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Science of the Mediterranean Sea and its applications

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TABLE OF CONTENTS

1. OBJECTIVES, GOALS AND ORGANIZATION

Progress in the study of the Mediterranean Sea, predominantly in terms of its semi-independent Eastern and Western Basins, provides a timely and substantial basis for the emergence of a modern science of the whole Mediterranean Sea.

The goals of the workshop were:

(i) To identify scientific issues and to define research directions for the study of the entire Mediterranean Sea, and

(ii) To assess the potential for timely practical applications of recent and anticipated scientific advances in the context of:

- A comprehensive review of present scientific knowledge, and
- An overview of technical needs for environmental management, maritime operations, and marine technology.

Recent basin oriented research has revealed the structures and scales of the circulation elements and their variabilities, processes of water mass formations and transformations, including the dramatic replacement of the deepest water of the Eastern basin. Realistic interdisciplinary research is now feasible on synoptic and general circulation scales.

Topics, discussed from experimental and modelling viewpoints, include:

I. Transports, Exchanges, Transformations and Budgets

- Air-Sea, Straits, Littoral and Material Interactions and Exchanges
- Water Masses, Heat and Fresh Water Budgets
- Biogeochemical Cycles

II. General Circulation of the Upper Ocean

- Basin, Sub-basin, Meso and Sub-mesoscale Structures and Variabilities
- Forcings, Responses, Feedbacks and Multiscale Interactions

III. Thermohaline Circulation Cells - Four Cells: Eastern, Western, Whole Mediterranean and External Cells

- Connectivities, Feedbacks and Variabilities
- Global Analogies and Influences

IV. The Mediterranean Ecosystem

- Regional Sub-components and Linkages
- Physical-Biological-Chemical Interactions
- Productivities, Food Webs and Limiting Factors

V. Time Variabilities and Climatic Change

- Annual, Interannual, Multiannual, Decadal and Longer Variabilities
- Teleconnections: Intrabasin, Interbasins and Global
- Natural and Forced Oscillations, Tides and Modes

VI. Coastal Processes and Interactions

- Coastal Zone Uses
- Inputs from Land and Land Uses

- Demographic Developments and Tourism
- Economics, Sustainable Development and Scientific Understanding of the Sea

VII. Mediterranean Prediction and Observation Systems:

- A Mediterranean Ocean Observing System, and
- Data Assimilative Interdisciplinary Management Model

The workshop focussed on research issues, needs and opportunities organized under the above seven topics. The first draft of the report was completed during the workshop. The plenary presentation and discussion of each topic was led by a team of three scientists, and seven larger topical groups were responsible for the related working and drafting group activities. Each of the seven topics was presented and discussed in one-quarter of a day in plenary sessions. The remainder of the time was devoted to topical working groups and drafting. A concluding session was held for plenary adoption of the final recommendations. See ANNEX I for the detailed agenda and the make up of the topical groups.

2. SUMMARY OF FINDINGS AND RECOMMENDATIONS

PROGRAMMATIC RECOMMENDATIONS

Mediterranean research requires cooperation of the scientific community in all the Mediterranean countries and the scientists outside the region interested in the Mediterranean because of its character and properties as a laboratory basin for global processes and semi-enclosed sea dynamics, and for its influence on adjacent and global circulations. Due to its basic mandate, IOC should continue to facilitate and coordinate requisite cooperative research. In particular, the IOC should now formulate, in coordination with other relevant bodies and programmes, a harmonized, regional cooperative research programme for the whole Mediterranean basin, building on recent research results, taking into account relevant global programmes, *e.g.*, of the IGBP, and avoiding duplication. In doing this, the IOC will continue its association with Mediterranean research over the last 1-2 decades. The IOC should ensure in this process the involvement of scientists from the South Mediterranean institutions.

Having held the July 1997 Mediterranean Science workshop, an institutional consultation between IOC and EU, and possible other organizations and programmes active in Mediterranean research, should be organized after the EU science meeting (Rome, November 1997), so as to help ensure proper coordination, harmonization, to avoid duplication and to acknowledge their partnership.

A meeting of the July Mediterranean Science workshop task leaders should be organized to be held in spring 1998, to formulate a science plan for the IOC Mediterranean programme, which can be submitted to the IOC Executive Council meeting in the fall of 1998.

I. TRANSPORTS, EXCHANGES, TRANSFORMATIONS AND BUDGETS

STRAIT OF GIBRALTAR

Although the analysis of data previously gathered in the Gibraltar Strait is far from complete, a new and more complete understanding of the role played by the strait in controlling (determining) the exchange water of the Mediterranean with the world ocean is starting to appear. However, due to the apparent internal variability found in other processes within the Mediterranean (i.e. deep water formation rate and location, extreme high seasonal and interannual variability as that in the Corsican Channel, etc.) it is uncertain to what extent the flows measured at Gibraltar are affected by these internal processes and this is where a continuation of the measurements is clearly required. The EU under the MAST Programmes (Harry Bryden, Sen Hanplain, Uwe Send, Karl and J-Gencia, Malaga) has initiated a two-year measuring programme in the strait. With reference to the transport observed at Gibraltar compared with that observed across the other passages in the Mediterranean, this is being pursued at this time of the analysis stage.

THE STRAIT OF SICILY

After a one-year interruption, the current time series has started again (September 1996) as a part the EU Project MATER. Current meters will be maintained until the end of 1998. This poses the question of a further continuation of the current measurements to observe the interannual variability of the exchange between the eastern and western Mediterranean. We need to better understand the role of dynamical processes affecting the Levantine flow when crossing the strait (aspiration, topographic effects, friction, mixing, etc.) as well as the role of the mesoscale activity in controlling the transport of the Atlantic flow. It should be equally necessary to start a long-term control of nutrients and other bio-chemical properties across the strait.

The investigation should be extended to the Sicily channel as well as to the eastern sill of the basin in order to check directly the flow coming from the eastern Mediterranean basin. The investigation should also be extended to the southern part of the strait where the major flow of MAW often occurs. This region is part of the Tunisian transitional waters. Sea level measurements should be made across the strait.

STRAIT OF OTRANTO

Dynamics of the strait and biogeochemistry are crucial for estimating budgets and long term trends in the Eastern Mediterranean. The quantitative estimates of the role played by the forcing mechanisms on the strait dynamics and a more detailed analysis of the transport variability at seasonal and interannual time scales should be addressed and considered. The distribution of biogeochemical properties in the straits and surrounding areas is very poorly documented and known. Further studies should be addressed to estimate the active contribution of organic and particulate forms of nitrogen and phosphorus to the exchanges through the strait and to establish their total budgets. The residence time of surface and intermediate waters of Ionian origin can greatly affect the chemical content and the remineralization processes occurring into the Southern Adriatic.

CRETAN ARC STRAITS

Long-term monitoring of the straits, through an interdisciplinary approach, in order: to study interannual and longer period variability; to study possible effects on the ecosystems of the adjacent basins; to investigate possible effects on the thermohaline circulation and general circulation.

II. GENERAL CIRCULATION OF THE UPPER OCEAN

Forcing, Response, Feedbacks and Multiscale Interactions

Forcing and Response

An effort must be made to review the existing data and to assess new sources of data such as recent sea level measurements, the meteorological reanalyses available from the various operational forecasting centers, and measurements from new technologies. Efforts should be concentrated on reducing the uncertainties in the forcing functions. Further studies of the response of the Mediterranean will depend crucially on a proper understanding and assessment of the forcing. Studies should include both field measurements as well as intensive modelling efforts with an emphasis on specific process studies as well as a general understanding of the overall response of the system.

Feedbacks

To properly address the issue of two way air sea interaction, it is necessary to implement a coupled ocean atmosphere model for the Mediterranean and conduct appropriate studies.

Multiscale Interactions

Further studies of the multiscale interactions will rely heavily on modelling studies in the form of process studies (idealized simulations), high resolution regional or sub-basin scale simulations, as well as long term basinwide simulations.

Upper Ocean Circulation: Basin, Sub-basin, Meso and Sub-mesoscale Structures and Variabilities

There is a necessity to extend the studies of upper ocean circulation variability from the seasonal scale (investigated until now) to interannual and multiannual scales. Integrated extensive observational programmes are needed to address interannual and multiannual variability of both the Eastern and Western Mediterranean. These programmes should use the state-of-the art technology already developed for the world oceans. They should include hydrographic surveys, drifter/float measurements, long-term mooring and remote sensing monitoring. Studies including surface forcings, internal dynamics and circulation instabilities should be conducted.

Realistic interdisciplinary simulations and nowcasting/forecasting of the upper ocean circulation with the proper spatial and temporal variabilities are essential for modelling and prediction of the different ecosystems of the Mediterranean, especially in the broad shelf areas (e.g., the Nile Delta, the Rhone Fan, and the Northern Adriatic Sea), as well as for the societal consequences and human resources of the riparian countries.

Intermediate water mass (LIW) pathways

Assessment of LIW pathways, spreading, and dispersion is crucial for ecosystem modelling and prediction with respect to the permanent cyclonic/anticyclonic structures and the cyclonic/anticyclonic sides of the jet like currents; upwelling and resupply of nutrients to the surface layer in cyclonic areas.

Reanalysis of available multi-decadal meteorological fields (wind stress, surface heat and moisture fluxes) for the construction of a synthetic atmosphere based upon the identification of the dominant synoptic modes of variability; identification of multidecadal datasets available from meteorological datasets available from meteorological centers (time periods, space resolution); quality control of data; identification of most advanced and suitable methods of statistical analysis for the evaluation of the dominant modes of variability.

Definitive assessment of the building blocks of the upper thermocline circulation of the Mediterranean. This assessment has been basically completed in the Eastern Mediterranean on the basis of coordinated multinational quasi-synoptic surveys that have led the identification of the dominant space scales of motion. While knowledge of circulation features is advanced in some sub-basins of the Western Mediterranean, such an assessment is still lacking for the overall Western basin; planning and execution of coordinated multinational surveys in the Western basin; use of advanced observational technologies to seed the Mediterranean with drifters and floats.

Definitive identification of Intermediate Water Mass Pathways in the entire Mediterranean (LIW, CIW). The assessment of major LIW pathways has been basically completed in the Eastern Mediterranean through quantitative dynamical analysis and interpretation of quasi-synoptic datasets. Such a quantitative identification of major LIW pathways is, however, still missing for the Western Mediterranean.

Investigation of the long time scales of variability (interannual to multiannual) of the upper/intermediate layer circulation (analysis of seasonal cycle has been extensively investigated); Observations component through repeated surveys of different sub-basins in successive years (example: late 90s field programme in the Ionian sea); strong modelling effort focused especially on multiannual variability (observationally more difficult); identification of major causes: variabilities of surface forcings, internal dynamical variabilities.

Construction of a synthetic ocean through the fitting *via* data assimilation of a dynamical model to the observations: use of models as interpolations/extrapolations to fill data gaps both in space and time for the investigation of the above circulation processes and, in general, for process studies; identification of priority periods of assimilation experiments on the basis of available observations and observed major circulation changes; use of most promising synthesis methods (examples: Kalman filter adjoint methods).

III. THERMOHALINE CIRCULATION CELLS

Further improvement is needed in determining the formation and pathways of deep and intermediate waters, including inter- and multiannual variations and interlinking. To achieve this, existing data, carefully selected new observations, and modelling efforts must be combined (this applies similarly to items 2 and 3).

The Eastern Mediterranean deep water transient must be monitored over the coming decades, with the aim to catch the essential features of this unique event, and to allow one to ascertain the underlying dynamics and the way it was initiated.

The upward return pathways of the deep and intermediate waters must be studied with the aim to determine their essential physics, distinguishing in particular between return within the Eastern respectively Western Mediterranean and return *via* westward escape through the respective major strait. One tool will be to set up multiparameter density classes in each basin. A region of particular concern is the Tyrrhenian Sea, where the indications are that internal water mass conversion aided by mixing occurs on large scale.

Numerical modelling of the thermohaline circulation needs to be improved further, although it is expected that much will be learned by the modelling in the context of items 1 to 3. Specific points are to validate the Lagrangian aspect (i.e. transports), and to find suitable ways to assure appropriate simulation in the immediate vicinity of topography.

IV. THE MEDITERRANEAN ECOSYSTEM

The analysis and validation of historical data sets on biogeochemical and ecologically relevant observations (including physical observations). The data could be collated in a CD-ROM and circulated.

Establish a quality control programme specific to biogeochemically oriented measurements, which could also build new capacity and favor technology transfer.

Define a scientific programme at the Mediterranean scale applying *mutatis mutandis* the concepts, strategies and methods developed for the study of the Global Ocean, with the appropriate corrections (WOCE, JGOFS, LOICZ, GLOBEC, GOEZS). In particular the following issues are considered urgent to be addressed:

- A general budget of nutrients both for the internal fluxes and for the input at the boundaries (land, atmosphere);
- A better estimate of the productivity of the basin, possibly based on both *in situ* observations and remote sensing, this particularly in the open sea areas that are poorly covered with *in situ* measurements of primary production;

- A more detailed description of elemental fluxes in the food web and of the flipping between new and regenerated production as well as of the organisms responsible for;
  - (i) A better knowledge of the coupling between different time/space scale especially because of the observed variability of the system;
  - (ii) An understanding of the main causes of the jelly fish swarmings that has been observed irregularly in the last 20 years;
- The monitoring of the geochemical dynamics and biota in order to detect and understand their response to the recent changes in the thermohaline circulation;
- The monitoring of fluxes at boundaries to evaluate changes in forcing on the hydrological cycle due to climate and/or anthropogenic activity;
- In view of remote sensing applications of the ocean color to estimate primary production, the implementation of a better algorithm for atmospheric correction and for chlorophyll retrieval, specifically calibrated for the Mediterranean;
- In addition to the above it is important in studying any ecosystem, not specifically the Mediterranean one, to take into account the processes that occur at the scale proper of planktonic organisms (i.e. micrometer to centimeters) and that are strictly related with diffusion and microturbulence. This because the nonlinear interactions between fluctuations as well as the response of the organisms at the microscale is probably relevant to the stability of the ecosystem.

Final recommendation is:

- To find the proper institutional framework to promote the studies/projects proposed.

V. TIME VARIABILITIES AND GLOBAL CHANGE

The launching of a monitoring system of the whole Mediterranean Sea for the physical and biochemical components of the ecosystem with near-real time data collection capabilities. Major aim of such a system should be to start to obtain long time series of marine parameters and to validate numerical models.

Initiate a concerted effort to study the role of ocean-atmosphere processes at different time scales for the physical and biochemical components. Part of this effort should aim at encouraging coupled ocean-atmosphere modelling of the Mediterranean Sea and start water cycle studies in a large atmospheric Mediterranean area (with land).

Initiate an effort to study the coupling of the open sea to the coastal zone and the coupling of the coastal sea to the land on seasonal to interannual time scale. Such initiative should concentrate in the comparison between different Mediterranean coastal regimes and their fertilization mechanisms.

Such research directions should be complementary to already finished and on-going research projects and duplication of effort should be avoided.

VI. COASTAL PROCESSES AND INTERACTIONS

The approach adopted at the workshop towards defining research directions which would improve the existing science support to ICAM efforts in the Mediterranean basin, was first to identify the main societal concerns in relation to the coastal zone and then to outline relevant research priorities. The interaction between the open sea and the coastal zone was also considered in this context, and it was concluded that understanding dynamical processes is a prerequisite to adequately address regional environmental concerns. Four process studies are considered of paramount importance for their biochemical implication and ecosystem modelling and prediction:

- dynamics of river induced buoyant plumes and interaction with shelf waters;
- cross-continental slope exchanges between the outer shelf and the basin interior;
- instabilities of the coastal currents such as the Algerian/North African current leading to formation and detachment of anticyclonic structures;
- cross-shelf/deep interior exchanges in the straits (Gibraltar, Sicily, Otranto, Cretan Arc) possibly constrained by straits dynamics, that is especially important in the Mediterranean.

Main social concerns related to the Mediterranean coastal zone and relevant research needs:

Water resources management:

- Process studies on the role of the sea and sea-air interaction in the regional hydrological cycle;
- Development of extended range (seasonal) precipitation forecasts;
- Assessment of the possible impacts of climatic change and associated sea-level rise on regional water budgets (shifts in precipitation patterns, changes in surface and groundwater flows and river regimes, sea water intrusion into coastal aquifers).

Coastal marine pollution: effects of anthropogenic substances

- Estimation of the fluxes of nutrients and contaminants into and out of the coastal zone (mainly riverine and atmospheric input and transfer across the shelf - open sea boundary), and development of models for predicting changes in these fluxes;
- Studies on the cause and effect relationships between introduction of anthropogenic substances into the coastal zone and environmental changes, and development of relevant predictive models;
- Identification and evaluation of specific environmental health indicators for the Mediterranean coastal zone amenable for routine monitoring.

Coastal erosion

- Definition of regional littoral cells (boundaries, sediment sources and sinks), assessment of sediment budgets for these cells and monitoring of large scale and local coastal changes (erosion, accretion) within the cells;
- Development and application of both simple and more complex advanced techniques for monitoring coastal changes including remote sensing and automated monitoring techniques;
- Studies aimed at improved understanding and modelling of sediment dynamic processes (the relationship between hydrodynamic processes and sediment transport, with emphasis on the water-sediment boundary layer);
- Scientific assessment of methods for prevention of coastal erosion, protection of coastal cliffs and rehabilitation of eroded coastlines.

Changes / loss of biodiversity

- Preparation of species inventories for the Mediterranean coastal zone (taxonomy, distribution, abundance);
- Regional studies to quantify trends in coastal habitats and biodiversity, and to understand ecosystem processes including effects of various stressors;
- Studies on foreign species introduction processes and impacts.

Extreme events

- Studies on interaction of atmospheric and open sea variability (internal, edge waves) that can originate sudden sea level rises in the coastal zone (seiches);
- Development of operational forecasting models of storm surges and other potentially catastrophic events of atmospheric origin;

- Scientific assessment of methods for monitoring the environmental conditions that can produce coastal algal or jellyfish blooms and other harmful biological events;
- Development of forecasting models for the prediction of floods.

SPECIFIC RECOMMENDATIONS:

A coordinated Mediterranean coastal science programme to address the issues listed above would contribute significantly to coastal zone management efforts in the region. Such a management-driven programme should include observational networks, process studies and development of predictive models, and should be closely linked to the basin scale open-sea research activities in the Mediterranean. A meeting of experts on coastal processes and interactions in the Mediterranean should be convened as a further step towards the programme design. The preparation of a detailed review of existing coastal research programmes and initiatives in the Mediterranean region as a background document for the meeting is highly desirable.

To provide a proper basis for regional assessments the Mediterranean coastal science programmes should cover the great variety of Mediterranean coastal ecosystems; this would require broad transnational involvement in the programme. In this context capacity building needs should be examined.

VII. MEDITERRANEAN PREDICTION AND OBSERVATION SYSTEMS

Research directions should involve: the development of an adequate observing system for both *in situ* and satellite measurements, development of multiparametric sensors for ecosystem monitoring, further improvement of general circulation models and nested regional models, development of synchronous and asynchronous coupling with the atmospheric models, improvement of data assimilation components for *in situ* and satellite data.

Future directions should involve especially:

1. development of the basin-wide ship of opportunity system for the monitoring of the upper thermocline physical and biochemical parameters;
2. development of the *in situ* buoy system for monitoring of currents, optical properties and phytoplankton biomass;
3. development of the components of the coastal monitoring system nested into the large scale monitoring system;
4. start proof of concept exercises for the short to medium term forecasts of physical parameters at overall and regional scales;
5. development of the ecosystem model implementations and their calibration with available data.

With regard to the mediterranean forecasting system:

1. A Science Plan should be developed in the interests of all the Mediterranean countries. The long lead times necessary for the implementation of an operational ocean observing and forecasting system for the Mediterranean requires its definition and planning through a Science Plan. This task possesses many critical challenges of modern times in organization, scientific knowledge, technology and financial resources.
2. International support should be given to the Mediterranean Forecasting System (MFS).
3. The science plan to be developed should involve:
    - development of the basin-wide ship-of-opportunity system for the monitoring of the upper thermocline physical and biochemical parameters;

- development of the components of the coastal monitoring system nested into the large scale monitoring system;
- initiation proof of concept exercises for the short to medium term forecasts of physical parameters at overall and regional scales;
- development of the ecosystem model implementations and their calibration with available data.

In the short term, national and multinational agencies working in the mediterranean should concentrate on the following actions, (*inter alia*):

1. Holding workshops to identify economical & social priorities for marine forecasting in the Mediterranean;
2. Analyze present observing instrument deployment, and encourage flip development of structural real time data transmission to a common system;
3. Exchange experience a currently used operational models;
4. Develop a standard high precision gridded bathymetry for the Mediterranean basin & coastline;
5. Promote the distribution of real time data products;
6. Study the developments of a Mediterranean Ferry - Box programme;
7. National agencies should be lobbied to encourage the formation of national GOOS committees;
8. Negotiate with offshore oil and gas companies and commercial met - ocean companies to write real data available in the public domain;
9. Participate in collaborative data assimilation experiments.

3. FINDINGS AND RECOMMENDATIONS

I. TRANSPORTS, EXCHANGES, TRANSFORMATIONS AND BUDGETS

INTRODUCTION

In 1985, during a workshop organized at IOC, it was recognized that a significant increase in the knowledge of the Mediterranean circulation could come from the Mediterranean straits and passages. In 1994, during a workshop organized by EU it was further pointed out that the study of straits could be substantial for all the marine disciplines, including Biology and Chemistry. At present, all the most important straits of the Mediterranean are investigated as a part of different projects of the EU. The results of different experiments have shown that straits are to be considered observationally and dynamically strategic. The first item refers to the fact that mass, heat and chemical budgets for the individual basins can be formulated in terms of fluxes measured at straits using a small number of instruments. The second refers to the fact that the physical phenomena occurring in straits may have a significant impact on general circulation processes and associated chemical and biological events. In addition, straits are to be considered privileged places for the comparison/check for the general circulation models.

Due to these aspects, and considering that the scientists involved in straits were allowed to meet together for the first time, all the most important straits in the Mediterranean were considered and discussed individually. The overall discussion could enjoy the contribution of scientists of the international community outside Europe. People involved in topic discussions recommended that, besides the straits considered in the discussion, also the Corsica Channel and the Sardinia Channel are worthy of attention due to their influence on the Western Mediterranean circulation.

CONCEPTUAL REMARKS

Straits connecting ocean basins can play a major role in controlling the internal properties of the basins. This is particularly true with respect to the depth of the strait, as it blocks the exchange of deep waters between the basins. Topical Mediterranean examples include the Straits of Gibraltar and Sicily. The importance of the lateral constriction of a strait is less clear, but it seems to be related to the concept of maximal *versus* sub-maximal exchange. In the former case, mixing in the interior of the basin has driven to a so-called overmixed limit, in which the density between inflow and outflow is the minimum consistent while the surface buoyancy flux in the basin and the dynamics of the exchange flow, which in its limit reaches a maximum. In this case the strait width is a controlling feature. Submaximal exchange is weaker than this limit, with a larger density difference between inflow and outflow; the width of the strait is of minor importance.

If the exchange through a strait is submaximal, then the exchange through it should show seasonal and interannual variability in response to changes in the surface buoyancy fluxes of the interior basin. On the other hand, seasonal and interannual changes in transport should not be seen at a strait through which the CA change is maximal.

A sub-maximal strait is thus a more convenient location for monitoring time dependent changes in the behaviors of the interior basin. A maximal short is much less responsive to interior changes, through in both types of strait measurements of the average exchange can provide accurate estimates of the long-term average budgets of the interior basins. A maximal strait is controlled in the sense that if the interior basin remains overmixed, its properties are controlled by the many limitations of the exchange through the straits. This can lead to unique prediction of changes in basin V in different climatic regimes, whereas this uniqueness is impossible for submaximal straits. It is this clear that (i) straits should be exploited as convenient locations for assessing the basins budgets, and that (ii) for each strait, it is important to determine if the exchange is maximal or sub-maximal. With respect to the main straits of the Mediterranean Sea, it appears that the exchange through the Strait of Sicily seems to be sub-maximal; thus the Eastern Mediterranean is not over mixed. Significant seasonal changes are observed in the flux and water properties in the Strait. On the other hand, the exchange through the Strait of Gibraltar does not show seasonal changes between maximal and marginally sub-maximal exchange. The question is important with conflicting evidence, but needs to be resolved if we want to achieve predictive capabilities for future exchanges.

STRAIT OF GIBRALTAR

STATUS

After the year-long (Oct. 85 - Oct. 86) Gibraltar Experiment (GIBEX), the Spanish Hydrographic Institute, IEO and WHOI conducted a 2.5 year (April 94 - Oct. 96) measuring programme sponsored jointly by the US NSF and ONR funding agencies. Since Gibraltar represents the only connection of the Mediterranean to the world ocean, it is indispensable to keep a continuous monitoring of different fluxes (water, heat and salt) occurring through this fundamental connection. The most important conclusion derived from this new data set is that the exchange flow at Gibraltar, i.e. the Atlantic surface layer inflow and the deep Mediterranean water outflow do not show an appreciable seasonal signal, apart from a more energetic variability of the exchange during the winter with respect to the summer period. The same data tend to point to a mean transport of about 1 SV. This magnitude is about 1/6 SV higher than that estimated during the 85-86 GIBEX Experiment. The fact that there is no seasonal variability in the exchange might imply that during the two years of measurement, the exchange at Gibraltar was at a maximal state.

RESEARCH DIRECTION

Although the analysis of these new measurements is far from complete, a new and more complete understanding of the role played by the strait in controlling (determining) the exchange water of the Mediterranean with the world ocean is starting to appear. However, due to the apparent internal variability found in other processes within the Mediterranean (i.e. deep water formation rate and location, extreme high seasonal and interannual variability as that in the Corsican Channel, etc.) it is uncertain to what extent the flows measured at Gibraltar are affected by these internal processes and therefore a continuation of the measurements is clearly required. The EU under the MAST Programmes (Harry Bryden, Sen Hanplain, Uwe Send, Karl and J-Gencia, Malaga) have initiated a two-year measuring programme in the strait. With reference to the transport observed at Gibraltar compared with that observed across the other passages in the Mediterranean, this is being pursued at this time of the analysis stage.

THE STRAIT OF SICILY

The Sicily Strait represents the western boundary of the Sicily Channel, the relatively wide intermediate basin connecting the eastern and the western Mediterranean. A central ridge arising from the bottom makes this connection to happen *via* the separated channels, which constrain the flux flowing from the eastern Mediterranean. A fairly long current time series (November 1993-July 1995) collected in both passages as well as periodic hydrographic comparisons carried out as part of EU projects allowed us to achieve some definite information about the characteristics of the Levantine flow.

1. The Levantine flow is divided by the presence of the ridge, and the estuary veins show pretty different dynamic properties.
2. The Levantine flow is actually formed of the water types of which the new one endeavored is colder and denser than the classical intermediate water and flows at the bottom of the western part of the strait. This is somewhat in contrast with the direction of the flow.
3. The transport of the Levantine water was about 1 SV in summer and 1.25 SV in winter; that shows a clear seasonal variability.
4. In the final part of measurements a systematic investigation of the nutrient content and the most important biological parameter was initiated.

RESEARCH DIRECTION

After a one-year interruption the current time series is started again as a part of the EU project MATER. This needed that the current time series be further improved in order to have information about the interannual variability of the exchange between the eastern and the western Mediterranean.

- We need to better understand the role of dynamical processed affecting the Levantine flow when crossing the Strait (aspiration, topographic effects, friction, mixing, etc.).

- The investigation should be extended to the Sicily channel as well as to the eastern sill of the basin in order to check directly the flow coming from the eastern Mediterranean basin.

- The investigation should also be extended to the southern part of the strait where the major flow often occurs. This region is part of the Tunisian transitional waters.

- Sea level measurements should be made across the strait.

STRAIT OF OTRANTO

STATUS

The Otranto Strait has been investigated for about two years revealing new aspects of its dynamics and volume transports. Seasonal hydrological surveys were carried out contemporaneously to long-term current measurements. The annual average flow patterns revealed by those experiments were quite similar to the well known flux structure, however total outflow/inflow rates are of a bit more than 1 SV, which is several times higher then the ones previously estimated by Gore-Armanda and Pucher-Petkovic (1976). Furthermore, very energetic mesoscale eddies of height scales of about 10 km, which were not resolved by the mooring array, were revealed by the survey.

The annual average water exchange pattern shows a two-layer structure of the strait interior, whereas the western and eastern flanks are characterized by a cyclonic shear over the entire water column. The time varying water flow is larger than the residual steady flow, with the exception of the eastern flank where a more stable inflow of Ionian water occurs.

The Adriatic Deep Water outflow manifests a discontinuity consisting of a series of pulses having a time scale of ten days, and is mostly concentrated on the western continental slope area. The total monthly mean transport rates show a seasonal signal with a minimum in spring/early autumn period of about 0.83+-0.3 SV, whereas during the winter the transport increases to about 1.5+-0.38 SV (Poulain et al., 1996).

The brochured characteristics of the strait were investigated as well, to estimate the exchange of dissolved and particulate matter between the Adriatic and Ionian. Annual flux computations reveal a net outflow into the Ionian of nutrients mostly concentrated in the layer between 200m depth and the bottom. On the other hand, a net inflow into the Adriatic of organic fraction is documented in the uppermost layer from the surface down to 200m depth.

RESEARCH DIRECTION

Dynamics of the strait and biogeochemistry are crucial for estimating budgets and long term trends in the Eastern Mediterranean. The quantitative estimates of the role played by the forcing mechanisms on the strait dynamics and a more detailed analysis of the transport variability at seasonal and interannual time scales should be addressed and considered. The distribution of biogeochemical properties in the straits and surrounding areas is very poorly documented and known. Further studies should be addressed to estimate the active contribution of organic and particulate forms of nitrogen and phosphorous to the exchanges through the strait and to establish their total budgets. The residence time of surface and intermediate waters of Ionian origin can greatly affect the chemical content and the remineralization processes occurring into the Southern Adriatic.

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CRETAN ARC STRAITS

Exchange of water and associated material through the Cretan Arc Straits is a scientific area of considerable importance. This is in particular true in view of the recent dramatic changes in the Eastern Mediterranean Deep Thermohaline Cell.

STATUS

The first efforts to investigate water flow through the Straits of the Cretan Arc were made in 1986-89 with the deployment of current meters at all straits in the framework of POEM and National Activities. During recent years (1994-1995) systematic studies, (through an interdisciplinary approach) of the Straits of the Cretan Arc, were made within the framework of the CEC/MAST supported Project PELAGON, during which a great diversity of oceanographic data were collected. These included current meter deployment at all straits, ADCP measurements, CTD casts and the measurement of a large number of biogeochemical parameters (e.g., nutrients, trace elements in sea water, radioisotopes, major and trace elements in SPM, phytoplankton, zooplankton, primary production, etc.). These studies suggested that the deep water outflow which has been intensified after 1987 presents a seasonal variability (0.3-1 SV), while the transport in the upper layers is highly variable. In addition, the above studies enabled detailed estimations of the deep water inflow from the Aegean Sea, which considerably contributes to the formation of the new, warmer, saltier and denser deep water of the Eastern Mediterranean, as well as the estimates of biogeochemical fluxes through the straits.

RESEARCH DIRECTION

Long-term monitoring of the straits, through an interdisciplinary approach, in order:

- to study interannual and longer period variability;
- to study possible effects on the ecosystems of the adjacent basins;
- to investigate possible effects on the thermohaline circulation and general circulation.

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II. GENERAL CIRCULATION OF THE UPPER OCEAN

FORCING, RESPONSE, FEEDBACKS, AND MULTISCALE INTERACTIONS

Forcing

The primary forcing functions for the Mediterranean circulation are: topography, surface forcing (wind stress, heat flux, atmospheric pressure), exchanges through straits, and fresh water input (river input, E-P). Various estimates for all of these fields are available but all have important uncertainties that must be quantified and reduced.

Response

The response of the Mediterranean occurs over a wide spectrum of both spatial (basinwide, sub-basin, mesoscale, sub-mesoscale) and temporal (hours to inter-decadal) scales. These have been seen in both the observational data as well as in results from recent modelling studies (e.g., POEM 1990s; Pinardi et al., 1997).

Feedbacks

Feedbacks can occur in two ways - (a) through air sea interaction (the mutual adjustment of the sea surface temperature and the heat/moisture fluxes from or to the atmosphere), and (b) through internal, dynamical energy conversions among the various scales of motion. Some preliminary assessments of both of these processes have been done through the analysis of historical data and in recent modelling studies.

Multiscale Interactions

In addition to the internal, dynamical, energy conversion cycle, multiscale interactions appear to be important in the process of intermediate and deep water formation and the spreading and redistribution of various properties. Evidence for this has been seen in some of the recent modelling studies.

RESEARCH DIRECTION

Forcing

An effort must be made to review the existing data and to assess new sources of data such as recent sea level measurements, the meteorological reanalyses available from the various operational forcecasting centers, and measurements from new technologies. Efforts should be concentrated on reducing the uncertainties in the forcing functions.

Response

Further studies of the response of the Mediterranean will depend crucially on a proper understanding and assessment of the forcing. Studies should include both field measurements as well as intensive modelling efforts with an emphasis on specific process studies as well as a general understanding of the overall response of the system.

Feedbacks

To properly address the issue of two-way air sea interaction, it is necessary to implement a coupled ocean atmosphere model for the Mediterranean and conduct appropriate studies.

Multiscale interactions

Further studies of the multiscale interactions will rely heavily on modelling studies in the form of process studies (idealized simulations), high resolution regional or sub-basin scale simulations, as well as long term basinwide simulations.

UPPER OCEAN CIRCULATION: BASIN, SUB-BASIN, MESO AND SUB-MESOSCALE STRUCTURES AND VARIABILITIES

STATUS

A variety of indirect and direct methods were employed to explore the surface circulation in the Mediterranean and, in particular, to study its spatial structure and temporal variability. They included core methods by which different water masses such as the low salinity Atlantic Water (MAW) were traced throughout the basin (e.g., Nielsen, 1972; Lacombe, 1976). The dynamic method is another indirect way of obtaining estimates of near surface currents from density (i.e. temperature and salinity) measurement assuming geostrophic equilibrium (e.g., Ovchinnikov, 1966). Various global and regional hydrographic surveys provided maps of the surface circulation with respect to an implied level of no motion. Inverse techniques (Tziperman and Malanotte-Rizzoli, 1991), the melding of dynamics with the data (Robinson and Golnaraghi, 1993) and satellite remote sensing (Le Traon, 1997) removed this arbitrary dependence and yielded maps of absolute geostrophic surface currents. The structure of sea surface temperature remotely sensed by satellites also helped to infer, at least on a qualitative basis, the surface currents (e.g., Millot, 1987).

Direct current measurements from moored current meters and Acoustic Doppler Current Profiler (ADCP) - Eulerian observations - and from ship-board ADCPs confirmed and/or refined the above maps at selected sites and regional locations. Starting in the 1980s, the trajectories of surface drifters tracked by satellite provided new direct measurements of the surface circulation which, by their Lagrangian nature, yielded a large geographical coverage and defined the main pathways of the surface waters (e.g., Millot, 1991; Artale et al, 1996; Matteoda and Glenn, 1996; Poulain, 1997). These drifter observations are generally in good agreement with the geostrophic maps, despite the fact that they contain direct Ekman wind- induced currents.

The above data sets reveal the following structure of the surface circulation in the Mediterranean. There is a global large scale cyclonic in the entire Mediterranean composed of embedded cyclonic systems in each of the basins with the MAW proceeding eastward from Gibraltar to the Levantine basin and being mixed and modified. The fast currents contributing to this water circulation actually appear prominent at the sub-basin scale (100 km). They consist of jets or free currents such as the Algerian

Current, the Atlantic-Ionian Stream, the Mid-Ionian and Mid-Mediterranean Jets meandering in between cyclonic circulation systems to their north and anticyclonic gyres to the south, which can be permanent robust features (Algerian anticyclones, Pelops, Ierapetra, Mersa Matruh, Rhodes Gyre, etc.) or of a more recurrent/transient nature (e.g., Ionian anticyclones).

Mesoscale (10 km) features are associated with variability/instability of the sub-basin current systems and with regional coastal dynamics (eddies and filaments of up-welled waters along specific coasts). Yet at a smaller but still sub-tidal scale (a few kilometers), convection regions or chimneys in the Gulf of Lions, the Levantine basin and the southern Adriatic are important sites of intermediate and deep water formation. They have a strong surface signature in terms of horizontal currents.

The Mediterranean surface circulation features mentioned above are characterized by substantial temporal variability, mostly imposed by the forcings (atmosphere and river runoffs) from the synoptic scale (a few days) to interannual and decadal scales. For instance, seasonal variability can be important, especially in the Eastern Mediterranean.

Up to now, observational programmes and modelling studies have addressed this temporal variability at the seasonal scales. Recently, dramatic inter-annual and even inter-decadal changes have been observed in the Mediterranean circulation (Malanotte-Rizzoli et al., 1997) that are associated with global changes in the Mediterranean Conveyer Belt (Roether et al, 1996). Inter-annual changes have been confirmed by modelling studies (Pinardi et al., 1997).

RESEARCH DIRECTION

Necessity of extending the studies of upper ocean circulation variability from the seasonal scale (investigated until now) to interannual and multiannual scales.

Integrated extensive observational programmes are needed to address interannual and multiannual variability of both the Eastern and Western Mediterranean. These programmes should use the state-of-the art technology already developed for the world oceans. They should include hydrographic surveys, drifter/float measurements, long-term mooring and remote sensing monitoring. Studies including surface forcings, internal dynamics and circulation instabilities should be conducted.

IMPLICATIONS FOR APPLICATIONS

(Upper ocean circulation; forcing, response, feedbacks, and multiscale interactions)

Realistic simulations and nowcasting/forecasting of the upper ocean circulation with the proper spatial and temporal variabilities are essential for modelling and prediction of the different ecosystems of the Mediterranean, especially in the broad shelf areas (e.g., the Nile Delta, the Rhone Fan, and the Northern Adriatic Sea), as well as for the societal consequences and human resources of the riparian countries.

INTERMEDIATE WATER MASS (LIW) PATHWAYS

STATUS

1. Eastern Mediterranean

LIW pathways in the Eastern Mediterranean have recently been well defined from known formation sites: the traditional formation region of the Rhodes gyre (1980s) and the Aegean formation region - Cretan Intermediate Water (CIW - the 1990s).

Two major pathways have been found: (a) directly towards the Sicily Straits and (b) towards the southern Adriatic in the Ionian along the Greek side (Rizzoli et al., 1997). The balance between the pathways seems to depend sensitively on the winds. There is veering by permanent cyclonic and anticyclonic structures. There is important recirculation in the Ionian interior.

2. Western Mediterranean

It seems established that LIW reaches the Gulf of Lions where it plays an important role in preconditioning of the deep MEDOC convection chimney. But the LIW pathways are rather less well defined than in the Eastern Mediterranean. Two patterns have been proposed: (a) the traditional spreading path along a direct route from Sicily to Gibraltar (Lacombe, 1970s) and (b) along the periphery of the different subbasins (Tyrrhenian and Balearic) in a general cyclonic pattern (Millot, 1990s).

RESEARCH DIRECTION

1. Observational - Eastern Mediterranean
   - Multi-time scales of LIW variabilities, formation sites, and pathways inter-annual to multi-annual).
   - LIW conversion to CIW in the Aegean Sea - dependence on changing patterns of winds *versus* surface fluxes *versus* basin long-term internal variability.

2. Observational - Western Mediterranean
   - Definitive identification of possible multiple pathways and relative strengths: boundary currents (cyclonic circulation) and southern route along the North African coast.
   - Multi-time scales of variability: inter-annual to multi-annual.
   - Overall issue: eddy *versus* mean transport and LIW dispersion.

3. Modelling
   - Mixing of LIW during dispersion and transformation phase: core water changes.
   - Inter-annual to multi-annual variability studies.
   - Assimilation studies (altimetry, Western Mediterranean tomography) to assess LIW pathways in the 1990s through the synthesis of observations and dynamics (Menmelis & Wunch, Nature, 1997).

IMPLICATIONS FOR APPLICATIONS

Assessment of LIW pathways, spreading, and dispersion is crucial for ecosystem modelling and prediction with respect to the permanent cyclonic/anticyclonic structures and the cyclonic/anticyclonic sides of the jet like currents; upwelling and resupply of nutrients to the surface layer in cyclonic areas.

RECOMMMENDATIONS

Reanalysis of available multi-decadal meteorological fields (wind stress, surface heat and moisture fluxes) for the construction of a synthetic atmosphere based upon the identification of the dominant synoptic modes of variability; identification of multidecadal datasets available from meteorological datasets available from meteorological centers (time periods, space resolution); quality control of data; identification of most advanced and suitable methods of statistical analysis for the evaluation of the dominant modes of variability.

Definitive assessment of the building blocks of the upper thermocline circulation of the Mediterranean. This assessment has been basically completed in the Eastern Mediterranean on the basis of coordinated multinational quasi-synoptic surveys that have led the identification of the dominant space scales of motion. While knowledge of circulation features is advanced in some sub-basins of the Western Mediterranean, such an assessment is still lacking for the overall Western basin; planning and execution of coordinated multinational surveys in the Western basin; use of advanced observational technologies to seed the Mediterranean with drifters and floats.

Definitive identification of Intermediate Water Mass Pathways in the entire Mediterranean (LIW, CIW). The assessment of major LIW pathways has been basically completed in the Eastern Mediterranean through quantitative dynamical analysis and interpretation of quasi-synoptic datasets. Such a quantitative identification of major LIW pathways is, however, still missing for the Western Mediterranean.

Investigation of the long time scales of variability (interannual to multiannual) of the upper/intermediate layer circulation (analysis of seasonal cycle has been extensively investigated); Observations component through repeated surveys of different sub-basins in successive years (Example: late 90s field programme in the Ionian sea); Strong modelling effort focused especially on multiannual variability (observationally more difficult); Identification of major causes: variabilities of surface forcings, internal dynamical variabilities.

Construction of a synthetic ocean through the fitting *via* data assimilation of a dynamical model to the observations: use of models as interpolations/extrapolations to fill data gaps both in space and time for the investigation of the above circulation processes and, in general, for process studies; identification of priority periods of assimilation experiments on the basis of available observations and observed major circulation changes; use of most promising synthesis methods (examples: Kalman filter adjoint methods).

III. THERMOHALINE CIRCULATION CELLS

STATUS

About 1 Sv of LIW with S~39 and p~29.05 is formed each year in the N. Levantine. Weak stratification due to winds and bathymetry encourages most formation in the Rhodes gyre (Lascaratos et al., 1993). This LIW forms a salinity maximum level throughout the rest of the Mediterranean, although core pathways with peak salinity can be found, and LIW is the main contributor to Mediterranean water in the Atlantic at a rate of ~1 SU with S~38 psu.

EMDW was formed exclusively in the Adriatic prior to 1987 (Roether and Schlitzer). A well observed and modeled LIW path northwards in the Eastern Ionian increases Adriatic salinity, encouraging denser water formation in winter at a rate ~0.4 Sv passing 0tranto. The EMDW path flows down slope along the Western Ionian and turns east to fill the deep Ionian and Levantine basins. No confirmed DW path across Sicily is known.

WMDW forms exclusively in the Gulf of Lions where wind-generated and topographically stabilized cyclone circulations prevail in winter. A subsurface LIW layer also contributes to reduced stability. Deep convection in non-hydrostatic plumes has been observed during strong Mistrals, with baroclinic eddies involved in recapping, although non-hydrostatic effects are probably unnecessary for modelling thermohaline effects of WMDW. WMDW paths need further research, although Tyrrhenian and Gibraltan pathways have been demonstrated.

LIW paths in the west in boundary currents and eddies have been demonstrated but further work is needed. EMDW changed in the 1990s to an Aegean source. Evidence that LIW path has also shifted, with reduced Adriatic path and Adriatic water formation. Aegean water amounts and paths are known although budgets and causes and future evaluation are unknown.

GCMs can now reproduce qualitative aspects of thermohaline circulation without climate drift and with reliable basin scale fluxes although sensitivities and interannual variability need more work.

RESEARCH DIRECTIONS

While the principal formation areas of deep and intermediate waters, and the mean rate and mechanisms of formation are known adequately, more has to be learned concerning interannual and interdecadal variations and trends, and about the causes of such variabilities, for which varying air-sea fluxes, winds and perhaps freshwater input by rivers and precipitation are the main candidates.

These variations will also lead to different characteristics of the waters formed, and to a variation in the depths at which the waters finally stabilize. These depths are potentially partially variable, where formation occurs by open-ocean convection in the principal basins of the (Levantine Intermediate Water (LIW), Western Deep Water) rather than in marginal basins. These effects must be studied and quantified.

In important issue are the pathways and mechanisms by which the deep and intermediate waters return to the surface. The mechanisms include upwelling, large scale or boundary mixing, and westward escape via the principal straits, into the Western Mediterranean or the Atlantic. A dedicated study of the internal pathways (upwelling and mixing) is needed, and the rates and characteristics of the intermediate and deep waters escaping through the major straits has to be quantified. Transient tracer observations and budgets for density intervals can assist in unraveling this issue.

The role of mixing is of particular concern in the Tyrrhenian Sea. In this sea, overflow from the Eastern Mediterranean, Western Deep Water, recirculated LIW, and possibly Winter Intermediate Water (formed in the Gulf of Lion shelf), all meet here. Density differences are moderate and mixing is assisted by rugged topography. Moreover, the sea is a dead end for the waters in question. The area is known for developing staircase structures indicative of double-diffusive mixing. A study is needed to quantify the internal water mass conversions and mixing in this sea.

A further issue is continuous monitoring of the Eastern Mediterranean deep-water transient. A new quasi-steady state will not be reached for some decades at the least, and its development including the relative roles of the Adriatic and the Aegean in forming deep water will influence the transports and budgets of salinity, nutrients, and other properties in the Eastern Mediterranean. At the same time, the cause of the transient must be investigated, in order to understand better the local dynamics of the thermohaline circulation, and to find out whether lessons can be learned regarding the stability of the global conveyor belt.

Lastly, it has to be shown to what degree the present models are capable of simulating the formation and spreading/recirculation of the intermediate and deep waters. It is also clear that various kinds of model developments must be performed before this can be accomplished in an adequate fashion.

APPLICATIONS AND IMPLICATIONS

An important application of a good knowledge of thermohaline circulation is to constrain the nutrient budget in various regions of the Mediterranean. Nutrient regeneration from deep waters and export to other basins in intermediate waters will severely affect ecosystem dynamics. This overlaps strongly with topics I, II, and IV. The ongoing EDW transient will clearly have implications in changing the nutrient and sediment budgets within the eastern basin.

Ability to model deep water paths has recently proven important in understanding dispersal of bottom sources, either of pollution or of natural sea floor emissions, in the open oceans. A need for such modelling in the Mediterranean may occur in the future.

The thermohaline circulation clearly has changed since the last ice age. An ability to understand these changes and their causes will be necessary to understand ongoing or possible future changes in the Mediterranean climate. This topic has wider implications in understanding general conditions for thermohaline collapse in the global oceans for which the Mediterranean might be considered a test case in terms of processes.

The transport of heat by the thermohaline orientation may influence local climate. The path of LIW to the North Adriatic and Gulf of Lions transports heat, which is released when deep water is formed. The amounts of heat have an unquantified impact on local coastal environments, (e.g., around the South Adriatic), which could change particularly after the Aegean transient.

Nutrient data is available only locally. Strait transports are needed. Better assessment of mean nutrient budgets is feasible. Models are now becoming available which can be used for transport modelling. Advances in subgridscale parameterization (e.g., Gent and McWilliams, 1980) and in improved numerical advection schemes will allow budget studies. More direct model data comparisons are needed which emphasize water properties and distributions. These will show where new data is needed and will feed back to the observation programme.

It is feasible to model whole thermohaline circulation, and physical and biogeochemical modelers need to collaborate closely to simulate the ecosystem.

RECOMMENDATIONS

1. Further improvement is needed in determining the formation and pathways of deep and intermediate waters, including inter- and multiannual variations and interlinking. To achieve this, existing data, carefully selected new observations, and modelling efforts must be combined (this applies similarly to items 2 and 3).

2. The Eastern Mediterranean deep-water transient must be monitored over the coming decades, with the aim to catch the essential features of this unique event, and to allow one to ascertain the underlying dynamics and the way it was initiated.

3. The upward return pathways of the deep and intermediate waters must be studied with the aim to determine their essential physics, distinguishing in particular between return within the Eastern respectively Western Mediterranean and return *via* westward escape through the respective major strait. One tool will be to set up multiparameter density classes in each basin. A region of particular concern is the Tyrrhenian Sea, where the indications are that internal water mass conversion aided by mixing occurs on large scale.

4. Numerical modelling of the thermohaline circulation needs to be improved further, although it is expected that much will be learned by the modelling in the context of items 1 to 3. Specific points are to validate the Lagrangian aspect (i.e. transports), and to find suitable ways to assure appropriate simulation in the immediate vicinity of topography.

IV. THE MEDITERRANEAN ECOSYSTEM

Any macroscopic volume of the biosphere can be looked at as an ecosystem. This does not necessarily mean that such a system would display relevant differences with other parts to the point to be considered a distinct ecosystem. Because Mediterranean Sea is connected with the open ocean and reproduces most of its properties, at least for the same latitudinal band, a Mediterranean ecosystem as a unique, distinct entity can hardly be characterized. By contrast, specific coastal areas in the basin (bays, estuaries, etc.) do show peculiar features so as to be possibly classified as specific ecosystems, but they are not the focus of the workshop. The description of the Mediterranean ecosystem would actually be the synthesis of current knowledge on the physical, chemical and biological processes within the basin and their mutual interactions, i.e. it would be part of the overall synthesis of the Mediterranean functioning. The debate on the geophysical dynamics of the basin is significantly more advanced and hard-grounded than that on coupled physical-biological interactions. In fact it involved, most of the attention of the workshop. In addition, the relevant processes to be considered at the ecosystem level are so numerous and complex that a much bigger effort would have been necessary to produce a satisfactory depiction. Therefore, the notes that follow, reflecting what was discussed, deal only with the planktonic domain. They do not pretend to be an exhaustive synthesis of the state-of-the art of Mediterranean ecology.

Most of the relevant physical processes occurring in the global ocean take place within the basin but, because of its narrow latitudinal extension and of the dominant role played by salinity in the dense (i.e. intermediate and deep) water formation, both the horizontal and vertical temperature ranges are much smaller as compared to the open ocean. This, in turn, favors a greater homogeneity in the deep fauna and reduces the need for overwintering strategies.

The Mediterranean Sea is a semi-enclosed extension of Atlantic Ocean. Because of its negative water budget, it imports low nutrient, surface Atlantic Water and exports deep and intermediate, nutrient-rich Mediterranean water. This implies that the replenishment of the internal reservoir very much depends on the inputs at the interfaces. The rate of primary production relies on the internal reservoir which in the greatest part of the basin prevalently consists of the nutrient pool in the LIW, the water mass underlying the surface layer. The transfer of nutrients from the LIW to the surface layer, which in the basin interior is basically MAW, through entrainment/diffusion or local convection accounts for a significant part of the new production in the basin. To date, the amount of new production in the basin is far from having been clearly assessed, but an upper limit is probably around 40 g C m-2 y. Different approaches have been chosen to evaluate new production in different areas of the Mediterranean. Phosphorus (Bethoux, 1981 and 1989) or Nitrogen (Dugdale & Wilkerson, 1988) budget considerations give lower values (11 to 20 g C m-2 y), whereas computations based on CZCS derived chlorophyll field (Morel & Andr, 1991; Antoine et al., 1995) with an average f ratio of 0.25 enlarge the value to approximately 30 g C m-2 y. Both approaches confirm the higher oligotrophy of the Eastern basin which accounts for 2/3 of the overall production but is twice as large as the Western basin.

Notwithstanding this low average value, intense primary production has been recorded in different areas, particularly in frontal zones (Almeria front Mediprod, etc.), river influenced coastal areas and/or upwelling regions mostly generated by cyclonic gyres abundant in the northern half of the basin. This could partially solve what has been defined the "Mediterranean paradox", i.e. signs of production higher than it could be expected on the base of available irregular measurements.

A zonal analysis of the Mediterranean would show that new production is enhanced where the nutrient content of the LIW is higher and/or its core is shallower or, alternatively, in areas close to terrestrial runoff or to sites of strong vertical convection (e.g., dense water formation sites). In addition, the subsurface nutricline in the WMED is steeper than in large areas of the Atlantic Ocean at similar latitudes, but deep concentrations are definitely lower. This feature would limit the total potential production of the basin but makes the productivity of the WMED slightly higher than that of, for example, Sargasso Sea. Moreover it does not call for a different ecophysiology of photosynthetic organisms, i.e. processes are similar inside and outside the basin.

Vertically diffused nutrients reach the surface very seldom, especially in the stratified season. Therefore, autotrophic biomass maxima are normally located in the subsurface layer, as in most of the world ocean, and form the so-called DCM (Deep Chlorophyll Maximum). No quantitative assessment has been made of the relative weight of subsurface *versus.* surface production in the basin, but the definitely longer time of existence of the DCM as compared the surface blooms, suggests that the role of DCM is extremely important. The formation and evolution of the Mediterranean DCM has also been satisfactorily reproduced by both 1-D and 3-D models (Varela & Cruzado, 1992; Zavatarelli et al, 1997).

Poorly known is, instead, the relevance on the overall production of the basin of episodic blooms. Because of the interplay of biological response to mesoscale activity unexpected high concentration of biomass has been recorded for example in the Southern Adriatic Sea, (Marasovic, personal communication) in Southern Tyrrhenian Sea (Ribera d'Alcala, unpublished data), etc. with values 5 to 10 fold the usual concentration. This lack of knowledge adds to the uncertainty in the basin production.

Also a quantitative assessment of the contribution of terrestrial runoff was found to be difficult. The values formerly produced by UNEP (1977) seem unrealistic and have not been updated in order to take into account possible trends in terrestrial inputs due to anthropogenic activity. Measurements conducted recently (EROS 2000, FANS) in the two major rivers of the WMED (Rhone and Ebro) show a Nitrate/Phosphate ratio always exceeding 20 (Cruzado, personal communication) which significantly differs from the N/P ratio of 7 in the UNEP estimates.

By contrast a better evaluation, based on reliable data, is now possible on the atmospheric contribution to nutrient inputs (Loye-Pilot et al., 1989, Herut & Krom, 1997). A sensible part of the new primary production can be accounted for including this source, although the response of phytoplankton to atmospheric deposition (both wet and dry) is not easy to detect, because of the presumably slow transfer rate.

Mass balances of both N and P (Nitrate and Phosphate), even considering the uncertainties in the sources, show that nutrient fluxes at the boundaries greatly contribute to the production in the basin. They also suggest that the Nitrate/Phosphate ratio higher than 15.0, the average value in the open ocean, is probably due to an unbalance in the sources. They finally show that N and P budget for the WMED is not balanced, the inputs being apparently greater than the outputs.

The unbalance in N/P ratio could imply a P limitation for algal growth in the basin. If this limitation is really impeding or depressing photosynthetic activity has not yet been unequivocally demonstrated. In an anticyclonic gyre in the Eastern Levantine has been clearly shown that DIN was still present when phosphate concentration was beyond the limit of detection (Krom et al., 1993), but fertilization experiments were not parallelly conducted to show that P was indeed limiting the growth. On the other side, mesocosm enrichment experiments with alternatively N and P given in unbalanced quantities have demonstrated that low P relative to N favors the growth of species with a lower DNA/C ratio, certainly because of the phosphorus need for nucleotide synthesis.

The N/P ratio anomaly is a feature unique to the Mediterranean Sea, for what large basins are concerned. On the other side, the atmospheric deposition of iron compounds is 5 to 10 time larger than iron flux in most of the open ocean, which makes iron limitation unlikely. The species composition of both phytoplankton and zooplankton closely resemble that of the temperate ocean, neither Mediterranean endemic species, if any, create significant qualitative differences in the functioning of the pelagic realm.

Similarly, strong similarities in abundances, role, diversity of different size classes of autotrophic and heterotrophic plankton with the temperate ocean and in different areas of the basin, has been demonstrated by recent works, with the only difference of a lower ratio of bacterial to picophytoplanktonic cells than the temperate ocean in a wide area of the EMED, which suggests one pelagic food web exists in the Mediterranean ecosystem. A consensus pelagic food web structure, as regards the plankton, was developed in 1988 (NATO ASI, etc.) and it could be accepted as a model structure with minor changes, not specifically related to the Mediterranean environment. Among the possible ones, the distinction between fish larvae and other metazoa, the introduction of the role of viruses as a bottom up control of smaller size classes of protists and of coccolithophorides as a separate algal class, could be considered.

There is no evidence in the Mediterranean of Phaeocystis blooms, but other processes with great production of extra-cellular polysaccharides, have been occasionally observed, particularly in coastal areas. They might respond to similar forcing as acting in Phaeocystis blooms in northern seas. As for what seasonality concerns, a spring phytoplankton bloom is not a recurrent process in the Mediterranean, particularly in the Eastern basin. In addition its timing, extension and amplitude is strongly correlated with the dynamics of cyclonic and anticyclonic sub-basin gyres and with the outcrop, when it happens, of intermediate water at the surface. Because of the reduced shelf area, cross-shelf fluxes that exchange biomass and solutes between coastal areas and open sea are strong and effective.

To date no convincing evidence has yet been gathered that recent changes in the thermohaline circulation of the basin have already caused a response at the organism or community level so as to modify species abundances, fluxes, etc.

The only region where a change in the water and nutrient exchange has been monitored and convincingly proven has affecting biota is the area facing the Nile delta. A total dissolved phosphate loss of approximately 200000 tons of phosphate in the last 30 years because of the damming of the river in Assuan, is considered as a lower limit. As a consequence of this, fish catches fell to 20% of the pre-dam period. Only after ten years a slow recovery has been recorded, probably also due to the increase of agricultural runoff and increased coastal urbanization.

RECOMMENDATIONS

Taking into account the current status of knowledge on the Mediterranean and the identified research needs we recommend:

1. The analysis and validation of historical data sets on biogeochemical and ecologically relevant observations (including physical observations). The data could be collated in a CD-ROM and circulated.

2. The establishment of a quality control programme, specific to biogeochemically oriented measurements, which could also build new capacity and favor technology transfer;

3. The definition of a scientific programme at the Mediterranean scale applying *mutatis mutandis* the concepts, strategies and methods developed for the study of the Global Ocean, with the appropriate corrections (WOCE, JGOFS, LOICZ, GLOBEC, GOEZS). In particular the following issues are considered urgent to be addressed:
   - A general budget of nutrients both for the internal fluxes and for the input at the boundaries (land, atmosphere);
   - A better estimate of the productivity of the basin, possibly based on both *in situ* observations and remote sensing, this particularly in the open sea areas that are poorly covered with *in situ* measurements of primary production;
   - A more detailed description of elemental fluxes in the food web and of the flipping between new and regenerated production as well as of the organisms responsible for;
   - A better knowledge of the coupling between different time/space scale especially because of the observed variability of the system;
   - An understanding of the main causes of the jelly fish swarmings that has been observed irregularly in the last 20 years;
   - The monitoring of the geochemical dynamics and biota in order to detect and understand their response to the recent changes in the thermohaline circulation;
   - The monitoring of fluxes at boundaries to evaluate changes in forcing on the hydrological cycle due to climate and/or anthropogenic activity;
   - In view of remote sensing applications of the ocean color to estimate primary production, the implementation of a better algorithm for atmospheric correction and for chlorophyll retrieval, specifically calibrated for the Mediterranean;

4. In addition to the above, it is important in studying any ecosystem, not specifically the Mediterranean one, to take into account the processes that occur at the scale proper of planktonic organisms (i.e. micrometer to centimeters) and that are strictly related with diffusion and microturbulence. This is because the nonlinear interactions between fluctuations as well as the response of the organisms at the microscale is probably relevant to the stability of the ecosystem.

5. The identification of the proper institutional framework to promote the studies/projects proposed.

5. The identification of the proper institutional framework to promote the studies/projects proposed.

V. TIME VARIABILITIES AND GLOBAL CHANGE

The past ten years have seen the growth of scientific awareness of the importance of time variability for the circulation, water masses and ecosystem fluctuations. Both atmospheric and oceanic variabilities were studied. This section outlines the assessment of these studies.

ATMOSPHERIC VARIABILITY

Atmospheric variability is important for ocean response from the weekly to interannual time scale. Different meteorological data sets have been examined. They have shown inaccuracies and incompatibilities with respect to wind stress and heat flux computations. There is an unsolved question of compatibility between surface flux computations and heat content of the ocean. Advanced air-sea physical parametrization has been developed and used in ocean modelling. Large wind stress variability at the whole Mediterranean scale and regional scale is recognized to be important for circulation and water mass formation rates. Short-term winter time changes can influence major changes in the thermohaline structure.

Precipitation data have been lagging behind the needs of the community because of the unreliability of precipitation observations at sea. Connections between Med SST and Sahelian rainfall has been elucidated. The influence of North Atlantic atmospheric variability on Western Mediterranean Sea variability is also recognized.

OCEAN VARIABILITY

Novel understanding of basin scale and sub-basin scale circulation structures have emerged together with their variability. Multiscale variability (spatial and time) have been assessed both in observations and models. Seasonal, interannual and decadal time scales of variability have been recognized to be central.

Most of the observed variability seems to be linked to atmospheric forcing variability. The internal variability has been recognized from observations and modelling at the mesoscale but its role at larger scales needs further studying. Coupling between seasonal and interannual time scales of variability has been recognized for the winter time and especially in the Eastern Mediterranean from modelling results. Differences between Western and Eastern Mediterranean time variability (seasonal the first and more interannual the second) have been assessed from modelling results and work is needed for observations. The importance of open ocean variability for the coastal zone is recognized also in an ecosystem sense. The Mediterranean outflow has been assessed to be central to the North Atlantic conveyor belt.

RESEARCH DIRECTION

1. *Study of atmospheric forcing conditions* – "Synoptic" *climatologies* Atmospheric teleconnections patterns.
2. Continue the air-sea interaction physics for model boundary conditions.
3. Extend head flux measurements at Straits to calibrate global and regional heat budgets (Straits of Gibraltar, Sicily, Ontario, etc.).
4. Start water cycle studies in the Mediterranean area and variability.
5. Fresh water inputs to be reconfirmed and assessed for regional studies.
6. Continue to study externally driven *versus* internally driven variability at seasonal, interannual, decadal time scales.
7. Start to connect interannual physical variability to ecosystem variability.
8. Studies of interactions between spatial and temporal scales of variability with special attention to questions of memory/persistence/recovery of the circulation system at the basin and sub-basin scales.

9. Increase process oriented observational studies to sample the seasonal cycle of circulation structures.
10. Study the role of Mediterranean outflow variability in North Atlantic thermohaline circulation.
11. Extend historical data banking and quality check for biochemical components. Study fluctuations and correlations between physical and ecosystem parameters (intercalibration, etc.).
12. Define methods to detect anthropogenic signals in the ecosystem variability via modelling studies at basin and regional scales (Nile, Northern rivers, atmospheric inputs, etc.).
13. Define climatic indices for the ecosystem variability, marine teleconnection patterns.
14. Connect open sea variability to coastal regimes.

IMPLICATIONS FOR APPLICATIONS

Variability is a key concept for applications. They are:

- water resources variability and changes;
- coastal biomass fluctuations;
- coastal erosion long-term trend;
- marine food resources fluctuations connected to long-term atmospheric and oceanic variability;
- probability of extreme events in ecosystem fluctuations.

WHAT IS AVAILABLE

- New and updated historical hydrological data sets at basin scale.
- *In situ* Eastern Mediterranean basin scale quasi-synoptic realizations.
- Meteorological data sets analysis and flux computations (NCEP, ECMWF, COADS, Arpege, etc.).
- Numerical models at basin scales - regional and mesoscale.
- Ecosystem numerical models at basin and regional scales.
- Data assimilation tools developed for satellite altimetry with both physical, statistical and Kalman filter approaches.
- Remotely sensed data (SST, T/P and ERS2 CZCS) special analysis for the Mediterranean.

WHAT IS NEEDED

Continuous *in situ* monitoring for air-sea interaction and water column multi-disciplinary data sets.

1. Advance model resolution

2. Improve models with:
   - longer model runs
   - validation and calibration data sets for models at the basin scale
   - develop ocean-atmospheric synchronous and asynchronous coupling
   - further develop the coupled physical-biochemical models at the basin
   - and regional scales.

Societal aspects should become a constraint/components of future research directions. It is evident already that eutrophication phenomena in the shelf area could benefit from this plan as well as water resources forecasts.

RECOMMENDATIONS

To achieve the research goals outlined above we recommend:

1. The launching of a monitoring system of the whole Mediterranean Sea for the physical and biochemical components of the ecosystem with near-real time data collection capabilities. Major aim of such a system should be to start to obtain long time series of marine parameters and to validate numerical models.

2. Initiate a concerted effort to study the role of ocean-atmosphere processes at different time scales for the physical and biochemical components. Part of this effort should aim at encouraging coupled ocean-atmosphere modelling of the Mediterranean Sea and start water cycle studies in a large atmospheric Mediterranean area (with land).

3. Initiate an effort to study the coupling of the open sea to the coastal zone and the coupling of the coastal sea to the land on seasonal to interannual time scale. Such initiative should concentrate in the comparison between different Mediterranean coastal regimes and their fertilization mechanisms.

4. Such research directions should be complementary to already finished and on-going research projects and duplication of effort should be avoided.

BOUNDARY CONDITIONS

1. Bathymetry and Topography are available from the International Bathymetric Chart of the Mediterranean (IBCM), prepared by IOC-CIESM-FAO in the 70's and published in 1981 at the scale 1:1.000.000 (ten sheets). A reduction at 1:5.000.000 is also available.

2. For the study of the sub-bottom conditions, at the same scales and format were also published - the Bougner Gravity Anomalies Map (IBCM - G), the Magnetic Anomalies Map (IBCM-M), the Seismicity Map (IBCM-S), the Plio-Quaternary Thickness Map (IBCM-P/Q) and the Recent Sediments Map (IBCM-RS).

3. All the maps are accompanied by an explanatory leaflet (IBCM-S also by an Earthquakes Catalogue). IBCM digital contours are available also on CD-ROM.

4. The coordination work is done by the IOC Ocean Mapping.

5. Due to the increasing requests, technological advances and accuracy improvements, an IBCM-2^{nd} ed. is in preparation, in digital format, in cooperation between IOC and IMO, based on a substantial increase of data. This will allow the user, especially in the coastal zone, to produce, by himself, the maps in any desired scale, format, model, etc.

VI. COASTAL PROCESSES AND INTERACTIONS

STATUS

The coastal zone is the most sensitive part of the Mediterranean ecosystem, strongly influenced by natural interactions with the land and the open sea, and by multiple human activities. The Mediterranean countries, individually and collectively, are now placing increased emphasis on Integrated Coastal Area Management (ICAM) programmes, in order to achieve sustainable development of the coastal zone. Scientific understanding of the coastal ecosystem and its interactions with the land, the atmosphere and the open sea, is essential for the success of these efforts.

Numerous local and national research programmes have addressed and are now addressing various aspects of ICAM. During the workshop it was not possible to conduct a detailed review of these programmes. However, it was generally felt that the existing knowledge of coastal processes and interactions in the Mediterranean is insufficient for providing sound scientific support to critical coastal zone management issues. It was also noted that to date, except in the context of selected marine pollution problems, local and national programmes were not coordinated in a regional framework, and most research issues were not examined in a regional perspective. Furthermore, these research programmes were hardly if at all associated with and related to basin scale, open sea research programmes in the Mediterranean.

scale studies (POEM, PRIMO), clearly shows the important role of open sea processes and air-sea interactions in the Mediterranean in controlling coastal processes, and hence the direct relevance of basin scale open-sea research to coastal zone management issues. For example, it is now apparent that coastal transport processes are essentially controlled by the general circulation of the Mediterranean, and in particular are influenced by the gyres and jets of the sub-basin features. The time variability of coastal processes is also to a large extent imposed by the variability of open sea processes.

RESEARCH DIRECTION

The approach adopted at the workshop towards defining research directions which would improve the existing science support to ICAM efforts in the Mediterranean basin, was first to identify the main societal concerns in relation to the coastal zone and then to outline relevant research priorities. The interaction between the open sea and the coastal zone was also considered in this context, and it was concluded that understanding dynamical processes is a prerequisite to adequately address regional environmental concerns. Four process studies are considered of paramount importance for their biochemical implication and ecosystem modelling and prediction:

- dynamics of river induced buoyant plumes and interaction with shelf waters;
- cross-continental slope exchanges between the outer shelf and the basin interior;
- instabilities of the coastal currents such as the Algerian/North African current leading to formation and detachment of anticyclonic structures;
- cross-shelf/deep interior exchanges in the straits (Gibraltar, Sicily, Otranto, Cretan Arc) possibly constrained by straits dynamics, that is especially important in the Mediterranean.

MAIN SOCIETAL CONCERNS RELATED TO THE MEDITERRANEAN COASTAL ZONE AND RELEVANT RESEARCH NEEDS:

Water resources management

- Process studies on the role of the sea and sea-air interaction in the regional hydrological cycle;
- Development of extended range (seasonal) precipitation forecasts;
- Assessment of the possible impacts of climatic change and associated sea-level rise on regional water budgets (shifts in precipitation patterns, changes in surface and groundwater flows and river regimes, sea water intrusion into coastal aquifers).
-

Coastal marine pollution: effects of anthropogenic substances

- Estimation of the fluxes of nutrients and contaminants into and out of the coastal zone (mainly riverine and atmospheric input and transfer across the shelf - open sea boundary), and development of models for predicting changes in these fluxes;
- Studies on the cause and effect relationships between introduction of anthropogenic substances into the coastal zone and environmental changes, and development of relevant predictive models;
- Identification and evaluation of specific environmental health indicators for the Mediterranean coastal zone amenable for routine monitoring.

Coastal erosion

- Definition of regional littoral cells (boundaries, sediment sources and sinks), assessment of sediment budgets for these cells and monitoring of large scale and local coastal changes (erosion, accretion) within the cells;
- Development and application of both simple and more complex advanced techniques for monitoring coastal changes including remote sensing and automated monitoring techniques;

- Studies aimed at improved understanding and modelling of sediment dynamic processes (the relationship between hydrodynamic processes and sediment transport, with emphasis on the water-sediment boundary layer);
- Scientific assessment of methods for prevention of coastal erosion, protection of coastal cliffs and rehabilitation of eroded coastlines.

Changes / loss of biodiversity

- Preparation of species inventories for the Mediterranean coastal zone (taxonomy, distribution, abundance);
- Regional studies to quantify trends in coastal habitats and biodiversity, and to understand ecosystem processes including effects of various stressors;
- Studies on foreign species introduction processes and impacts.

Extreme events

- Studies on interaction of atmospheric and open sea variability (internal, edge waves) that can originate sudden sea level rises in the coastal zone (seiches);
- Development of operational forecasting models of storm surges and other potentially catastrophic events of atmospheric origin;

- Scientific assessment of methods for monitoring the environmental conditions that can produce coastal algal or jellyfish blooms and other harmful biological events;
- Development of forecasting models for the prediction of floods.

RECOMMENDATIONS

1. A coordinated Mediterranean coastal science programme to address the issues listed above would contribute significantly to coastal zone management efforts in the region. Such a management-driven programme should include observational networks, process studies and development of predictive models, and should be closely linked to the basin scale open-sea research activities in the Mediterranean. A meeting of experts on coastal processes and interactions in the Mediterranean should be convened as a further step towards the programme design. The preparation of a detailed review of existing coastal research programmes and initiatives in the Mediterranean region as a background document for the meeting is highly desirable.

2. To provide a proper basis for regional assessments the Mediterranean coastal science programmes should cover the great variety of Mediterranean coastal ecosystems; this would require broad transnational involvement in the programme. In this context capacity building needs should be examined.

VII. MEDITERRANEAN PREDICTION AND OBSERVATION SYSTEMS

STATUS

The present research activities in the Mediterranean concerned with its marine ecosystems are not designed by any means for the purpose of providing predictive ecosystems and environmental models with data assimilative forecasting operational capabilities that utilize long-term, real- or near real-time systematic observations. In other words, a Mediterranean Forecasting and Observations Systems research and applications programme encompassing the entire basin in a unified manner does not exist.

It is realized that the long lead times necessary for the implementation of an operational ocean observing and forecasting system for the Mediterranean requires its definition and planning now. This task possesses many critical challenges of modern times in organization, scientific knowledge, technology and financial resources.

A forecasting and observations systems programme for the Mediterranean ecosystems is needed for the reasons set forward in the sequel.

The high costs associated with finding remedies to environmental problems of the Mediterranean Sea will increase rapidly as its environmental quality declines further. Potential effects of long term natural variability and climate change aggravate current environmental problems and add another dimension to their complexity, uncertainties existing with regard to the causes, rate and timing of various types of variability. Therefore, the sooner future environmental changes in the Mediterranean Sea are predicted adequately, the sooner actions can be taken to address options and funding requirements for solutions. It is also clear that inadequate marine environmental prediction systems often result in lack of investment in projects which appear environmentally sensitive, but which could be acceptable and beneficial.

On the other hand, failure to exploit the previous investments in the ocean science for prediction of the environmental states of the Mediterranean Sea, and failure to invest further by developing the skills of government agencies, regulatory authorities, and industrial users in the Mediterranean Sea region will lead to less efficient maritime industries, increased losses from poor environmental management and marine pollution, and increased public health risk.

Stated succinctly, forecasting capabilities of the state of coastal seas and deep waters of the Mediterranean Sea for days to decades into the future will increase the effectiveness and revenues of all maritime activities including industries through optimum and sustainable management.

Specifically, the Mediterranean requires a special vigilance because:

- the Mediterranean Sea is a logistically accessible part of the world ocean where critical parameters can be collected to monitor an to initialize models capable of forecasting marine conditions.
- the Mediterranean Sea is an area with large and increasing economic and tourist development of the coastal areas, of strategic and political importance for Europe, thus requiring the set up of a monitoring and forecasting system of the marine environment, including living resources.
- extreme algae growth and episodic coastal area anoxia events, with related problems of sea health, may occur in the eutrophic shallow areas of the Mediterranean. There is need for planning and handling of emergencies.
- the Mediterranean Sea surface conditions (sea surface temperature) are potentially important for practical atmospheric long range forecasts over the neighbouring land, especially over the whole Southern Europe and Northern Africa.
- by implementation of a Mediterranean Forecasting System, monitoring and prediction of contaminants and oil discharges in the open sea and coastal areas is timely.
- the Mediterranean Sea is of global interest because it is a natural test arena for coupled interdisciplinary models developed for understanding oceanographic phenomena common to other areas of the world ocean. It is an ideal "laboratory" basin to study the effects of anthrophogenic forcing, synoptic and climatic variability on nonequilibrium ecosystems.
- significant efforts are needed from the countries of the Mediterranean region to address the call from United Nations Conference on Environment and Development and the Convention on Biodiversity, stressing the importance of a scientific basis for decision-making, and establishment of observation and data base management systems for sources, types, amounts and effects of marine pollutants.

It is clear that there is a strong and urgent need for goal-specific studies in the Mediterranean Sea to be carried out within a permanent framework of observations, predictive modelling and analysis of ocean variables.

RESEARCH DIRECTION

A Priority Area In Forecasting And Observation Systems

Operational oceanography in terms of forecasting - observations systems already exists for the Mediterranean Sea at local levels for a limited number of sea state and related variables. These include wind velocity and direction over the sea; wave height, direction and spectrum; surface currents, tides, storms surges, and sea surface temperature.

There are other forecasting - observation systems, however, which are of value to industry and government agencies and which can be made available soon, or for which the forecast periods and accuracies can be increased. These include systems concerned with indicators of marine pollution and contamination, movement of oil slicks, prediction of water quality, concentrations of nutrients, primary productivity, sub-surface currents, temperature and salinity profiles, sediment transport, and erosion.

A priority issue in the Mediterranean Sea is, therefore, a research and development programme designed to involve specifically the studies on the effects of anthrophogenic forcing, synoptic and climatic variability on the Mediterranean Sea's non-equilibrium ecosystems within a permanent framework of observations, modelling and analysis of ocean variables needed to support the related environmental science research and the operational ocean services.

SPECIFIC RESEARCH DIRECTIONS

Research directions should involve: the development of an adequate observing system for both *in situ* and satellite measurements, development of multiparametric sensors for ecosystem monitoring, further improvement of general circulation models and nested regional models, development of synchronous and asynchronous coupling with the atmospheric models, improvement of data assimilation components for *in situ* and satellite data.

FUTURE DIRECTIONS SHOULD INVOLVE ESPECIALLY:

1. development of the basin-wide ship-of-opportunity system for the monitoring of the upper thermocline physical and biochemical parameters;

2. development of the *in situ* buoy system for monitoring of currents, optical properties and phytoplankton biomass;

3. development of the components of the coastal monitoring system nested into the large scale monitoring system;

4. start proof of concept exercises for the short to medium term forecasts of physical parameters at overall and regional scales;

5. development of the ecosystem model implementations and their calibration with available data.

WHAT IS AVAILABLE AND OPPORTUNITIES

The following summary of the pertinent research programmes and the opportunities they offer, available models and the scientific strengths are of special importance.

GOOS, EUROGOOS AND THE REQUIREMENT FOR MEDGOOS

The Global Ocean Observing System (GOOS) was established by a Memorandum of Understanding between its sponsoring agencies in October 1993. The objective is to provide a global system of measuring instruments, including remote sensing satellites, which will transmit data to computer models so as to monitor, describe, and predict the state of the world ocean and coastal seas.

GOOS must satisfy the economic, social, and environmental goals of Member States. This means that data must be measured, transmitted, processed, and the results distributed in a sufficiently short time that decisions can be taken before the information is out of date. This sequence and time scale is known as operational oceanography. It places immense demands upon robust instrumentation, rapid data transmission, and powerful modelling computers. Time scales for different variables and parameters from measurement to delivery of operational product may be 6 hours to 3 months, or even 1 year, depending upon the environmental circumstances.

At the GOOS Planning Meeting in May 1996 it was agreed that regional development of GOOS was an approved and practical way forward. At that time both EuroGOOS and NEAR-GOOS were planning their first stages of implementation. The importance of regional development was further stressed by the report of the GOOS Coastal Workshop, and I-GOOS-III, 1997.

EuroGOOS was formed by a Memorandum of Understanding between its 17 founding Member Agencies in 1994. Membership is open to any governmental agency of national status which has the objective of promoting operational oceanography within the framework of GOOS, provided that the country of origin is a member of the EU, the ESF, or the Council of Europe. EuroGOOS has created a structure of over-arching Goals, functional Aims, and technical and scientific projects, which have been described in a series of brochures, Strategy documents, and Plans. EuroGOOS held a major conference at the Hague, Netherlands, in October 1996, and the proceedings will be published during 1997.

The implementation of the EuroGOOS Plan consists of operational projects at the level of regional seas (Baltic, adjacent Arctic, North West Shelf Seas, and Mediterranean), plus an Atlantic/Global component. The latter project will constitute a European contribution to GODAE. European countries bordering the north shore of the Mediterranean have a strong economic, social, and environmetal interest in monitoring and forecasting the Mediterranean, and it is logically necessary for European countries to be concerned with modelling the whole Mediterranean. It is not scientifically possible to model and forecast the northern part of the Mediterranean as a separate entity. This interest has taken the form of a EuroGOOS project entitled the Mediterranean Forecasting System (MFS). Preparation of the MFS has included correspondence with representatives of research groups and agencies in most of the North African and East Mediterranean states who have been sent all technical papers, and have been invited to meetings.

A Mediterranean regional GOOS programme, to be called MedGOOS, has been planned and a preparatory meeting was held in Malta in Nov. 1997. MedGOOS should be initiated by representatives of governments or agencies from all, or almost all, Mediterranean coastal states. All Mediterranean states should be entitled to join, even if they cannot be present at the first meeting. The goals and objectives of MedGOOS should be established by a meeting of such representatives, who should take into account the special economic, social, and environmental needs of all Mediterranean countries, especially in North Africa and the Middle East. The scientific and technical criteria for MedGOOS should be based on the background information available from existing systems, from workshops such as the Workshop on the Science of the Mediterranean Sea and its Applications, and on the EuroGOOS Mediterranean Forecasting System. The first step is to identify the operational oceanography requirements of the Mediterranean coastal states, especially the non-European states. EuroGOOS has already carried out surveys of operational ocean data requirements in Spain, Italy, and Greece.

EuroGOOS will consider assistance to the development of MedGOOS in any way which may be requested by the Member States of MedGOOS, or requested by IOC. EuroGOOS will assist in workshops to define the economic and social benefits which would be created by MedGOOS, and to promote technical development through collaboration between MedGOOS and MFS. So far as is practically possible, the EuroGOOS view is that MedGOOS and EuroGOOS should be twin organizations, with many independent objectives, but also with many overlapping and identical objectives, and with a common membership along the northern coast of the Mediterranean Sea. Duplication in the Mediterranean area itself should thus be avoided, but both organizations would be free to set their own agendas and priorities. A unified scheme of nested models and observing systems at the scales of the Atlantic, European coastal seas, and the Mediterranean Sea, would be scientifically and economically efficient.

THE MEDITERRANEAN FORECASTING SYSTEMS PROGRAMME

The EuroGOOS community has developed during the past two years a plan to start monitoring and predicting the Mediterranean Sea coastal ecosystem fluctuations from the time scales of few weeks to months.

The plan for a Mediterranean Forecasting System (MFS) considers the preparation of the Observing System, the modelling and data assimilation capabilities and the dissemination of results in order to start a proof-of-concept exercise of global Mediterranean and coastal regions short to medium term forecasts.

Models Available

There is a wealth of numerical models already implemented in the Mediterranean region - among them:

1. The Modular Ocean Model implemented at different resolutions (from 3 to 1/8 degree in horizontal and 20-30 levels in vertical), the main development carried out during the Mast-I and II EU Programmes (Mediterranean Targeted Project I). The next generation model is being prepared in the Mast-III EU Programme (Mediterranean Targeted Project II).

2. The Princeton Ocean Model applied to the overall Eastern Mediterranean and the regional seas, such as Adriatic and Aegean. Other regions, such as the Levantine basin, are also considered.

3. The LODYC model (OPA) implemented in the Western Mediterranean and developed during the Mast-I to Mast-III Projects (Mediterranean Targeted Projects I and II).

4. The Harvard Ocean Prediction System (HOPS) implemented in the Sicily channel region at different resolutions and with nesting.

5. The GHER model, implemented at different resolutions in both the overall Mediterranean Sea and the North-Western Mediterranean region.

Ecosystem models have also been developed at the basin and regional scales. The basin scale model (aggregated, for the nitrogen limited phytoplankton groups) and the regional models (complex biochemical model, ERSEM, and POM) have been developed during the Mediterranean Targeted Project I and II.

Data assimilation techniques have been developed and implemented in the Mediterranean Sea for satellite altimetry during the Mediterranean Targeted Project I, and they will be extended to *in situ* temperature data during the Mediterranean Targeted Project II. They consist of reduced order Kalman filters and physical/statistical extrapolation methods for sea surface height. Future directions involve especially:

Assets

The strengths of the ocean science community with interests in the Mediterranean forecasting and observations systems programme can be summarized as follows:

- Access to routine ocean observing satellite data sets, archival and operational.

- A multinational fleet of marine research vessels, and submersible technology.

- Network of meteorological offices providing meteorological & marine meteorological forecasts.

- Wide-ranging experience of instrument deployment, and a range of manufacturers and service companies with technical expertise.

- A very large archival climatic data set coming to last 100 years, which is at present being assembled into a single machine - readable data base.

- A community of national and regional marine research laboratories and universities with marine research programmes.

- Successful Collaborative International programmes accomplished (POEM, PRIMO).

- Active marine industries, offshore oil and gas, shipping, tourism, fisheries, which can provide data and use forecasts; so as to improve wealth and protect the environment.

- World class competence in numerical modelling of ocean processes.

Applications

The overall results of the research and development programme to be developed are expected:

1. to provide extensive benefits in management of the marine environment, marine operations and protection of public health and safety; and

2. to assist in the sustainable development of the Mediterranean Sea's marine resources;

3. international collaboration is anticipated in programme related efforts;

4. studies to be carried out under the envisaged programme will lead to capabilities in operational oceanography of the Mediterranean Sea as related to the environmental factors affecting its ecosystems and marine operations. Such capabilities will allow routine measurements both at the sea and the atmosphere, and dissemination/interpretation of these measurements for the purpose of:
    - forecasting continuously future states of the sea within lead times as large as possible;
    - describing, to a required accuracy, the present states of the sea, including those related to its living resources; and
    - assembling long term data sets and continues time series describing of past states of the sea and displaying trends and changes.

RECOMMENDATIONS

1. A Science Plan should be developed in the interests of all the Mediterranean countries. The long lead times necessary for the implementation of an operational ocean observing and forecasting system for the Mediterranean requires its definition and planning through a Science Plan. This task possesses many critical challenges of modern times in organization, scientific knowledge, technology and financial resources.

2. International support should be given to the Mediterranean Forecasting System (MFS).

3. The science plan to be developed should involve:

    - development of the basin-wide ship-of-opportunity system for the monitoring of the upper thermocline physical and biochemical parameters;
    - development of the *in situ* buoy system for monitoring of currents, optical properties and phytoplankton biomass;
    - development of the components of the coastal monitoring system nested into the large scale monitoring system;

- initiation proof of concept exercises for the short to medium term forecasts of physical parameters at overall and regional scales;
- development of the ecosystem model implementations and their calibration with available data.

3. In the short term, national and multinational agencies working in the Mediterranean should concentrate on the following actions, (*inter alia*):

- Holding workshops to identify economical & social priorities for marine forecasting in the Mediterranean;
- Analyze present observing instrument deployment, and encourage flip development of structural real-time data transmission to a common system;
- Exchange experiences currently used operational models;
- Develop a standard high precision gridded bathymetry for the Mediterranean basin & coastline;
- Promote the distribution of real time data products;
- Study the developments of a Mediterranean Ferry - Box programme;
- National agencies should be lobbied to encourage the formation of national GOOS committees;
- Negotiate with offshore oil and gas companies and commercial met - ocean companies to write real data available in the public domain;
- Participate in collaborative data assimilation experiments.

PLENARY PRESENTATIONS

I. TRANSPORTS EXCHANGES, TRANSFORMATIONS AND BUDGETS

Chair: Mario Astraldi

I.1 The Transport Variability of Levantine Water in the Strait of Sicily

by: Mario Astraldi[1], Gian Pietro Gasparini[1], and Stefania Sparnocchia[2]

Introduction

The Strait of Sicily is the western boundary of the Sicily Channel, the relatively wide and deep central basin dividing the Eastern and the Western Mediterranean. At the strait section, a two-layer system has been recognized with an eastward surface flow of Modified Atlantic Water (MAW) and a westward bottom flow of Levantine Intermediate Water (LIW). The latter is constrained in two deep channels created by a central ridge arising from the bottom. The eastern channel, adjacent to the Sicily shelf, is very narrow and deeper, while the western one, on the Tunisian side, is wider and shallower. The sills are at about 430 m and 360 m of depth respectively, about 20 miles apart from the other. The characteristics of the Levantine flow were determined by a nearly two-year-current time series (November 1993 to July 1995) obtained at each side of the ridge, and by periodic (seasonal) hydrographic campaigns over the entire strait region. Prior to that period, there were discussions about the principal features of this flow. These included both the dynamic properties (is there or not a seasonal variability of this flow across the Strait of Sicily?) as well as the transport, spanning over a too wide range to be considered realistic (see Table 1). The principal results achieved from this investigation were presented in dedicated papers (Astraldi *et al.*, 1996; Sparnocchia *et al.*, 1997).

The Hydrography

The vertical salinity distribution at the strait section indicates that the Levantine flow fills both deep parts of the two channels connecting the Eastern and Western Mediterranean. Well-defined cores can be identified between 250 and 270 m of depth at each of the two veins. According to the periods, they range between S3D38.740 and S3D38.755, without any evident seasonal oscillation. Below the core, salinity progressively decreases to the bottom, whereas at the narrower eastern channel, the isohalines are horizontal and do not change significantly in the course of the year. At the western channel they are generally inclined towards the Tunisian coast, and the inclination significantly increases during winter. The temperature distribution at the same section shows that, during all seasons, a vein of cold water is present at the bottom of the Tunisian side of the strait. Though slightly less saline, this water is significantly colder than the classical LIW and dense enough to be maintained at the bottom of the strait. Its reference values can be indicated as follows: S3D38.75, Theta 3D13.65, Sigma-Theta 3D29.15. Thus, the hydrographic measurements clearly indicate that two Levantine water types, rather than the one known so far, flow through the Strait of Sicily towards the Western Mediterranean. The presence of the colder water appears in the historical data (Garzoli and Maillard, 1979) and is recognizable below LIW at the Maltese sill, at the eastern boundary of the Sicily Channel (Guibout, 1987). We may think that this water is a common feature of the Strait region both at the seasonal and the interannual scales. As to its origin, it is our opinion that this colder vein is the result of a mixing between LIW and Eastern Mediterranean Deep Water in the Ionian Basin, and, following Pollak (1951), we refer to it as a transitional Eastern Mediterranean Deep Water.

Our measurements also show that the total stream outflowing from the Strait of Sicily, moves towards the Tyrrhenian Sea under the prevailing control of the topography and the Coriolis effect. It is interesting to remark that, after the sill, an abrupt vertical separation verifies between the two water types forming the Levantine flow. In fact, while the classical LIW flows at the known depth for this type of water (namely between 500 and 800 m), a considerable volume of transitional EMDW was seen to sink from

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the sill to a maximum depth of 1850 m in the Tyrrhenian, where it floats over the Tyrrhenian Deep Water. The sinking is a consequence of the higher density of the incoming water with respect to that of the resident Tyrrhenian waters and can be observed in the evolution of the isotherms, isohalines and isopycnals. The mean hydrographic properties of this water progressively change due to the intense mixing it is subject along the route after the sill. The inflow of transitional EMDW in the Tyrrhenian Sea plays an important role in the deep salt and nutrient budgets of this basin.

The Dynamic Properties

The current meters position within the moorings was such to allow the sampling of the Levantine flow across the strait section. The observed currents showed independent features at the two sides of the central ridge. At the eastern sill an energetic, impulsive flow, clearly constrained by topography, crossed the strait all year round. In the considered period, the annual mean exceeded 35 cm/s, with peaks higher than 50 cm/s. At the other side of the strait the flow was significantly weaker, though it also impulsive and constrained by bathymetry. The impulses were coherent at both channels with a periodicity of about 15–20 days. Their energy increased significantly during winter, so that the mean value of the current at the western sill nearly doubled in this season. Thus, we can say that the Levantine flow showed a marked seasonal variability, and this feature was mostly evident in the western side of the strait.

The Transport

We computed the seasonal geostrophic currents from the hydrographic profiles carried out at the two sides of the mooring at the western sill. The geostrophic velocities were then adjusted to the corresponding current values. Since the seasonal geostrophic profile was seen to closely fit the current profile deduced by the current meters, we infer it realistically represents the actual current conditions across the strait. From it, we can say that in winter two well developed currents flow in opposite directions at the strait section, with an interface at about 160 m of depth. Starting from winter, the interface between the two flows progressively rises up to autumn when it is at about 50 m of depth. This is associated with a decrease in the current velocities in both layers. Thus, the geostrophic computations indicate that the Levantine flow is affected by a significant seasonal variability concerning both its energy and the height of the interface with the MAW above. We have used the salinity (conductivity) of the current meter at 100 m (the average depth of the oscillating interface) to estimate the isohaline more closely representing the level of zero velocity, and we found that it corresponded with the value of S3D37.70.

The transport of the Levantine Water was then computed by linearly interpolating the actual current data and extending them to the corresponding section of the strait. The transport was thus determined from the strait bottom to the depth of the current inversion, or, in case of absence, to the depth of the indicated isohaline. Although fairly rough, this procedure provides a realistic estimate of the transport, as indicated by the fact that the values thus obtained during the cruise periods closely fitted the geostrophic transport. Figure 1 shows that the transport time series at both sills is subject to a coherent impulsive regime. The impulses appear significantly enhanced at the western sill compared with the eastern one. Their energy increases during winter and mainly at the western sill. Peaks as high as 1.5 Sv were found at this sill, while at the other section, despite the higher current values, they always kept lower than 1.0 Sv. Thus, during winter, peaks of 2.5 Sv were found, while in summer they reduced to half. This seasonal variability was reflected in the mean transport, ranging from 1.2 Sv in winter to 1.0 Sv in summer, with a standard deviation of 40% of the mean value. These values show that the transport at the Strait of Sicily is of the same order as that observed at Gibraltar (Bryden *et al.*, 1989). However, it is affected by a significant seasonal variability. Using the current values and the corresponding hydrographic sections, we could check that the contribute of the transitional EMDW to the total transport was 0.2–0.3 Sv, the variability depending on the choice of the upper boundary of the vein.

Conclusion

The systematic experimental program carried out between 1993 and 1995 in the Strait of Sicily region presented a first definite balance of the hydrographic and dynamic conditions governing the strait. The continuation of measurements is needed to evaluate the variability of the strait's conditions at the interannual time scales.

Acknowledgements

The experimental activity in the Strait of Sicily was supported by the European Community, under the contracts: MAS2 CT93 0066 (EUROMODEL), AVI CT93 003 (SALTO), and MAS3-ct96-0051 (MATER) and by the CNR Physical Committee. Measurements were effected by the CNR R/V Urania, whose officers and crew gave a significant support to the work at sea.

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		AW	LIW	
Morel (1972)			0.6/0.8	Water salt budget
Molcard (1972)		0.84	0.65	Current meters (May 1970)
Garzoli and Maillard (1979)		1.23	1.15	Geostrophic computation (winter data)
Bethoux (1979)		1.27	1.21	Heat, water, and salt budget
Bryden and Stommel (1984)		3.53	3.47	Hydraulic control prediction
Hopkins (1985)		1.46	1.40	Salt conservation
Grancini and Michelato (1987)		Winter flux 2–3 times greater than summer		Current Meters
Manzella *et al.* (1998)	March June	3.34 1.56	3.20 1.50	Adjusted geostrophic velocity and salt conservation
Moretti *et al.* (1998)	Winter Summer	0.41 0.63	0.37 0.69	Geostrophic computation

Table 1
The values for the transport of MAW and LIW for the Strait of Sicily computed by different authors.

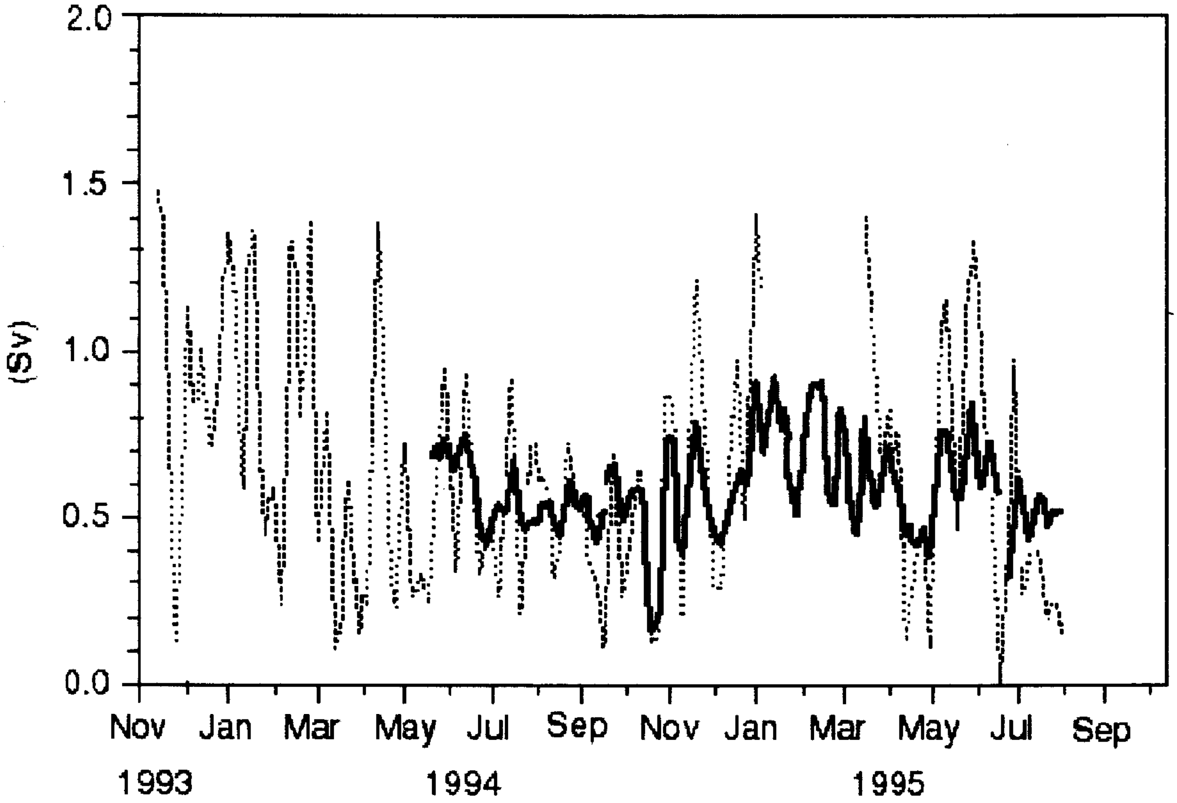

Figure 1
The time evolution of the LIW transport at the eastern sill (continuous line) and the western sill (dotted line) from November 1993 to July 1995.

I.2 The Role of Surface Fluxes and the Strait of Gibraltar in Determining the Properties of the Mediterranean Sea

by: Christopher Garrett[1]

The overall character of the Mediterranean Sea as a lagoon, or inverse estuary, is clearly established by the constricted connection to the North Atlantic through the Strait of Gibraltar and by the surface buoyancy loss resulting from net evaporation and surface cooling. Understanding the detailed properties and circulation of the Mediterranean requires an understanding of the role of the Strait of Gibraltar and a precise knowledge of the surface fluxes.

The depth of the sill at the Strait of Gibraltar clearly inhibits the exchange of water below that depth (although some "Bernoulli suction" occurs), but the role of the constricted width is less clear. General theoretical developments in the last decade, however, building on earlier work, have suggested that if a strait is wider than a certain amount, the exchange through it is not limited; this is the case of "submaximal exchange," with an interior sea that is not "overmixed." The strait cannot then be described as controlling the properties of the sea, though changes in those properties will be seen at the strait, which is then a useful choke point for monitoring purposes.

On the other hand, if the strait is sufficiently narrow, the exchange through it becomes "maximal," with an interior sea that is overmixed. The strait then more clearly controls the properties of the sea, but the flow and properties at the strait do not respond quickly to changes in the sea, so that the strait is less useful for monitoring purposes. These subtle issues, and their relevance to the Strait of Gibraltar, are discussed in more detail in reviews by Bryden and Kinder (1991) and Garrett *et al.* (1990a,b) which refer to earlier work.

The state of the exchange through the Strait of Gibraltar is still unclear. A case can be made for the argument that the exchange flips between maximal and submaximal on a seasonal basis (see Garrett (1996) for a recent review which contains references to the extensive work by many scientists), with the most dramatic evidence perhaps coming from the observed seasonal cycle in the monthly mean sea level drop from Cadiz in the Atlantic to Malaga just inside the Mediterranean (Figure 1). As discussed in the above reviews, the amount of the change in the sea level drop corresponds rather well to the predictions of simple hydraulic models for the exchange.

Other observations also support the idea of a seasonal switch, but a thorough analysis of thirteen months of tide gauge data from the strait failed to find the expected two groupings in a two-dimensional plot of the low frequency sea level differences across and along the strait (Garrett *et al.*, 1989). The conclusion of Garrett (1996) is that we still lack adequate models of the strait exchange, and cannot answer the important question of submaximal versus maximal. (The issue is important not just for addressing the monitoring versus controlling question in the modern era, but also affects models of the Mediterranean in past, or future, conditions with different surface forcing.)

Future progress on this important issue requires extensive, and long-term, observational programs in the Strait of Gibraltar and for renewed modeling efforts that deal more completely with time-dependence (especially tides) and internal frictional and mixing processes.

Turning now to the other critical issue of interior forcing of the Mediterranean, there have been many attempts to define the surface fluxes, usually based on measurements from ships of opportunity and bulk formulae. The uncertainty of the results is generally illustrated by a mismatch of tens of Watts per square meter between the annual and spatial average surface heat loss and that which can be estimated from estimates or measurements of the heat flux through the Strait of Gibraltar (e.g. Bunker *et al.*, 1982). Gilman and Garrett (1994) attributed some of the discrepancy to the role of atmospheric aerosols, of human as well as natural origin, in reducing the insulation. They also emphasized the way in which the oceanic and atmospheric water budgets give the net evaporation over the sea, and hence, if

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[1] University of Victoria

precipitation and runoff are known, the actual evaporation and heat flux. This permitted Gilman and Garrett (1994) to rule out a large increase in latent heat flux which had been proposed earlier, though uncertainty over the precipitation remains. The spatial distribution of the annual average heat flux is probably not too different from that shown in Figure 2, but changes in observing practice mean that we do not have a clear idea of trends and interannual variability.

This question of interannual variability and trends is important for many applications in the Mediterranean. In particular, the hydrological cycle is of great concern; the ability to predict, or even influence, rainfall in the countries around the Mediterranean would be of immense value. Figure 3 shows a large apparent trend in average cloudiness over the Mediterranean, and one wonders firstly whether this is in any way a consequence of increasing industrial aerosol emissions, and secondly whether it, in turn, is affecting precipitation rates. Further investigation and long-term monitoring of air-sea interaction, including comprehensive measurements at sea, and perhaps from space, of precipitation and heat flux, are essential.

In conclusion, fundamental scientific questions remain about the role of the Strait of Gibraltar and about surface fluxes over the Mediterranean. In planning to address these questions we must also bear in mind the pressing societal problems of the region, with the hydrological cycle being one that requires the input of oceanographers. I believe that we should bear these bigger questions in mind in proposing future oceanographic programs, though it is likely that plans to meet societal concerns, and plans to answer our fundamental scientific questions, will have much in common.

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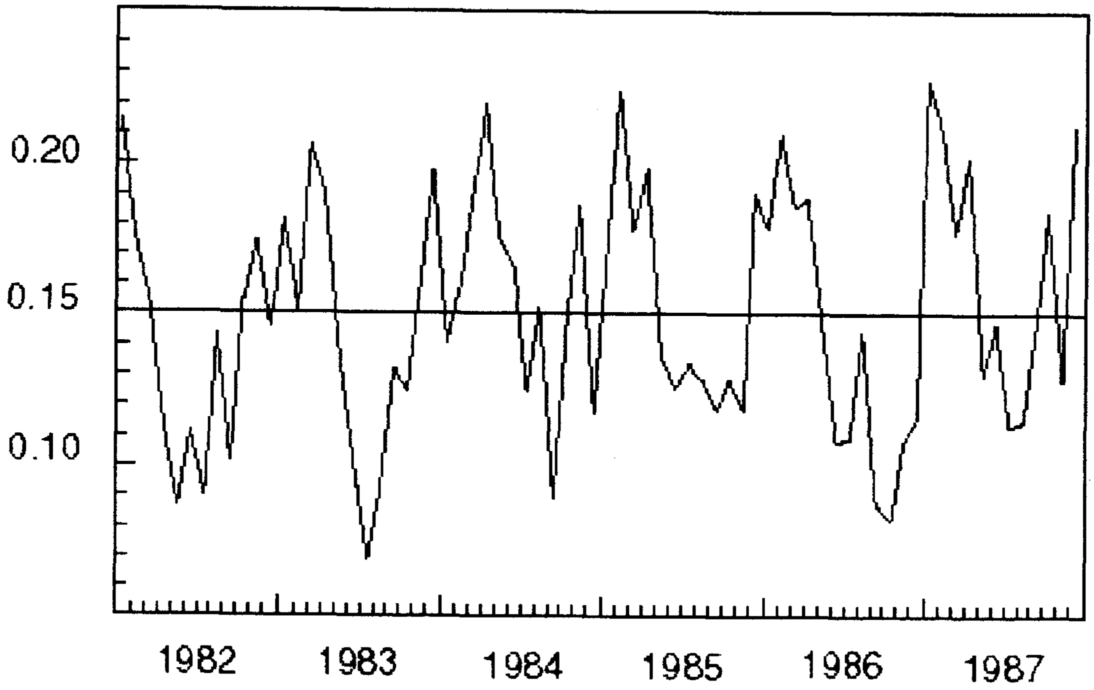

Figure 1
Monthly mean sea-level drop (in meters) from Cadiz to Malaga, based on data from 1982 through 1987. (From Garrett *et al.*, 1990b)

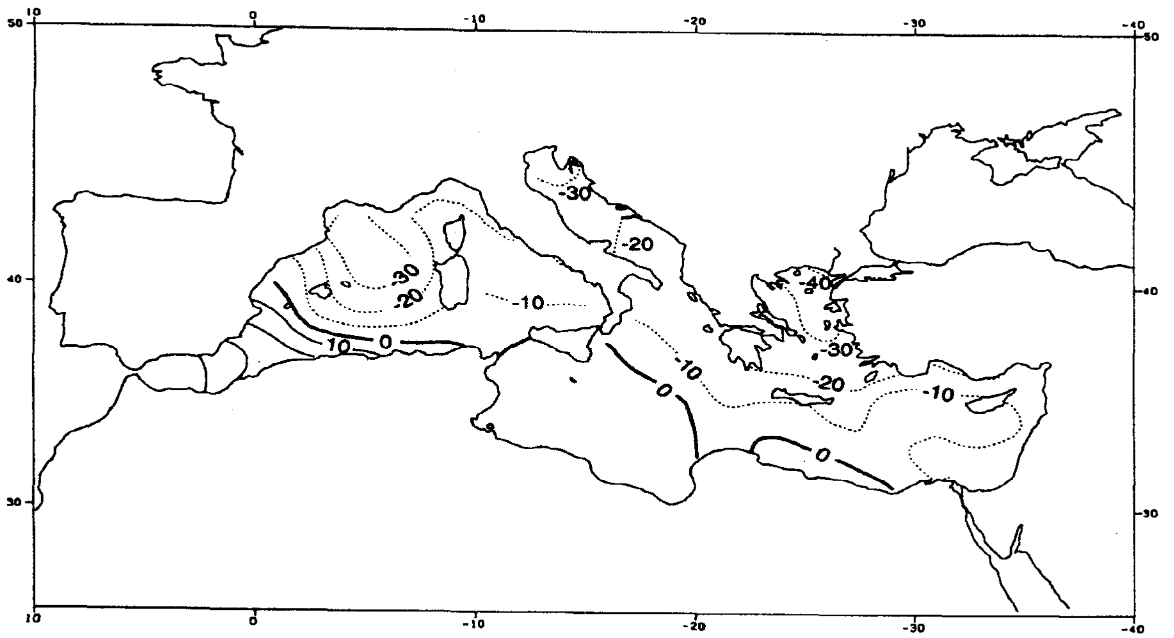

Figure 2
Spatial distribution of the annual average surface heat loss from the Mediterranean, adjusted, by reduction of the insulation, to have a spatial average of -7 Watts per square meter. (From Garrett *et al.*, 1993)

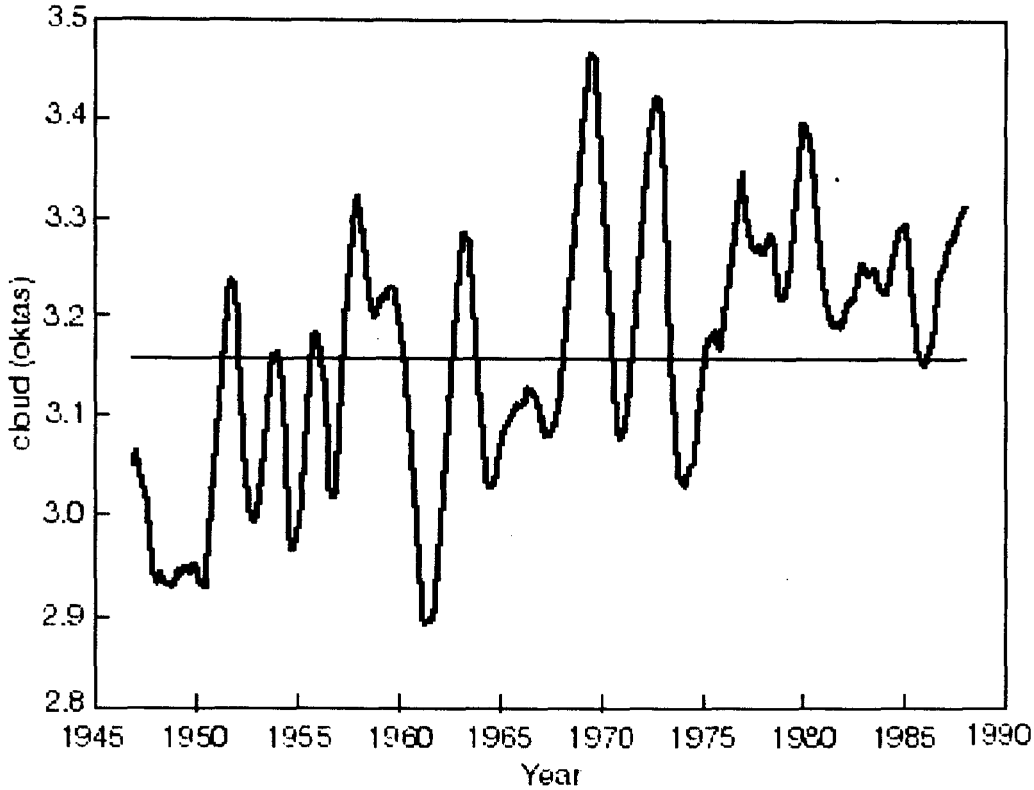

Figure 3
Low-passed COADS cloud cover averaged over the Mediterranean. (From Garrett *et al.*, 1993)

I.3 Recent Exchange Measurements in the Strait of Gibraltar

by: Julio Candela[1], Richard Limeburner[2], and Juan Rico[3]

In October 1996, a 2.5-year measurement program in the Strait of Gibraltar was concluded. Two years (October 1994 to October 1996) of continuous measurements obtained from a mid-sill, upward-looking, bottom-mounted ADCP in the Strait of Gibraltar are discussed in this presentation, in relation to the exchange estimates obtained from these measurements.

There are three main components to the flow (Lacombe and Richez, 1982; Candela, 1991): Tidal (mainly barotropic, with magnitudes of up to 2.5 m/s, Candela *et al.*, 1990), barotropic subinertial (driven by atmospheric pressure variability within the Mediterranean and with magnitudes of about 0.4 m/s, Candela *et al.*, 1989) and baroclinic subinertial (driven by the internal pressure gradient due to the density difference between the Mediterranean and the Atlantic Ocean's, with magnitudes of about 0.5 m/s, which is subject to hydraulic control, Armi and Farmer, 1988).

On April 1996, during a cruise on-board the R/V Poseidon, consecutive crossings of the strait were performed over the sill section. These permitted to obtain an idea of the across-strait current structure. Figure 1 shows a map of the strait indicating the current profiles obtained with the shipboard ADCP during the sill crossings. Figure 2 is a composite of twelve consecutive crosssections. Since the ship took about one hour in each crossing, the sections shown are about one hour apart and roughly cover a complete semi-diurnal tidal period during neap tides. Morocco is to the left in each section and Spain to the right, so the Atlantic Ocean is into the page. The numbers in the lower right hand corner of each panel indicate the estimated transport for the section.

From these sections it is clear that the currents at the sill present large cross-strait variability, however, the mid-sill moored ADCP measurements capture the main time variability of the currents and are used here to estimate a time series of the exchange through the strait. When estimating the exchange through the strait, it is important to obtain estimates of the quality, as well as, the quality of the water being exchanged. Therefore it is essential to have simultaneous measurements of the density structure of the water column along with those of the currents. More so, at the sill, due to the high degree of correlation between the barotropic (tidal and subinertial) currents and the depth of the interface separating Atlantic and Mediterranean water types, it is mandatory to take into account the contribution of this correlation on the mean exchange (Bryden *et al.*, 1994). For this reason, simultaneously with the bottom-mounted ADCP measurements at the sill an additional mooring was installed that contained several (3 to 5) instruments (depending on the deployment period) in the water column that would measure the water properties continuously at the same time as the upward looking ADCP current profiler would measure the currents.

With the aid of these extra moorings, it was possible to construct time series of the depth of the interface between the main Atlantic and Mediterranean water cores. Based on previous work (Bryden *et al.*, 1994), as well as these observations, it was decided to use the 37 psu salinity value as the characteristic value delimiting the boundary between the two layers. Using hourly time series of current velocities at 10 m depth intervals from the surface to the bottom of the sill, hourly time series of the depth of the interface and a realistic cross-section bottom relief, estimates of Atlantic and Mediterranean water exchanges were calculated. These, after being low-passed filtered to keep only periods longer than 38 hours, are shown in Figure 3.

The first, and most relevant result from these calculations, is the fact that both the Atlantic or Mediterranean water transports show small, but appreciable, seasonal cycle. Of the two the outward Mediterranean lower layer flow is a more reliable estimate, showing an annual transport range of 0.25 Sv with minimum outflow around early summer (July/95) and maximum in early spring (March/96). The calculated barotropic or total transport shows a mean value of 0.086 Sv, which is about twice of the

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[2] WHOI, Woods Hole, Massachusetts, U.S.
[3] IHM, Cadiz, Spain.

expected value based on estimates of net evaporation over the Mediterranean Basin (Garrett *et al.*, 1993). This points to uncertainties in our estimates of the upper layer inflow, where the cross-section is wider and transport estimates based on only mid-strait current measurements become unreliable. However, the fact that the seasonal cycle present by the barotropic flow has at least the correct phase (the amplitude is a factor of 4 larger) to be responsible for the seasonal sea-level raise within the Sea, indicates that a better estimate of surface transport is possible if these measurements are properly constrained with Mediterranean sea-level observations. There is a clear increase of variability of the exchange in both layers during the late fall and winter period. Also, it is noteworthy that the mean exchange values are close to ± 1 Sv, rather than the values 25% smaller calculated from earlier data (Bryden *et al.* 1994).

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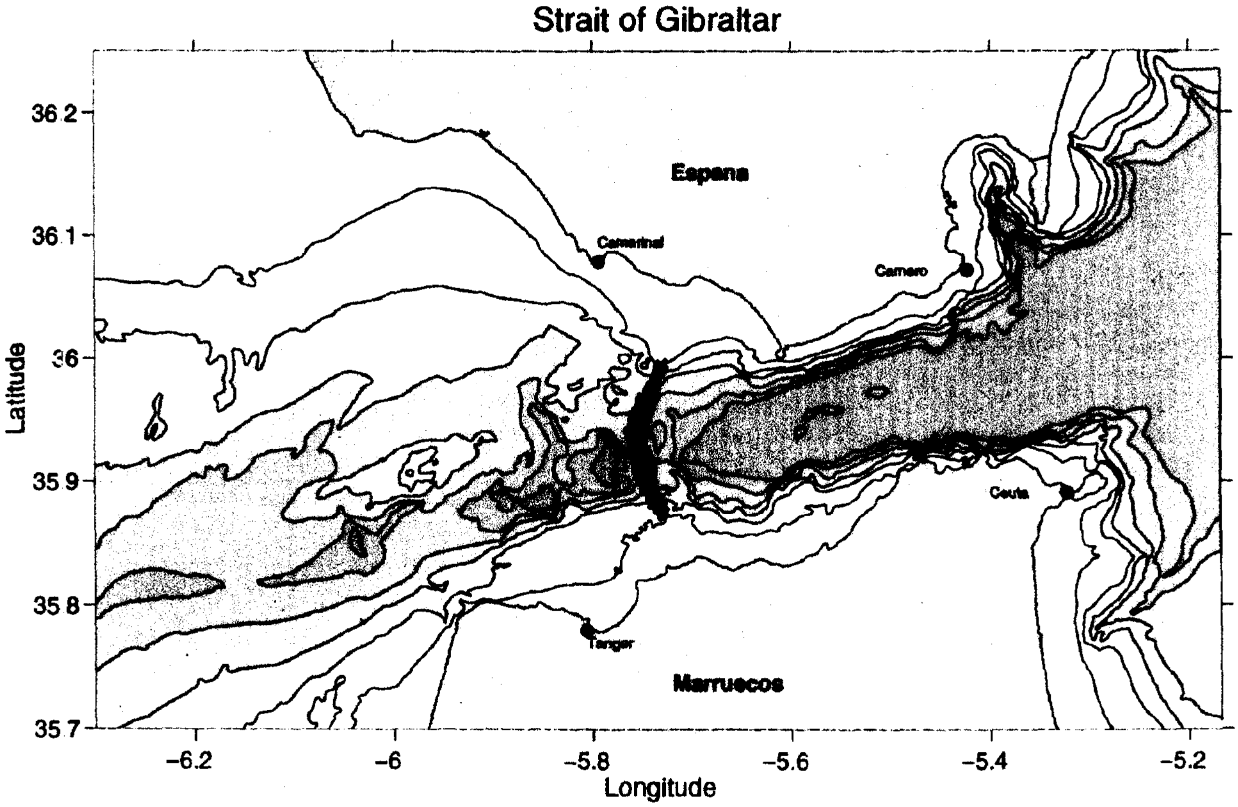
Strait of Gibraltar
36.2
36.1
36
35.9
35.8
35.7
Latitude
-6.2
-6
-5.8
-5.6
-5.4
-5.2
Longitude
Espana
Marruecos
Ceuta
Tanger

Figure 1

I.4 Variations of the Fluxes and Water Mass Exchanges through the Deep Layers of the Cretan Arc Straits and their Influence in the Deep Thermohaline Circulation of the Eastern Mediterranean (1986–1995).

by Alexander Theocharis[1]
with contributions from E. Papageorgiou, H. Kontoyiannis, and K. Nittis

The Cretan Arc region is the boundary between the Aegean Sea and the West Eastern Mediterranean. Along an arc-shaped line, a series of six straits connect the South Aegean Sea (max. depth 2500 m), with the Ionian in the west and the Levantine Basin in the east. The bottom of the area is characterized by a very high relief. Outside the straits, the sea-bed plunges towards the deep basins of the Hellenic Trench (3000–4000 m). On the west, there are the Elafonissos, Kithira, and Antikithira Straits; and on the east, the Kassos, Karpathos, and Rhodes Straits. Three of them have sill depths exceeding 700 m, and are considered most important for the deep water exchanges: the Antikithira (sill depth ~700 m), Kassos (sill depth ~l000 m), and Karpathos (sill depth ~800 m). The Cretan Sea plays a significant role in the dynamics of the upper and deep circulation of the Eastern Mediterranean. The thermohaline properties of the exchanged water masses, the dominant circulation features in the vicinity of the straits, the local atmospheric forcing and the strait geometry are the key factors controlling the flow through the straits. The exchange processes along the Cretan Arc are of considerable importance in view of the recent dramatic change in the Eastern Mediterranean thermohaline cell (Theocharis *et al.*, 1992; Roether *et al.*, 1996).

Since the beginning of this century and until the eighties, sparse information on water circulation through the straits of the Cretan Arc existed in literature (Kontoyiannis *et al.*, in press). The first systematic current measurements in all the straits were performed during 1986–1989 in the frame of the international POEM (Physical Oceanography of the Eastern Mediterranean) program and the Greek national "Open Sea Oceanography" project and continued in 1994–1995 on a yearly basis within the PELAGOS MTP-I/MAST project.

The dominating water mass outside the straits in the intermediate depths until 1989 was the relatively warm and saline Levantine Intermediate Water (LIW), while in deep and bottom layers the Eastern Mediterranean Deep Water (EMDW) of Adriatic origin. Furthermore, the Cretan Intermediate Water (CIW), slightly colder and more saline thus denser than LIW and the Cretan Deep Water (CDW), slightly colder than CIW but warmer and more saline than EMDW are the characteristic South Aegean water masses. The CDW occupies most of the volume of the Cretan Sea from 500 to 2500 m. The Aegean Sea has also been reported as a possible secondary but rather sporadic source of intermediate and deep waters of the Eastern Mediterranean (Theocharis, 1992). Waters of Cretan origin were usually observed outside the Cretan Arc, below the LIW and above the EMDW, losing rather quickly their characteristics due to mixing. Since the beginning of this decade the deep layers of the Eastern Mediterranean have been filled by warmer, saltier thus denser and young waters outflowing from the Aegean Sea (Theocharis *et al.*, 1992; Roether *et al.*, 1996). This recent drastic change in the deep thermohaline cell of the Eastern Mediterranean is basically induced by the increase of the CDW density and volume that occurred during the last eight to nine years, between 1987–1995 (Theocharis *et al.*, 1996). The gradual transformation of the CDW to a very dense ($\sigma\theta \sim 29.4$) water mass increased the transport activity through the straits. Therefore, since 1989, we observe a massive outflow of CDW through the deep straits of the Cretan Arc. The older deep waters and new EMDW of Adriatic origin are lifted up several hundred meters enriching with nutrients the intermediate layers of the Eastern Mediterranean. The evolution of the deep water exchanges through the Cretan Arc Straits during the period 1986–1995 was presented by Papageorgiou and Theocharis (1996) (Figure 1). In 1986, the waters over the sills of the deep straits had almost the same deep Cretan hydrological characteristics ($\theta > 14°C, S \sim 38.9$) with densities ranging from 29.150–29.165. The current meter observations show a deep outflow namely through the Antikithira and Karpathos Straits with maximum mean velocities up to 7.2 cm/s and estimated transports 0.2 Sv during spring and 0.1 Sv during early winter. An increased outflow (0.5 Sv) of dense water ($\sigma\theta \sim 29.16$) was observed during spring 1987 through Kassos Strait,

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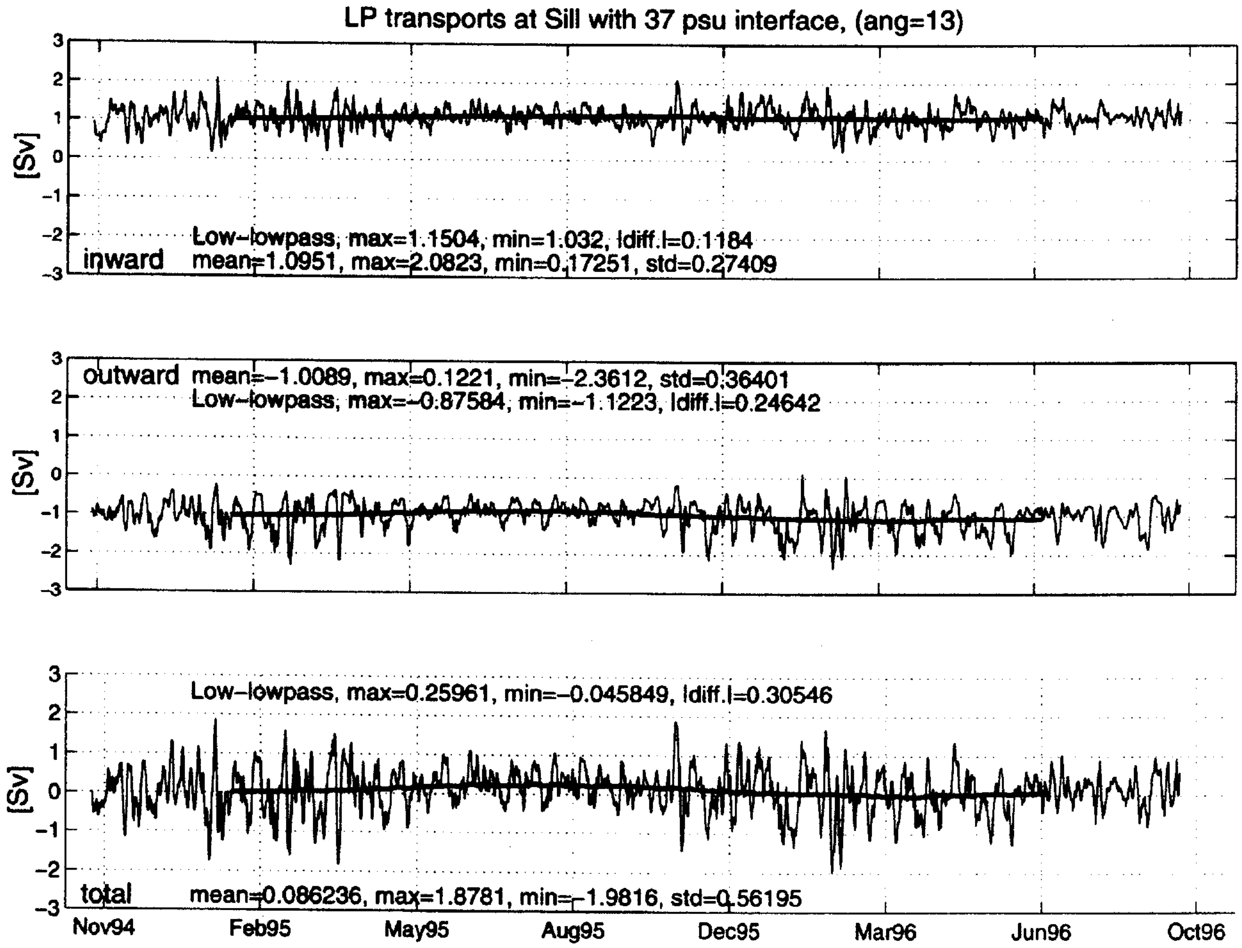
LP transports at Sill with 37 psu interface, (ang=13)
[Sv]
Low-lowpass, max=1.1504, min=1.032, ldiff.l=0.1184
inward mean=1.0951, max=2.0823, min=0.17251, std=0.27409
outward mean=-1.0089, max=0.1221, min=-2.3612, std=0.36401
Low-lowpass, max=-0.87584, min=-1.1223, ldiff.l=0.24642
Low-lowpass, max=0.25961, min=-0.045849, ldiff.l=0.30546
total mean=0.086236, max=1.8781, min=-1.9816, std=0.56195
Nov94
Feb95
May95
Aug95
Dec95
Mar96
Jun96
Oct96

Figure 3

I.4 Variations of the Fluxes and Water Mass Exchanges through the Deep Layers of the Cretan Arc Straits and their Influence in the Deep Thermohaline Circulation of the Eastern Mediterranean (1986–1995).

by Alexander Theocharis[1]
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The dominating water mass outside the straits in the intermediate depths until 1989 was the relatively warm and saline Levantine Intermediate Water (LIW), while in deep and bottom layers the Eastern Mediterranean Deep Water (EMDW) of Adriatic origin. Furthermore, the Cretan Intermediate Water (CIW), slightly colder and more saline thus denser than LIW and the Cretan Deep Water (CDW), slightly colder than CIW but warmer and more saline than EMDW are the characteristic South Aegean water masses. The CDW occupies most of the volume of the Cretan Sea from 500 to 2500 m. The Aegean Sea has also been reported as a possible secondary but rather sporadic source of intermediate and deep waters of the Eastern Mediterranean (Theocharis, 1992). Waters of Cretan origin were usually observed outside the Cretan Arc, below the LIW and above the EMDW, losing rather quickly their characteristics due to mixing. Since the beginning of this decade the deep layers of the Eastern Mediterranean have been filled by warmer, saltier thus denser and young waters outflowing from the Aegean Sea (Theocharis *et al.*, 1992; Roether *et al.*, 1996). This recent drastic change in the deep thermohaline cell of the Eastern Mediterranean is basically induced by the increase of the CDW density and volume that occurred during the last eight to nine years, between 1987–1995 (Theocharis *et al.*, 1996). The gradual transformation of the CDW to a very dense ($\sigma\theta \sim 29.4$) water mass increased the transport activity through the straits. Therefore, since 1989, we observe a massive outflow of CDW through the deep straits of the Cretan Arc. The older deep waters and new EMDW of Adriatic origin are lifted up several hundred meters enriching with nutrients the intermediate layers of the Eastern Mediterranean. The evolution of the deep water exchanges through the Cretan Arc Straits during the period 1986–1995 was presented by Papageorgiou and Theocharis (1996) (Figure 1). In 1986, the waters over the sills of the deep straits had almost the same deep Cretan hydrological characteristics ($\theta > 14°C, S \sim 38.9$) with densities ranging from 29.150–29.165. The current meter observations show a deep outflow namely through the Antikithira and Karpathos Straits with maximum mean velocities up to 7.2 cm/s and estimated transports 0.2 Sv during spring and 0.1 Sv during early winter. An increased outflow (0.5 Sv) of dense water ($\sigma\theta \sim 29.16$) was observed during spring 1987 through Kassos Strait,

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while during late summer 1987, the total transport was 0.24 Sv, with increased densities ($\sigma\theta \sim 29.17$)at Karpathos Strait. A considerable change in the flow regime occurred in 1989. Both density and transport rates increased. More than 1.0 Sv outflow of denser ($\sigma\theta \sim 29.19$)water through Kassos Strait is estimated for both spring and summer. Mean velocities reached 27cm/s. On the other hand, we observe at Karpathos Strait a weak inflow of waters with characteristics between the LIW and EMDW, namely Transition Mediterranean Waters (TMW). During the period 1989–1992, deep water densities increased. The whole Cretan Basin was filled with young water with densities that reached 29.34 (Souvermezoglou *et al.*, 1996). In the same time, we observe a massive outflow of dense water ($\sigma\theta \sim 29.2$). The new water can be traced for the first time down to depths more than 2000 m far away from the straits. This is considered the first substantial contribution of the Aegean to the Eastern Mediterranean deep and bottom waters (Theocharis *et al.*, 1992). Finally, during the period 1994–1995, a persistent and continuous outflow of the newly formed CDW ($\sigma\theta \sim 29.2$) from Antikithira and Kassos Straits throughout the entire year was recorded (Kontoyiannis *et al.*, 1998). The total transports have been calculated to be 1.0 Sv for spring and summer, and 0.6 Sv for autumn and early winter. Insignificant inflow of TMW occurs through the Karpathos Strait. The total volume of the Aegean water that entered the Eastern Mediterranean within seven years is estimated to be about 2.3 $\times$ $10^{14}m^3$ (Roether *et al.*, 1996) with a mean transport (considered steady) of I.0 Sv. This is consistent with the current meter observations, although there seems to be both seasonal and interannual modulation of this mean value.

The new knowledge obtained in the physics, as well as in chemical and biological oceanography of the Eastern Mediterranean during the last ten to eleven years through both national and international experimental and modeling activities (POEM, MAST/MTP, etc.), and the fact that this Basin experiences a very important climatic "shift" in its deep thermohaline circulation, showed that systematic multidisciplinary work was needed for a better understanding of the Basin's complex ecosystem and its evolution. Thus, continuous research of interdisciplinary nature was carried out in 1991–96 (POEM-II, PELAGOS/MTP-I/MAST). The water mass exchanges, not only in the deep layers but throughout the entire water column, between the Aegean and the rest of the Eastern Mediterranean, also have biogeochemical implications on either side of the Cretan Arc Straits (The Pelagos Group, 1996). In this context, the need for a long-term monitoring program of the Mediterranean Straits was recognized and a relevant activity is under implementation within the MATER (Mass Transfer and Ecosystem Response)/MTP-II/MAST program of the EU (1997–1999). New basinwide surveys, measurements at the straits and modeling efforts are the ongoing research activities to study, define and predict, among others (i) the evolution of the deep thermohaline circulation in conjunction with the hydrology of the South Aegean Sea and (ii) the variability, at different scales, of the water and biogeochemical fluxes through the Cretan Straits.

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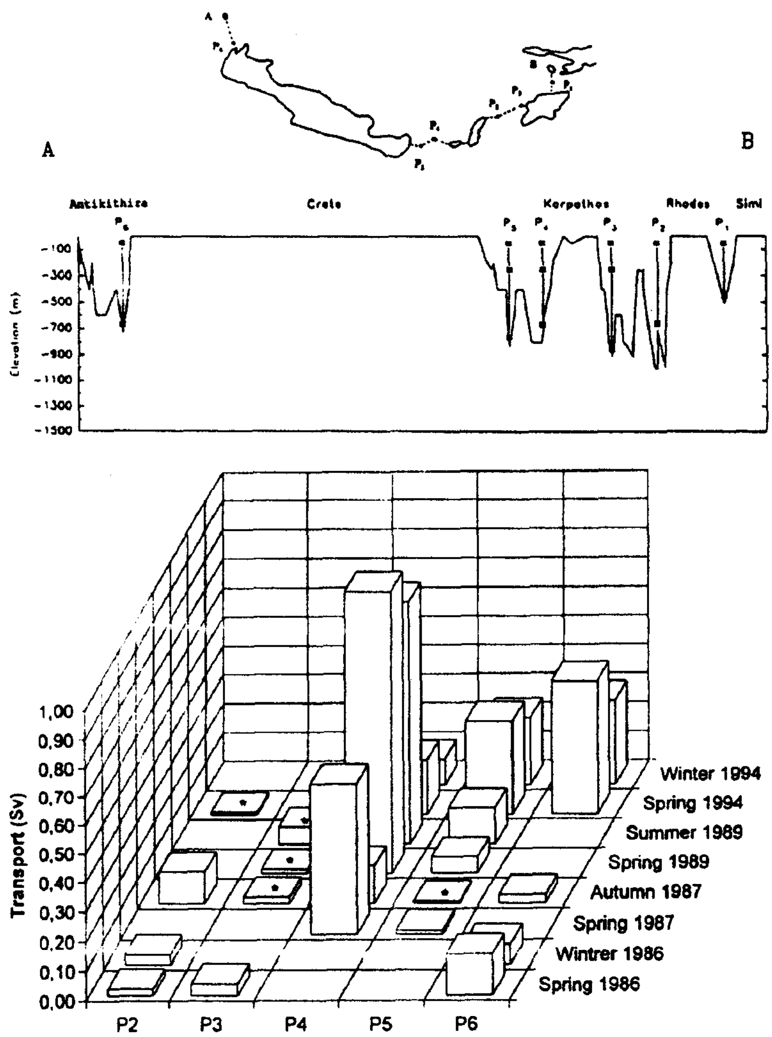

Figure 1
Deep outflowing transports through the Cretan Straits (stars indicate inflow).

II. GENERAL CIRCULATION OF THE UPPER OCEAN
Chair: Paola Malanotte-Rizzoli

II.1 The Eastern Mediterranean in the 80s and in the 90s: The Big Transition Emerged from the POEM-BC Observational Evidence
by: Paola Malanotte-Rizzoli[1]

The thermohaline circulation of the Eastern Mediterranean underwent a dramatic change between 1987 and 1995. In 1987, the "engine" of the Eastern Mediterranean "conveyor belt" was the convective cell of the Southern Adriatic, while in 1995 the active convective region moved to the Aegean Sea. This change actually started as early as 1991. The phenomenological evidence of the POEM program shows that in 1987 the source of Levantine Intermediate Water (LIW) mass was the Levantine Basin and the bottom water mass was formed in the Southern Adriatic. In 1991, all the intermediate/deep water masses on the horizons σ_θ = 29.00 to 29.18 kg/m^3 were formed inside the Aegean Sea, from which they spread out into the entire Eastern Mediterranean through the Cretan Arc Straits.

In the last decade, the Eastern Mediterranean has been the object of the multinational collaborative program P.O.E.M. (Physical Oceanography of the Eastern Mediterranean) sponsored by UNESCO, IOC, and CIESM. Under this programme, a series of general hydrographic surveys was carried out by the R/Vs of Greece-Israel-Italy and Turkey in the period 1985–1987, culminating in POEM–AS87 in which the German "Meteor" was the leader vessel. In 1987, the regular CTD surveys were implemented by a transient-tracer survey (Roether and Schlitzer, 1991). The observational data set collected in these surveys was intercalibrated, pooled and distributed to all the participating scientists in a series of UNESCO sponsored workshops. The joint analyses and interpretation led first to a group paper summarizing the new findings that included extended modeling results (POEM Group, 1992); second a special issue of Deep-Sea Research was devoted to this POEM–Phase 1 research (Deep-Sea Research, A.R. Robinson and P. Malanotte-Rizzoli, 1993). Recently, the entire POEM–Phase 1 data set has been revisited for the Ionian Sea with an in-depth complete reanalysis that has led to important new findings (P. Malanotte-Rizzoli *et al.*, 1997). These include the first detailed definition of the upper thermocline circulation in the Ionian Sea, with the discovery of the strong Mid-Ionian Jet (MIJ) crossing the basin interior in north/south direction and then becoming the Mid-Mediterranean Jet (MMJ); and the first definition of the pathways of the intermediate LIW and of the Eastern Mediterranean Deep Water (EMDW).

In 1990, POEM evolved into POEM–BC (Biology and Chemistry); a fully interdisciplinary program, with the major overall objective of establishing the phenomenology of the 1990s for the chemical and biological parameters together with a reassessment of the phenomenology of the physical properties, contrasted to that of the 1980s, (POEM–Phase 1). The first interdisciplinary general survey of the entire basin was carried out in 1991, POEM–BC91, followed by a more restricted survey in March 1992 (the Ionian Basin only) and a final overall survey by the R/V Meteor (Germany) in January 1995 with a second transient tracer network of stations. This was part of the LIWEX experiment aimed to investigate the successive phases of the LIW formation and concentrated in the Northern Levantine region of the Rhodes Gyre during the successive months, February through April 1995. The analysis of the Meteor cruise, including the transient tracer observations revealed a very important, dramatic change in the deep thermohaline circulation, the Eastern Mediterranean "conveyor belt." Specifically, in 1987, the driving engine of the deep, closed thermohaline cell was the Southern Adriatic, where deep convection leads to the formation of the Adriatic Deep Water (ADW) that exits from the Otranto Straits, becomes EMDW and spreads throughout the eastern Levantine in the bottom layer. General upwelling to the intermediate transitional layer (below 1,000 m) provides the return pathways to the Southern Adriatic closing the cell (Roether and Schlitzer, 1991). In winter 1995, the situation was completely different: the engine of the deep thermohaline circulation was now the Aegean Sea, with deep, denser water masses

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exiting from the Cretan Arc Straits, spreading throughout the entire basin and pushing to the west, while simultaneously lifting, the less dense EMDW of southern Adriatic origin (Roether *et al.*, 1996).

We present here the first observational evidence that this dramatic change in the Eastern Mediterranean circulation actually started in 1991 and involved not only the deep water mass pathways but the intermediate ones as well, specifically the LIW origin and pathways. This evidence is based on the first joint analysis of the POEM-BC91 general survey. This analysis revealed first that the upper thermocline circulation (upper ~250 dbar) was actually extremely similar in the 1980s and 1990s. Most importantly, the MIJ, emanating from the Atlantic Ionian Stream (AIS) entering the Sicily Straits, is quite strong, crossing the Ionian interior from north to south and surrounding a general anticyclonic region in the Southwestern Ionian both in the 1980s and 1990s. Recent results based on drifter observations confirm the persistence of the MIJ from the 1980s throughout 1995–96 (Poulain, personal communication).

On the other hand, a dramatic change is observed from 1987 to 1991 in all the intermediate and deep water mass pathways. In 1987, the LIW was formed in the proper Levantine Basin, entered the Cretan passage south of Crete, with a major branch proceeding directly to the Sicily Straits and successive branches "peeling off" and being veered northward by the anticyclonic gyres of the Ionian interior. The LIW pathways on its typical horizon, the isopycnal surface σ_θ = 29.05 kg/m^3, is shown in Figure 1. This behavior is observed consistently on all the isopycnal surfaces from 29.00 to 29.15 kg/m^3.

In 1991, all the water masses on the horizons of σ_θ = 29.00 to 29.18 kg/m^3 are formed inside the Aegean Sea, they exit from the Cretan Arc Straits, and spread into the Ionian interior "blocking" the traditional LIW route from the Levantine. In Figure 2, we show the LIW on the horizon σ_θ = 29.05 kg/m^3 exiting from the Western Cretan Arc Straits with the major branch reaching the Straits of Sicily, and a second branch spreading northward along the Greek side after being veered anticyclonically by the Pelops Gyre. An important homogenized anticyclonic recirculation region is present in the Ionian interior. On the other hand, LIW on the horizon 29.10 kg/m^3 (and on all the deeper horizons), shown in Figure 3, does not reach the Sicily Straits. The intrusive tongue exiting from the Aegean Sea recirculates entirely anticyclonically all around the Ionian interior, which is filled by a homogenized water mass with S ~ 38.87.

Thus the change in the deep thermohaline circulation observed in Winter 1995 (Roether *et al.*, 1995) actually started as early as Winter 1991, with the deep convective processes leading to intermediate/deep water mass formation now occurring in the Aegean Sea. The October 1991 evidence shows the persistence of this situation until 1995 with the massive salty tongues spreading out from the Aegean through the Cretan Arc Straits. The primary cause of this shift in the convective "engine" of the basin from the Southern Adriatic to the Aegean is still unknown.

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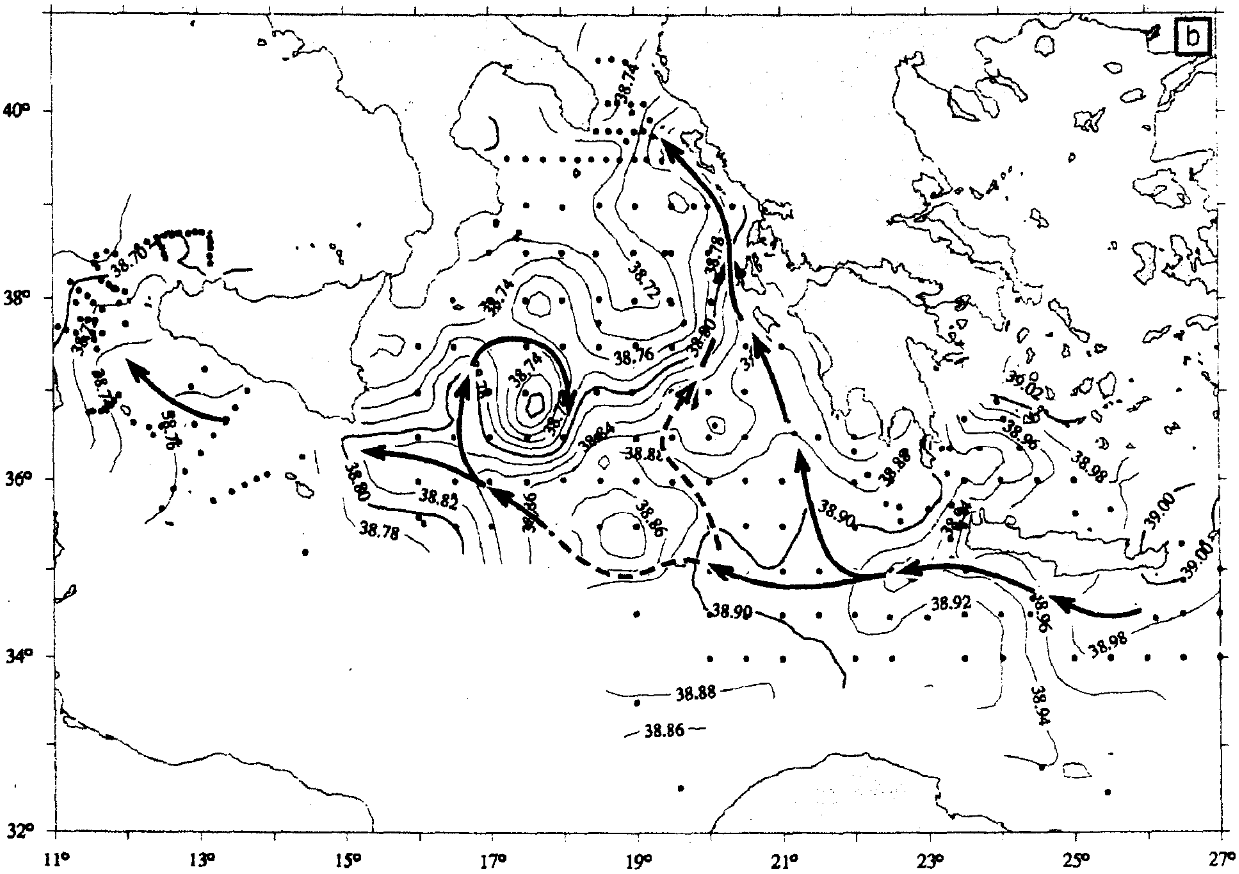

Figure 1
Cruise, POEM–AS87. Salinity at density = 29.05 kg/m^3

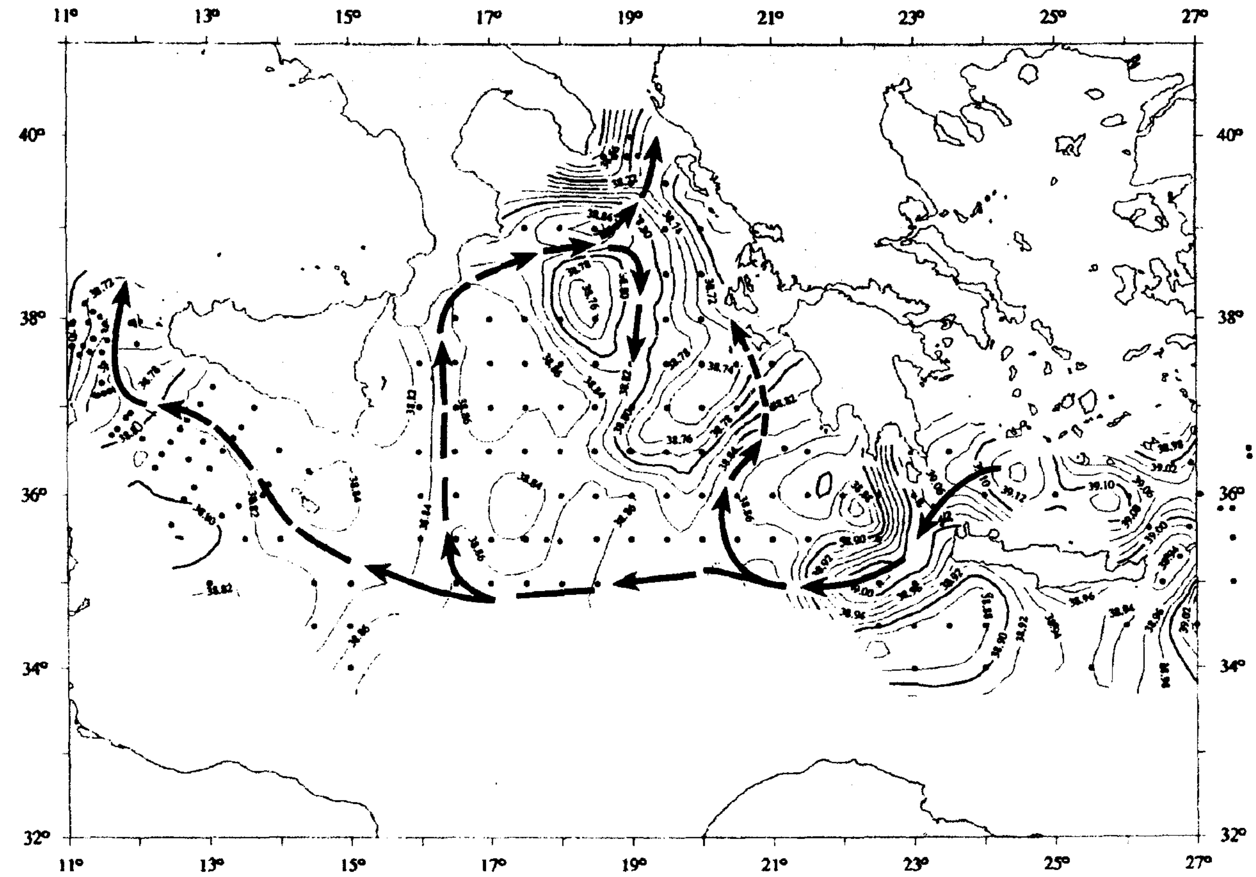

Figure 2
Cruise, POEMBC–O91. Salinity at density = 29.05 kg/m^3

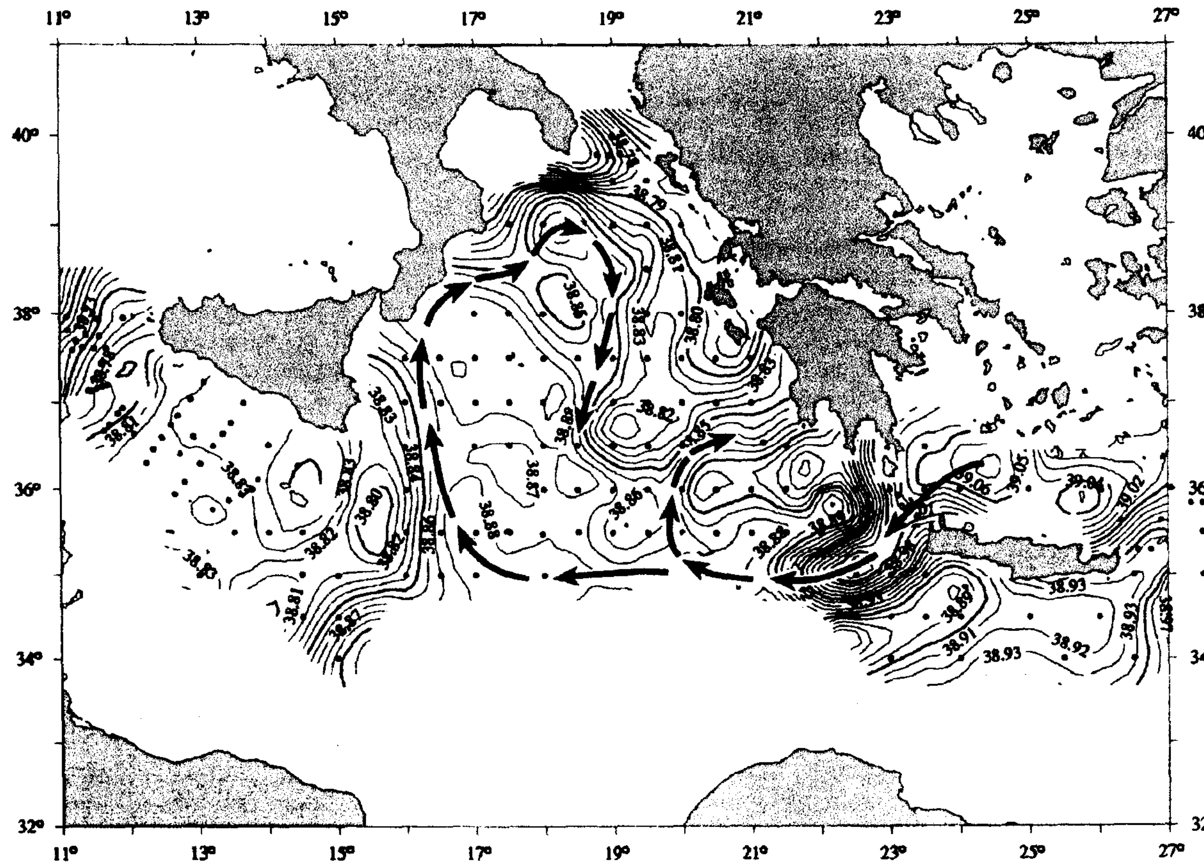

Figure 3
Cruise, POEMBC–O91. Salinity at density = 29.10 kg/m^3

II.2 General Circulation of the Upper Mediterranean Sea

by: Pierre-Marie Poulain[1]

The first qualitative diagrams of currents for the Mediterranean Sea were produced in the 1910s by the "core" method, in which the mean circulation patterns were inferred from the motion of the different water masses (e.g., Nielsen, 1912). It is only in the 1950–1960s that quantitative charts of dynamic topography and relative geostrophic currents were produced for selected areas of the Mediterranean (e.g., Le Floch and Romanosky, 1954; Zore, 1956).

As more hydrographic measurements became available, the geostrophic circulation for the entire Mediterranean was calculated with respect to a single established reference level. Charts of geostrophic currents were compiled by Ovchinnikov (1966) for the four seasons of the year (Figure 1). These maps indicate that Atlantic Waters flow through the Strait of Gibraltar and follow the African coast as far as the Nile Delta. There the North African Current bifurcates. One branch is deflected to the north and forms the Rhodes cyclonic Gyre, the other runs east and then turns north along the coast of Israel. Cyclones are found to the left of the North African current in most basins of the Mediterranean (e.g., Alboran Gyre, Tyrrhenian Gyre, Rhodes Gyre). They correspond to zones of mean divergence and upwelling of deeper waters. Anticyclonic and convergent current systems are found to the right of the North African Current in the southern Ionian (Syrtis Gyres) and in the Levantine Basin (Mersa-Matruh Gyre). These mean surface circulation patterns are modulated seasonally with enhanced (reduced) current strength in winter (summer). Comparison with wind observations showed that the mean transport of water in the Mediterranean is essentially wind-driven and that thermohaline forcing plays only a minor role.

The above mean surface circulation picture was refined using nearly synoptic and higher resolution hydrographic data and ancillary data sets, such as satellite sea-surface temperature fields and moored direct current measurements. In the Western Mediterranean, Millot (1987) produced a surface circulation schematic map (Figure 2) that delineates the dominance of mesoscale eddies in the Algerian Current, the sardino-Balearic and Tyrrhenian basins, and the existence of coastal currents contributing to the global cyclonic circulation in the Western Basin (e.g., Western Corsican Current, Ligurian Current). As part of the Physical Oceanography of the Eastern Mediterranean (POEM) program, multi-ship extensive hydrographic surveys were carried out in the 1980s in most of the Eastern Basin (Robinson and Golnaraghi, 1993; Malanotte-Rizzoli *et al.*, 1998). These observations indicated that Ovchinnikov's North African Current takes the form of meandering current systems like the Atlantic-Ionian Stream, the Mid-Ionian Jet and the Mid-Mediterranean Jet (see Figures 3 and 4). To their right, anticyclones prevail (Ionian Anticyclones, Mersa-Matruh, Shikmona) and to their left, cyclonic gyres dominate (Cretan Cyclone, Rhodes and W. Cyprus Gyres). An exception to this rule is the Pelops Anticyclone, a permanent circulation pattern southwest of the Peloponnesian Peninsula to the left of the Mid-Ionian Jet.

More recently, low-cost drifting buoys tracked by satellite were utilized to explore the surface circulation in selected basins of the Mediterranean (Millot, 1991; Artale *et al.*, 1994, Poulain, 1998; Matteoda and Glenn, 1996). Their Lagrangian nature provided direct current measurements over extended sea areas. The drifter-inferred currents generally correlate remarkably with the indirect geostrophic estimates. For example, the surface currents in the Sicily Straits and the Ionian Sea were investigated as part of a multi-year program involving more than 60 drifters. Partial trajectory segments of these drifters for the period November 1994 to March 1997 are shown in Figure 5 whenever the speed exceeded 40 cm/s. The structures of the meandering Atlantic-Ionian Stream extending into an anticyclonic Gyre in the northern Ionian and continuing as a strong meridional jet in the northeast Ionian are in good agreement with the POEM circulation map for the late 1980s (see Figure 4; Malanotte-Rizzoli *et al.*, 1998).

Both indirect and direct measurements of the surface circulation of the Mediterranean indicate that variabilities occur on three energetic scales: the basin scale, the sub-basin scale and the mesoscale. The most energetic one is the sub-basin scale which includes the cyclones and anticyclones. The basin scale circulation is dominated by jet systems like the Atlantic-Ionian Stream and the Mid-Mediterranean Jet. The mesocale corresponds to the meandering of jets and gyre borders. These scales interact

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actively. Wind stress is the major forcing mechanism acting on these structures. It can introduce important seasonal and interannual variations in some Mediterranean basins (Pinardi *et al.*, 1997). The global surveying and monitoring of surface currents using indirect and direct measurements along with the acquisition of reliable wind observations should be planned in the future as they are key ingredients to understanding the Mediterranean Sea dynamics and to creating an effective Mediterranean forecasting system.

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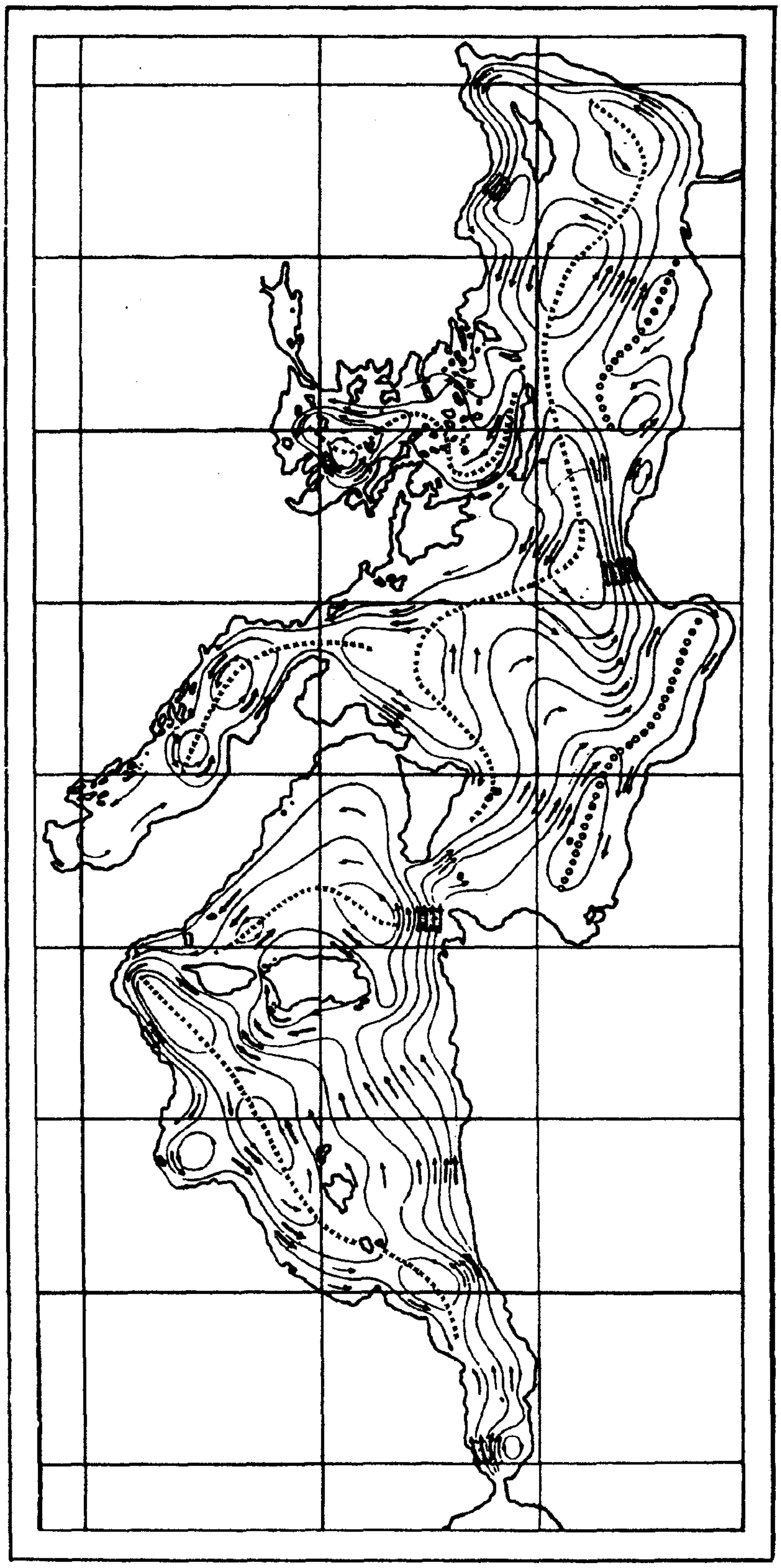

Figure 1
Surface geostrophic currents with respect to a 1000 m reference level for the entire Mediterranean in winter (from Ovchinnikov, 1966).

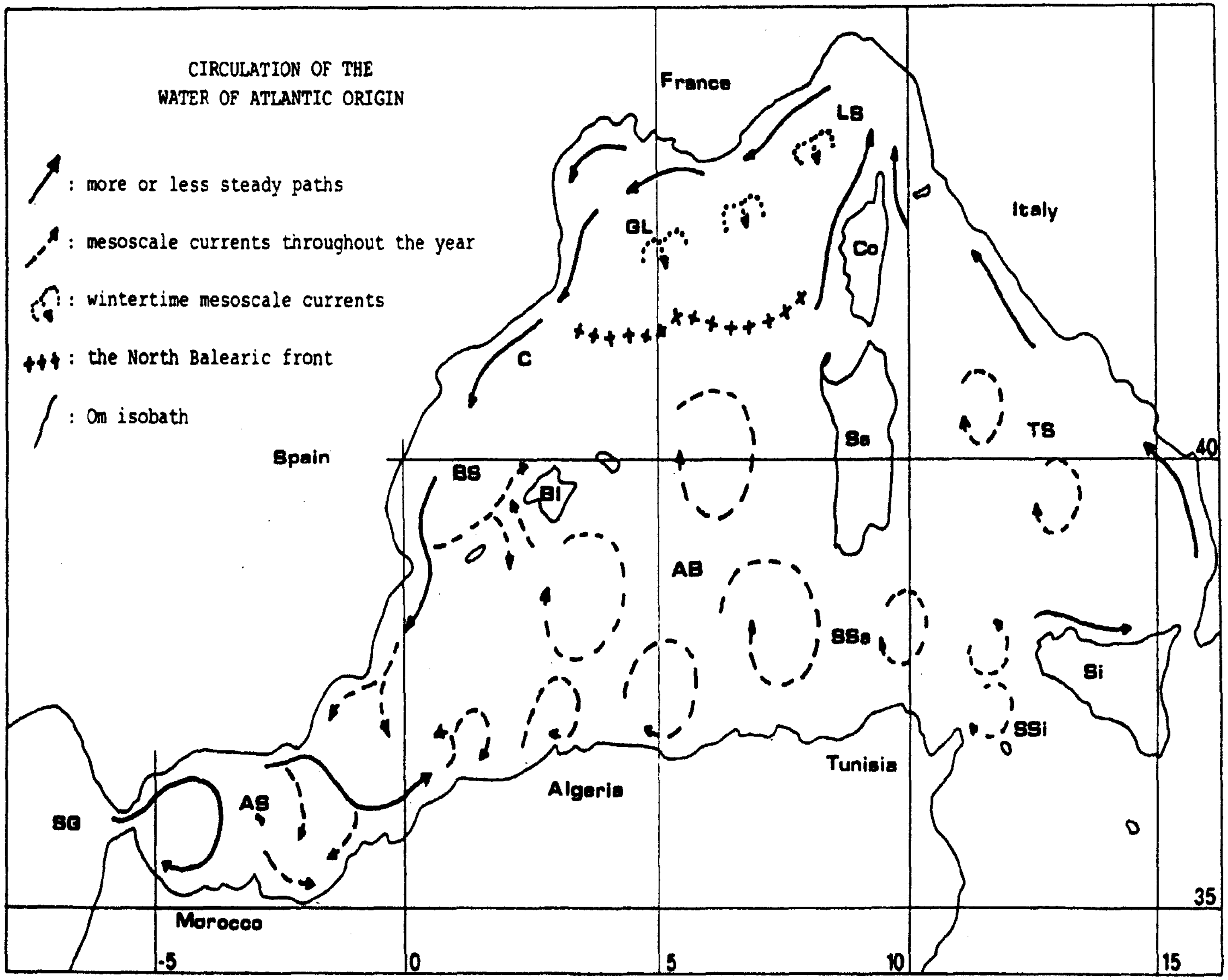

Figure 2
Schematic diagram of the surface circulation in the Western Mediterranean (from Millot, 1987).

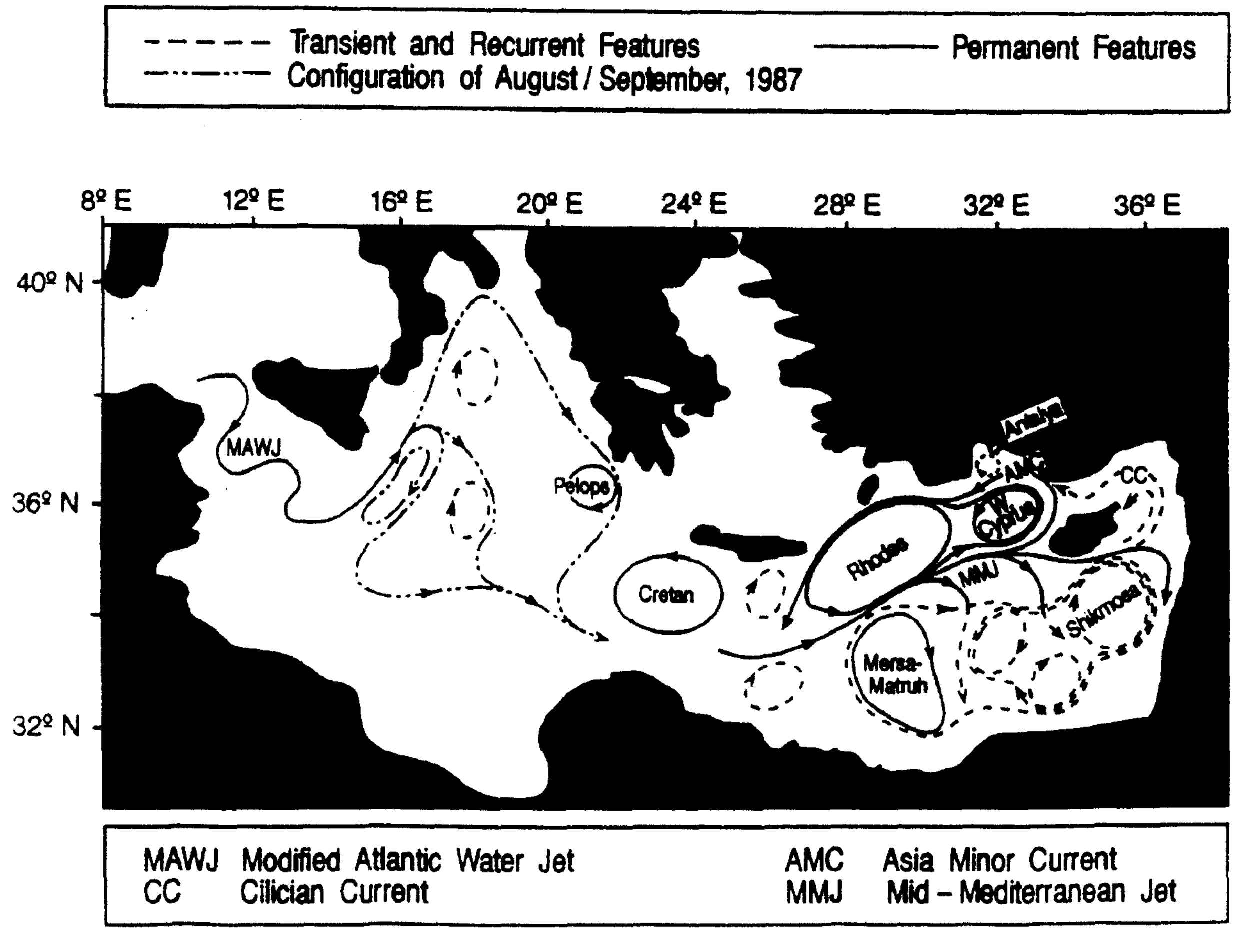

Figure 3
Schematic upper thermocline general circulation extended from melding of POEM data and dynamics in the Eastern Mediterranean (from Robinson and Golnaraghi, 1993).

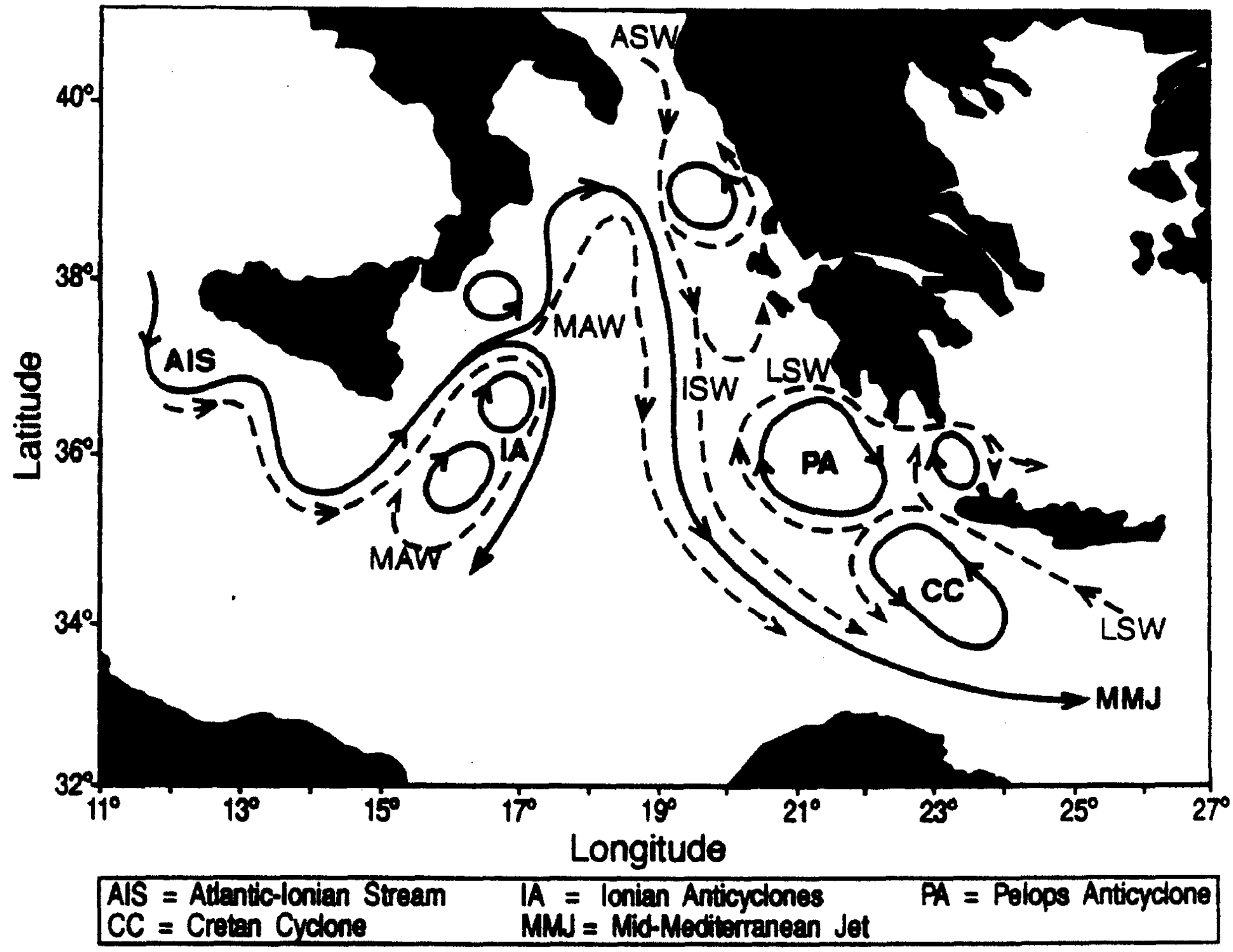

Figure 4
Schematic of the surface circulation in the Ionian (from Malanotte-Rizzoli *et al.*, 1997).

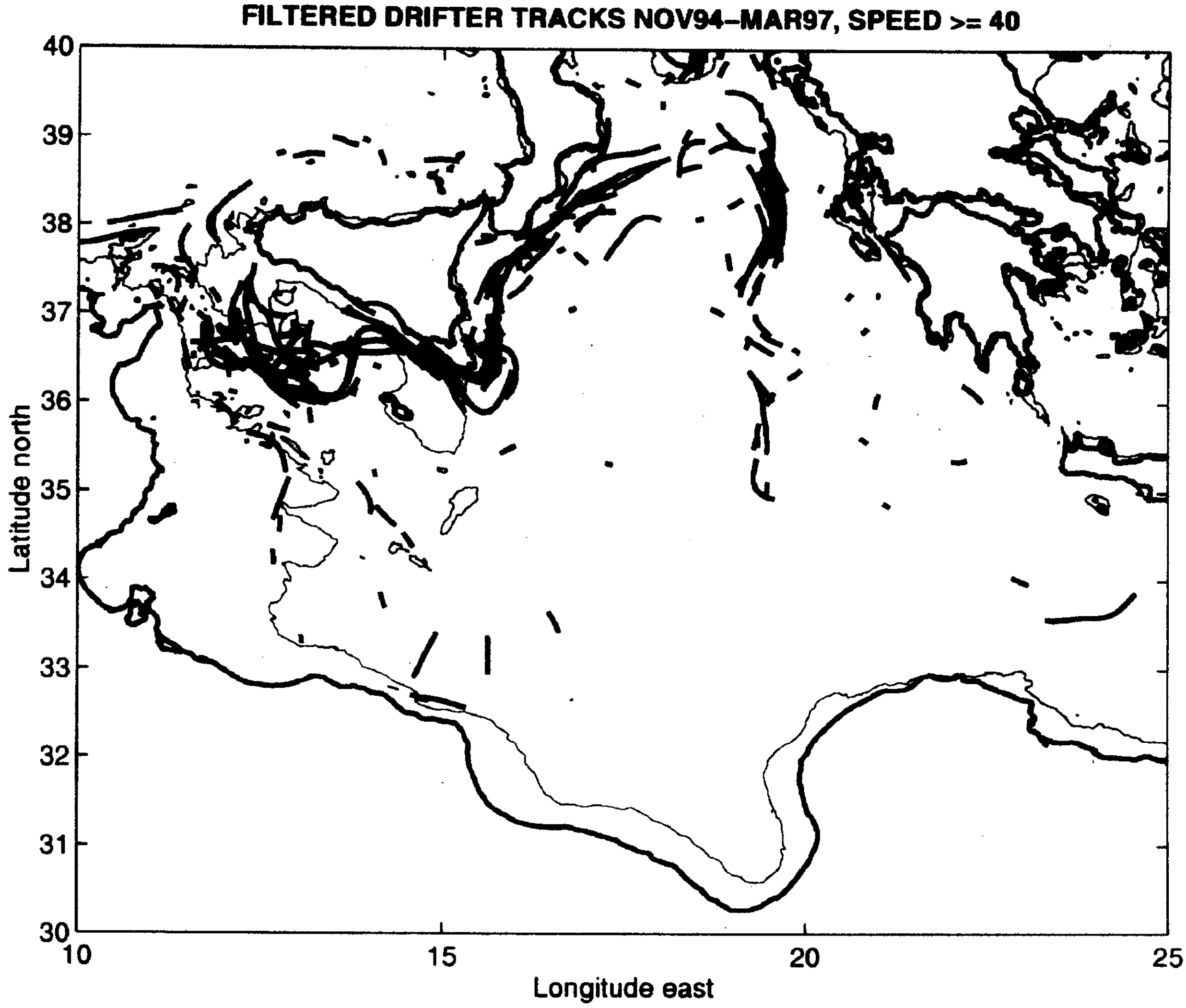

Figure 5
Drifter trajectory segments corresponding to speed superior to 40 cm/s in the Sicily Straits and the Ionian Sea between November 1994 and March 1997.

II.3 General Circulation Of The Upper Ocean: Forcing, Response, Feedbacks, and Multiscale Interactions

by: Stephen Brenner[1]

Forcing

The primary forcing functions for the Mediterranean circulation are: topography, surface forcing, exchanges through straits, and fresh water input. Topography affects the circulation directly through the sea bottom bathymetry and indirectly through the mountain ranges that surround the Mediterranean rim which in turn control the local wind systems. Surface forcing consists of wind stress, heat fluxes (radiative, latent, and sensible), and atmospheric pressure (inverse barometer effect). Surface forcing fields can be obtained from long-term, climatological means (e.g., May, 1982; Garrett *et al.*, 1993) or from daily synoptic meteorological analyses and forecasts.

Exchanges through the Strait of Gibraltar affect the basinwide circulation (e.g., Lacombe and Richez, 1982; Candela, 1991; and Bryden and Kinder, 1991) while the flow through the Sicily Strait affects the interaction between the eastern and western basins (e.g., Manzella *et al.*, 1988). Fresh water input occurs as precipitation (although the net E-P is positive as the Mediterranean is a concentration basin) and as river outflow. The most dramatic change in the latter is related to the closing of the Nile by the Aswan High Dam in 1964 (Bethoux and Gentili, 1994).

Various estimates of surface forcing, exchanges through the straits, and fresh water input are available but all have important uncertainties that must be quantified and reduced. An effort must be made to critically review the existing data and to assess new sources of data such as recent sea-level measurements, the meteorological re-analyses available from the various operational forecasting centers, and measurement from new technologies. Efforts should be concentrated on reducing the uncertainties in the forcing functions for use in both basinwide budget studies as well as in model simulations.

Response

The response of the Mediterranean occurs over a wide range of both spatial and temporal scales. Spatial scales include Mediterranean-wide and basin scale (eastern and western) thermohaline cells, sub-basin scale gyres and associated current systems, mesoscale eddies, and sub-mesoscale features such as convective chimneys (see Robinson and Golnaraghi, 1994 for a comprehensive review). The latter three are highly energetic and quite variable. These various features also have associated time scales and variabilities ranging from interdecadal down to several days. Furthermore, they can be classified as permanent, recurrent, transient, or indicative of long term trends. Many of these features have been seen in both the analysis of observational data (e.g., Millot, 1987; The POEM Group, 1992) as well as in results from recent modeling studies (e.g., Zavatarelli and Mellor, 1993; Roussenov *et al.*, 1995; and Wu and Haines, 1996).

Further studies of the response of the Mediterranean will depend crucially on a proper understanding and assessment of the forcing. Studies should include both field measurements as well as intensive modeling efforts with an emphasis on specific process studies as well as a general understanding of the overall response of the system.

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Feedback

Feedback can occur in two ways: (a) through air-sea interaction (the mutual adjustment of the sea-surface temperature and the heat/moisture fluxes from or to the atmosphere); and (b) through internal, dynamical energy conversions among the various scales of motion. The former is especially important in winter when atmospheric forcing plays a crucial role in deep and intermediate water formation while at the same time the distribution of sea-surface temperature can have a major impact on the development of storms and the cyclone tracks. Some preliminary assessments of both of these processes have been done through the analysis of historical data and in recent modeling studies.

To properly address the issue of two-way air-sea interaction, it is necessary to implement a coupled ocean atmosphere model for the Mediterranean and conduct appropriate studies.

Multiscale Interactions

In addition to the internal, dynamical, and energy conversion cycle, multiscale interactions appear to be important in the process of intermediate and deep water formation and the spreading and redistribution of various properties. Evidence for this has been seen in some of the recent modeling studies such as Wu and Haines, 1996.

Further studies of the multiscale interactions will rely heavily on modeling studies in the form of process studies (idealized simulations), high resolution regional or sub-basin scale simulations, as well as long term basinwide simulations.

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III. THERMOPHALINE CIRCULATION CELLS

Chair: Wolfgang Roether

III.1 Mediterranean Thermohaline Circulation Modeling with GCMs

by: Keith Haines[1]

A number of important advances have been made in the modeling of the thermohaline circulation of the Mediterranean in recent years. Three of the main achievements are discussed here.

(1) The simulation of a statistically steady climate circulation with reasonably realistic currents, surface and strait heat, freshwater, and volume exchanges.

(2) Simulation of Levantine water pathways in baroclinic eddies.

(3) Simulation of transient tracer concentrations, in particular, CFC distributions in the eastern basin.

Each of these areas may in future have potential applications. The first will increase understanding of when and how perturbations to the basins (e.g., changing river or air-sea fluxes) may affect the basin overturning. The second shows why high resolution modeling is necessary, even for thermohaline simulations over long times, because eddies play an important role in mean water transports. The third helps elucidate the details of the deeper circulations and demonstrates that models can successfully simulate Lagrangian transports on long time scales, an ability which will in future permit better simulation of the biogeochemical environment around the Mediterranean.

1. Modeling the Mediterranean Heat and Freshwater Budget

Direct measurements of air-sea fluxes are very difficult to make. Bethoux (1979) provided the first set of flux estimates suggesting a heat loss over the Mediterranean of about $7Wm^{-2}$ and a net water loss of about I m/yr. The freshwater budget contributes more to the buoyancy loss in the basin which drives the thermohaline exchanges and the current best estimates are around 70 cm/yr. The best estimates are made by studying the fluxes of heat and freshwater through Gibraltar and assuming the basin is in equilibrium, as discussed by Garrett and Candela later in this document. There is evidence that the small size of Gibraltar means that hydraulic considerations may control the exchanges with the Atlantic, e.g., Bryden and Kinder (1991).

Given the uncertainties in the detailed flux distributions, Wu and Haines (1997) took the considerably improved monthly estimates of surface water properties prepared by Brasseur *et al.* (1996) in the Mediterranean Oceanographic Data Base (MODB), as a basis for forcing a 1/4 degree GCM of the whole Mediterranean. By relaxing towards the MODB surface data they were able to simulate a repeating seasonal cycle over 100 years. Using the last forty years, they examined water property distributions and diagnosed the surface heat and freshwater fluxes and strait transports. The table gives the figures they obtained, which are remarkably consistent with observational estimates. The modeled distributions and properties of Levantine intermediate and eastern and western Mediterranean deep waters are also in reasonable agreement with hydrographic data.

It is still too early to expect such models to give many quantitative details correctly, such as the transports in particular currents. The forcing distributions for wind and fluxes will need improvement to achieve this. However, sensitivity of the global thermohaline circulation has become a hot topic in recent years recognizing the possibility of thermohaline collapse.

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It is possible that similar behavior may occur in the Mediterranean. Paleo records, e.g., Rohling (1994), and recent observations, Roether *et al.* (1996) suggest that radical changes to the Mediterranean thermohaline circulation have, and may again occur, with unexpected consequences. Despite current limitations, further modeling with sophisticated GCMs offers the only means of examining details of changes in thermohaline flows, induced, for example, by damming the Nile or rivers flowing into the Black Sea.

Mediterranean Model Budgets, from Wu and Haines (1997)

Region	Whole Med.	West Med.	East Med.	Adriatic
Area (m^2)	2.35×10^{12}	0.81×10^{12}	1.54×10^{12}	0.08×10^{12}
S. Ht Flux (Wm^{-2})	-5.8	-7.8	-4.7	-23.5
S. Fr. Flux ($cmyr^{-1}$)	-67	-64	-69	+ 41
Strait	Gibraltar	Sicily	Otranto	
Ht. Flux (W)	1.37×10^{13}	0.74×10^{13}	0.19×10^{13}	
Fr. Flux (Sv)	0.054	0.036	-8×10^{-4}	
Vol. Flux (Sv)	1.34	1.14	0.44	

2. Modeling the LIW Pathways

Levantine Intermediate Water plays a critical role in the Mediterranean because it is present as an intermediate salinity maximum to a greater or lesser extent in all parts of the Mediterranean Sea, where it reduces water column stability encouraging deep water production in the north in winter. Description of the pathways of LIW in the Mediterranean go back to Wust (1961). Observations have often shown the presence of LIW cores within gyre and eddy features in both eastern and western basins, e.g., Özsöy *et al.* (1993), Millot (1991). Wu and Haines (1996) demonstrated that simulating baroclinic instability in a GCM was critical to dispersing LIW from its water formation sites in the Levantine to all parts of the basin. Madec *et al.* (1991) and Jones and Marshall (1993) have studied the role of baroclinic eddies in water formation in idealized models while recently Lascaratos (this report) has studied the effect of model resolution on LIW production simulations. While higher resolution models are always preferable, the problem of the minimum model resolution needed to 'adequately' simulate the role of LIW in thermohaline processes is still unclear but probably lies between 1/4 and 1/8 degree.

Another problem of some importance is the pathway of LIW in the western Mediterranean. Most models show two LIW paths, as in Wust (1961), with one path directly towards Gibraltar from Sicily and the other northwards towards the Gulf of Lions. However, no observational evidence of mean westward currents have been found along the Algerian coast, Millot (1991), although LIW is often found in this region. This discrepancy has yet to be adequately resolved.

3. Modeling CFC Distributions in the Eastern Mediterranean

Transient tracer distributions offer a means of testing model thermohaline flows quantitatively. Analysis of CFC distributions in the eastern Mediterranean measured in 1987 (Roether and Schlitzer, 1991), provide details of the path and speed of Adriatic deep water formation and dispersal. In particular, they reveal a mid-depth minimum in CFCs in the Ionian basin around 2000 m, and a maximum concentration in a deep western boundary current south of Italy, see Figure 1. Many attempts to simulate eastern Mediterranean deep waters within a GCM were unable to get the dense water flowing to the bottom of the Ionian outside Otranto e.g., Wu and Haines (1996).

One new approach to this problem is presented in Haines and Wu (1997) who use the Gent and McWilliams (1990) advective parameterization scheme for sub-gridscale processes. This scheme provides a consistent downward velocity along a density front such as occurs when Adriatic deep waters flow out of Otranto. This is more effective at getting water down to the deep Ionian without excessive mixing. This alone is not sufficient for simulating the CFC distribution in Figure 1 since the strong CFC gradients lead to numerical problems and negative values, Beitzel (1997). A new advection scheme developed by Thuburn (1996) and introduced to oceanography by Stratford (1997) seems to cure these problems. Figure 2 shows a CFC12 distribution in a GCM for 1987, which should be compared, to Figure 1. The model has 1/4 degree by 31 level resolution and is based on the MOMA code, Myers and Haines (1997). The model, which is forced with data from MODB, as described in section 1, is run for twenty-seven years with surface CFC12 concentrations beginning in 1960. The section shows a mid-depth minimum in CFC12 concentrations which is higher in the water column than Figure 1, and a CFC12 maximum in the deep boundary current which is slightly lower than in Figure 1. The CFC minimum at the western edge of the Ionian basin is also absent from observations, but otherwise agreement is good. There are other methods for simulating dense overflows in numerical models, such as the use of a topography following bottom boundary layer, e.g., Beckmann and Doscher (1997), although they have yet to be applied to the Mediterranean. These results demonstrate that Lagrangian modeling of tracer distributions is now possible and may be used regularly in future to model Mediterranean water property distributions.

In conclusion, there has been a rapid improvement in the ability of GCMs to simulate mean thermohaline flows in the Mediterranean. As yet the changes in thermohaline flows due to extreme cold winters or due to slow trends in freshwater inputs from rivers, or even from persistent changes in surface wind patterns, have not been assessed. This will be an important future step towards improving understanding of recent climatic changes over the Mediterranean, such as those discussed by Roether *et al.* (1996) or Rohling and Bryden (1992).

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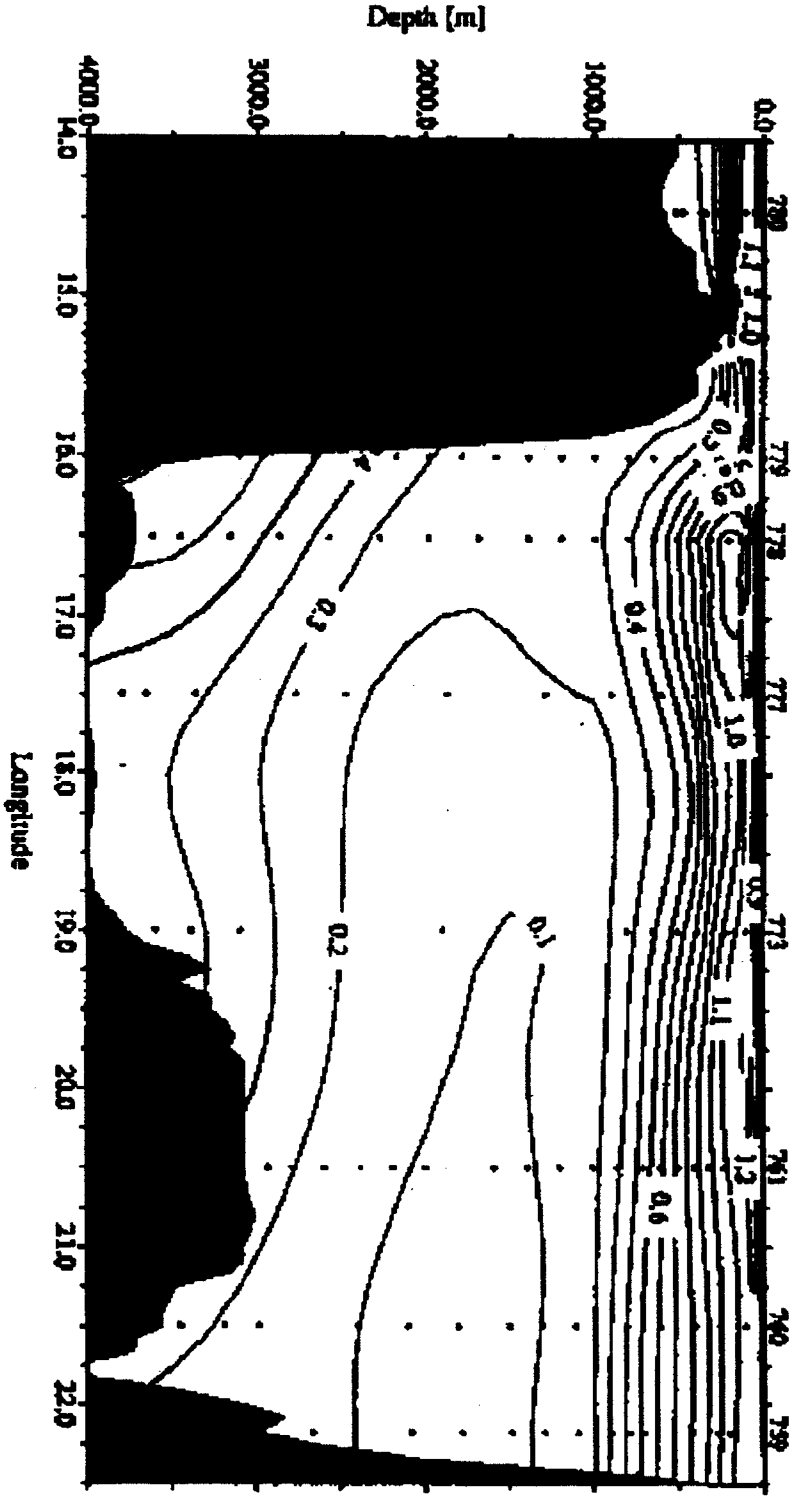

Figure 1
Shown is CFC12 concentration in pmol/l during 1987 along a west-east section across the Ionian Sea around the latitude of Crete.

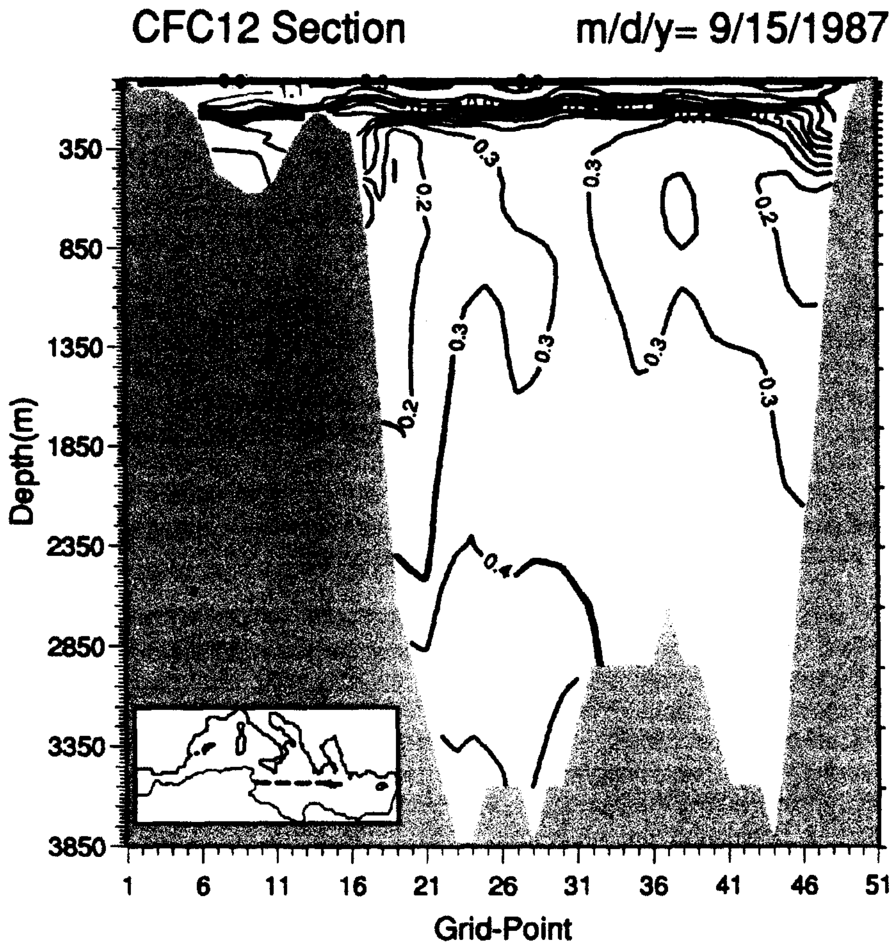

Figure 2
Shown is a model simulation of CFC12 concentration in 1987 from a GCM using the Gent and McWilliams parameterization and a flux limiting advection scheme.

IV. THE MEDITERREAN ECOSYSTEM

Chair: Antonio Cruzado

IV.1 Physical Chemical Biological Interactions Interdisciplinary Models

by: Jacques C. J. Nihoul[1]

One cannot discuss interactions between physical processes and ecosystems without addressing first the problem of scales.

The natural variability of the marine system has long been recognized. Physical processes, forced by external (atmospheric...) stresses and modulated by eigenmodes of responses to these stresses, which both have many different length- and time- scales, display as a result of nonlinear interactions a continuous spectrum of motions of all scales with peaks—associated with external or internal forcings—and valleys. Ecological and biogeochemical processes have, similarly, a scale-dependent hierarchical organization and many recent investigations have emphasized the possible resonant interactions of physical and biogeochemical processes of similar time-scales resulting in an adjustment of biogeochemical and ecological length-scales to the length-scales of the resonant physical processes, as a result of the permanent strain exerted by them on the system.

Two main "spectral windows" (i.e., ranges of time-scales and length-scales) of resonant interactions are readily identified, the first one—associated with typical production rates—corresponds to characteristic times from hours to days; the second one—associated with typical life times—corresponds to characteristic times from weeks to months. The physical processes include, for the first window, diurnal variations of light and air-sea interactions, inertial oscillations, tides, storm surges and, for the second window, mesoscale/synoptic eddies, frontal currents meandering and instabilities. Larger frequency processes such as internal waves, Langmuir cells, and 3-D turbulence have been traditionally regarded as stirring mechanisms increasing the encounter rates between particles which themselves react passively to the physical forcing at those scales. One realizes, however, now that, with length-scales from a few meters to less than one millimeters, small-scale physical "fluctuations" interact with (most often induced) behavioral/physiological variations in phytoplankton, zooplankton and higher trophic levels at the scale of the individuals or aggregates of individuals (chains, filaments, bundles..., in the case of phytoplankton for instance). Such behavioral/physiological variations (related to the way of feeding, communicating or moving, protecting oneself, aggregating or desaggregating...) generate what one may regard as a form of "biological turbulence."

One can thus see the need to consider a third spectral window in the largest scales and to develop interdisciplinary studies of interactions in the behavioral/physiological domain. Only a good understanding of the small-scale ecosystem fluctuations, as induced by hydrodynamic fluctuations and behavioral/physiological responses to them, will provide the necessary information to parameterize them in larger scale models describing diurnal or seasonal evolutions.

One of the first steps in constructing an interdisciplinary model is the definition of a limited number of representative state variables. There must be sufficiently few of them for their evolution equations to be amenable to analysis but enough of them to describe adequately the system's behavior. No matter how frustrating it can be, if one doesn't have enough information to express the interaction rates between different parts of the food-web in mathematical form to give reliable values to the parameters implanted in these mathematical formulations, or if suitable initial and boundary conditions are not available, corresponding pathways must be abandoned in the system's flow-chart and some appropriate closure must be devised to clog the model. This may require leaving out state variables and

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interaction processes or "aggregating" variables and processes (i.e., lumping together state variables belonging to some broader category and reformulating the interaction processes).

In degrading or upgrading ecosystem models, one must pay a particular attention to the fact that model ecosystems may have considerably different dynamics according to the number of variables used to describe them. In particular, chaotic behavior may exist in a n-dimensional model and disappear in models of n + 1 or n – 1 dimensions.

IV.2 Productivity, Food Webs, and Limiting Factors

by: Maurizio Ribera d'Alcala[1]

The classical picture of the Mediterranean Sea emphasizes three aspects: the Mediterranean Sea is oligotrophic. In fact, it is characterized by low resident autotrophic biomass, low values of dissolved nitrogen and phosphorus in the photic zone, and low values of primary production; the Oligotrophy increases heading east; and species diversity decreases toward the east. The above characteristics are normally attributed to the inverse estuarine dynamics of the basin, i.e., to the fact that nutrient exploited surface water enters the Straits of Gibraltar.

Jacques (1989) questioned the first statement, at least for the Western Basin. Transients in biomass concentration up to 10–20 mg/m^3 as chlorophyll a, observed by CZCS in the Alboran Sea, or in situ in the Algerian Current and in the Ligurian Sea are quoted by Jacques to support the point that old estimates based on sporadic C14 measurements cannot be generalized and tend to underestimate total production in the basin. The value reported by Sournia (1973) averaging C14 incubation data are 30–50 gm^{-2} y^{-1} of fixed carbon for the EMED and 90 gm^{-2} y^{-1} for the WMED, respectively.

Quantification of yearly new or regenerated production for the two subbasins has been attempted using CZCS time series or elemental budget (P or N, depending on the authors). The latter approach (P budget) allowed Bethoux (1981) to conclude that EMED new production is in the range of 6 gm^{-2} y^{-1} and the WMED one in the order of 36 gm^{-2} y^{-1}. The former value has been corrected to 12 gm^{-2} y^{-1} by the same author a few years later, which is very close to the value of 11 gm^{-2} y^{-1} computed by Dugdale and Wilkerson (1988), who based their computation on nitrogen flux to the euphotic layer. It is worth noting that nutrient concentrations are quite law in the MED, particularly for phosphorus, and data sets relatively poor, which introduce a significant uncertainty in total fluxes and, consequently, in production values.

An independent estimation of primary production in the Western and Eastern basins derives from the application of a big-optical model by Morel and coworkers (Morel & André, 1991; Antoine *et al.*, 1995) to CZCS data which resulted in 158 gm^{-2} y^{-1} for the WMED and 108 gm^{-2} y^{-1} for the EMED. A comparison of the above numbers with the values derived from the other approaches, using an *f* ratio of 0.3, which is reasonable for an oligotrophic area, leads to the conclusion that WMED production could be slightly overestimated, whereas EMED production is definitely different if determined from nutrient fluxes or from biomass distribution.

Nevertheless, the order of magnitude of primary production does not change significantly and the MED can still be classified as an oligotrophic basin not very differently from the open Ocean at similar latitudes. It is also evident that more accurate values of primary production are needed and that the uncertainty due to episodic or transient events has to be resolved. This is particularly true for the EMED which does not show any evident seasonal signal in the biomass abundance, neither definite temporal patterns, thus making occasional blooms, if any, significant on a yearly time scale.

CZCS data also confirm the longitudinal decrease in biomass from west to east, though with a clear discontinuity east of the Straits of Sicily rather than following a more or less continuous gradient. This is also apparent in the numbers of annual production. Internal dynamics of the two basins and fluxes at the interfaces are putative causes for this behavior. What are the groups of autotrophs mostly contributing to carbon fixation, how efficiently fixed carbon is channeled to the consumers and what are the prevailing paths for carbon transfer are the processes usually referred to as the food web structure.

In a proper sense, the food web is the network of sources, sinks, and fluxes for energy and matter flow in the ecosystem. It is general and qualitative in nature, and does not depend on the quantities involved and/or on the "actors" playing the game. It focuses on roles and functions. If so, it can hardly be assumed that in Mediterranean pelagic environment there is more than just one food web. Missing links, dominance of specific pathways or of specific classes of organisms over the others (e.g. picoplankton vs. nanoplankton, etc.) allow to differentiate among areas or regions, or between

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subsystems in the marine environment (e.g., coastal vs. open sea; benthic vs. pelagic, etc.). In this respect, many traits of the Mediterranean food web have yet to be explored.

The ratio between new and regenerated production only recently has been systematically investigated, but this information is not available at basin scale. Jacques (1989) hypothesizes that the Mediterranean food web is particularly efficient because of being highly diversified and dominated by the microbial loop which allows an efficient recycle of nutrients and carbon. In addition, he points out that gelatinous plankton (salps, appendicularians, medusae), which abundance is generally underestimated by the traditional sampling techniques, plays a relevant role in storing and channeling carbon from the smallest planktonic size fractions to higher predators. This would not be a peculiar feature of the Mediterranean Sea, being more or less common to many oligotrophic oceanic environments. But it should be intensively investigated to better quantify what are the most important pathways of energy flow, which in turn would permit to conceptually model the system and to forecast its fluctuations and trends due to changes in the forcings.

The presumed greater importance of extreme classes in plankton communities could also challenge the paradigm of a W-E diversity gradient, being the observed lower diversity in the EMED possibly confined to medium size classes of nanophytoplankton and mesozooplankton. The oligotrophy of the basin clearly depends on the lower availability of *P* and *N* in the photic zone, being iron relatively abundant because of atmospheric inputs. Apart from coastal areas, regions showing higher biomass and production rely on vertical transport or diffusion of nutrients from the intermediate layers, due to both cyclonic or anticyclonic dynamics. Cyclonic circulation generally prevails in the areas of higher production (e.g., Northwestern Mediterranean Rhodes Gyre, etc.). Definitely peculiar is the availability ratio in P and N. Nitrate-Phosphate ratio in the basin is always higher than the classical Redfield ratio of 16, or of the oceanic value of 14.5, reaching 20 in the WMED and 25 in the EMED.

To date, there is no definitive proof of phosphate being the factor limiting the plankton growth, even if complete depletion of phosphate in presence of dissolved inorganic nitrogen has been recorded in the Eastern Levantine (Krom *et al.*, 1991) or in the Adriatic Sea. A fertilization experiment is less feasible than the Iron Fertilization Experiment because of the quantities involved. Nevertheless the anomaly in the N/P ratio has been puzzling Mediterranean oceanographers since many years. Recent data on atmospheric contribution, observed ratios off the mouth of main rivers and values at the straits strongly suggest that the fluxes at the boundaries (land and even more atmosphere) produce the observed anomaly, making the Mediterranean Sea a "coastal ocean." This, in turn, implies that Mediterranean is strongly dependent on changes that can affect those fluxes. Anthropogenic activity increasing or decreasing element availability, climatic fluctuations modifying wind, precipitation and circulation patterns can produce dramatic changes in the of the basin, as it is also testified by the anoxia crises experienced on time scales of thousands years.

The two basic questions, who and how much, about production of the MED, could now be better addressed relying on systematic observation of the sea, based also on remote techniques. Satellite data are of paramount importance, but bio-optical algorithms should be tuned specifically for the MED. Some of the simplifying assumptions used for the open ocean on the atmospheric correction, particularly about aerosol composition and homogeneity, do not hold for this "coastal" basin. Also retrieval algorithms for chlorophyll should be probably calibrated for the most abundant size classes of autotrophic plankton.

In addition to space platforms, buoys should be deployed to monitor fluctuations and episodic events and to quantify their occurrence and amplitude. Parallel time series of species and size composition of plankton communities should become routine practice in different regions of the basin, to detect trends in diversity and community structure. The Mediterranean Sea is very likely far from a steady state and is less buffered towards change in the forcings than the global ocean, thus being more exposed to rapid shifts in its functioning. This deserves particular attention also considering that most of the coastal regions are heavily occupied by humans and that huge migration waves are currently taking places within its boundaries.

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V. TIME VARIABILITIES AND CLIMATIC CHANGE

Chair: Nadia Pinardia

V.1 Mediterranean Sea Climate Study Project

by: Michel Crepon[1], R. Sadourny, and L. Moriter

The Mediterranean Sea is a semi-enclosed sea, which affects the life of more than three million people living in its nearby vicinity. Its climatic variations deserve interest as it can modify the economy of the riparian people. We propose to study the long-term evolution of the Mediterranean Sea, the so-called Mediterranean Sea climate, for periods ranging from the decade up to the millenary, with an air-sea coupled model. The Mediterranean air-sea coupled model will allow us to answer specific needs and interrogations of Mediterranean people for the next future.

We expect to improve the accuracy of air-sea fluxes which are essential ingredients of an accurate modeling of the circulation of the Mediterranean Sea, to improve the hydric cycle on the Mediterranean basin leading to a better determination of the precipitations which dramatically condition the buoyancy forcing of the sea and the agriculture on the surrounding lands. We expect to identify the major cycles of the Mediterranean Sea climate and to determine their causes.

This will lead us to analyze the interactions between the interannual variability of the Mediterranean SST and atmospheric variables like for instance, precipitation anomalies throughout the Mediterranean basin (Harzallah *et al.*, 1993). Several studies have shown that, on interannual time scales, the variations of precipitation in Northern and Southern (or Mediterranean) Europe are closely linked, with opposite phases (Fraedrich *et al.*, 1993). At longer time scales, global climate change simulations suggest a climate change signal over both regions. It is therefore important to start studying the European-Mediterranean climate variability problem as an interactive sea-atmosphere-land surface problem, and developing adequate modeling approaches. Another motivation is the need for climate change detection and forecasting over Europe and the Mediterranean area. First, the deep temperature of the Mediterranean Sea is an indicator of climate change (Bethoux and Gentili, 1994). Further, the need for climate forecasting is particularly marked in view of the large number of nations and populations involved, and the very large impact that changes temperature and hydrology may have on the life and welfare of these populations. In particular, there is a need to focus global climate change scenarios over this particular region. More focused climate change simulations would be a stronger basis for specific impact studies. This will allow us to define strategy to manage the consequences of climatic changes on the Mediterranean basin as the occurrence of draughts for agriculture.

The Mediterranean Coupled Model

1) The atmospheric model

The atmospheric model to be used in the project is a general circulation model of LMD, with a typical basic resolution of three degrees in both directions and 19 levels (Harzallah *et al.*, 1995). The model is a new version of the original atmospheric model of LMD, used up to now in a large number of climate studies ranging from variability analysis and sensitivity studies to climates scenarios. The model includes soil-hydrology parameterizations, which simulate soil thermal and hydrological processes in a very efficient way and have been used successfully in various studies. The inclusion of this model will permit to simulate with high degrees of confidence the hydrology over the complex land masses of the region. Coordinate stretching can increase the resolution of the model: here, the increase of resolution will be focused on the Euro-Mediterranean area, resolution being augmented smoothly when one approaches this region. The variable resolution model has been already validated for various regions including the Mediterranean. In this project, the resolution will be increased to 50 km in the Euro-Mediterranean.

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2) The oceanic model

The oceanic model is a Mediterranean-adapted version of the general circulation model of LODYC. Both the general circulation model and the Mediterranean-adapted version were used successfully for several climate studies (e.g., the study of ENSO dynamics and of the Mediterranean water circulation). The Mediterranean Sea model suitable for coupled simulations has a resolution of 1/4 degree. This resolution has been shown to be adequate for the thermohaline circulation (Haines *et al.*, 1996) and for the general circulation patterns at the surface. Vertical mixing and convection are handled by a turbulence kinetic energy closure of order 1.5. Several parameterizations have also been shown to specifically enhance the deep flows and overflows (Herbaut *et al.*, 1996, 1997).

3) The coupling

The coupling will be performed using the "Delocalized Physics" method which was proven to be easy to set up and provides more realistic air-sea interactions (Vintzileos *et al.*, 1997). In the traditional coupling, the exchange of information between the ocean and the atmosphere is done by using interpolations at the surface between the respective grids, while in the delocalized physics coupling, the physical processes of an atmospheric column (boundary layer, convection and radiation) are computed directly on the ocean grid. First the atmospheric variables are interpolated to the ocean grid to calculate the physical parametrizations and associated ocean-atmosphere interactions, then the fluxes or tendencies obtained are integrated back to the atmospheric grid. The delocalized physics method thus treats atmosphere-ocean interactions at the ocean scale. The interpolation-integration algorithms are flux-conserving and obey the action-reaction constraint. The delocalized physics approach has been successfully used in modeling ENSO dynamics (Vintzileos *et al.*, 1997). Outside the Mediterranean area, the atmospheric model will be forced by prescribed SSTs provided from either observations or other coupled global model.

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VI. INTERACTION BTWEEN LAND AND SEA

Chair: Yuval Cohen

VI.1 The Mediterranean Coastal Zone: Environmental Concerns and Scientific Issues

by: Yuval Cohen[1]

The coastal zone of the Mediterranean is characterized by great natural variability and high social, economic, cultural and political diversity. The already strong multiple human stresses in this area and in its catchment continue to grow. Their harmful impacts on the coastal ecosystem are visible all around the Mediterranean and are well documented (UNEP, 1996). At many locations, the degradation of natural resources and the decline in environmental quality pose severe limitations on further socio-economic development. Initially, the focus of national and international environmental policies and action plans in the region was on marine pollution control but this sectoral approach has produced only limited results. By the mid-1980s, it was realized that due to the interdependence of activities and resources in the coastal zone, both site-specific and regional-scale environmental problems can only be resolved within a comprehensive resource management framework which aims to harmonize development with the receiving capacity of the natural system. Consequently, the Mediterranean countries adopted the concept of integrated coastal management (ICM) as the key approach towards achieving sustainable development and lasting environmental protection in the coastal zone.

ICM is a continuous and adaptive decision-making process, which requires comprehensive understanding of the coastal ecosystem and its interactions with the hinterland, the open sea and the atmosphere and an ability to predict and assess its response to various human activities. Thus, scientific research and monitoring are essential for all aspects of ICM: from the identification of issues and priorities to the planning and implementation of management actions and the evaluation of their effectiveness (GESAMP, 1996). In the Mediterranean, the existing information base on coastal resources and the knowledge of coastal processes and interactions are still insufficient for effective ICM. Furthermore, although it has long been recognized that important coastal management problems transcend national and even subregional boundaries, many of the relevant scientific issues were not yet examined in a regional perspective.

Following the examples of successful coordinated, international open-sea research programs in the Mediterranean (e.g., POEM•BC), it is proposed to develop a coordinated Mediterranean Coastal Science Program in support of both national and regional ICM efforts. This management-driven program should include observational networks, process studies and development of predictive models, and should focus on key scientific issues related to the main environmental concerns in the coastal zone: water security, marine pollution, erosion and changes/loss of biodiversity. The program should also address the potential impacts of regional climatic changes and sea-level rise, which most likely would exacerbate the existing environmental problems (Jeftic *et al.*, 1992). Specifically, the following scientific issues should be considered:

Water security

- Process studies on the role of land-sea and sea-air interactions in the regional hydrological cycle.
- Development of extended range (seasonal) precipitation forecasts.
- Assessment of the possible impacts of climatic change and associated sea-level rise on regional water budgets.

Coastal marine pollution

- Estimation of the fluxes of nutrients and contaminants into and out of the coastal zone and development of models for predicting changes in these fluxes.

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- Studies on the cause and effect relationships between introduction of anthropogenic substances into the coastal zone and environmental changes, and development of relevant predictive models.

- Identification and evaluation of specific "environmental health" indicators for the Mediterranean coastal zone amenable for routine monitoring.

Coastal erosion

- Definition of regional littoral cells (boundaries, sediment sources and sinks), assessment of sediment budgets for these cells and monitoring of large-scale and local coastal changes (erosion, accretion) within the cells.

- Development and application of advanced techniques for monitoring coastal changes including remote sensing and automated monitoring techniques.

- Studies aimed at improved understanding and modeling of sediment dynamic processes.

- Scientific assessment of methods for prevention of coastal erosion, protection of coastal cliffs and rehabilitation of eroded coastlines.

Change/loss of biodiversity

- Preparation of species inventories for the coastal zone (taxonomy, distribution, abundance).

- Regional studies to quantify trends in coastal habitats and biodiversity, and to understand ecosystem processes including effects of various stressors.

- Studies on foreign species introduction processes and impacts

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VI.2 Physical and Dynamical Processes Relevant for the Mediterranean Coastal Management

by: Jordi Font[1]

The Mediterranean Coastal Zone

In the Mediterranean region, as in most of the oceans, the population concentrates in the coastal areas. The different dynamical processes that take place in this coastal zone, as well as the fluxes of the multiple physical, chemical, biological and geological parameters through its interfaces with the land, the atmosphere and the open sea, are far from being fully understood and quantitatively estimated. This means that by now the coastal Mediterranean system cannot be modeled to an extent of allowing an efficient assessment of its global functioning, and its response to anthropogenic or natural changes.

The understanding of these fluxes and processes is not only a crucial issue for the fate of the unsteady coastal zone, but also for the whole Mediterranean ecosystem. Modifications of the freshwater runoff, sediment transport, fluxes of carbon, nutrients or pollutants, at specific areas, can strongly affect the behavior of the coastal system. But the open sea is also responding to this kind of phenomena, since, besides the atmospheric fluxes, all the relevant changes in external forcings will come to it from its coastal boundary. The variability of the coastal conditions will then play a key role in the control of the Mediterranean ecosystem at larger scales. And vice versa, the coastal zone can receive strong impacts from changing open-sea conditions. For example, a significant sea-level rise could alter the coastal morphology and affect the different inputs from the continent, in such a way that the eutrophication of a coastal area could be dramatically modified.

Research efforts are needed to understand the various dynamical processes acting in the coastal zone, as well as to determine their complex interactions at different temporal and spatial scales. This will be a first step in achieving an understanding of the different cells of the coastal ecosystem, and their multiple interactions. Of course, developing methods to precisely estimate the fluxes through the interfaces of the coastal system will then allow using this understanding in predicting its evolution under changing external forcings. These scientific issues will definitively contribute helping the responsible managers to adequately react to the societal concerns on the coastal zone. There is a general feeling that not always the coastal system natural response could counteract these external changes, in order to maintain its original equilibrium.

Dynamical Processes

The geographic position of the Mediterranean basin, at the boundary between the atmospheric polar jet and the westerlies, is the cause for a large climatic variability. The Mediterranean rivers, due to the prevailing regional climatic conditions, have usually very irregular regimes. In the coastal zone is where the Mediterranean mesoscale, very small compared to open oceans, is manifested more dramatically. The complex orography enhances the interaction of different scale atmospheric and marine dynamic processes, and produces large differences of forcing mechanisms (like wind stress) within short distances. In addition, the Mediterranean continental shelf, with very few exceptions, is extremely narrow. The Mediterranean, often described as a small-scale model of an ocean, offers in its coastal zone a suitable laboratory to study the impact of global change and human activities, due to its great sensitivity and the high concentration of research resources. Understanding and predicting the evolution of the Mediterranean coastal zone is not only a crucial need for its riverine countries, but a major contribution to understanding and predicting the evolution of the global world system.

Most of the atmospheric processes that are relevant for the behavior of the whole Mediterranean system are especially important in the coastal zone, where, for example, the concentration of atmospheric pollutants is higher due to the proximity to their sources. Storms, and the coupling of atmospheric and sea waves, are at the origin of sudden anomalous sea-level variability at the coast (i.e., surges, seiches).

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The Mediterranean is a negative estuary dominated by the seasonal signal, and hence its circulation has a marked thermohaline character. Its continental shelves are usually bounded by along-slope currents due to the geostrophic balance between salty offshore waters and fresher and lighter waters under the influence of continental discharges. The circulation in the coastal zone is mainly driven by the general offshore circulation, that forces the circulation over the narrow continental shelf, later modified at shorter scales by the local variable forcings. These frontal currents are affected by intense mesoscale variability, that can contribute in a very significant way to the exchange between coastal and open sea waters; that is, strongly influence the environmental conditions of the coastal zone.

The coastal area is extremely variable, not only due to the atmospheric and marine processes acting on it, but also to natural or human forcings from the continent. If climatological, or at least mesoscale-averaged, conditions can be quite realistic to describe the Mediterranean dynamics at basin or regional scales, no similar information is reliable for the coastal zone. The effect of short-lived river discharges or local winds can completely distort the response of the coastal zone to the prevailing seasonal conditions. Predicting the behavior of the coastal environment, in the dynamical, biogeochemical, and ecological aspects, under the action of these various external processes and forcings, is far from an operational stage. Not only improvements in numerical modeling are strongly needed, but also the lack of systematic monitoring is a major obstruction: intensive surveys, multiparametric time series, and an adequate use of remote sensing, are key points to be solved.

The coastal ecosystem is very diverse and productive, and hence very difficult to model its response to external inputs. Lots of different internal and external processes, acting and interacting at different spatial and temporal scales, drive the evolution of the system. Unlike the open ocean, the physical dynamics of the coastal and shelf/slope region is essentially anisotropic. Energetic mesoscale features, as meandering fronts, eddies and filaments, play a major role in the dynamics of the open boundaries of the coastal zone, and hence in determining the coastal circulation. This means that nonlinear interactions are significantly present, which makes more any attempt difficult to efficiently model the overall coastal system. Process studies are still necessary to fully understand these interactions and adequately introduce them in the coastal models. Examples of this are the interaction of along-slope currents with the topography (submarine canyons produce important cross-shore matter flow in the NW Mediterranean), the mechanisms responsible for the hydrodynamic instabilization of shelf/slope fronts, the physical, chemical and biological mechanisms participating in the bottom boundary layer dynamics, or the different time response of the living organisms to changing environmental conditions. In many cases, a multidisciplinary approach is absolutely necessary.

Scientific Issues Relevant for Coastal Management

A good understanding of dynamical processes is a prerequisite to efficiently address the different environmental concerns in the coastal zone. And this does not only refer to coastal processes, but mostly to processes at larger scales in the Mediterranean basin. At the present moment, the following points are key issues to be investigated: nonlinear dynamics of the different cells of the coastal system; quantification and prediction of fluxes at interfaces; sensitivity of the coastal ecosystem to natural and anthropogenic changes; prediction of extreme events of large-scale origin (for example, atmospheric); effects of global climatic changes, as sea level rise; and biogeomorphodynamics.

To achieve this, several techniques and approaches have to be developed: process studies are still needed, since only a full understanding of the different dynamic processes will allow its correct integration into global system models; development of coupled physical-biological models; nonlinear interaction between different scales; nesting local-regional-global models; set up regular on-site surveys and monitoring systems; development of new chemical and biological sensors; operational use of remote sensing, and availability of new satellites (optical sensors, wide swath radars); and development of Coastal Zone Information Systems, including on-site and remotely sensed information, is a prerequisite for any operational control of the coastal zone.

VII. PREDICTION AND MONITORING

Chair: Umit Unluata

VII.1 Harvard University—SACLANTCEN Efforts in the Mediterranean: A Model Case for Data Acquisition and Assimilation into a Real-Time Dynamic Ocean Prediction System

by: Jürgen Sellschopp[1]

In the past years, SACLANT Undersea Research Centre and Harvard University carried out a series of joint at-sea programs for a better understanding of the physics of the Mediterranean Sea and the progress of numeric modeling and prediction skill. The oceanographic instrumentation and expertise of SACLANTCEN and the NATO Research Vessel ALLIANCE were combined with a suite of advanced numeric models, the Harvard Ocean Prediction System (HOPS). The oceanographic cruises in the collaborative programme in the Mediterranean Sea were AIS94 in November 1994, AIS95 in October 1995, AIS96 in August 1996, and Skerki96 in October 1996. The AIS cruises were all directed to the Sicilian Channel and the western Ionian Sea. The last cruise covered the Sardinia Channel and the western entrance to the Sicilian Channel. It is named after the bank that separates both parts of the central Mediterranean. The series of cruises will be continued in August 1997 with a multi-ship survey of the Ionian Sea.

The CTD probe lowered from a ship on station is still the main and most important instrument for the acquisition of physical properties of the sea water. Because of limited ship time and of the demand of synopticity, track design and station spacing must be a compromise between the necessary resolution of mesoscale features and the double time constraints. On track, the distance between stations was generally between 15 and 20 km; between tracks, up to three times this value. CTD casts at every station would have been too time-consuming. Therefore on many locations, expendable devices, such as XBTs or XCTs, were deployed instead.

There is a principal problem with XBT profiles in straits and coastal waters and their usage for assimilation into dynamic models. An offset of only one tenth of a degree integrates up to a dynamic height error of centimeter order. In basins with homogeneous deep water, it is possible to assess the accuracy of an XBT. In straits and coastal waters, salinity may change with range. Temperature differences in the deeper part of the profile may well be balanced by salinity differences. Expendable probes for both temperature and salinity, XCTDs, overcome this problem. The experience of SACLANTCEN with XCTDs is quite positive. One only has to take into account that to an unpredictable degree, the salinity can be low at the surface asymptotically approximating the true value in the course of the first 50 m. The stations for CTD replacement by XBTs or XCTDs are now carefully selected due to the expected complexity of profiles.

In a section across the Pantelleria Channel and continuing to the Sicilian coast, the profiles of temperature, salinity and density change abruptly in all cruises indicating the presence of a frontal jet, the Atlantic Ionian Stream. It is found to meander through the Sicilian Channel on a changing path that keeps its general appearance in summer and autumn. Model calculations came to the result that the preferred wave length of the AIS meander in a summer stratification fits between Adventure Bank and Malta Plateau. The meander is trapped.

CTD profiles assimilated into the HOPS produced the correct currents. A nice example is the eddy northeast of Malta. Four drifters were placed into this feature. As predicted, they underwent several circulations before they followed the AIS jet into the Ionian Sea in NNE direction. A verification of calculated currents was also available through shipboard ADCP measurements. Contaminations of ADCP measurements by tidal and inertial oscillations turned out to be smaller than expected. There is a remarkable similarity between the flow patterns resulting from ADCP measurements of the years 1995 and 1996. It is also visible in the tracks of surface drifters that were released on a western cross section of the Sicilian Channel.

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[1] SACLANTCEN Undersea Research Centre.

The surface water with the lowest salinity, brought from the west by the Algerian coastal current, is found close to Cap Bon. Its southward velocity, if present, is generally small in summer and autumn. The flow of surface water that reduces the salinity in the top layer of the Ionian Sea starts on the Sicilian side of the Channel and crosses Adventure Bank towards Pantelleria. It turns left to the Sicilian coast and right to cross the Malta Plateau. At the shelf break, it either continues as a week current in ESE direction or, as a higher velocity jet, proceeds to the Calabrian coast. Without additional wind forcing, the AIS reaches a speed of about 50 cm/s. The salinity in its subsurface core is down to less than 37.4. The cyclonic eddies on the eastern slopes of Adventure Bank and the Malta Plateau are usually visible by their lower temperature in satellite images.

In 1996, HOPS was used for operational forecasting supporting a naval exercise. Assessment of forecast quality was possible by a posterior) comparison with the dynamic analysis of the forecast day containing freshly assimilated data and with sea-surface temperature images of that day. In most of the cases (70%) that were taken for a first quality check, the direction of feature changes was correctly predicted. During the modeling exercise, atmospheric forcing was mostly small. Dynamic balancing produced the changes in the fields. End of September, wind stress became important and influenced greatly the field of surface currents. Precise predictions of surface fluxes are needed for a good prediction of the upper ocean.

The counterpart to the flow of modified Atlantic Water through the Sicilian Channel into the Ionian Sea is the westward flow of Levantine Intermediate Water (LIW). The LIW is identified everywhere in the Mediterranean (preferably in the T-S diagram) by the salinity maximum at approximately 300 m depth. Due to various mixing processes, the LIW salinity decreases from east to west. A marked front between Tyrrhenian Sea type LIW and LIW of the western Mediterranean was observed in the Sardinia Channel running from 100 km west of southern Sardinia in SE direction. Only close to the African coast where the bottom ascends to LIW depth, the transition between both LIW types is gradual indicating that this might be an area for LIW transformation by cross-pycnal mixing.

In the Sicilian Channel, LIW is a homogeneous water mass different from both the Ionian and the Tyrrhenian counterparts. Along the African shelf in the Sicilian Channel, temperature and salinity profiles were measured, however, with western Mediterranean type LIW. Instead of being a one way passage for modified LIW coming from the Ionian Sea, the Sicilian Channel thus merges also a component advected from the west.

The measurements of transports through the Sicilian Channel are opposed by the complicated underwater topography. Three moorings were deployed around Pantelleria from August to October 1996 with current meters in the surface layer above and below the thermocline, in the depth of the LIW and below sill depth. In all three moorings, there was a strong (20 cm/s) southward flow of the surface layer. West of Pantelleria the same velocity to the north was measured in 220 m and only gradually less in 550 and 700 m. This stream was directed to the trench passing west of Adventure Bank. The deep current north of Pantelleria was less strong and directed NW in direction to the same trench. Southeast of Pantelleria, the currents in 220, 550, and 1250m depth were only few cm/s decreasing with depth and always directed southwest thus indicating a counterclockwise circulation in the deep basin. This result fits well with the observed CTD profiles at the African shelf.

There is indication that similar as between Tyrrhenian Sea and Western Mediterranean LIW on the shelf west of the Skerki Bank, the transformation of Ionian Sea LIW to Sicilian Channel LIW happens by cross-pycnal mixing in the bottom boundary layer. The transition occurs when the LIW stream passes Medina Bank before it arrives in the basin. Significant LIW transformation is also observed close to the shelf break of the Malta Plateau.

HOPS

Real-time dynamic analysis of the actual oceanographic situation and forecasts for up to nine days were accomplished in the Mediterranean Sea with the Harvard Ocean Prediction System (Robinson *et al.*, 1997), a modular package of data handling, assimilation and modeling programs, the core of which is a double-sigma-coordinate primitive equation physical model. Model runs, with appropriate synoptic measurements and validations, were made in the Sardinia and Sicilian Channels. In 1996, HOPS was used for rapid environmental assessment and prediction prior and during a military exercise in the Sicilian Channel (Sellschopp and Robinson, 1997). The computed results served as inputs for Navy systems.

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Sellschopp, J., and A.R. Robinson, 1997. Describing and Forecasting Ocean Conditions during Operation Rapid Response, Proceedings for the Conference on Rapid Environmental Assessment, Lerici.

VII.2 GOOS, EUROGOOS, and the Requirement for MEDGOOS

by: Nic Flemming

Summary Report

The Global Ocean Observing System (GOOS) was established by a Memorandum of Understanding between its sponsoring agencies in October 1993. The objective is to provide a global system of measuring instruments, including remote sensing satellites, which will transmit data to computer models so as to monitor, describe, and predict the state of the world oceans and coastal seas. GOOS must satisfy the economic, social, and environmental goals of member states. This means that data must be measured, transmitted, processed, and the results distributed in a sufficiently short time that decisions can be taken before the information is out of date. This sequence and time scale is known as operational oceanography. It places immense demands upon robust instrumentation, rapid data transmission, and powerful modeling computers. Time scales for different variables and parameters from measurement to delivery of operational products may be six hours to three months, or even one year, depending upon the environmental circumstances.

At the GOOS Planning Meeting in May 1996, it was agreed that regional development of GOOS was an approved and practical way forward. At that time both EuroGOOS and NEAR-GOOS were planning their first stages of implementation. The importance of regional development was further stressed by the report of the GOOS Coastal Workshop, and I-GOOS-III 1997.

EuroGOOS was formed by a Memorandum of Understanding between its 14 founding member agencies in 1994. There are now 25 member agencies from 14 countries. More are planning to join during 1997. Membership is open to any governmental agency of national status, which has the objective of promoting operational oceanography within the framework of GOOS, provided that the country of origin is a member of the KU, the ESF, or the Council of Europe. EuroGOOS has created a structure of overarching goals, functional aims, and technical and scientific projects, which have been described in a series of brochures, strategy documents, and plans. EuroGOOS held a major conference at The Hague, Netherlands, in October 1996, and the proceedings will be published during 1997.

The implementation of the EuroGOOS Plan consists of operational projects at the level of regional seas (Baltic, adjacent Arctic, North West Shelf Seas, and Mediterranean), plus an Atlantic/Global component. The latter project will constitute a European contribution to GODAE. European countries bordering the north shore of the Mediterranean have a strong economic, social, and environmental interest in monitoring and forecasting the Mediterranean, and it is logically necessary for European countries to be concerned with modeling the entire Mediterranean. It is not scientifically possible to model and forecast the northern part of the Mediterranean as a separate entity. This interest has taken the form of a EuroGOOS project entitled the Mediterranean Forecasting System (MFS). Preparation of the MFS has included correspondence with representatives of research groups and agencies in most of the North African and East Mediterranean states who have been sent all technical papers, and have been invited to meetings.

A Mediterranean regional GOOS program, which might be called MedGOOS, has not yet been planned. MedGOOS should be initiated by representatives of governments or agencies from all, or almost all, Mediterranean coastal states. All Mediterranean states should be entitled to join, even if they cannot be present at the first meeting. The goals and objectives of MedGOOS should be established by a meeting of such representatives, who should take into account the special economic, social, and environmental needs of all Mediterranean countries, especially in North Africa and the Middle East. The scientific and technical criteria for MedGOOS should be based on the background information available from existing systems, from workshops such as the Workshop on the Science of the Mediterranean Sea and its Applications, and on the EuroGOOS Mediterranean Forecasting System. The first step is to identify the operational oceanography requirements of the Mediterranean coastal states, especially the non-European states. EuroGOOS has already carried out surveys of operational ocean data requirements in Spain, Italy, and Greece.

EuroGOOS will consider assistance to the development of MedGOOS in any way which may be requested by the Member States of MedGOOS, or requested by IOC. EuroGOOS will assist in workshops to define the economic and social benefits, which would be created by MedGOOS, and to promote technical development through collaboration between MedGOOS and MFS. So far as is practically possible, the EuroGOOS view is that MedGOOS and EuroGOOS should be twin organizations, with many independent objectives, but also with many overlapping and identical objectives, and with a common membership along the northern coast of the Mediterranean Sea. Duplication in the Mediterranean area itself should thus be avoided, but both organizations would be free to set their own agendas and priorities. A unified scheme of nested models and observing systems at the scales of the Atlantic, European coastal seas, and the Mediterranean Sea, would be scientifically and economically efficient.

ANNEX I

AGENDA

DAY 1: TUESDAY, 29 JULY

9:00-9:10 Opening Remarks:

- Welcome to IOC -Dr. Gunnar Kullenberg
- Workshop Objectives and Agenda -Professor Allan R. Robinson

PLENARY PRESENTATIONS BY TOPICAL TEAMS

9:10-10:50 I. Transports, Exchanges, Transformations and Budgets
-Mario Astraldi, Chair

- Chairman's Remarks
  -Mario Astraldi
- "Why We Still Do Not Understand Surface Fluxes and the Role of the Strait of Gibraltar"
  -Chris Garrett
- "Recent Exchange Measurements in the Strait of Gibraltar"
  -Julio Candela
- "The Transport Variability of Levantine Water in the Strait of Sicily"
  -Mario Astraldi
- "Variations of the Fluxes and Water Mass Exchanges through the Deep Layers of the Cretan Arc Straits and their Influence in the Deep Thermohaline Circulation of the Eastern Mediterranean"
  -Alex Theocharis
- "The Water Exchange in the Strait of Otranto and Consequences in the Adriatic Sea"
  -Bruno Manca

10:50-11:10 Coffee Break

11:10-12:50 II. General Circulation of the Upper Ocean
-Paola Malanotte-Rizzoli, Chair

- "General Circulation of the Upper Ocean"
  -Pierre Poulain
- "Forcings, Responses, Feedbacks and Multiscale Interactions"
  -Steve Brenner

12:50-14:00 Lunch

14:00-15:40 III. Thermohaline Circulation Cells
-Wolfgang Roether, Chair

- "The Thermohaline Cells of the Mediterranean Features and Processes, Observations Available and Needed in the Future"
-Wolfgang Roether

- "Modeling I: Interannual Variation of LIW Formation, How Good are the Present Models?"
-Alex Lascaratos

- Modeling II: Modeling the Whole Thermohaline Circulation Cell Interactions, Where Will Modeling Go?"
-Keith Haines

15:40-16:00 Coffee Break

16:00-17:40 IV. The Mediterranean Ecosystem
-Antonio Cruzado, Chair

- "The Mediterranean Sea, Regional Subcomponents and Linkages"
-Antonio Cruzado

- "Physical-Biological-Chemical Interactions"
-Jacques Nihoul

- "Productivities, Food Webs and Limiting Factors"
-Maurizio Ribera d'Alcala

DAY 2: WEDNESDAY, 30 JULY

9:00-10:40 V. Time Variabilities and Climatic Change
-Nadia Pinardi, Chair

- "On the Externally Forced Interannual Variability of the Overall Basin"
-Nadia Pinardi

- "Short and Long Term Sea Level Fluctuations"
-Julio Candela

- "Air-Sea Coupled Model of the Mediterranean Sea and its Impact on Water Budget of the Mediterranean Basin"
-Michel Crepon

10:40-11:00 Coffee Break

11:00-12:40 VI. Interaction Between Land and Sea
-Yuval Cohen, Chair

- "The Mediterranean Coastal Zone and Environmental Concerns and Scientific Issues"
  -Yuval Cohen

- "The Mediterranean - Relevant Scientific Needs"
  -Gunnar Kullenberg
- "Coastal Management in the Mediterranean - Physical and Dynamical Processes"
  -Jordi Font

- "Economic Applications in the Mediterranean"

12:40-14:00 Lunch

14:00-15:40 VII. Prediction and Monitoring
-Umit Unluata, Chair

- "Harvard-SACLANT Efforts in the Mediterranean, its Application of Data Assimilative Interdisciplinary Model"
  -Jurgen Sellschopp

- "The Mediterranean Forecasting System"
  -Nadia Pinardi

15:40-16:00 Coffee Break

16:00-16:30 Set up and charge to working groups

16:30-18:00 Working groups in session

DAY 3: THURSDAY, 31 JULY

8:30-9:00 Working group chairs (only) meet

9:00-9:30 VII. Prediction and Monitoring (continued)
-Umit Unluata, Chair

- "EuroGOOS, GOOS and Requirements for a Potential MedGOOS"
  -Nic Flemming

9:30-10:30 Working Groups meet

10:30-11:00 Coffee Break

11:00-11:30 Working Groups resume

11:30-13:00 Preliminary reports from topical working groups and discussion of common problems (10 min. each)

1. Transports, Exchanges, Transformations and Budgets

2. General Circulation of the Upper Ocean
3. Thermohaline Circulation Cells
4. The Mediterranean Ecosystem
5. Time Variabilities and Climatic Change
6. Interaction between Land and Sea
7. Prediction and Monitoring

13:00-14:00 **Lunch**

14:00-15:30 **Working Groups meet**

15:30-16:00 **Coffee Break**

16:00-18:00 **Final Plenary Session**

1. Final presentation of Working Group Reports (15 min. each)
2. Adoption of recommendations
3. Conclusion of Meeting
4. Collection of first draft report material

ANNEX II

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ANNEX III

LIST OF ACRONYMS

ADCP	Acoustic Doppler Current Profiler
ADW	Adriatic Deep Water
AIS	Atlantic Ionian Stream
AW	Atlantic Water
BC	Biology and Chemistry
CD-ROM	Compact Disk with a Read Only Memory
CDW	Cretan Deep Water
CEC	Commission of the European Communities
CIEM	Conseil international pour l'exploration de la mer
CIESM	Commission internationale pour l'exploration scientifique de la mer Méditerranée
CIW	Cretan Intermediate Water
CNR	National Research Council
COADS	Comprehensive Ocean/Atmosphere Data Set
CTD	Conductivity-Temperature-Depth probe
CZCS	Coastal Zone Colour Scanner
DCM	Deep Chlorophyll Maximum
DNA/C	Designated National Agency
DW	Deep Water
ECMWF	European Centre for Medium-range Weather Forecasting
EMDW	Eastern Mediterranean Deep Water
EMED	Eastern Mediterranean
ENSO	El-Nino - Southern Oscillation
E-P	Evaporation-Precipitation
EROS-2000	European River-Ocean Systems Programme
ERS2	Earth Resources Satellite
ERSEM	European Regional Seas Ecosystem Model
ESF	European Science Foundation
EU	European Union
EuroGOOS	European GOOS
GCM	General Circulation Model
GESAMP	Group of Experts on the Scientific Aspects of Marine Environment Protection (IMO- FAO-UNESCO/IOC-WMO-WHO-IAEA-UN-UNEP)
GLOBEC	Global ocean Ecosystems Dynamics
GODAE	Global Ocean Data Assimilation Experiment (GOOS)
GOEZS	Global Ocean Euphotic Zone Study
GOOS	Global Ocean Observing System
HOPS	Harvard Ocean Prediction System
IBCM	International Bathymetric Chart of the Mediterranean
IBCM-G	International Bathymetric Chart of the Mediterranean – Bougner Gravity Anomalies Map
IBCM-M	International Bathymetric Chart of the Mediterranean – Magnetic Anomalies Map
IBCM-P/Q	International Bathymetric Chart of the Mediterranean – Plio-Quaternary Thickness Map
IBCM-RS	International Bathymetric Chart of the Mediterranean – Recent Sediments Map
IBCM-S	International Bathymetric Chart of the Mediterranean – Seismicity Map

ICAM	Integrated Coastal Area Management
ICES	International Council for the Exploration of the Sea
ICM	Instituto de Ciencias de Mar (Barcelona, Espana)
ICSEM	International Conference for the Scientific Exploration of the Mediterranean
IFREMER	Institut Français de Recherche pour l'Exploitation de la Mer (France)
IGBP	International Geosphere-Biosphere Programme
IOC	Intergovernmental Oceanographic Commission
JGOFS	Joint Global Ocean Flux Study
LIW	Levantine Intermediate Water
LODYC	Laboratoire d'oceanographie dynamique et de climatologie (France)
LOICZ	Land-Ocean Interaction in the Coastal Zone
MAP	Mediterranean Action Plan
MAST	Marine Science and Technology
MATER	Mass Transfer and Ecosystem Response
MAW	Modified Atlantic Water
MED	Mediterranean
MedGOOS	Mediterranean GOOS
Med SST	Mediterranean Sea Surface Temperature
MFS	Mediterranean Forecasting System
MMJ	Mid Mediterranean Jet
MODB	Mediterranean Oceanic Data Base
MTP	Mediterranean Targeted Project
NATO	North Atlantic Treaty Organization
NEAR-GOOS	North-East Asian Regional GOOS
N/P	Nitrate/Phosphate
NORDA	Naval Oceanographic Research and Development Administration (USA)
ONR	Office of Naval Research (USA)
POEM	Physical Oceanography of the Eastern Mediterranean
POM	Pilot Ocean Monitoring
PRIMO	International Research Research Programme in the Western Mediterranean (France)
R/V	Research Vessel
SECEG	Seminario sobre la oceanografia fisica del Estrecho de Gibraltar
SST	Sea Surface Temperature
SV	Surface Velocity
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNEP	United Nations Environment Programme
US NSF	United States National Science Foundation
WHOI	Woods Hole Oceanographic Institution (USA)
WMDW	Western Mediterranean Deep Water
WMED	Western Mediterranean
WOCE	World Ocean Circulation Experiment
XBT	Expendable BathyThermograph
XCT	Expendable Conductivity Temperature
XCTD	Expendable Conductivity Temperature Depth

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No.	Title	Languages
1	CCOP-IOC, 1974, Metallogenesis, Hydrocarbons and Tectonic Patterns in Eastern Asia (Report of the IDOE Workshop on); Bangkok, Thailand, 24-29 September 1973 UNDP (CCOP), 138 pp.	E (out of stock)
2	CICAR Ichthyoplankton Workshop, Mexico City, 16-27 July 1974 (UNESCO Technical Paper in Marine Sciences, No. 20).	E (out of stock) S (out of stock)
3	Report of the IOC/GFCM/ICSEM International Workshop on Marine Pollution in the Mediterranean; Monte Carlo, 9-14 September 1974.	E, F E (out of stock)
4	Report of the Workshop on the Phenomenon known as 'El Niño'; Guayaquil, Ecuador, 4-12 December 1974.	E (out of stock) S (out of stock)
5	IDOE International Workshop on Marine Geology and Geophysics of the Caribbean Region and its Resources; Kingston, Jamaica, 17-22 February 1975.	E (out of stock) S
6	Report of the CCOP/SOPAC-IOC IDOE International Workshop on Geology, Mineral Resources and Geophysics of the South Pacific; Suva, Fiji, 1-6 September 1975.	E
7	Report of the Scientific Workshop to Initiate Planning for a Co-operative Investigation in the North and Central Western Indian Ocean, organized within the IDOE under the sponsorship of IOC/FAO (IOFC)/UNESCO/EAC; Nairobi, Kenya, 25 March-2 April 1976.	E, F, S, R
8	Joint IOC/FAO (IPFC)/UNEP International Workshop on Marine Pollution in East Asian Waters; Penang, 7-13 April 1976.	E (out of stock)
9	IOC/CMG/SCOR Second International Workshop on Marine Geoscience; Mauritius, 9-13 August 1976.	E, F, S, R
10	IOC/WMO Second Workshop on Marine Pollution (Petroleum) Monitoring; Monaco, 14-18 June 1976.	E, F E (out of stock) R
11	Report of the IOC/FAO/UNEP International Workshop on Marine Pollution in the Caribbean and Adjacent Regions; Port of Spain, Trinidad, 13-17 December 1976.	E, S (out of stock)
11 Suppl.	Collected contributions of invited lecturers and authors to the IOC/FAO/UNEP International Workshop on Marine Pollution in the Caribbean and Adjacent Regions; Port of Spain, Trinidad, 13-17 December 1976.	E (out of stock), S
12	Report of the IOCARIBE Interdisciplinary Workshop on Scientific Programmes in Support of Fisheries Projects; Fort-de-France, Martinique, 28 November-2 December 1977.	E, F, S
13	Report of the IOCARIBE Workshop on Environmental Geology of the Caribbean Coastal Area; Port of Spain, Trinidad, 16-18 January 1978.	E, S
14	IOC/FAO/WHO/UNEP International Workshop on Marine Pollution in the Gulf of Guinea and Adjacent Areas; Abidjan, Côte d'Ivoire, 2-9 May 1978.	E, F
15	CPPS/FAO/IOC/UNEP International Workshop on Marine Pollution in the South-East Pacific; Santiago de Chile, 6-10 November 1978.	E (out of stock)
16	Workshop on the Western Pacific, Tokyo, 19-20 February 1979.	E, F, R
17	Joint IOC/WMO Workshop on Oceanographic Products and the IGOSS Data Processing and Services System (IDPSS); Moscow, 9-11 April 1979.	E
17 Suppl.	Papers submitted to the Joint IOC/WMO Seminar on Oceanographic Products and the IGOSS Data Processing and Services System; Moscow, 2-6 April 1979.	E
18	IOC/UNESCO Workshop on Syllabus for Training Marine Technicians; Miami, U.S.A., 22-26 May 1978 (UNESCO reports in marine sciences, No. 4 published by the Division of Marine Sciences, UNESCO).	E (out of stock), F, S (out of stock), R
19	IOC Workshop on Marine Science Syllabus for Secondary Schools; Llantwit Major, Wales, U.K., 5-9 June 1978 (UNESCO reports in marine sciences, No. 5, published by the Division of Marine Sciences, UNESCO).	E (out of stock), E, S, R, Ar
20	Second CCOP-IOC Workshop on IDOE Studies of East Asia Tectonics and Resources; Bandung, Indonesia, 17-21 October 1978.	E
21	Second IDOE Symposium on Turbulence in the Ocean; Liège, Belgium, 7-18 May 1979.	E, F, S, R
22	Third IOC/WMO Workshop on Marine Pollution Monitoring; New Delhi, 11-15 February 1980.	E, F, S, R
23	WESTPAC Workshop on the Marine Geology and Geophysics of the North-West Pacific; Tokyo, 27-31 March 1980.	E, R
24	WESTPAC Workshop on Coastal Transport of Pollutants; Tokyo, Japan, 27-31 March 1980.	E (out of stock)
25	Workshop on the Intercalibration of Sampling Procedures of the IOC/ WMO UNEP Pilot Project on Monitoring Background Levels of Selected Pollutants in Open-Ocean Waters; Bermuda, 11-26 January 1980.	E (superseded by IOC Technical Series No. 22)
26	IOC Workshop on Coastal Area Management in the Caribbean Region; Mexico City, 24 September-5 October 1979.	E, S
27	CCOP/SOPAC-IOC Second International Workshop on Geology, Mineral Resources and Geophysics of the South Pacific; Nouméa, New Caledonia, 9-15 October 1980.	E
28	FAO/IOC Workshop on the effects of environmental variation on the survival of larval pelagic fishes. Lima, 20 April-5 May 1980.	E
29	WESTPAC Workshop on Marine Biological Methodology; Tokyo, 9-14 February 1981.	E
30	International Workshop on Marine Pollution in the South-West Atlantic; Montevideo, 10-14 November 1980.	E (out of stock) S
31	Third International Workshop on Marine Geoscience; Heidelberg, 19-24 July 1982.	E, F, S
32	UNU/IOC/UNESCO Workshop on International Co-operation in the Development of Marine Science and the Transfer of Technology in the context of the New Ocean Regime; Paris, France, 27 September-1 October 1982.	E, F, S
32 Suppl.	Papers submitted to the UNU/IOC/UNESCO Workshop on International Co-operation in the Development of Marine Science and the Transfer of Technology in the Context of the New Ocean Regime; Paris, France, 27 September-1 October 1982.	E
33	Workshop on the IREP Component of the IOC Programme on Ocean Science in Relation to Living Resources (OSLR); Halifax, 26-30 September 1963.	E
34	IOC Workshop on Regional Co-operation in Marine Science in the Central Eastern Atlantic (Western Africa); Tenerife, 12-17 December 1963.	E, F, S
35	CCOP/SOPAC-IOC-UNU Workshop on Basic Geo-scientific Marine Research Required for Assessment of Minerals and Hydrocarbons in the South Pacific; Suva, Fiji, 3-7 October 1983.	E
36	IOC/FAO Workshop on the Improved Uses of Research Vessels; Lisbon, Portugal, 28 May-2 June 1984.	E
36 Suppl.	Papers submitted to the IOC/FAO Workshop on the Improved Uses of Research Vessels; Lisbon, Portugal, 28 May-2 June 1984.	E
37	IOC/UNESCO Workshop on Regional Co-operation in Marine Science in the Central Indian Ocean and Adjacent Seas and Gulfs; Colombo, 8-13 July 1985.	E
38	IOC/ROPME/UNEP Symposium on Fate and Fluxes of Oil Pollutants in the Kuwait Action Plan Region; Basrah, Iraq, 8-12 January 1984.	E
39	CCOP (SOPAC)-IOC-IFREMER-ORSTOM Workshop on the Uses of Submersibles and Remotely Operated Vehicles in the South Pacific; Suva, Fiji, 24-29 September 1985.	E
40	IOC Workshop on the Technical Aspects of Tsunami Analysis, Prediction and Communications; Sidney, B.C., Canada, 29-31 July 1985.	E
40 Suppl.	First International Tsunami Workshop on Tsunami Analysis, Prediction and Communications, *Submitted Papers;* Sidney, B.C., Canada, 29 July - 1 August 1985.	E
41	First Workshop of Participants in the Joint FAO/IOC/WHO/IAEA/UNEP Project on Monitoring of Pollution in the Marine Environment of the West and Central African Region (WACAF/2); Dakar, Senegal, 28 October-1 November 1985.	E
43	IOC Workshop on the Results of MEDALPEX and Future Oceanographic Programmes in the Western Mediterranean; Venice, Italy, 23-25 October 1985.	E
44	IOC-FAO Workshop on Recruitment in Tropical Coastal Demersal Communities; Ciudad del Carmen, Campeche, Mexico, 21-25 April 1986.	E (out of stock) S
44 Suppl.	IOC-FAO Workshop on Recruitment in Tropical Coastal Demersal Communities, *Submitted Papers;* Ciudad del Carmen, Campeche, Mexico, 21-25 April 1986.	E
45	IOCARIBE Workshop on Physical Oceanography and Climate; Cartagena, Colombia, 19-22 August 1986.	E
46	Reunión de Trabajo para Desarrollo del Programa "Ciencia Oceánica en Relación a los Recursos No Vivos en la Región del Atlántico Sud-occidental"; Porto Alegre, Brazil, 7-11 de abril de 1986.	S
47	IOC Symposium on Marine Science in the Western Pacific: The Indo-Pacific Convergence; Townsville, 1-6 December 1966.	E
48	IOCARIBE Mini-Symposium for the Regional Development of the IOC-UN (OETB) Programme on 'Ocean Science in Relation to Non-Living Resources (OSNLR)'; Havana, Cuba, 4-7 December 1986.	E, S
49	AGU-IOC-WMO-CPPS Chapman Conference: An International Symposium on 'El Niño'; Guayaquil, Ecuador, 27-31 October 1986.	E
50	CCALR-IOC Scientific Seminar on Antarctic Ocean Variability and its Influence on Marine Living Resources, particularly Krill (organized in collaboration with SCAR and SCOR); Paris, France, 2-6 June 1987.	E
51	CCOP/SOPAC-IOC Workshop on Coastal Processes in the South Pacific Island Nations; Lae, Papua-New Guinea, 1-8 October 1987.	E

No.	Title	Languages
52	SCOR-IOC-UNESCO Symposium on Vertical Motion in the Equatorial Upper Ocean and its Effects upon Living Resources and the Atmosphere; Paris, France, 6-10 May 1985.	E
53	IOC Workshop on the Biological Effects of Pollutants; Oslo, 11-29 August 1986.	E
54	Workshop on Sea-Level Measurements in Hostile Conditions; Bidston, UK, 28-31 March 1988	E
55	IBCCA Workshop on Data Sources and Compilation, Boulder, Colorado, 18-19 July 1988.	E
56	IOC-FAO Workshop on Recruitment of Penaeid Prawns in the Indo-West Pacific Region (PREP); Cleveland, Australia, 24-30 July 1988.	E
57	IOC Workshop on International Co-operation in the Study of Red Tides and Ocean Blooms; Takamatsu, Japan, 16-17 November 1987.	E
58	International Workshop on the Technical Aspects of the Tsunami Warning System; Novosibirsk, USSR, 4-5 August 1989.	E
58 Suppl.	Second International Workshop on the Technical Aspects of Tsunami Warning Systems, Tsunami Analysis, Preparedness, Observation and Instrumentation. *Submitted Papers*; Novosibirsk, USSR, 4-5 August 1989.	E
59	IOC-UNEP Regional Workshop to Review Priorities for Marine Pollution Monitoring Research, Control and Abatement in the Wider Caribbean; San José, Costa Rica, 24-30 August 1989.	E, F, S
60	IOC Workshop to Define IOCARIBE-TRODERP proposals; Caracas, Venezuela, 12-16 September 1989.	E
61	Second IOC Workshop on the Biological Effects of Pollutants; Bermuda, 10 September-2 October 1988.	E
62	Second Workshop of Participants in the Joint FAO-IOC-WHO-IAEA-UNEP Project on Monitoring of Pollution in the Marine Environment of the West and Central African Region; Accra, Ghana, 13-17 June 1988.	E
63	IOC/WESTPAC Workshop on Co-operative Study of the Continental Shelf Circulation in the Western Pacific; Bangkok, Thailand, 31 October-3 November 1989.	E
64	Second IOC-FAO Workshop on Recruitment of Penaeid Prawns in the Indo-West Pacific Region (PREP); Phuket, Thailand, 25-31 September 1989.	E
65	Second IOC Workshop on Sardine/Anchovy Recruitment Project (SARP) int he Southwest Atlantic; Montevideo, Uruguay, 21-23 August 1989.	E
66	IOC *ad hoc* Expert Consultation on Sardine/Anchovy Recruitment Programme; La Jolla, California, U.S.A., 1989.	E
67	Interdisciplinary Seminar on Research Problems in the IOCARIBE Region; Caracas, Venezuela, 28 November-1 December 1989.	E (out of stock)
68	International Workshop on Marine Acoustics; Beijing, China, 26-30 March 1990.	E
69	IOC-SCAR Workshop on Sea-Level Measurements in the Antarctica; Leningrad, USSR, 28-31 May 1990.	E
69 Suppl.	IOC-SCAR Workshop on Sea-Level Measurements in the Antarctica; *Submitted Papers*; Leningrad, USSR, 28-31 May 1990.	E
70	IOC-SAREC-UNEP-FAO-IAEA-WHO Workshop on Regional Aspects of Marine Pollution; Mauritius, 29 October - 9 November 1990.	E
71	IOC-FAO Workshop on the Identification of Penaeid Prawn Larvae and Postlarvae; Cleveland, Australia, 23-28 September 1990.	E
72	IOC/WESTPAC Scientific Steering Group Meeting on Co-Operative Study of the Continental Shelf Circulation in the Western Pacific; Kuala Lumpur; Malaysia, 9-11 October 1990.	E
73	Expert Consultation for the IOC Programme on Coastal Ocean Advanced Science and Technology Study; Liège, Belgium, 11-13 May 1991.	E
74	IOC-UNEP Review Meeting on Oceanographic Processes of Transport and Distribution of Pollutants in the Sea; Zagreb, Yugoslavia, 15-18 May 1989.	E
75	IOC-SCOR Workshop on Global Ocean Ecosystem Dynamics; Solomons, Maryland, U.S.A., 29 April-2 May 1991.	E
76	IOC/WESTPAC Scientific Symposium on Marine Science and Management of Marine Areas of the Western Pacific; Penang, Malaysia, 2-6 December 1991.	E
77	IOC-SAREC-KMFRI Regional Workshop on Causes and Consequences of Sea-Level Changes on the Western Indian Ocean Coasts and Islands; Mombasa, Kenya, 24-28 June 1991.	E
78	IOC-CEC-ICES-WMO-ICSU Ocean Climate Data Workshop Goddard Space Flight Center; Greenbelt, Maryland, U.S.A., 18-21 February 1992.	E
79	IOC/WESTPAC Workshop on River Inputs of Nutrients to the Marine Environment in the WESTPAC Region; Penang, Malaysia, 26-29 November 1991.	E
80	IOC-SCOR Workshop on Programme Development for Harmful Algae Blooms; Newport, U.S.A., 2-3 November 1991.	E
81	Joint IAPSO-IOC Workshop on Sea Level Measurements and Quality Control; Paris, France, 12-13 October 1992.	E
82	BORDOMER 92: International Convention on Rational Use of Coastal Zones. A Preparatory Meeting for the Organization of an International Conference on Coastal Change; Bordeaux, France, 30 September-2 October 1992.	E
83	IOC Workshop on Donor Collaboration in the Development of Marine Scientific Research Capabilities in the Western Indian Ocean Region; Brussels, Belgium, 12-13 October 1992.	E
84	Workshop on Atlantic Ocean Climate Variability; Moscow, Russian Federation, 13-17 July 1992.	E
85	IOC Workshop on Coastal Oceanography in Relation to Integrated Coastal Zone Management; Kona, Hawaii, 1-5 June 1992.	E
86	International Workshop on the Black Sea; Varna, Bulgaria 30 September - 4 October 1991.	E
87	Taller de trabajo sobre efectos biológicos del fenómeno «El Niño» en ecosistemas costeros del Pacífico Sudeste; Santa Cruz, Galápagos, Ecuador, 5-14 de octubre de 1989.	S only (Summary in E, F, S)
88	IOC-CEC-ICSU-ICES Regional Workshop for Member States of Eastern and Northern Europe (GODAR Project); Obninsk, Russia, 17-20 May 1993.	E
89	IOC-ICSEM Workshop on Ocean Sciences in Non-Living Resources; Perpignan, France, 15-20 October 1990.	E
90	IOC Seminar on Integrated Coastal Management; New Orleans, U.S.A., 17-18 July 1993.	E
91	Hydroblack'91 CTD Intercalibration Workshop; Woods Hole, U.S.A., 1-10 December 1991.	E
92	Réunion de travail IOCEA-OSNLR sur le Projet « Budgets sédimentaires le long de la côte occidentale d'Afrique » Abidjan, Côte d'Ivoire, 26-28 juin 1991.	F
93	IOC-UNEP Workshop on Impacts of Sea-Level Rise due to Global Warming. Dhaka, Bangladesh, 16-19 November 1992.	E
94	BMTC-IOC-POLARMAR International Workshop on Training Requirements in the Field of Eutrophication in Semi-Enclosed Seas and Harmful Algal Blooms, Bremerhaven, Germany, 29 September - 3 October 1992.	E
95	SAREC-IOC Workshop on Donor Collaboration in the Development of Marine Scientific Research Capabilities in the Western Indian Ocean Region; Brussels, Belgium, 23-25 November 1993.	E
96	IOC-UNEP-WMO-SAREC Planning Workshop on an Integrated Approach to Coastal Erosion, Sea Level Changes and their Impacts; Zanzibar, United Republic of Tanzania, 17-21 January 1994.	E
96 Suppl. 1	IOC-UNEP-WMO-SAREC Planning Workshop on an Integrated Approach to Coastal Erosion, Sea Level Changes and their Impacts; *Submitted Papers* 1. Coastal Erosion; Zanzibar, United Republic of Tanzania 17-21 January 1994.	E
96 Suppl. 2	IOC-UNEP-WMO-SAREC Planning Workshop on an Integrated Approach to Coastal Erosion, Sea Level Changes and their Impacts; *Submitted Papers* 2. Sea Level; Zanzibar, United Republic of Tanzania 17-21 January 1994.	E
97	IOC Workshop on Small Island Oceanography in Relation to Sustainable Economic Development and Coastal Area Management of Small Island Development States; Fort-de-France, Martinique, 8-10 November, 1993.	E
98	CoMSBlack '92A Physical and Chemical Intercalibration Workshop; Erdemli, Turkey, 15-29 January 1993.	E
99	IOC-SAREC Field Study Exercise on Nutrients in Tropical Marine Waters; Mombasa, Kenya, 5-15 April 1994.	E
100	IOC-SOA-NOAA Regional Workshop for Member States of the Western Pacific - GODAR-II (Global Oceanographic Data Archeology and Rescue Project); Tianjin, China, 8-11 March 1994.	E
101	IOC Regional Science Planning Workshop on Harmful Algal Blooms; Montevideo, Uruguay, 15-17 June 1994.	E
102	First IOC Workshop on Coastal Ocean Advanced Science and Technology Study (COASTS); Liège, Belgium, 5-9 May 1994.	E
103	IOC Workshop on GIS Applications in the Coastal Zone Management of Small Island Developing States; Barbados, 20-22 April 1994.	E
104	Workshop on Integrated Coastal Management; Dartmouth, Canada, 19-20 September 1994.	E
105	BORDOMER 95: Conference on Coastal Change; Bordeaux, France, 6-10 February 1995.	E
105 Suppl.	Conference on Coastal Change: Proceedings; Bordeaux, France, 6-10 February 1995	E
106	IOC/WESTPAC Workshop on the Paleographic Map; Bali, Indonesia, 20-21 October 1994.	E
107	IOC-ICSU-NIO-NOAA Regional Workshop for Member States of the Indian Ocean - GODAR-III; Dona Paula, Goa, India, 6-9 December 1994.	E
108	UNESCO-IHP-IOC-IAEA Workshop on Sea-Level Rise and the Multidisciplinary Studies of Environmental Processes in the Caspian Sea Region; Paris, France, 9-12 May 1995.	E
108 Suppl.	UNESCO-IHP-IOC-IAEA Workshop on Sea-Level Rise and the Multidisciplinary Studies of Environmental Processes in the Caspian Sea Region; *Submitted Papers*; Paris, France, 9-12 May 1995.	E
109	First IOC-UNEP CEPPOL Symposium; San José, Costa Rica, 14-15 April 1993.	E
110	IOC-ICSU-CEC Regional Workshop for Member States of the Mediterranean - GODAR-IV (Global Oceanographic Data Archeology and Rescue Project) Foundation for International Studies, University of Malta, Valletta, Malta, 25-28 April 1995.	E

No.	Title	Languages
111	Chapman Conference on the Circulation of the Intra-Americas Sea; La Parguera, Puerto Rico, 22-26 January 1995.	E
112	IOC-IAEA-UNEP Group of Experts on Standards and Reference Materials (GESREM) Workshop; Miami, U.S.A., 7-8 December 1993.	E
113	IOC Regional Workshop on Marine Debris and Waste Management in the Gulf of Guinea; Lagos, Nigeria, 14-16 December 1994.	E
114	International Workshop on Integrated Coastal Zone Management (ICZM) Karachi, Pakistan; 10-14 October 1994.	E
115	IOC/GLOSS-IAPSO Workshop on Sea Level Variability and Southern Ocean Dynamics; Bordeaux, France, 31 January 1995.	E
116	IOC/WESTPAC International Scientific Symposium on Sustainability of Marine Environment: Review of the WESTPAC Programme, with Particular Reference to ICAM Bali, Indonesia, 22-26 November 1994.	E
117	Joint IOC-CIDA-Sida (SAREC) Workshop on the Benefits of Improved Relationships between International Development Agencies, the IOC and other Multilateral Intergovernmental Organizations in the Delivery of Ocean, Marine Affairs and Fisheries Programmes; Sidney B.C., Canada, 26-28 September 1995.	E
118	IOC-UNEP-NOAA-Sea Grant Fourth Caribbean Marine Debris Workshop; La Romana, Santo Domingo, 21-24 August 1995.	E
119	IOC Workshop on Ocean Colour Data Requirements and Utilization; Sydney B.C., Canada, 21-22 September 1995.	E
120	International Training Workshop on Integrated Coastal Management; Tampa, Florida, U.S.A., 15-17 July 1995.	E
121	Atelier régional sur la gestion intégrée des zones littorales (ICAM); Conakry, Guinée, 12-22 décembre 1995.	F
122	IOC-EU-BSH-NOAA-(WDC-A) International Workshop on Oceanographic Biological and Chemical Data Management Hamburg, Germany, 20-23 May 1996.	E
123	Second IOC Regional Science Planning Workshop on Harmful Algal Blooms in South America; Mar del Plata, Argentina, 30 October - 1 November 1995.	E, S
124	GLOBEC-IOC-SAHFOS-MBA Workshop on the Analysis of Time Series with Particular Reference to the Continuous Plankton Recorder Survey; Plymouth, U.K., 4-7 May 1993.	E
125	Atelier sous-régional de la COI sur les ressources marines vivantes du Golfe de Guinée ; Cotonou, Bénin, 1-4 juillet 1996.	F
126	IOC-UNEP-PERSGA-ACOPS-IUCN Workshop on Oceanographic Input to Integrated Coastal Zone Management in the Red Sea and Gulf of Aden Jeddah, Saudi Arabia, 8 October 1995.	E
127	IOC Regional Workshop for Member States of the Caribbean and South America GODAR-V (Global Oceanographic Data Archeology and Rescue Project); Cartagena de Indias, Colombia, 8-11 October 1996.	E only
128	Atelier IOC-Banque Mondiale-Sida/SAREC-ONE sur la Gestion Intégrée des Zones Côtières ; Nosy Bé, Madagascar, 14-18 octobre 1996.	E, F
129	Gas and Fluids in Marine Sediments, Amsterdam, the Netherlands; 27-29 January 1997.	E
130	Atelier régional de la COI sur l'océanographie côtière et la gestion de la zone côtière ; Moroni, RFI des Comores, 16-19 décembre 1996.	F
131	GOOS Coastal Module Planning Workshop; Miami, USA, 24-28 February 1997.	E
132	Third IOC-FANSA Workshop; Punta-Arenas, Chile, 28-30 July 1997	S/E
133	Joint IOC-CIESM Training Workshop on Sea-level Observations and Analysis for the Countries of the Mediterranean and Black Seas; Birkenhead, U.K., 16-27 June 1997.	E
134	IOC/WESTPAC-CCOP Workshop on Paleogeographic Mapping (Holocene Optimum); Shanghai, China, 27-29 May 1997.	E
135	Regional Workshop on Integrated Coastal Zone Management; Chabahar, Iran; February 1996.	E
136	IOC Regional Workshop for Member States of Western Africa (GODAR-VI); Accra, Ghana, 22-25 April 1997.	E
137	GOOS Planning Workshop for Living Marine Resources, Dartmouth, USA; 1-5 March 1996.	E
138	Gestión de Sistemas Oceanográficos del Pacífico Oriental; Concepción, Chile, 9-16 de abril de 1996.	S
139	Sistemas Oceanográficos del Atlántico Sudoccidental, Taller, TEMA; Furg, Rio Grande, Brasil, 3-11 de noviembre de 1997.	S
140	IOC Workshop on GOOS Capacity Building for the Mediterranean Region; Valletta, Malta, 26-29 November 1997.	E
141	IOC/WESTPAC Workshop on Co-operative Study in the Gulf of Thailand: A Science Plan; Bangkok, Thailand, 25-28 February 1997.	E
142	Pelagic Biogeography ICoPB II. Proceedings of the 2nd International Conference. Final Report of SCOR/IOC Working Group 93; Noordwijkerhout, The Netherlands, 9-14 July 1995.	E
143	Geosphere-biosphere coupling: Carbonate Mud Mounds and Cold Water Reefs; Gent, Belgium, 7-11 February 1998.	E
144	IOC-SOPAC Workshop Report on Pacific Regional Global Ocean Observing Systems; Suva, Fiji, 13-17 February 1998.	E
145	IOC-Black Sea Regional Committee Workshop: 'Black Sea Fluxes' Istanbul, Turkey, 10-12 June 1997	E
146	Living Marine Resources Panel Meeting, Paris, France, 23-25 March 1998	E
147	IOC-SOA International Training Workshop on the Intregration of Marine Sciences into the Process of Integrated Coastal Management, Dalian, China, 19-24 May 1997	E
148	IOC/WESTPAC International Scientific Symposium – Role of Ocean Sciences for Sustainable Development Okinawa, Japan, 2-7 February 1998	E
149	Workshops on Marine Debris & Waste Management in the Gulf of Guinea, 1995-97	E
150	First IOCARIBE-ANCA Worskshop Havana, Cuba, 29 June-1 July 1998	E
151	Taller Pluridisciplinario TEMA sobre Redes del Gran Caribe en Gestión Integrada de Áreas Costeras Cartagena de Indias, Colombia, 7-12 de septiembre de 1998	S
152	Workshop on Data for Sustainable Integrated Coastal Management (SICOM) Maputo, Mozambique, 18-22 July 1998	E
153	IOC/WESTPAC-Sida (SAREC) Workshop on Atmospheric Inputs of Pollutants to the Marine Environment Qingdao, China, 24-26 June 1998	E
154	IOC-Sida-Flanders-SFRI Workshop on Ocean Data Management in the IOCINCWIO Region (ODINEA project) Capetown, South Africa, 30 November-11 December 1998	E
155	Science of the Mediterranean Sea and its applications UNESCO, Paris 29-31 July 1997	E