interannual variations in salinity, calling the years with high salinity in the Adriatic “ingression” years. Adriatic ingressions can affect the whole Adriatic, even the shallow North Adriatic, enlarging the density of dense water which is formed during cold winter outbreaks. Zore-Armanda (1969) correlated ingression to meteorological parameters, while Grbec (1997) used EOF analysis on salinity series in the Middle Adriatic, to find a significant connection between the salinity in intermediate layer and air pressure difference between stations Trieste and Palagruza for the period between 1973 and 1980 but not from 1961 to 1970. As Aswan Dam was built during that period, the increase in salinity observed in that period is partially related to the decrease of Nile discharges, as the Nile river reduced its runoff almost four times.

More recent investigation encompassed the analyses of thermohaline parameters in the South (Vilibic and Orlic, 2001) and Middle (Vilibic, 2002) Adriatic. The series of temperature, salinity and dissolved oxygen saturation collected at the bottom of Jabuka Pit (Middle Adriatic) and section Bari-Dubrovnik (South Adriatic) are plotted in Figs. 1 and 2. As Jabuka Pit serves as a collector of dense waters generated on the North Adriatic shelf, the data show quantitative and qualitative characteristics of such episodes. Two types of events can be denoted: the first one, such as during the winters of 1956, 1981 and 1984, is typified by very low temperatures (Fig. 1a), and the second, for instance in 1955 and 1968, by very high salinities (Fig. 1b).

General characteristics of hydrological series at Jabuka Pit include an increase in salinity (linear trend counting all the data between 1951 and 1989 is +0.0036 per year, Fig. 1b) coupled by a decrease in dissolved oxygen saturation (linear trend equals -0.25 % per year in period between 1951 and 1981, Fig. 1d). Such changes, already observed in other sections of the Adriatic (Zore-Armanda *et al.*, 1991), reveal changes in Mediterranean salinity caused by reduced precipitations over the Mediterranean. Moreover, air pressure and associated wind long-term changes can drive the salty Levantine Intermediate Water into the Adriatic, additionally increasing the salinity and decreasing the oxygen content. Considering temperature data, a few periods can be distinguished: (1) between 1951 and 1962, with intense changes in temperature, (2) between 1966 and 1980 with relatively higher temperatures (11-12°C), and (3) between 1981 and 1989 with lower temperatures (10-11°C). A sharp change between the second and the third interval was caused by the cold, dry winters recorded between 1980 and 1983 over the most of the Mediterranean.

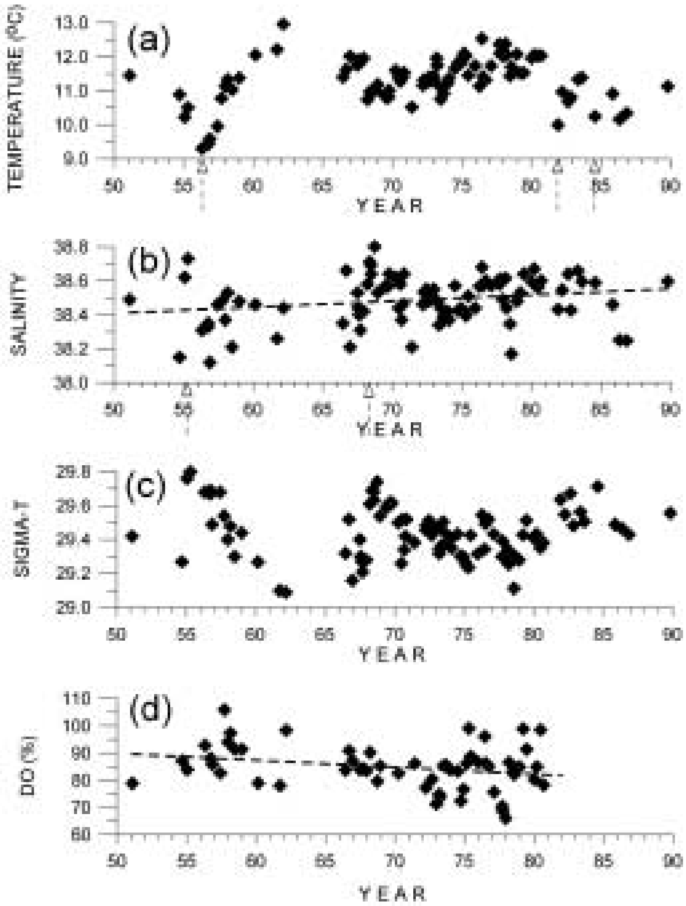

Fig. 1. Time series of (a) temperature, (b) salinity, (c) sigma-t and dissolved oxygen saturation at the bottom of the Jabuka Pit – Middle Adriatic (depth 260 m). Arrows indicate the cases when low temperature and/or high salinity were measured, while linear regression fits are marked dashed line) for salinity and dissolved oxygen saturation (after Vilibic, 2002).

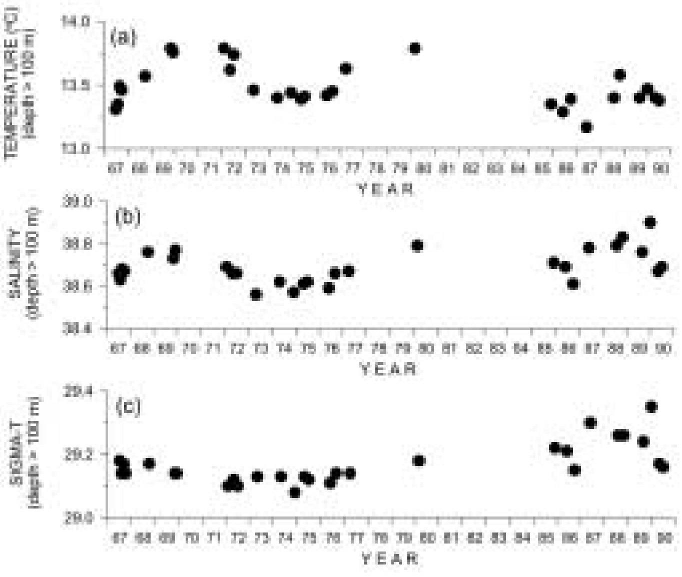

Fig. 2. Time series of (a) temperature (b) salinity and (c) sigma-t averaged for depths greater than 100 m over the whole Bari-Dubrovnik section (after Vilibic and Orlic, 2001).

Strong interannual fluctuations can also be traced in relatively deep South Adriatic waters (Fig. 2). Time series of temperature averages show interannual variations of averages below the pycnocline (d_1 = 100 m, d_2 = 1200 m) to stay within 0.8°C. Maximum values recorded between 1969 and 1971 can be related to the mild winters with high Po discharge in the 1966-1969 interval, and to an absence of dense water formation, particularly in the North Adriatic. Salinity had its maximum during the same years, thus sigma-t values are close to the long-term average. A second temperature maximum, also coupled with the maximum in salinity, occurred in 1980, but during the winter of 1980/81 extremely cold and dense water was generated (in the Middle Adriatic it had t ~ 8.5°C and $\sigma t > 29.8$, Artegiani and Salusti, 1987). As a consequence, characteristics of bottom water in South Adriatic Pit subsequently changed, decreasing in temperature and increasing in sigma-t. In addition, changes in the relationship between temperature and salinity occurred (Fig. 3), decreasing the difference in characteristic temperatures between Adriatic Deep Water and Levantine Intermediate Water. By analysing data from the beginning of the century it can be seen that such disruption did not occur until the 1980s, but temperature and salinity in the years between 1911 and 1914 had generally lower values.

To conclude, Jabuka and South Adriatic Pits have to be considered as areas where hydrological trends should be monitored, as they feel the dynamics of the dense waters generation and spreading both on the shelf

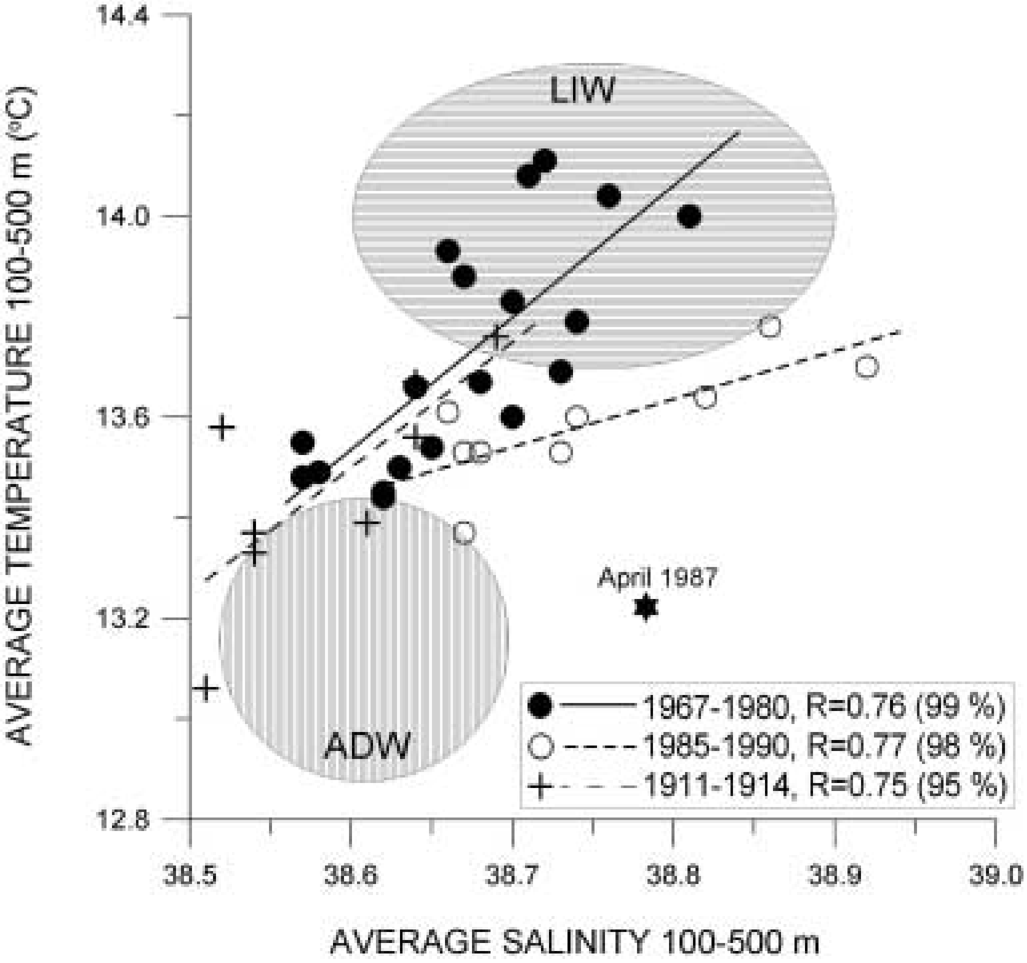

Fig. 3. TS diagram with correlation coefficients between the temperature and salinity, averaged for the layer 100-500 m, computed for different intervals (1911-1914, 1967-1980, 1985-1990). The case of April 1987 is treated separately. Shaded areas represent the characteristics (mean ± 1 standard deviation) of Adriatic Deep Water (ADW) and Levantine Intermediate Water (LIW) (after Vilibic and Orlic, 2001).

areas (North Adriatic) and during the deep-convection penetration processes (South Adriatic). Moreover, these two pits also feel the intrusions of the saline and deoxygenised Levantine Intermediate Water, which occasionally floods a great part or even the whole Adriatic Sea; such intrusions are driven by the seasonal and interannual variability of the atmospheric circulation over the Europe and Mediterranean Sea.

Low-Frequency changes of water masses structure, flow patterns and biochemical exchanges through the Eastern Mediterranean regions

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1. INTRODUCTION

Basin-wide hydrographic surveys conducted in the Eastern Mediterranean in 1999 and 2001 within the framework of national and international research programmes aimed at investigating the water mass properties, the status and the evolution of the thermohaline circulation as a consequence of the Eastern Mediterranean Transient (EMT). Since the last decade, the large climatic shift, which established in the Cretan Sea (Southern Aegean) an additional source of dense water, affected mainly the water mass properties and the chemical signatures in the intermediate and deep layers in the Eastern Mediterranean central region (Roether *et al.*, 1996; Klein *et al.*, 1999). Basic hydrographic observations in the water column and current measurements were conducted to answer the following questions.

- Which are the major water masses circulating in the upper, intermediate and deep layers in the current status of the transient in the Eastern Mediterranean?
- Which are their thermohaline properties and how do they correlate with the characteristics of the new Aegean dense water which spreads in the deep layer through the communicating zones, i.e. the Levantine basin, the Cretan passage and the Ionian Sea ?
- Which are the major dynamical features, and water exchanges among the different sub-basins, taking into account the expected ongoing and rapid hydrographic changes in the Eastern Mediterranean ?
- Is this change modifying the properties of the water mass that flows through the Sicily straits into the Western Mediterranean and through the Otranto strait into the Adriatic Sea ?
- How does the sub-basin scale dynamics and changes in the upper and deep thermohaline "conveyor belts" affect the chemical (oxygen and nutrients), biological (abundance and production of plankton biota) and optical properties (fluorescence and light transmissions) of water masses in the Eastern Mediterranean ?

The results of these observations, in addition to those of the earlier expeditions, allow us to better understand the long-term variability and to characterise the water masses discriminating between long-term/basin-wide effects from shorter ones (interannual and seasonal) at sub-basin scale. Moreover, these observations could help us to evaluate permanent or transient circulation features, which may affect the marine ecosystem. A brief summary of our investigations and a list of open questions have been addressed, in view of a possible strategy for the monitoring of long-term change structure of the water column, nutrient distributions, and impacts on the Mediterranean ecosystem.

2. DATA AND METHODS

The investigations were performed on board of the R/V *Meteor* (Germany) in the Eastern Mediterranean in April-May 1999 (M44/4) and in October-November 2001 (M51/2) with the same strategy. In 1999 these observations were complemented at the same time by a basin wide survey conducted in the Ionian Sea by the R/V *Urania* (Italy), within the framework of a scientific cooperative research programme (Fig. 1a). The hydrographic stations sampled from the R/V *Meteor* were positioned along zonal area running approximately in between 32-36° N across the Eastern Mediterranean, both in 1999 and 2001 (Fig. 1a and b).

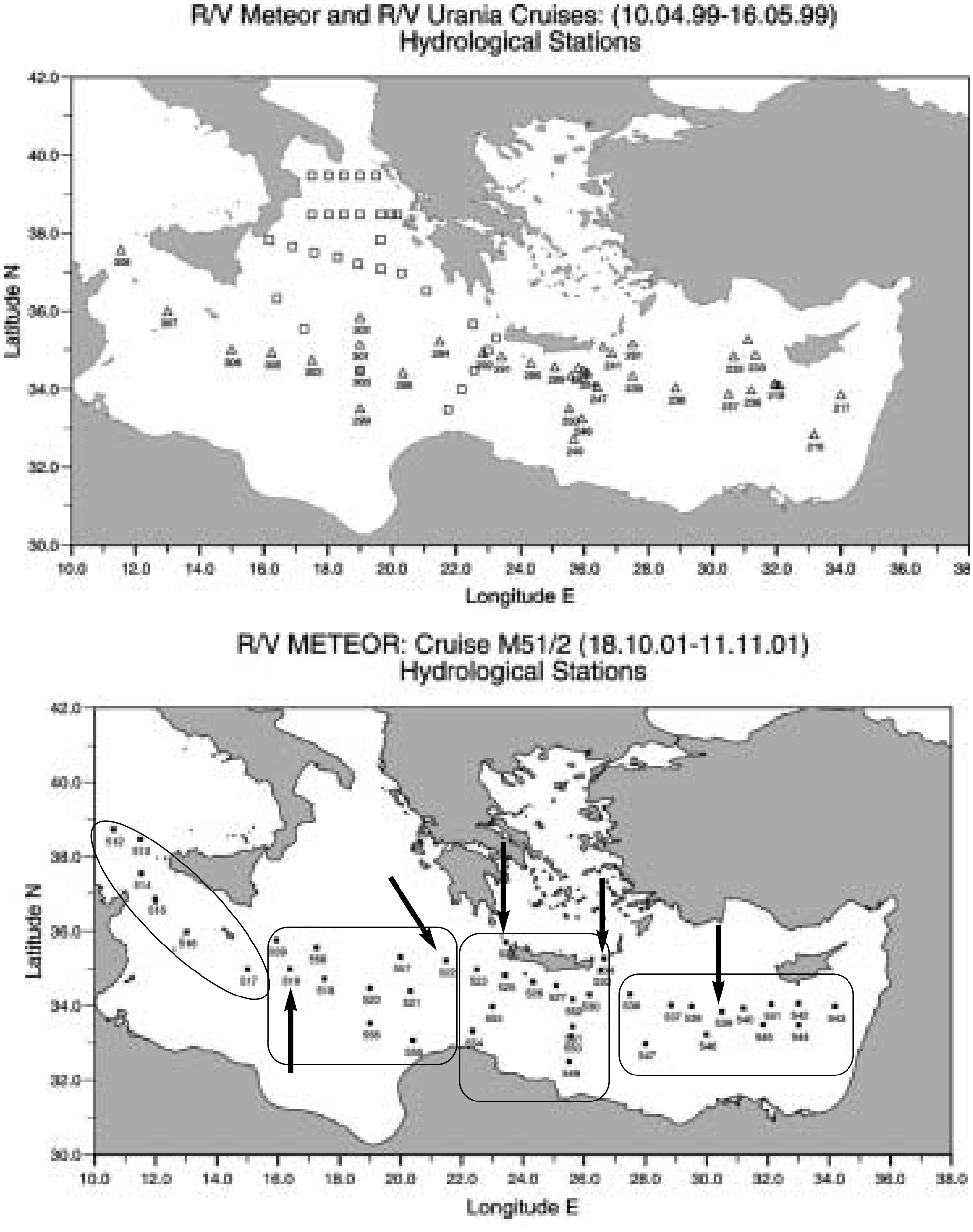


Fig. 1. Maps of the hydrographic stations occupied during the surveys conducted in the Eastern Mediterranean; (a) R/V *Meteor* cruise M44/4 (open triangles) and R/V *Urania* cruise (open squares) in April-May 1999, and (b) R/V Meteor cruise M51/2 in October-November 2001. The encircled CTD stations during the M51/2 cruise indicate the data used to construct the θ-S diagrams in Figure 2.

The parameters measured at each station were: temperature, salinity, dissolved oxygen, light transmission, light scattering and fluorescence. A SBE 911 CTD vertical profiler equipped with dual sensors of temperature and conductivity was used for data acquisition. Water samples were collected by means of CAROUSEL rosette multi-sampler for salinity calibrations, biochemical and transient tracer (CFC) determinations.

The hydrographic measurements were quality controlled at the common stations by checking discrepancies between different methods and standards used by laboratories. The salinity data were controlled vs. water sample analyses using an AUTOSAL Guildline bench salinometer. The dissolved oxygen data were derived from the polarographic sensor fitted on the CTD case and quality controlled vs. the data obtained on board using the Carpenter-Winkler titration analytical procedures on water samples. The precision of the latter was contained within the ± 0.3 % of the measurement (Kress, personal communication).

3. RESULTS AND DISCUSSION

3.1. Water mass properties across the Eastern Mediterranean

The complexity of the relationships between temperature and salinity are analysed grouping together the CTD stations in four main regions, i.e. the Sicily Straits, the Ionian Sea, the central region through the Cretan passage, and the Levantine basin (Fig. 1b). The Figure 2 depicts a composite of θ/S diagrams considering all data collected during the April-May 2001 survey in the four regions defined above. The recognised water masses include the Atlantic Water (AW), the Levantine Intermediate Water (LIW) and the Eastern Mediterranean Deep Water (EMDW) as well ass their variability across the Eastern Mediterranean.

In the upper layer, the relatively fresh AW is transformed from $S \cong 37.0\text{-}37.4$ in the Sicily Straits (Fig. 2a) to $S \cong 38.6\text{-}38.8$ as moving on the way into the Levantine basin (Fig. 2d). There, the AW is clearly distinguished and overlapped by the more saline local Levantine Surface Water (LSW), which has characteristics ($\theta = 21\text{-}25$ °C; $S>39.2$) largely determined by high rates of heating and evaporation.

In the intermediate layer, the LIW has the salinity maximum ($S > 39.0$) in the proper Levantine basin where it is characterised by a temperature of about 16.0-17.0 °C (Fig. 2d); the LIW, as moving to the west into the Cretan passage and Ionian Sea, gradually freshens and becomes colder and denser. In the Ionian (Fig. 2b) two different cores of salinity maximum may be distinguished. One core ($\theta \sim 14$ °C; $S \sim 38.80$) derives from the transformation of the proper LIW; a further core, more saline and warmer ($\theta \sim 15\text{-}16$ °C; $S \sim 39.0$) than the typical LIW, derives from the Cretan Intermediate Water (CIW). This water is thought to be formed in the proper Cretan Sea as LIW, and has characteristics very similar to those of LIW (Georgopoulos *et al.*, 2000). The CIW flows into the Ionian through the western straits of the Cretan Arc and propagates prevalently into the northern Ionian along the Greek coastline, where it may be distinguished from LIW due to its high oxygen content (Manca, 2000). Finally, it intrudes the Adriatic Sea at shallower depth than LIW, thus establishing more favourable conditions for the production of dense waters (Klein *et al.*, 2000).

In the deep layer, the modification of the water column structure, mainly dictated by the presence of the cold and less saline EMDW of Adriatic origin, is associated with the progression of the much denser water (i.e. warmer and saltier) of Aegean origin (i.e. the Cretan Deep Water - CDW), mainly detected in the Cretan Passage (Fig. 2c). A substantial difference between the western and the eastern regions emerges in the deep water range, i.e. below 2000 m. The presence of the densest water ($s_\theta >29.20$ kg·m^{-3}) of Aegean origin is much more evident in the Levantine basin (Fig. 2d) than in the Ionian (Fig. 2b). In the Ionian the signal is evident in some stations close to the source, which are under the influence of the deep Aegean outflow, whereas the western Ionian is mainly subject to the spreading of the EMDW of Adriatic origin. A significant part of the deep water column in the Sicily Straits (Fig.2 a) is composed of waters colder and less saline than the LIW, which clearly originate from the Adriatic Sea. In fact, in the western Ionian a consistent uplifting of the deep isopycnals ($s_\theta \cong 29.17\text{-}29.19$ kg·m^{-3}) up to the sill depth of the Sicily Strait (~ 700-1000 m) provides evidence to support this interpretation, allowing

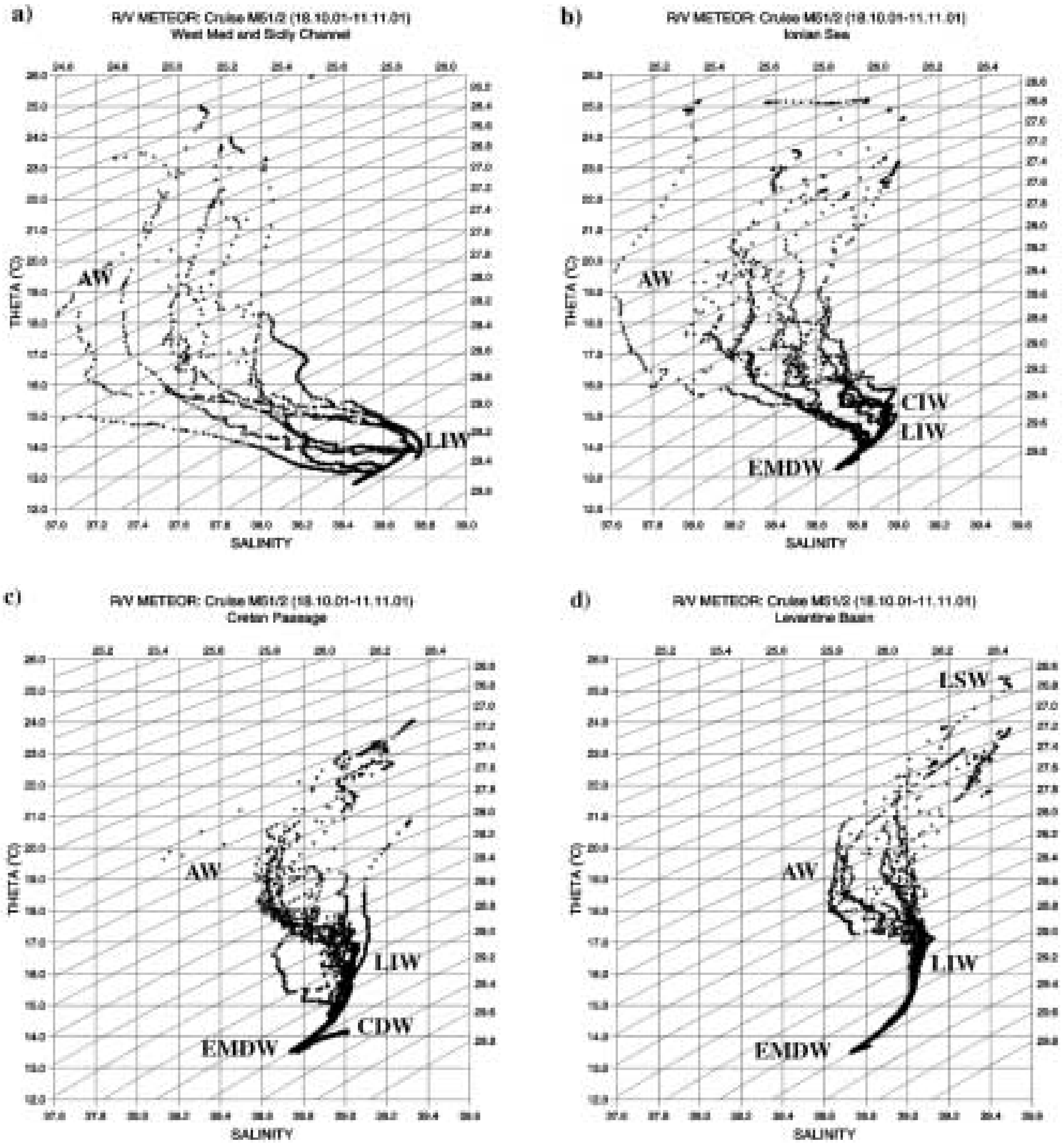


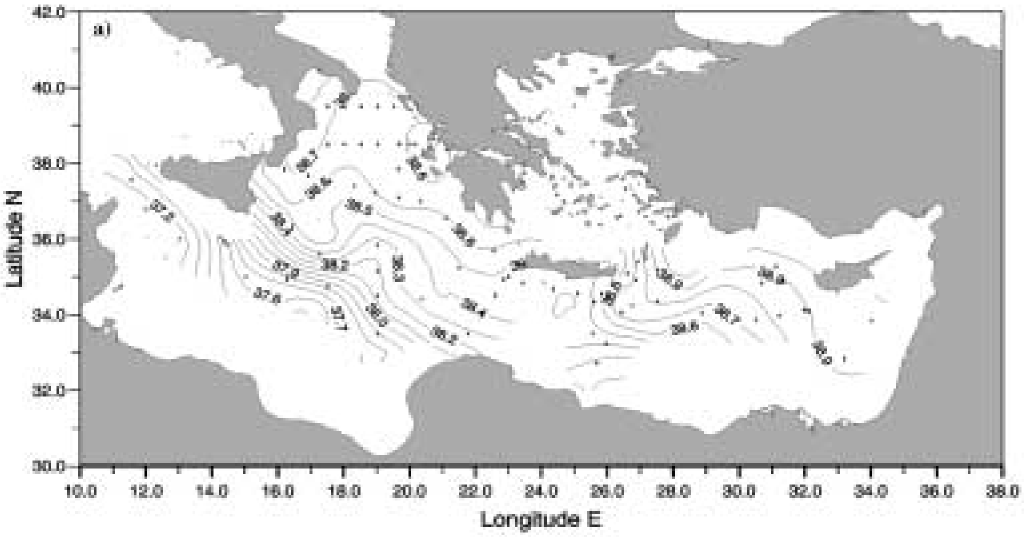
Fig. 2. Composite potential temperature (θ) *versus* salinity diagrams of all the data plotted grouping the CTD stations performed during the M51/2 cruise (i.e. October-November 2001) for the four regions indicated in Fig. 1b: (a) Sicily Strait, (b) Ionian Sea, (c) Cretan passage and (d) Levantine basin. The name of the region is also indicated at the top of the panels. The oblique lines across the diagrams indicate the potential density excess σ_θ (kg·m^{-3}) isopycnals; their values are on the top x-axis and on right y-axis. Note the different scale of the salinity in the diagram (a).

dense EMDW of Adriatic origin ($s_\theta \cong 29.18$) to be incorporated in the deep flow into the Western Mediterranean (Astraldi *et al.*, 2002a).

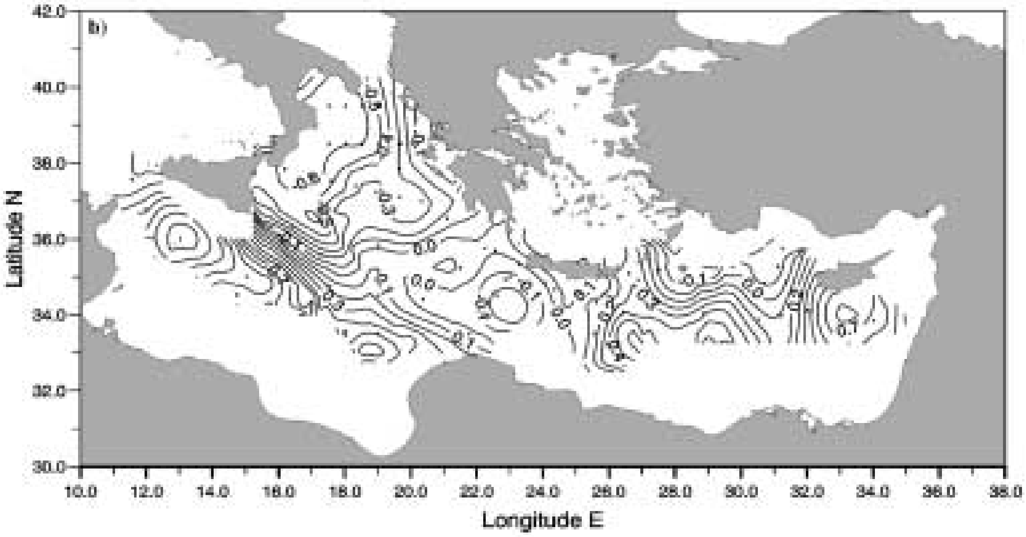
3.2. Long-term change of the circulation patterns in the Ionian Sea

Temperature, salinity and density fields sampled during the combined surveys conducted by the R/V *Meteor* and R/V *Urania* are investigated to deduce the major features of the basin-scale thermohaline circulation in the Eastern Mediterranean at the time of the cruises (i.e. April-May 1999). Here one of the most striking results in the surface layer is presented, whereas Manca *et al.* (2002) provide a comprehensive analysis of the hydrographic fields at full depth, further corroborated by current measurements performed in the Ionian Sea.

The horizontal distribution of the minimum of salinity in the upper 250 m layer and the dynamic height anomalies computed at surface with reference to 250 dbar (Fig. 3) allows us to infer the current status of the AW flow pattern in the interior of the Eastern Mediterranean. There is clear evidence that the AW, after entering the Strait of Sicily with salinities of less than 37.5, flows eastwards along the African coast. It leaves the Ionian Sea with a modified salinity of about 38.5 and intrudes the Levantine basin, where patches of low salinities (S < 38.9) may be recognised. The strong zonal front, joining the Central Mediterranean Current, called Mid-Mediterranean Jet by the POEM Group (1992), hinders the spreading of AW into the northern Ionian Sea, as it was instead observed during the previous basin-wide cruises (Malanotte-Rizzoli *et al.*, 1997; Klein *et al.*, 1999; Malanotte-Rizzoli *et al.*, 1999). In the northern Ionian Sea a cyclonic motion prevails and more saline waters are detected at surface being mostly up-welled from the intermediate layer. Analyses of low frequency time series of ECMWF re-analyses data for the period 1979-1999 have shown changes in wind stress curl over the Mediterranean region, and these changes in circulation patterns could simply be a response to this atmospheric forcing.



a) Cruise EMTEC-AM99: Salinity Minimum (0-250)



b) Cruise EMTEC-AM99: Dyn. Height 0/250 dbar

Fig. 3. Horizontal distributions of the salinity minimum in the upper 250 m (a) and of the dynamic height anomalies (m2 s-2) at surface with reference to 250 dbar (b), in April-May 1999. These fields, objectively analysed, represent the dispersal pathway of AW in the Eastern Mediterranean and the dynamics at surface, respectively. The dots denote the position of the CTD stations.

3.3. Long-term change of the vertical water column structure

Comparisons of temperature and salinity profiles obtained in some key areas of the Eastern Mediterranean during the M51/2 survey in 2001 with those observed during the early status of the transient in 1995, demonstrate that the deep basin is still affected by the strong Aegean outflow. Moreover, changes in water mass characteristics are observed in the deep, transitional and intermediate layers, the latter basically in proximity of the Cretan Arc Straits. A comparison of the salinity profiles for 1995 (thin lines) and 2001 (thick lines) at different location is shown in Figure 4.

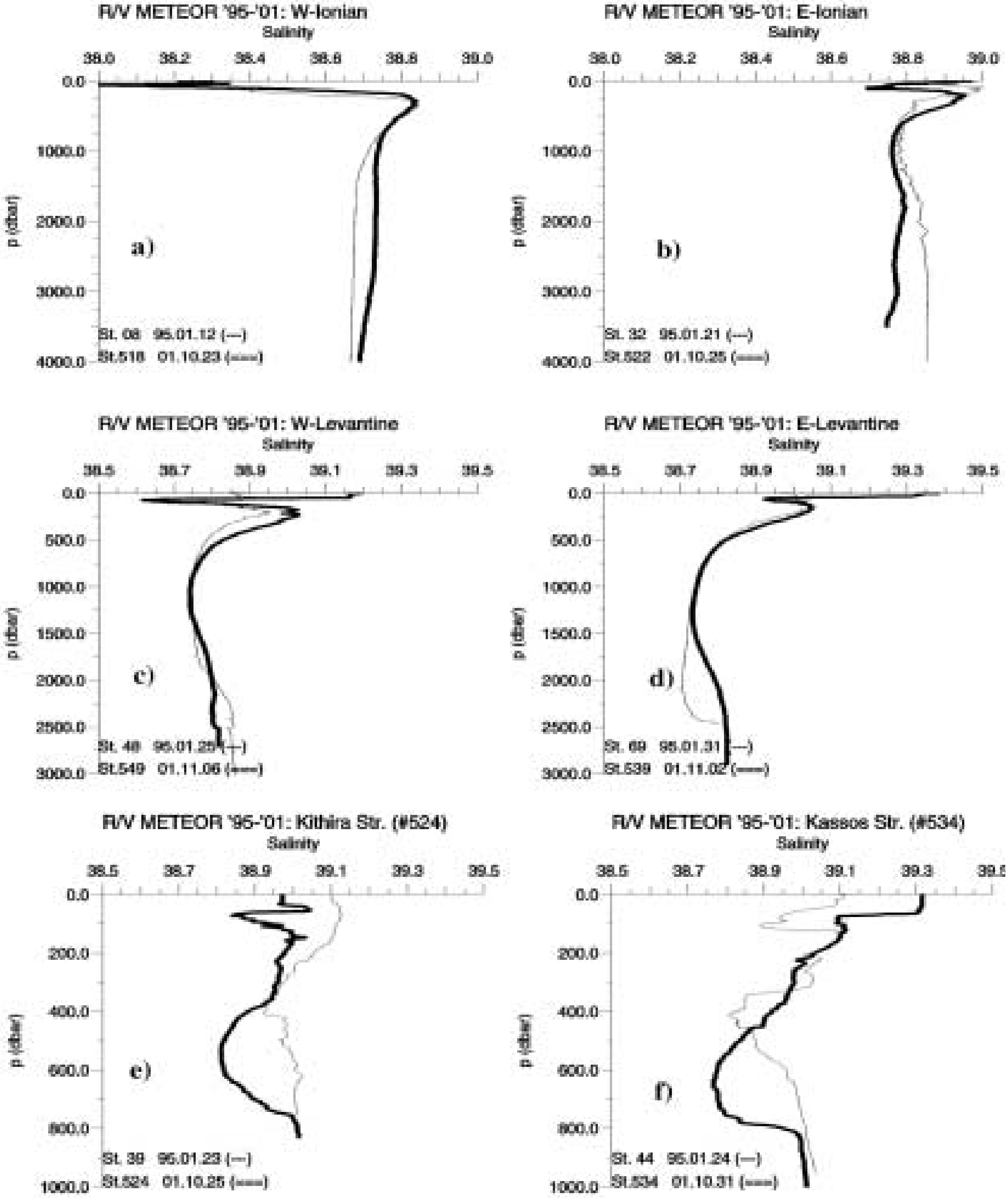


Fig. 4. Salinity profiles at selected stations in Fig in 1995 (thin lines) and 2001 (thick lines); (a) in the western Ionian, (b) in the eastern Ionian, (c) in the western Levantine basin, (d) in the eastern Levantine, (e) in the western, and (f) in the eastern Cretan Arc Straits. The location of stations are indicated by arrows in Fig. 1b.

The modifications of the vertical structure of the water column, due to the recent intrusion in the deep layer of the saline Aegean waters, are effective both in the western Ionian where an increase of salinity is documented (Fig. 4a) and in the eastern Ionian, where a decrease of salinity occurs (Fig. 4b). Similar signatures were manifested in the CFC data showing an increase in the western and a decrease in the eastern Ionian. This clearly indicates a relaxation of the dense water outflow from the Aegean Sea and a progression of the already discharged dense water far away from the Cretan Arc Straits. The same features have been observed in Levantine basin, where the western (Fig. 4c) and the eastern regions (Fig. 4d) are differently affected by the deep Aegean outflow. These long-term changes of water mass properties indicate the presence of a divergence zone in the deepest part of the central basin and a strong mixing in the deep Ionian basin (Manca *et al.*, 2002). This prominent circulation features might have important consequences on the physical and biochemical properties overall distribution and on marine ecosystem variability.

The comparison of salinity profiles at stations located in proximity of the western and eastern Cretan Arc Straits (Fig. 1b and Fig. 4e-f) shows a substantial modification of the water column due to the presence of a water mass less saline and colder (not shown) than previously, which is located between the 400 and 800 m. It simply represents the uplifted EMDW, which intrudes the Aegean Sea through the eastern Cretan Straits, partially compensating the deep outflow, and exits through the western straits. This water mass has been identified by Theocharis *et al.* (1999b) and Georgopoulos *et al.* (2000) with the Transitional Mediterranean Water (TMW) in the Cretan Sea (Southern Aegean), where it is sandwiched between two more saline water bodies, i.e. the CIW and the densest CDW.

3.4. Vertical sections

Contoured vertical sections of salinity running all along the Eastern Mediterranean in 1999 and 2001 are shown in Figure 5a and b respectively, addressing the temporal evolution of the water mass properties and dynamics.

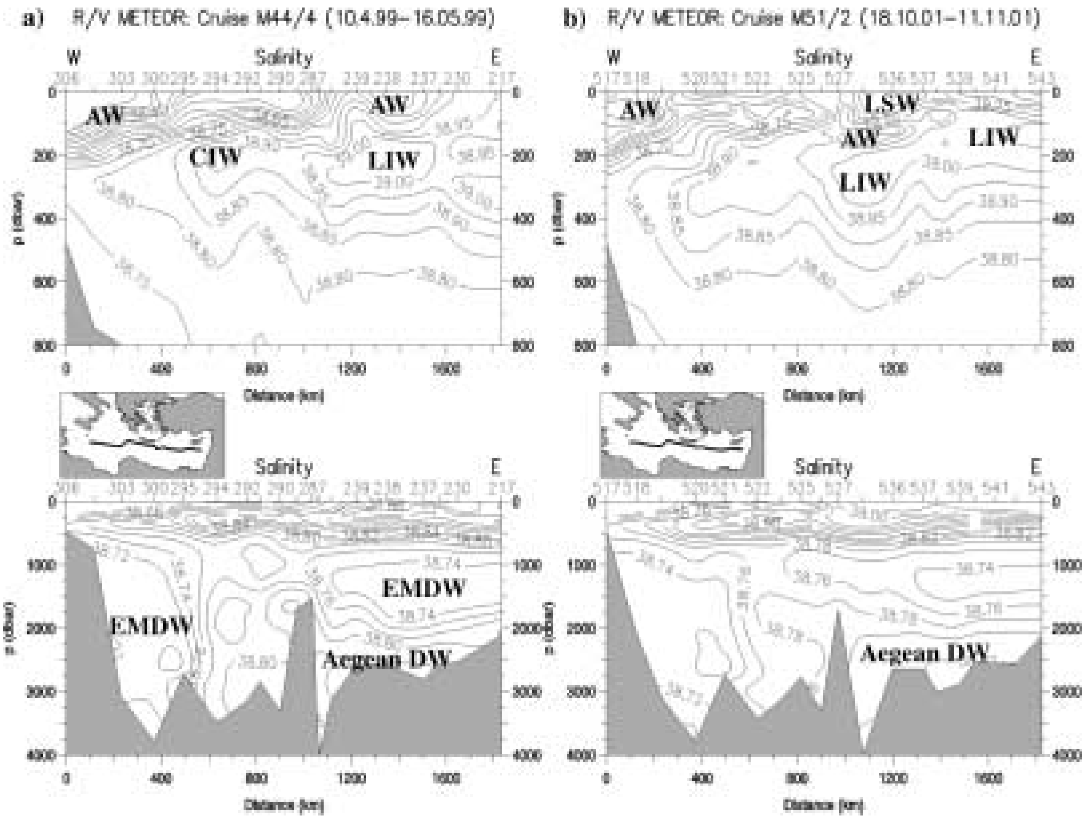


Fig. 5. Salinity distributions along the West-East cross section in the Eastern Mediterranean (a) in 1999 (R/V *Meteor* M44/4) and (b) in 2001 (R/V *Meteor* M51/2). The section are constructed for the upper 800 dbar (upper panels) and for the whole water column (lower panels). The position of the stations is indicated at the top. The insert depicts the geography of the section.

In the upper layer (Fig. 5, upper panels), the W-E salinity sections display fresh AW at the left side, which extends into the Cretan passage both in 1999 and 2001. In 2001, the AW penetrates deeply into the middle of the Levantine basin in a sub-surface layer, while in 1999 transformed fresh water patches of AW are detected at the eastern end of the Levantine basin in the surface layer. In the Levantine basin, the comparison of the hydrographic conditions in spring 1999 and in late summer 2001 manifests an overall salinity increase in summer 2001, due to an increase of heating and evaporative processes. These lead to the production of the LSW, which isolates patches AW in the sub-surface layer.

The intermediate layer is dominated by the westwards spreading of the LIW. In the eastern Levantine the LIW core has $S > 39.0$ and it is situated in the layer between 100-250 m. The LIW deepens to about 200-400 m as flowing through the Cretan passage due to anticyclonic local dynamics, and finally intrudes the eastern Ionian with salinity of about 38.90. Moreover, in 1999 a secondary source of saline water from the Cretan Strait (i.e. the CIW) has been noted in the eastern Ionian Sea, which extended deeply into the northern Ionian and intruded the Adriatic Sea (Manca *et al.*, 2002). The LIW reaches the western end of the Ionian with a salinity maximum of 38.80. It is worthy to remark that in the Levantine basin the LIW appears more abundantly in 2001 than in 1999, even if the observations in 1999 were performed in April-May, i.e. after the period of winter convective mixing. Moreover, far away from the source in proximity of the Sicily strait, in 2001 the LIW tongue ($S > 38.80$) is traced thicker (~ 200-600 m) than previously.

In the deep layer, property sections demonstrate the evolution and status of the vertical structure caused by the addition of warmer and saline dense water outflowing from the Aegean Sea. The influence of Aegean dense water extends deeply into the Levantine basin, where the temperature and salinity in the abyssal depths increased considerably. The core of the EMDW of Adriatic origin (cold and less saline) is situated below 1000 m and is marked by the salinity minimum 38.74. In 2001, the Aegean dense water outflow had contributed to the erosion of the EMDW, which presents a layer thinner than in 1999. Moreover, the EMDW lies at shallower depth than in 1999 throughout the Eastern Mediterranean and it seems able to intrude the Cretan Sea as compensatory effect of the deep Aegean outflow. Presumably, the intrusion of EMDW of Adriatic origin into the Aegean Sea could be effective in diminishing the salt content in this critical region of the Eastern Mediterranean, giving important implications for the dense water formation processes in the years to come.

A clear indication of westward spreading of the new dense water of Aegean origin into the western Ionian is missing; however, a general increase of temperature and salinity in the deep layers has been noted. In 2001, the core of the EMDW of Adriatic origin (relatively cold and less saline than the surrounding waters), extends below the 1000 m with properties of $\theta \cong 13.50$ °C, $S \cong 38.74$, $s_\theta \cong 29.19$ kg·m^{-3}. It is more saline than observed during the previous cruise in 1999 and lies around the isopycnal 29.19 kg m^{-3} (not shown). This suggests a production in the Adriatic Sea in small quantities that soon mixed with the background more saline water mass lateral advected in this region from the Aegean.

Oxygen measurements also support this scenario evidencing a relative high dissolved oxygen content in the bottom layer compared with the contiguous deep waters, throughout all the Eastern Mediterranean. The vertical sections of oxygen from the Ionian to the eastern end in the Levantine basin are traced in Figure 6, both in 1999 and 2001. They show the presence of an Oxygen Minimum Layer (OML) at intermediate depth (≅ 500-1500 m) in the whole basin, while more oxygenated waters lie at the bottom. This implies that the new dense water of Aegean origin have reached the easternmost part of the Levantine basin in 1999, while the older EMDW was lifted to the intermediate depth. It was possible to discern between the prevailing basin scale anticyclonic circulation feature in the Levantine basin from the cyclonic one in the Ionian Sea. In fact, the OML exhibits similar oxygen concentration of 4.10 ml/l and it is situated in the Ionian Sea at shallower depth than in the Levantine basin. In 2001, these general features did not change but it was clear evidence of the progressive erosion of the layer occupied by the older EMDW. Below 1500 m the Ionian Sea appears more oxygenated in 2001 than in 1999; moreover, the concentration is also higher than in the Levantine basin at the same water levels. This may be explained by a larger contribute of the Adriatic in filling the depths of the Ionian Sea, allowing

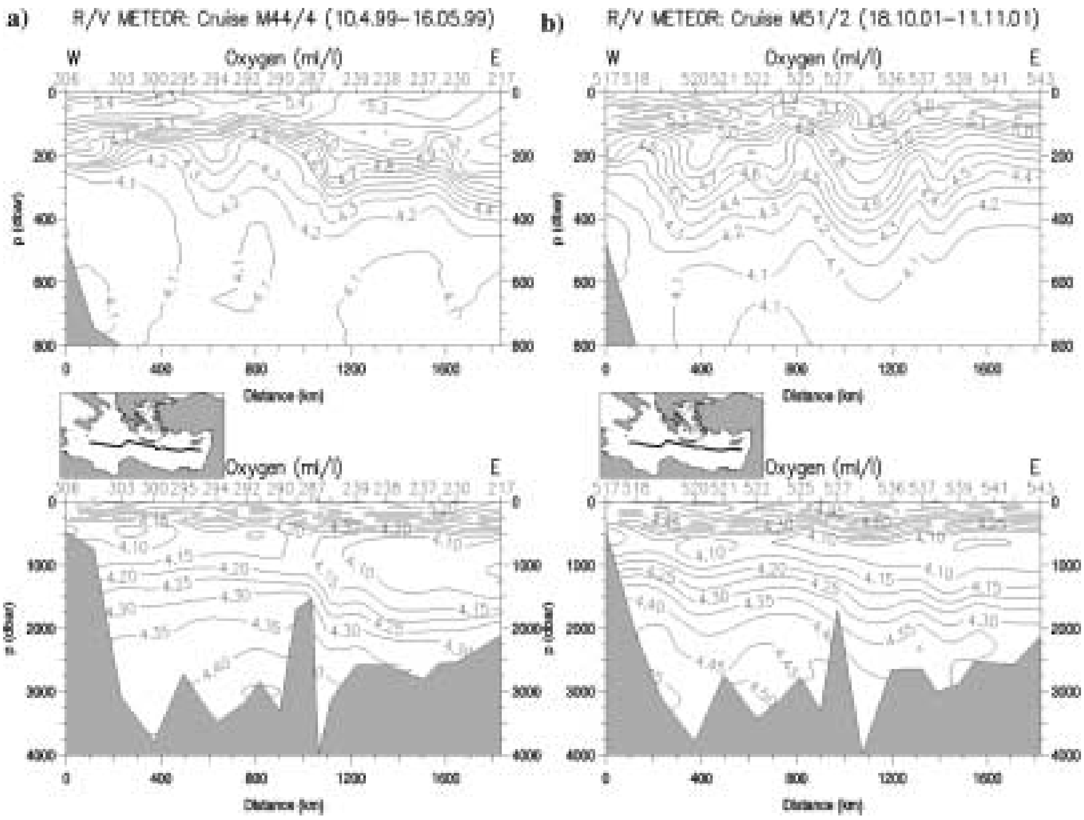


Fig. 6. Same as Fig. 5, but for dissolved oxygen concentrations in ml/l.

us to say that the Adriatic regained the leading role in the production of the dense waters of the Eastern Mediterranean.

4. CONCLUDING REMARKS

The preliminary results point out that the Eastern Mediterranean Sea is a basin in which the main processes act at time scale shorter than previously hypothesized. Previous investigations had revealed the occurrence of a abrupt climatic shift of the deep thermohaline circulation by the addition of the new dense water from the Aegean. This was revealed to occur in two-three years, and we have demonstrated that the system needs more than a decade to recover and re-organise itself to reach the so-called “steady state”. A detailed computation of this time-interval will be the primary research objective of future investigations, on the basis of the data collected during the previous (M44/4, 1999) and (M51/2, 2001) cruises.

These renewed investigations in the eastern Mediterranean definitively revealed that:

- the course of the events leading the southern Aegean as the major source of dense water is relaxed;
- in the upper layer, the quasi permanent anticyclonic circulation which transports Atlantic water into the northern Ionian, ceased. The mid-Mediterranean current reorganizes as a quasi-stable flow of the Atlantic water towards the eastern end of the Levantine basin. A large amount of Atlantic water has been observed in the Levantine basin together with a large seasonal variability of the upper thermocline water masses structures, while a salinity increase of the overall water column has been observed in the Ionian Sea;
- the LIW, which prevalently recirculated in the Levantine basin during the early stages of the transient, appears to resume the major component of the westward transport into the Ionian Sea;
- the EMDW of Adriatic origin dominates in the western Ionian below the 1000 m, while in the Levantine basin old EMDW is clearly sandwiched between the intermediate and deep layers. In fact, the bottom layer is still overall filled with the warmer and saltier dense water of Aegean origin.

All the above results raise the following questions:

- Why is the deep mixing in the Ionian so effective and much stronger than in the Levantine basin ?
- How effective are the mechanisms in restoring the steady state and what will be the characteristics of this steady state ?
- Are there risks of deep anoxia in the Levantine basin ?
- What is the impact of larger amount of salt imported in the Adriatic Sea and, more important, in the Western Mediterranean ?
- What will be the evolution of the nutrient pool and distribution in the Eastern Mediterranean ?

Further clarifications based on a comprehensive analysis of all existing data and their interpretation must be still conducted. However, our concerns may address future research activities in view of a monitoring program of the marine climatic changes in the Mediterranean Sea.

Variability of sea water properties in the Ionian, Cretan and Levantine seas during the last century

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Recent research (1985-1999) in the Eastern Mediterranean has revealed important variability of currents, mesoscale features and hydrological parameters, ranging from interannual to multiannual (Robinson *et al.*, 1991; Rohling and Bryden, 1994; Roether *et al.*, 1996; Theocharis *et al.*, 1999a; Lascaratos *et al.*, 1999; Malanotte-Rizzoli *et al.*, 1999; CIESM, 2000). The most important and evident event has been the so-called Eastern Mediterranean Transient (EMT). Most of these studies focus on the last 15 to 20 years.

In this presentation we study the evolution in the Eastern Mediterranean over the last century and we attempt to identify long-term variability and trends for the most important water masses in the Ionian, the Levantine and the Cretan Sea (Southern Aegean).

Data are taken from the MEDATLAS database, which combines pre-existing databases such as the MODB, with more recent data. We define three rectangular geographical areas (not shown) one for each study area (Ionian, Cretan, Levantine). We study the evolution of water mass characteristics from 1910 to 1999 at three levels within each sub-basin, namely:

1. the level of the Atlantic Water (AW) characterized by a subsurface salinity minimum,
2. the level of the Levantine Intermediate Water (LIW) characterized by an intermediate salinity maximum, and,
3. the level of 2000m for the Ionian and Levantine, as well as 1000m for the Cretan Sea, considered as characteristic of deep waters

The methodology we followed in constructing our time series is identical to the one described by Rohling and Bryden, 1994. For each of the three levels mentioned above, the parameters studied are: potential temperature, salinity, and sigma-theta. For the two first levels (AW and LIW) we have also constructed time series of the depth at which the characteristic Smin and Smax are present respectively. Data for each parameter are averaged in each sub-basin over the same year. It is obvious that discrepancies and noise cannot be totally excluded in our time series. This is true especially in the subsurface and intermediate layers not only because the natural variability is higher there, but also because the computation of a parameter at a characteristic level of variable depth such as Smin or Smax is less obvious than at fixed depths. On the other hand such a choice is richer in information. In any case, in our discussion below, we will only concentrate our attention on the main and most obvious trends or variability observed.

Subsurface Layer of Atlantic Water (Smin)

The data in this layer are rather noisy as mentioned above. Nevertheless, in the Levantine and Cretan Seas similar trends are evident. We observe (not shown) in both sub-basins during the period 55-95 a decrease of the potential temperature at the level of Smin (AW level), an increase in salinity S and consequently an important increase in potential density. In both areas the decrease in potential temperature is larger than 3°C. An exception to this, is a small increase (~ 1°C), observed from the mid-80's to 1991, which we believe is related to the preconditioning/first phase of the Eastern Mediterranean Transient (Roether, *et al.*, 1996; Lascaratos A. *et al.*, 1999; Theocharis *et al.*, 1999a; CIESM, 2000). The increase in salinity is of the order of 0.3 p.s.u. in both sub-basins, while in density from 27.9 to 29.1 and from 28 to 29.1 density units in the Levantine and Cretan Seas respectively. The data in the Ionian seem too noisy for a clear trend to be inferred, although a similar trend seems to be present too.

Intermediate Level of Levantine Intermediate Water (Smax)

At the core layer of the LIW a number of very interesting features are present. First of all a general increase of potential density is present in all three sub-basins (see Fig. 1, for the Ionian). This increase seems to be mainly caused by a similar decrease of potential temperature in those three areas, although it is interesting to note that we also observe a salinity increase primarily in the Cretan Sea and the Ionian and secondarily in the Levantine. This shows that the increase in salt content in the Cretan Sea is mainly directed through the western Cretan Straits towards the Ionian. This must be the signal of the so-called Cretan Intermediate Waters (CIW) (Schlitzer *et al.*, 1991). Note that Rohling and Bryden (1992) do detect a slight increase of salinity in the Levantine. This is not in contradiction with our results since the geographical coverage of the Levantine basin in that paper extends from 24 to 26.5°E longitude, which is the western part of the Levantine. In fact it is the area south of Crete. In this presentation we include the whole Levantine from 24 up to 36°E.

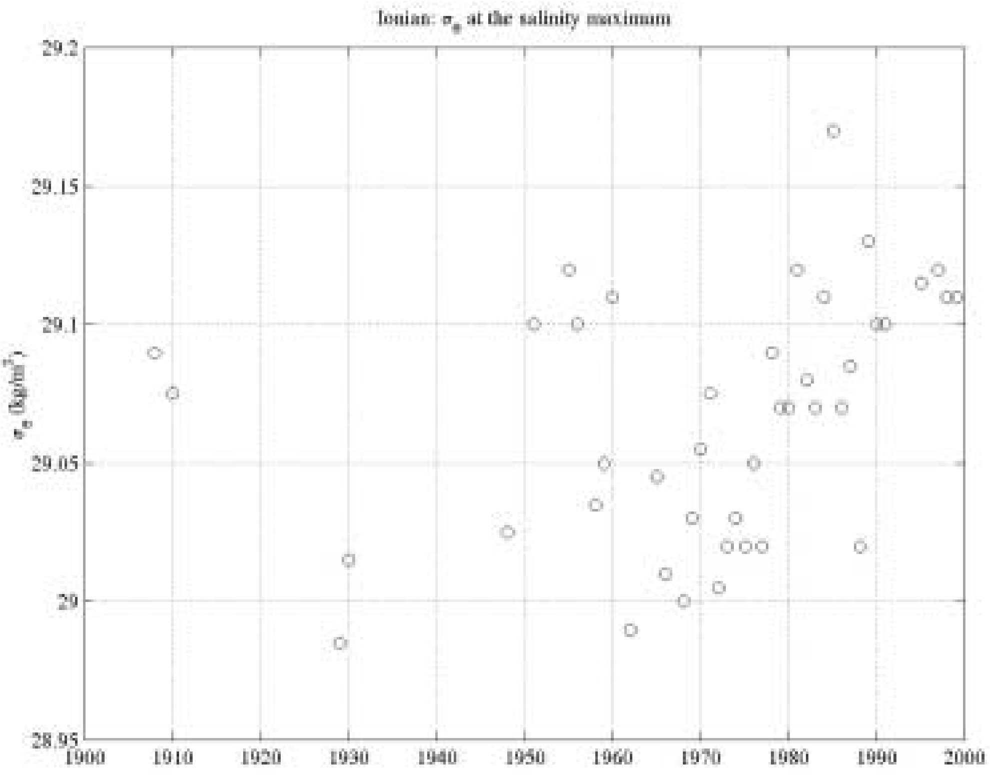

Figure 1.

Deep Layer (2000m for Levantine and Ionian and 1000m for Cretan Sea)

Two very distinct episodes can be distinguished, with maximum peaks of potential density in the early '70s and mid to late '90s in all three sub-basins. The second episode is clearly related

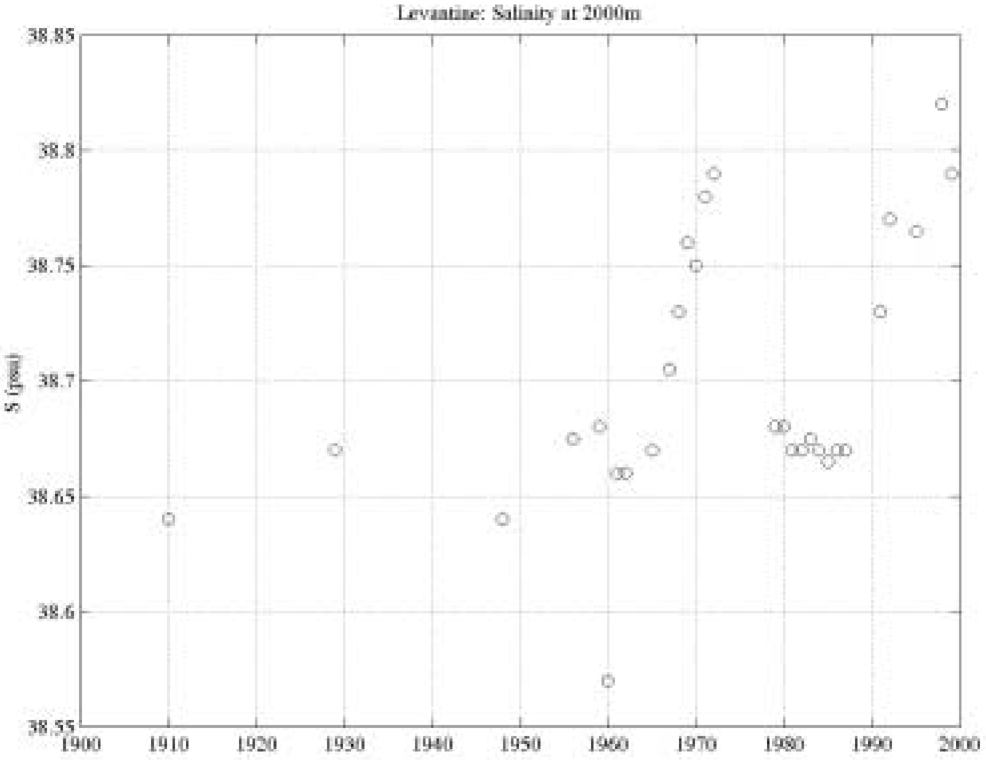

Figure 2.

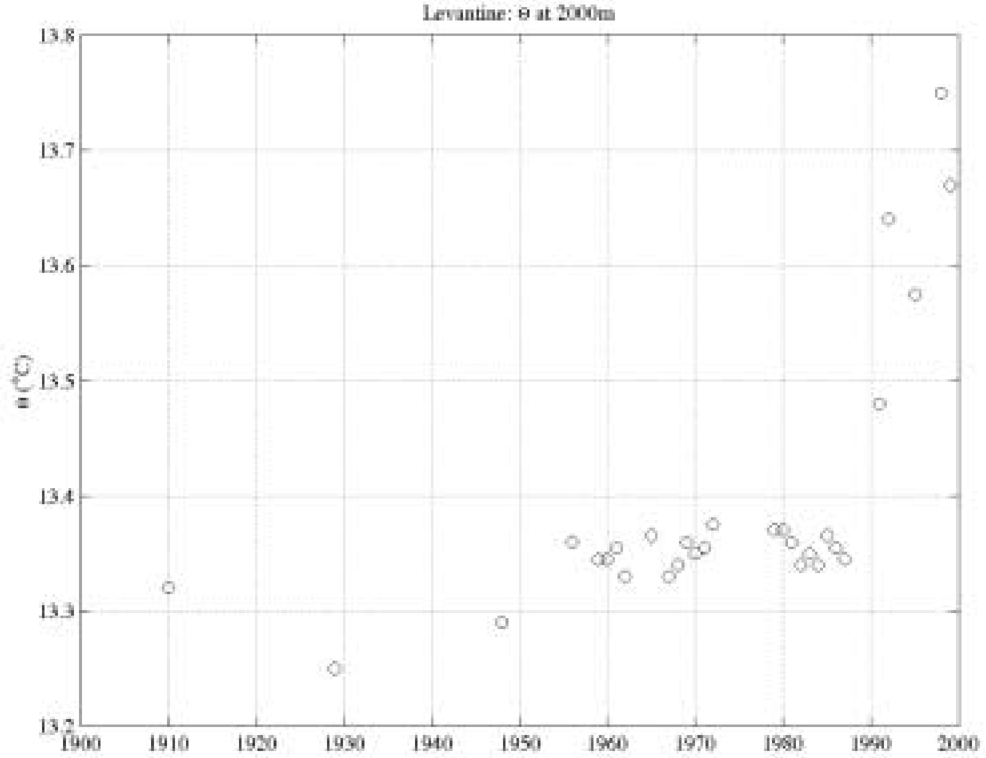

Figure 3.

to the EMT. In that event we observe a clear increase of both salinity and temperature preceding it (Figures 2 and 3). After the very cold winters of 1992 and 1993 a considerable decrease of temperature in the Cretan Sea (not shown) (by >0.3°C at 1000m) triggers the substantial increase of potential density and the formation of the very dense waters known as the second phase of the EMT. As we move away from the source of the EMT, the Cretan Sea, the signal of this cooling decreases. It is less than 0.1°C in the Levantine Basin, while it cannot be detected in the Ionian.

The first episode, which can be termed as a “transient” as well, is very interesting and seems to have slipped the attention of the scientific community so far. However, it differs substantially from the EMT in various points. The episode is evident in all three basins, with a maximum signal in the Levantine.

This “transient event” bares no relation to any temperature change (in contrast with the EMT, see also above discussion) and seems to be totally salinity induced. The data indicate that the source of this transient lies within the Levantine, (we will therefore give it the name of Levantine Transient, LT). From there, these very dense deep/bottom waters have moved westwards into the Cretan and Ionian Seas. Note that the densities of the LT waters are approximately 29.26, 29.23 and 29.26 in the Levantine, Cretan and Ionian respectively, whereas for the EMT the densities are 29.20, 29.32 and 29.20 respectively. The question which arises, of course, is why this event has not been traced in the next to the peak cruises. In other words it seems that the LT has quickly vanished away. The data in the Ionian seem to indicate such a rapid fading away. Note that based on the volume of waters produced during the EMT, it has been roughly estimated that its traces will be visible for a period of two decades or so. A possible explanation for the fast disappearance of the LT trace might be a reduced volume of waters produced during the LT but this, of course, is pure speculation at present.

Acknowledgments. We express our thanks to S. Kioroglou for data analysis.

Annual and long-term changes in the salinity and the temperature of the waters of the South-eastern Levantine Basin

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INTRODUCTION

During the summer, The Eastern Levantine Basin is covered by the Levantine Surface Water (LSW). This water mass is formed by intensive heating and evaporation and has the largest salinity and temperature of the entire Mediterranean Sea. Due to general cyclonic circulation of the Levantine Basin the LSW advects to the Rhodes gyre region and due to its large salinity appears to be the source water for the Levantine Intermediate Water (Hecht *et al.*, 1988; Hecht and Gertman, 2001). Moreover, via the Cretan Arc passages, the LSW advects into the Aegean Sea eastern shelf and participates in the intermediate and deep waters formation of the Aegean Sea (Theocharis *et al.*, 1999; Zervakis *et al.*, 2000). During 1987-1999 the Cretan Sea deep water overflowing via the Cretan Arc passages appeared to be denser than the water overflowing from the Adriatic, resulting in one of the most interesting phenomena of the Mediterranean hydrology – the Eastern Mediterranean Transient (Klein *et al.*, 1999). One of the suggested reasons for the Transient is a long-term increase in the salinity of LSW ingressing into the Aegean (Theocharis and Lascaratos, 2000) and one of the intriguing questions is role of the Nile damming in this increase (Klein *et al.*, 2000).

One of the pioneering investigations on the distribution of the Nile river plume (Hecht, 1964) shows a typical low salinity tongue of the water propagating northward on the south-eastern continental shelf of the Levantine Basin, from the Nile delta along the Israeli coast. The axis of this tongue, its minimum surface salinity, was located at a distance of about 3-5 miles offshore. These waters were observed regularly during September-October up to 1965, the year the Aswan High Dam was closed. In 1972 Oren and Hornung computed the climatic changes of temperature and salinity that occurred over the Israeli continental shelf for pre-Aswan and post-Aswan periods. They found that the September drop of about 0.8 ‰ in the annual changes of salinity ceased after 1965. Using all the data available to the Israel Marine Data Centre we investigated annual changes and long-term changes of temperature and salinity of the South-eastern Levantine Shelf Region as well as the changes of the South-eastern Levantine Deep Region (Fig. 1).

METHODS

In order to compute the annual changes of temperature and salinity all the data were interpolated to standard levels and grouped on two subsets: shelf data and deep-water data. For each level and each subset the annual changes of temperature and salinity were estimated by a medi-

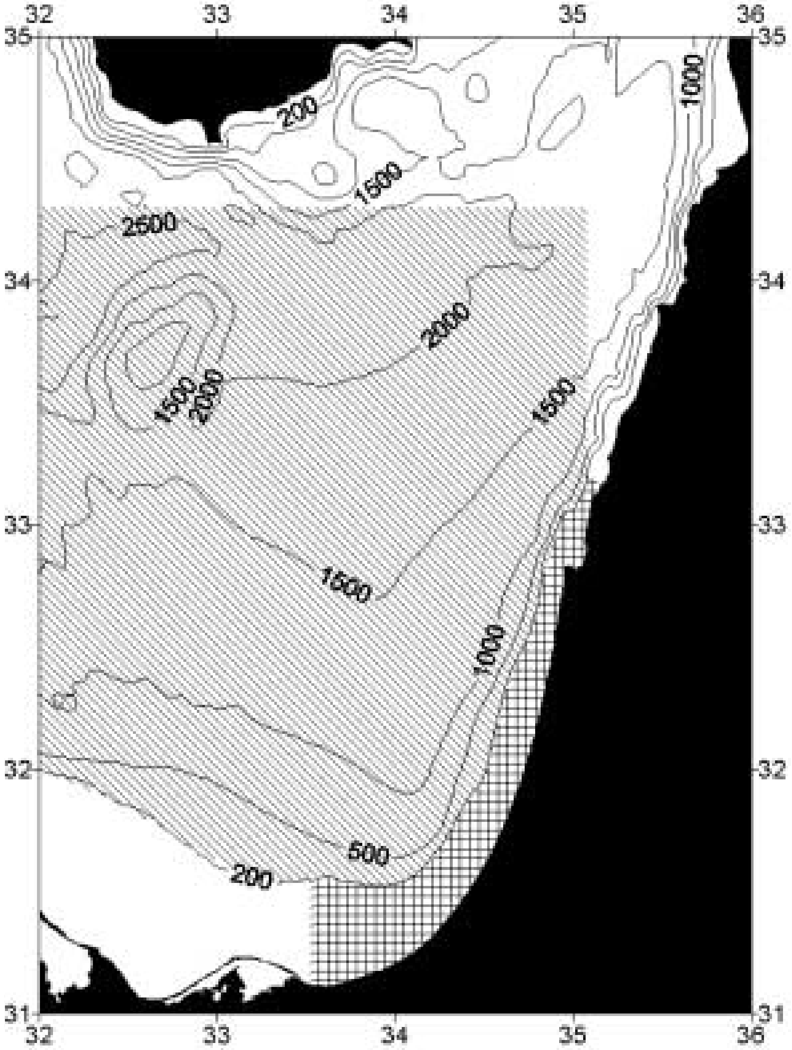

Fig. 1. Southeastern Levantine basin. The shelf region and the deep region used for casts selections have a different hatching.

an filter. Variability was estimated by 25 % and 75% lower and upper quartile. These estimates are considered to be more robust for small samples than estimates of mean and standard deviation. Annual changes for the upper levels were calculated separately for two time periods: pre-Aswan (1947-1964) and post-Aswan (1965-2000).

Long-term changes were estimated by calculating linear trends for each level and each subset. A linear trend was accepted as significant if at the 95% level of confidence the t-distribution did not includes a null value for the annual increment of the line trend. Moreover, a Fisher test was also carried out and at the 95% level of confidence the test indicated that the slope of the regression is significant.

RESULTS

As expected most of the changes appear to be in the salinity of the upper layer of the shelf waters. On Figure 2 we demonstrate the annual changes for the 10 m level, because the 10 m measurements are more accurate than the 0 m measurements. During the pre-Aswan period the data reveal a large number of observations of low salinities, in the range of 36.5-38.5 ‰. Hence the median yearly salinity variations in the upper layer exhibit two minima. One in February, 38.84‰ and one in October, 38.95 ‰. An average October salinity for that region results in a lower value, 38.78‰.

For the post-Aswan period, the October salinity median climatic value reached 39.35‰. Seasonal maximum of the upper layer salinity moved from August to November. The annual changes in salinity between the two periods are diminishing with increasing depth. But the variability of the salinity during the pre-Aswan period is about twice as large for all levels down to the bottom. Annual changes of temperature of the south-eastern shelf waters are quite similar for both periods.

According to Figure 2 the most intensive changes in the annual salinity pattern appear to be during autumn months. Therefore we computed the long-term changes in the shelf waters separately for the autumn (September-December) and for the winter (January-April).

The most intensive long-term increase of salinity (0.014‰ per year) was observed in the upper layer of the shelf region for autumn months (Fig. 3). Positive trends of salinity were found at all levels, but at 100 m the trend is not significant anymore. Winter positive trends of salinity for the region also are not significant for the entire water body of the shelf. The long-term

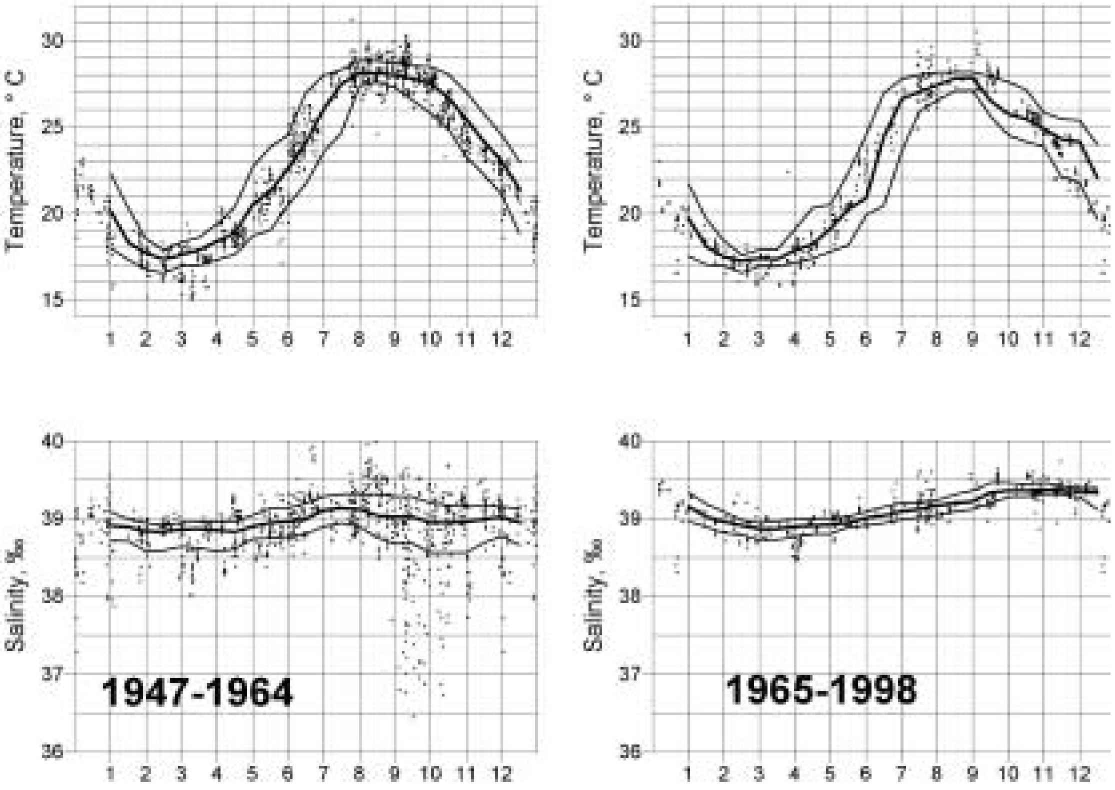

Fig. 2. Annual changes of temperature ans salinity of the upper layer (10 m depth) ot the Southeastern Levantine basin shelf regionfor the pre-Aswan and the post-Aswan periods.

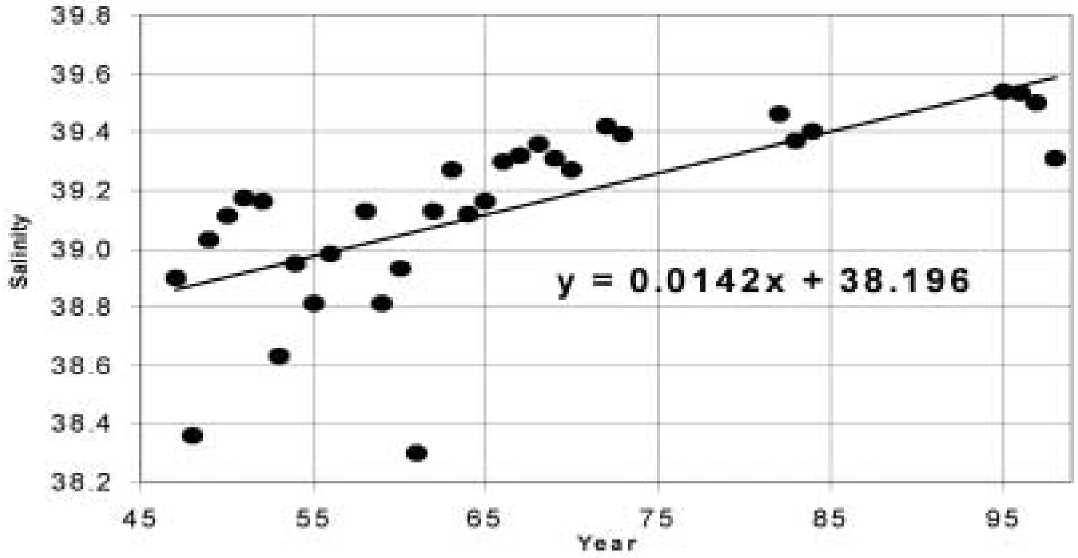

Fig. 3. Long-term changes in salinity of the South-eastern Levantine shelf region (September-December, 10m).

changes of water temperature on the shelf also did not reveal any statistically significant trend both for the winter and for the autumn.

The South-eastern Levantine Deep Region is not affected directly by the Nile floods, therefore we computed the seasonal changes for the entire observation period. The seasonal pattern of the upper layer salinity (Fig.4) is very close to the seasonal pattern of the shelf upper layer during the post-Aswan period. Seasonal values of the upper layer water temperatures are less than

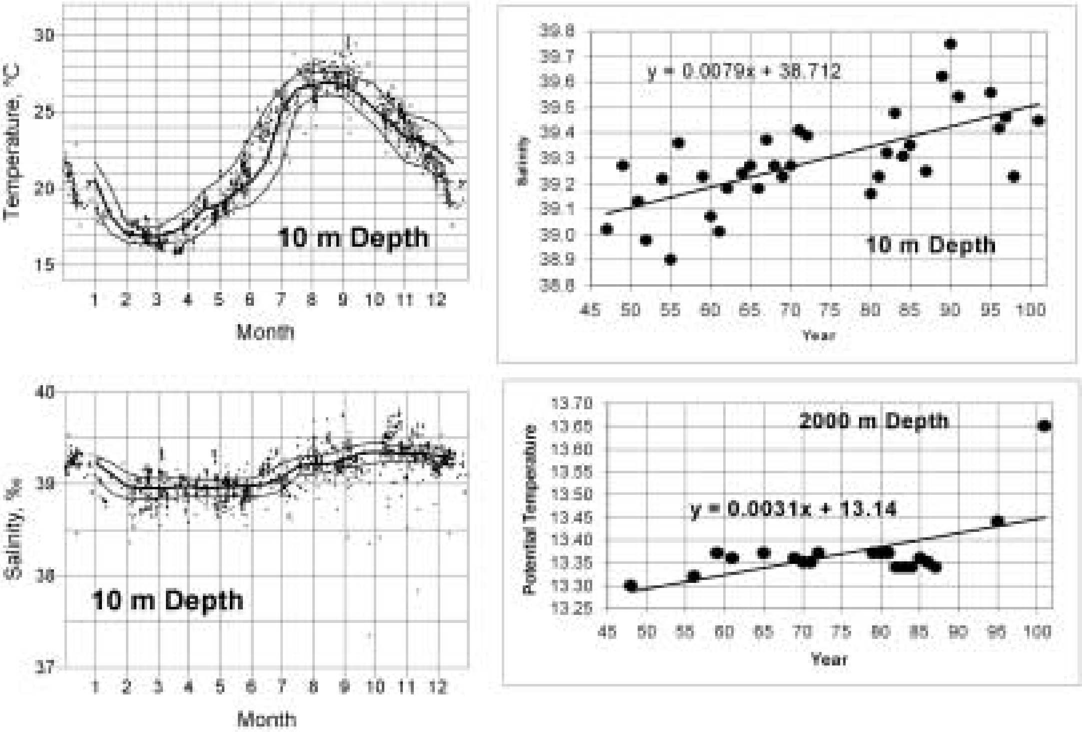

Fig. 4. Seasonal and long-term changes of temperature ans salinity of the Southeastern Levantine deep region.

the corresponding values of the shelf waters by about 0.5-1°C. In the upper layer of this region, we observed a significant positive autumn salinity trend of 0.008 ‰ per year. This trend appears to be significant above 50 m. Winter salinity changes do not indicate any significant trend.

Temperature changes in the upper layer do not exhibit any significant trend in the winter or in the autumn.

Other positive long–term tendencies, which satisfied the statistical tests, were found in the potential temperatures of the very deep waters below 1500 m. The annual increment is about 0.002-0.003 °C per year. It is important to note that if we reject the data measured in 1990 and in 2001 (i.e. data measured after the Transient) from the time series of potential temperature the trends will not satisfy statistical significance tests.

The monitoring of the evolution of the hydrological characteristics in the deep basins of the North Aegean Sea

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The North Aegean Sea is characterized by a number of isolated and deep basins communicating above the 400m isobath. The Black Sea Waters (BSW) and Levantine Surface Waters (LSW) occupy the upper thermocline while the Levantine Intermediate Water (LIW) is present down to 400-500m. The deep and bottom waters fill the deep basins. Occasionally, a salinity minimum can be detected under the LIW. This can be attributed to the BSW intrusion during the previous winter.

The ventilation depth, occurring annually or interannually, reaches the intermediate, deep and bottom layers depending on the weather conditions and the quantity of the BSW that intrudes the Aegean through the Dardanelles (Plakhin, 1972; Gertman *et al.*, 1990; Zervakis *et al.*, 2000). It seems that even in mild winters dense water can occur affecting different water depths (Theocharis and Georgopoulos, 1993). An event of deep and bottom waters ventilation in the North Aegean sub-basins was detected during winter 1987. Examining the evolution of deep and bottom water characteristics from summer 1986 to summer 1988 one can follow the replacement of the older water mass with the newly formed waters. Consequently, the old waters were uplifted over-passing the limit of 350-400m depth, thus reaching dynamically more active layers. This process permits also their southward transportation and eventually further ventilation during next winter. Interestingly, the water mass characteristics indi-

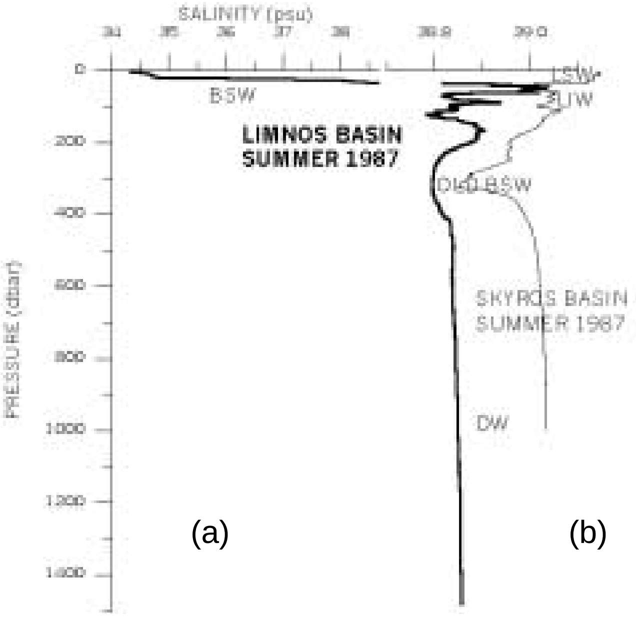

Fig. 1. Vertical salinity distribution in (a) Limnos basin and (b) Skyros basin

cate the different sources that supply the various basins with newly formed water, as well as the high values of density in the intermediate, deep and bottom layers (Fig. 2).

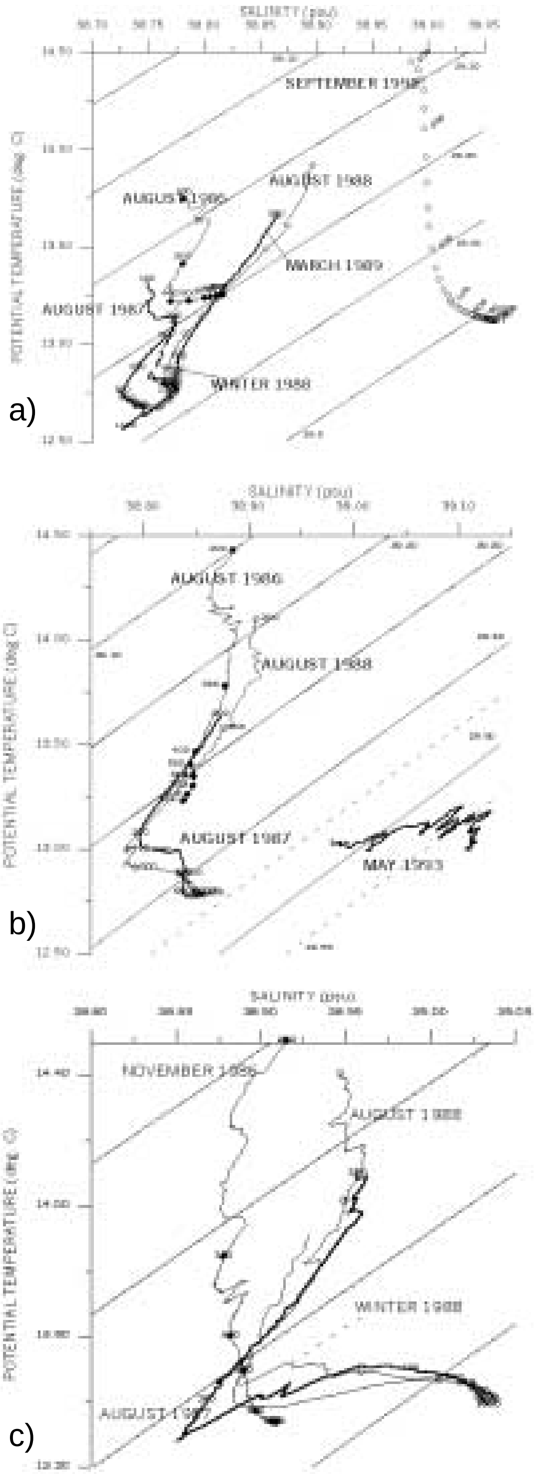

Fig. 2. θ/S diagrams showing the evolution of the hydrological characteristics of the (a) North Sporades, (b) Limnos and (c) North Skyros basins during 4 consecutive years (1986, 1987, 1988, 1989) and 1993, 1998.

In the North Sporades and Limnos basins, during the winter 1987 event, temperature differences played a major role in the modulation of the characteristics of DW, while in the North Skyros basin the salinity played a significant role. However, the change between 1989 and 1998, in the North Sporades basin was mainly salinity driven. In Figure 2b, the hydrological characteristics observed in May 1993 indicate that a second event of DW formation took place in the area during the period 1990-1993. The changes in this water mass was again salinity induced.

Examining long time series taken from the Hellenic Oceanographic Data Center (HNODC) there are indications of an important event of deep water formation in the late ’60s early. The above mentioned events of massive deep and bottom water formation can be considered as sporadic, separated by long stagnation periods. Even though, examining the distribution of the density during the last 55 years in the North Skyros basin a decrease of the depth of the 29.2 and 29.3 isopycnals is detected (Fig. 3). During the stagnation periods the deep waters of each sub-basin are excluded from interaction with other water masses through advection or isopycnal mixing, and the only process that changes their properties is diapycnal mixing with overlying waters. In Figure 2c the change in θ/S at approximately 300m depth (upper part of deepwater) smoothed progressively with time (from summer 1987 to summer 1988). The same behavior can be seen during the same time interval in the other two θ/S diagrams (Figs 2a and b). Utilizing a simple one-dimensional model, it is possible to estimate the vertical eddy diffusion coefficient K_ρ based on the observed rate of change of density and stratification. These estimates are performed for each of three sub-basins of the North Aegean, the different levels of diffusion suggesting the different dynamical characteristic of each basin.

The development of the conveyor belt in the North Aegean depends on the depth of the winter ventilation of the water column. The conveyor belt is open in its southern part, where surface waters are transported from the South Aegean while intermediate and occasionally deep and bottom waters move towards the south.

In conclusion, the deep basins constitute reservoirs of dense water, with hydrographic properties that are subject only to slow changes during the stagnation periods. It is preferable to mon-

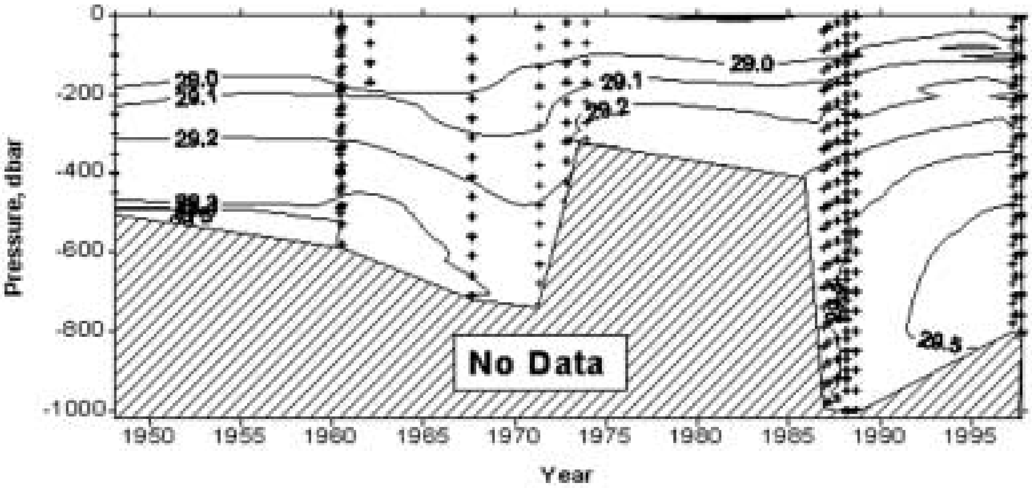

Fig. 3. Evolution of the hydrological characteristics in the North Skyros basin from 1945 to 1999.

itor deep basins, due to the absence of horizontal advection, which can significantly hinder the analysis. In a deep basin where there is no advective input of water-masses, the major processes are (i) formation of dense water identified with episodes of intense buoyancy exchange with the atmosphere, and (ii) stagnation periods, where the evolution of the deep-water properties is subject mainly to vertical turbulent diffusion. Thus, the trends to be monitored are not linear with time, but tend to have a saw-tooth-jagged form.

In the Aegean a network of 11 open sea oceanographic buoys (Sea Watch / Oceanor) equipped with meteorological and oceanographic sensors and a system of atmospheric/oceanic models, are operational since 1998. The meteorological sensors measure wind speed and direction, air temperature and atmospheric pressure while oceanographic sensors measure waves height and direction, surface current speed and direction, temperature, salinity, dissolved oxygen, chlorophyll-a and radioactivity in two buoys. Temperature and salinity are measured at five depths between 3 and 50m, while all other parameters are measured at 3m depth. Sampling is carried out every 3h and then data are automatically pre-processed on the buoy and transmitted to the operational center of NCMR via INMARSAT-C and GSM communications. The data set, after passing a first level quality control, are available on the Internet through the project's web page, www@poseidon.ncmr.gr (Nittis *et al.*, 2001). Since September 1999, after one year of pre-operational use, three numerical models run daily giving 72-h forecasts. The forecasting system is based on a hierarchy of three numerical models. The first is the atmospheric model based on the SKIRON model developed at the University of Athens. Its component is the ETA limited area model that was originally developed at the University of Belgrade (Kallos *et al.*, 1997; Janjik, 1994; Mesinger *et al.*, 1988). The second is an hydrodynamic model developed in the University of Athens and is based on the so-called POM. It is applied in the Aegean with a high-resolution grid of 0.05o in the horizontal and 30 layers in the vertical. In this resolution the model is able to reproduce eddy dynamics that play a mayor role on the circulation field especially in the synoptic time scale. The third model is the offshore waves model that simulates the dynamics of wind-generated waves in the open sea with a horizontal resolution of 0.05o. The prognostic parameter is the wave spectrum and all the deriving operational quantities such as significant wave height, main wave direction and significant-mean wave periods.