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The Mediterranean Forecasting System Science Plan

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Cover picture

Large image: "A water perspective of Europe", courtesy of Swedish Meteorological and Hydrological Institute. The white lines show the watershed boundaries between the different catchment areas flowing into the regional seas of Europe.

Inset image: Height of the sea surface in the north Atlantic and Arctic simulated by the OCCAM global ocean model, courtesy of David Webb, James Rennell Division, Southampton Oceanography Centre.

Mediterranean Forecasting System Pilot Project

EU-MAST Project

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September 1998 - March 2001

IMGA-CNR

Numerical Laboratory

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12.	Requirements Survey analysis	ISBN 0-904175-36-7
13.	The EuroGOOS Technology Plan Working Group Report	ISBN 0-904175-37-5

Contents

Preface

In 1995 the EuroGOOS Scientific Steering Group (EuroGOOS, 1996) decided to start a Mediterranean Test Case Task Team (EMTT) in order to elaborate the overall strategy for scientific research toward operational oceanography in the Mediterranean Sea.

The EMTT is composed of representatives from about 60 laboratories in Europe and the developing countries around the Mediterranean basin. The members of the EMTT Scientific Steering Committee are listed in section 7 of this document. The EMTT held three meetings during 1996 to establish the scientific and strategic planning of the EuroGOOS Mediterranean Regional Test Case, hereafter called the Mediterranean Forecasting System or MFS. This document explain the science plan for MFS which considers ten years of scientific research and capacity building activities toward operational oceanography in the Mediterranean area.

The first phase of implementation of MFS will start in September 1998 with the MFS Pilot Project, funded by the MAST Program of the European Union. The partners, associate partners and subcontractors of the MFS Pilot Project are listed in the Annex.

We would like to thank the EuroGOOS Science and Technology advisory Groups for support and assistance in preparing this science plan. Ms. E. Masetti of IMGA-CNR, Italy, and Ms. S. Marine of the EuroGOOS Office are acknowledged for skilful editorial help.

Executive Summary

The Mediterranean Forecasting System (MFS) science plan is based upon a major overall goal: " To explore, model and quantify the potential predictability of the marine ecosystem variability at the level of primary producers from the overall basin scale to the coastal/shelf areas for the time scales of weeks to months through the development and implementation of automatic monitoring and a nowcasting-forecasting modelling system". Specifically, the MFS overall pre-operational goal is: "... to show the feasibility of a Mediterranean basin operational system for predictions of currents and biochemical parameters in the overall basin and coastal/shelf areas and to develop interfaces to user communities for dissemination of forecast results".

The user community interested in Mediterranean Sea forecasting is clearly connected to the exploitation of coastal marine resources, protection of life and health, and the safeguarding of the local environment in addition to long term atmospheric forecasting and climate impact studies.

The MFS has established the strategy that will make possible the forecast of marine parameters in the coastal areas of the Mediterranean Sea. The rationale is that coastal-shelf areas around the basin are narrow and shelf breaks very steep so that the observational network and the modelling system should consider a hierarchy of nested observational monitoring systems and numerical models. In other words the general circulation flow field and its associated transport of chemical and biological parameters is a local source/sink process of paramount importance for the coastal areas, comparable to the terrestrial inputs and to the locally determined flow field structure.

The plan for technological and scientific development of the different components of the MFS is synthesised as follows:

1. Construction of a prototype permanent monitoring system for the physical-biochemical components of the ecosystem in the Mediterranean Sea at adequate space-time resolution for model initialisation and forecast;

2. Construction of a basin-wide ocean General Circulation nowcast/forecast Model and associated data assimilation techniques, for the physical components of the Mediterranean Sea ecosystem, capable of predicting the currents on the time scales of few weeks to several months, together with nested regional/coastal/shelf models;

3. Construction of a coupled atmosphere-ocean regional model over the Mediterranean area. Techniques for coupling with extended range atmospheric simulations will be assessed;

4. Construction of coupled biochemical-physical models capable of predicting the nutrients and phytoplankton biomass variability in the marine ecosystems of different coastal areas.

These developments should be implemented in three strategic phases, occurring on a total time range of 10 years.

The MFS first phase has started its activities with the launch of a Pilot Project funded by the European Union-MAST program. Extracts from the planning and working documents prepared for the Mediterranean Forecasting System Pilot Project are presented in the last section of this document.

In late 1997 the Mediterranean component of the Global Ocean Observing System (GOOS) was formed and recognised by the Intergovernmental Oceanographic Commission (IOC). The Mediterranean Forecasting System created by EuroGOOS and including participation from many non-European countries will be treated as a contribution to the authorities of MedGOOS as and when appropriate.

Introduction

What is ocean forecasting?

The goal of an ocean operational forecasting system is to produce **predictions of the 3-D physical sea state and related marine biochemical components** for a certain time period. In order to produce such predictions, the system should include, systematically, an observational network with real time data acquisition capabilities and analysis systems, numerical models and data assimilation procedures.

Ocean forecasts are useful as a component of any modern management of coastal marine resources in view of the anthropogenic stress put on these areas, the problems connected to the health of the sea and the safety and efficiency of marine industries. The scientific community will greatly benefit from the forecasting activities that can provide a co-ordinated and continuous data set of marine parameters to describe the ocean variability at unprecedented space-time resolution.

In the past five years, EuroGOOS (European Global Ocean Observing System, EuroGOOS, 1996) started to collaborate with and maximise the benefits from existing activities in operational oceanography and has helped to advance European operational oceanography in GOOS. Furthermore, it has promoted communications within the scientific community on the issues of ocean forecasting. Thus it has become possible to start investigations aimed at the implementation, calibration and validation of regional forecasting system test cases.

The present science and strategic plan defines the EuroGOOS Mediterranean Test Case (Pinardi et al., 1997) technological and scientific research goals together with a strategic plan. The aim is to define the steps which, in the next ten years, could give rise to an ocean forecasting system for the entire Mediterranean Sea region and its coastal areas.

Scientific background

Oceanographic forecasting for waves and currents in different regions of the world ocean started in the mid-eighties. Progress has been rapid and several systems have been put in place, especially for the wave component. Observational requirements for global ocean forecasting activities are very demanding so that in the past the development of ocean forecasting systems has mainly occurred for limited regions. Up to now, the existing examples of ocean forecasting systems have been mainly a proof-of-concept exercise.

Forecasting had its early successes in meteorology and is being continuously developed in operational weather forecasting centres. The daily to weekly forecast skill has increased steadily from the seventies (see Fig. 1). The reasons for the increased skill are: 1) the increased availability of high quality and good coverage data sets; 2) the development of more accurate schemes of numerical modelling and data assimilation (e.g., increased resolution of the models and multivariate assimilation techniques); 3) the advancement in understanding of some of the key processes which drive the atmospheric general circulation. Atmospheric weather forecasts can be now usefully accurate for up to a week - 10 days. More recently seasonal coupled ocean-atmosphere forecasts have shown skill on the range of 13 months or longer for the sea surface temperatures in the Tropical Pacific (Fig. 2) where ENSO occur (El Ninõ-Southern Oscillation phenomenon, Philander, 1990). This enhancement in predictability is connected to the tight coupling between atmosphere and ocean in the tropics. In this case it has been proved that the ocean initial condition for the seasonal forecast is of crucial importance for the forecast skill and thus an observational network (McPhaden, 1995) and data assimilation techniques have been developed for ocean models (Derber and Rosati, 1989, Anderson et al., 1996) in order to initialise the coupled models with more accurate ocean initial conditions (Latif et al., 1993).

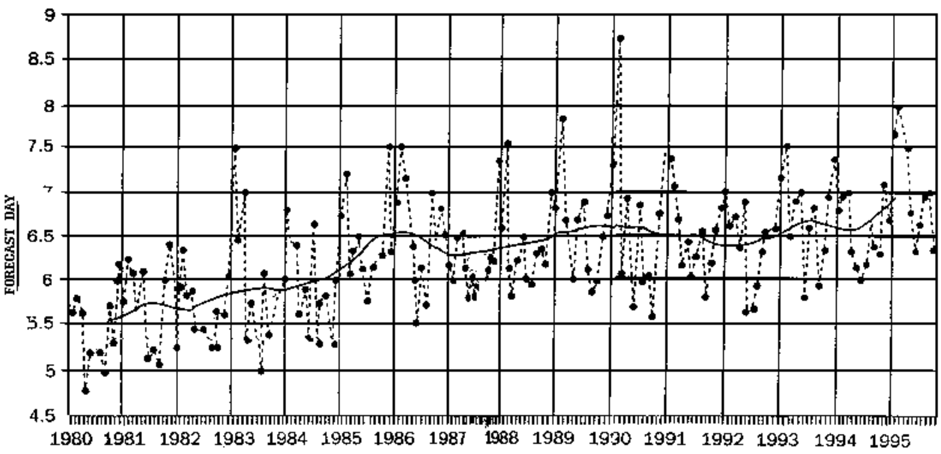


Figure 1: *Here we represent, as a function of the past 17 years, an index which is a measure of how many days a forecast can give "useful" information. The dashed line indicate monthly values and the continuous one the average value as a function of ECMWF years of forecast activities (courtesy of ECMWF).*

An Ocean Prediction System for deep oceanic waters adjacent to coastal areas is challenging with respect to the meteorological case because: a) the required modelling resolution is high (5-10 km) and it is necessary to consider narrow and topographic "steep" areas, such as shelves and shelf breaks; b) a number of user community needs require the implementation of ecologically based models which are extremely sensitive to details and accuracy in physical forcing description.

Nevertheless, ocean forecasting of some physical variables started as soon as numerical ocean modelling reached sufficient maturity at the beginning of the eighties. In the oceanographic community, different ocean forecasting systems have been developed depending on which marine state variable had to be predicted. Sea level and wave forecasting started first due to the obvious user demand for monitoring of coastal flooding and ship routeing.

Nowadays wave forecasting is operational for the world ocean (Komen et al., 1994). Both sea level and wave forecasts depend crucially on external forcing, such as surface wave information, tides and surface atmospheric winds, parameters which have been available for some time and the measurement accuracy of which has been increasing from the middle eighties. Several regional sea level and wave forecasting models exist for limited regions of the oceans such as the Baltic and North Sea. These models assumed that connection with the remaining parts of the ocean (deep and stratified) were less important than local wind effects and tidal forcing in the region. While this can be true for the Northern European shelf areas, it is not true for the remaining parts of the north-eastern Atlantic, the Mediterranean and other regions of the global ocean where deep ocean effects drive part of the sea level variability. The forecasting systems associated with both sea level and waves do not normally use data assimilation strategies in view of the fact that in those systems initial conditions play a minor role compared to external forcing.

Development of ocean current forecasting has progressed more slowly than for the sea level and waves because of the lack of routine and accurate measurements needed to initialise the models. Predictions of currents raise problems similar to those found in atmospheric weather forecasting since the predictability time scale of the system is practically set by the accuracy with which the initial condition is known. Therefore deep ocean and coastal current forecasts are at the stage of research exercises though some systems under development could soon start to become operational.

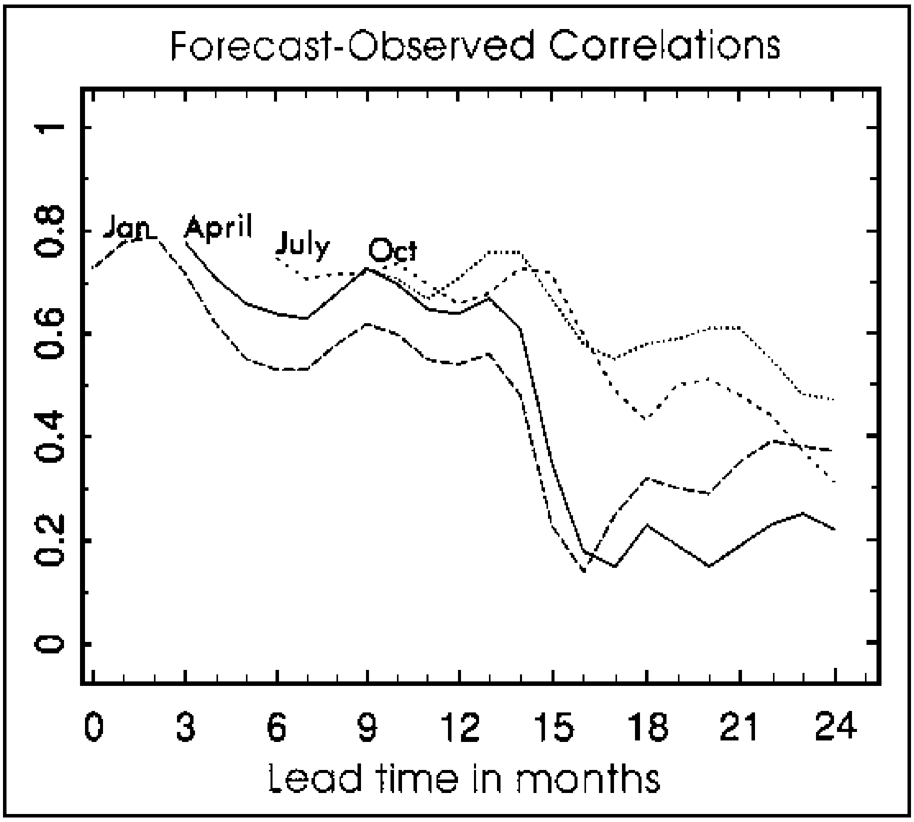


Figure 2: *Time dependence of the skill of ENSO forecasts measured by the correlation between observed and predicted sea surface temperature fields over the tropical Pacific Ocean. The curves represent forecasts commencing in January, April, July and October of the first year of a 2-year period (Cane, personal communication).*

The ocean current forecasting community grew up in the eighties mainly to forecast on the mesoscale (i.e., the "weather" of the ocean) for the North Atlantic Gulf Stream area. The problem here, as in atmospheric weather forecasting, is the acquisition of accurate initial conditions and thus the work has been largely limited to regions of the world ocean where such acquisition was possible by the scientific community itself. The most recent advances in this field consist of the development of original data treatment procedures to retrieve relevant information for assimilation in three dimensional hydrodynamic models (Lai et al., 1994). A real time shipboard forecasting system has also been developed (Fig. 3) (Robinson, 1994).

This system has proven to be capable of forecasting the mesoscales in the time frame of few days and weeks. An intermediate regional modelling approach has been taken for the Eastern North Atlantic where a primitive equation ocean model is forced by atmospheric analyses to produce nowcasts of SST and forecasts of water level in the coastal areas (Ezer et al., 1992) for few days in advance.

The economic and social importance of ENSO predictions generated the first global ocean assimilation system (Derber and Rosati et al., 1989), developments in the assimilation of satellite derived sea surface topography (Ezer and Mellor, 1994, Fukumori and Melanotte-Rizzoli, 1995) and intercomparison studies between *in situ* and satellite sea level assimilation (Carton et al., 1996). Forecasting at the global ocean scale is now under development at the NCEP (National Center for Environmental Predictions, Washington, DC, US), UK Meteorological Office and ECMWF, with fully coupled ocean and atmosphere models for the seasonal time scales.

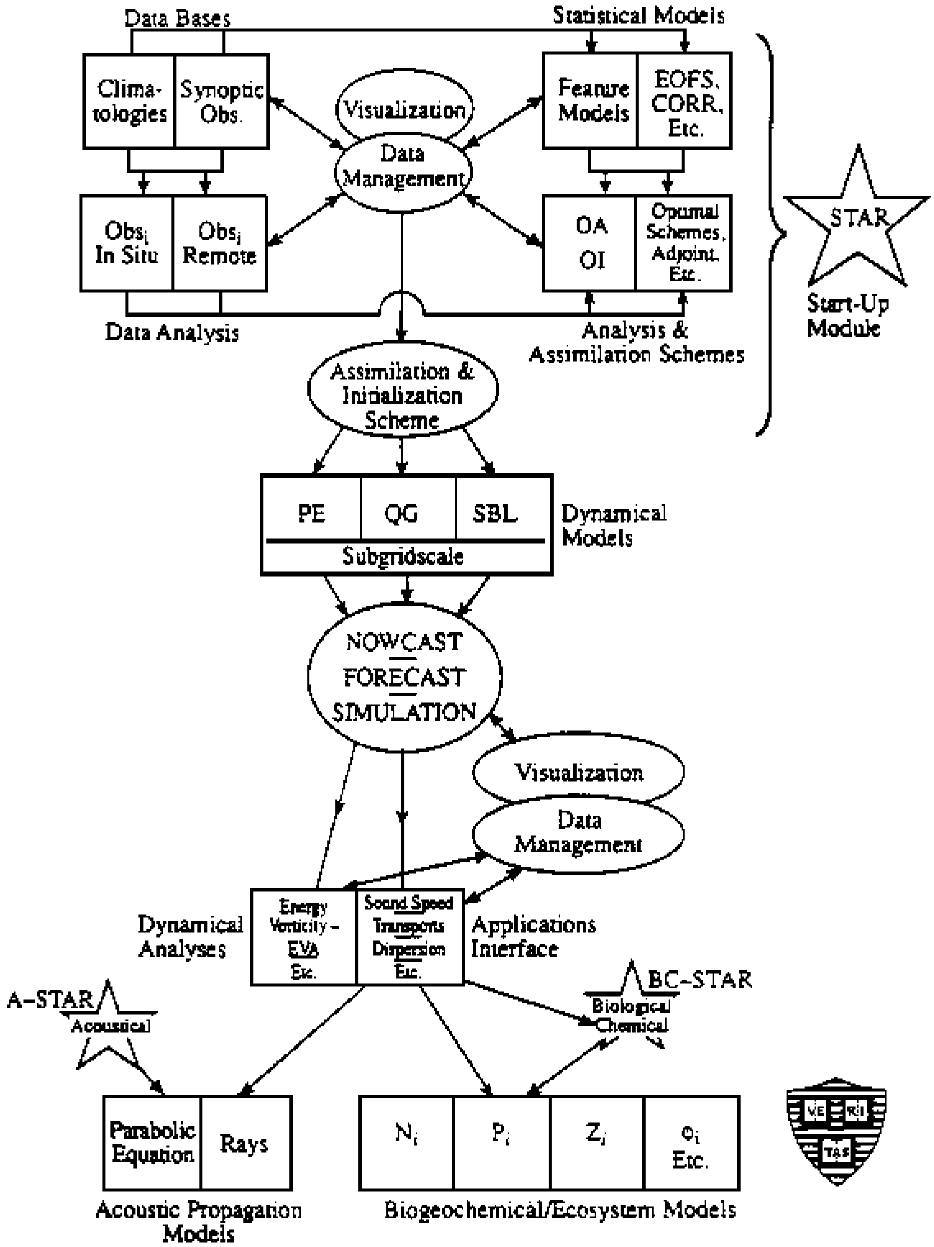


Figure 3: *Schematic of HOPS, the Harvard Ocean Prediction System.*

Ecosystem numerical models, e.g., biogeochemical process models coupled to three dimensional hydrodynamic models, are now capable of predicting the seasonal nutrient cycling in the water column with reasonable skill and they can also estimate levels of primary productivity of the open and coastal sea areas. During the eighties both "aggregated" biochemical models and detailed multicomponent models were developed for the pelagic subsystem. Simulation experiments have shown the tight coupling of primary production to the upper mixed layer evolution and several models have shown skill in capturing the primary production seasonal cycle in major ocean basins (Fasham, 1995, Sarmiento et al., 1993). Validation and calibration of complex ecological models has started only recently, especially for the North Sea and the ERSEM model (European Regional Seas Ecosystem Model, Baretta et al., 1995, see Fig. 4a). Future developments

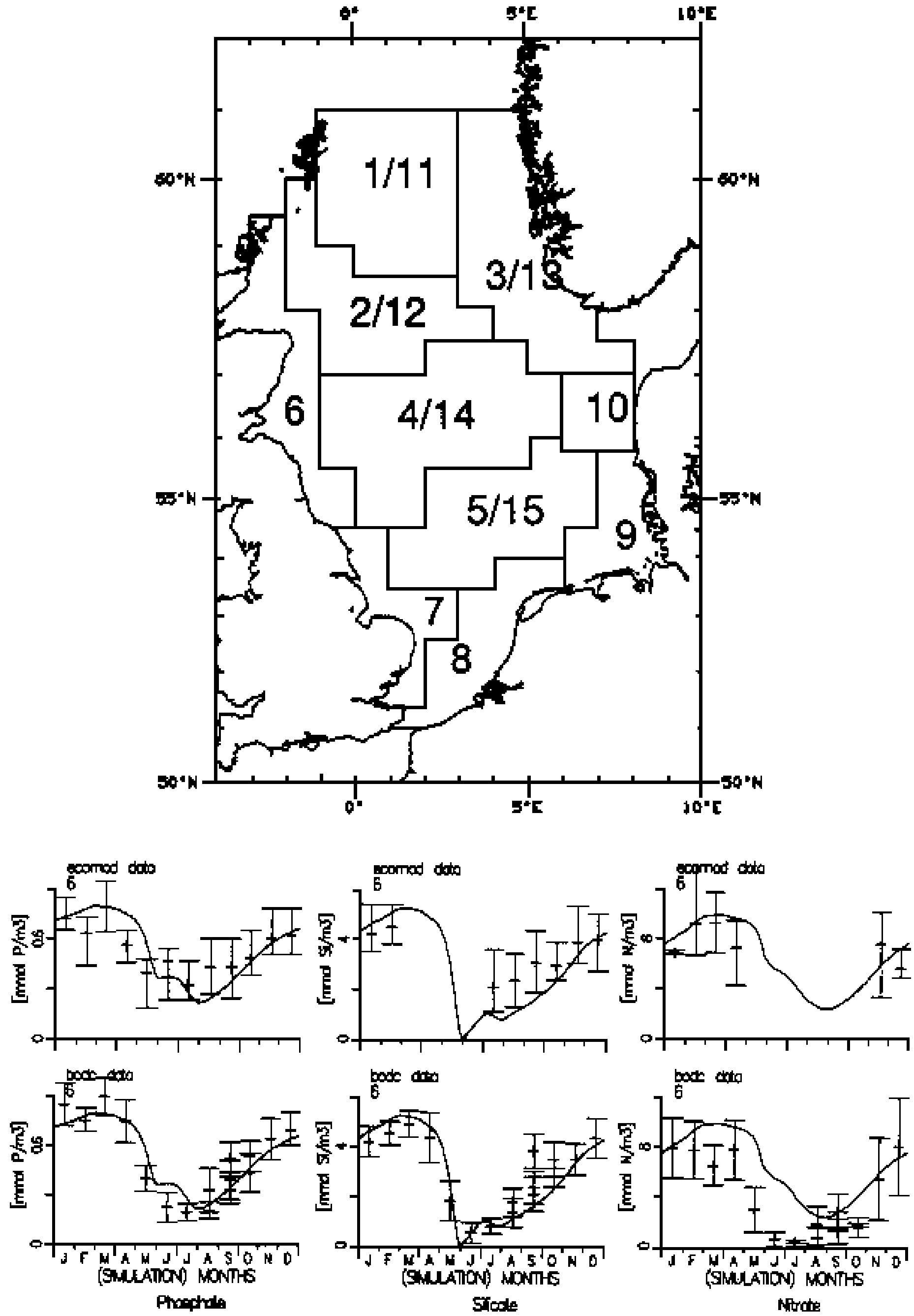
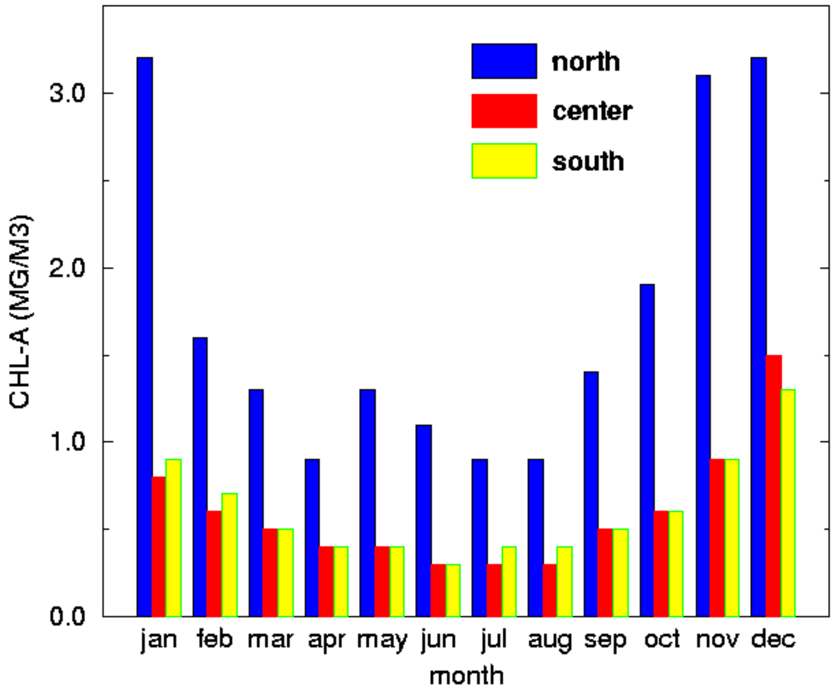


Figure 4a: *ERSEM box structure. The deep boxes are divided into two layers, the top 30m labelled as boxes 1 to 5 whilst the deep boxes are labelled 11 to 15. Field data for box 6 from the ECMOD dataset (upper panel) and the BODC data set (lower panel) compared to model simulations for phosphate, silicate and nitrate. (From Baretta et al., 1995)*

concern the representation of secondary production with a particular attention for mesozooplankton and higher trophic levels (GLOBEC, 1997). An advanced version of ERSEM coupled to a one dimensional mixing model (Allen et al., 1998) and to a fully three dimensional model of the Adriatic Sea has been recently set up (Zavatarelli et al., 1998) and the simulated primary productivity levels are being compared with data (Fig. 4b).



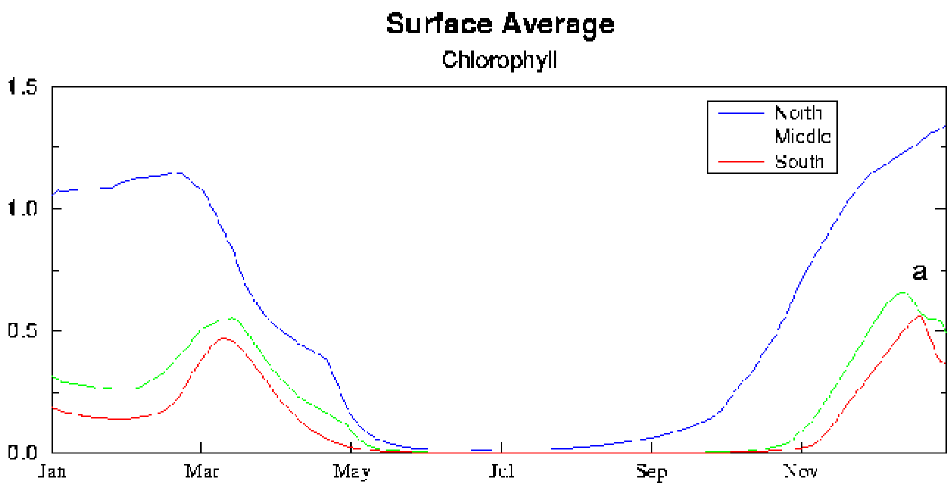


Figure 4b: Adriatic Sea ecosystem model simulation of the chlorophyll seasonal cycle. The upper panel shows the surface chlorophyll in the Northern, Central and Southern Adriatic as function of months from CZCS colour scanner satellite sensor. The lower panel show the surface Chlorophyll from a model simulation averaged over the same three regions.(from Zavatarelli et al., 1998)

Overall the prediction skill for waves and sea level is linked to the predictability time scale of the surface winds which is up to one week at middle latitudes. The predictability time scale for the three dimensional temperature field at middle latitudes is again of the order of few weeks limited by the errors in the initialisation field and the intrinsic nonlinearity of the system. Predictability time scales of several months for Sea Surface Temperature (SST) have been discovered in the Pacific tropical areas together with some of the atmospheric parameters (see fig. 5 by Moron et al., 1998). The potential for long range (several months to years) predictions

at mid-latitudes has not been fully investigated yet, either in the atmosphere or oceans. Furthermore, the computational requirements of fully coupled ocean atmosphere forecasting systems are still very high and the results are difficult to downscale to the coastal areas. The predictability of the ecological system, both in the open ocean and in the coastal/shelf areas, has still to be assessed. However, simulations of seasonal primary production show relevant skill at these time scales.

It is timely therefore to design ocean forecasting systems capable of ascertaining the potential of predictions at short and medium range time scales, e.g., from a week to few months, for the interesting marine parameters, from the open ocean to the coastal areas. The Mediterranean offers the opportunity for such a system to be built and to be an example for other parts of the world ocean.

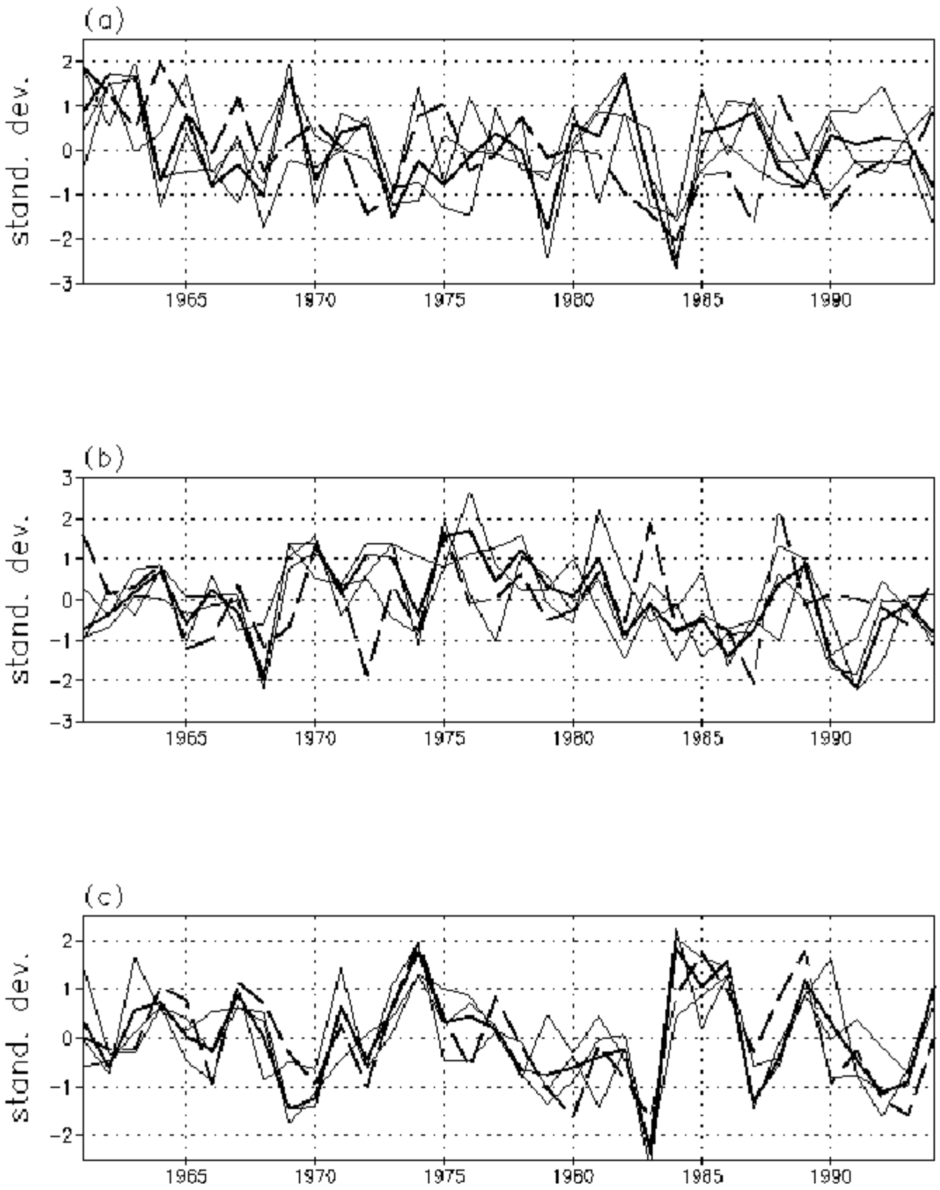


Figure 5 *Standardised rainfall anomaly indices for (a) Sahel, (b) India and (c) Nordeste. Thin solid lines show the three GCM simulations, thick solid is the ensemble mean of GCM, thick dashed is the observed. Since lines are very close we can say that potential predictability of rainfall is high. From Moron et al. (1998)*

Table 1: ^= variable relevant to topic or issue < = variable that can be af

VARIABLES	VARIABLES	ENVIRONMENTAL PROTECTION ISSUES					
				Ecosystem health - Biodiversity			
		Coral reef Ecosystems	Wetlands incl. Mangroves	Spawning & Nursery Areas	Macrophyte Communities	Habitat change Change	Genetic Change
Wind field							
Wave height		<^		^?	^?	^?	
Wave period				^?	^?	^?	
Sea level		^	^	^	^	^	
Wet precip.							
Dry precip.							
Reflectance		^					
PAR					^		
Sea ice							
Coastline change			^			^	
Depth correlated	Salinity	^	^	^	^	^	
	Temperature	^	^	^	^	^	
	Current speed		^		^	^	
	Curr. Direction		^		^	^	
	Diss. Oxygen	^				^	^
	PH						
	Nitrate			^	^	^	
	Phosphate			^	^	^	
	Silicate					^	
	pCO2, alkalinity						
	Susp. sed. conc.	^		^	^	^	
	Susp. sed. comp.					^	
Biomass	Phytopl. density	^			<^	^	
	Phytopl. prod'n	^					
	Phytopl. comp.						
	Zoopl. number			^		^	
	Zoopl. species			^		^	
	Nuisance spec.			^			
Bottom							
Sedimentary	Character				^	^	
	composition				^	^	
Benthic Comm.	Species	^					
	Numbers	^					
bathymetry							
[CONTAMINANTS]		^	^	^		^	^

Technological background

In 1997 the Global Ocean Observing System (GOOS) Committee (GOOS Coastal Workshop) prepared a set of tables (GOOS, 1997) which list the variables that are needed in the coastal zone for different purposes. Our Table 1 is a reproduction of some of the variables listed in GOOS (1997).

Some of the variables listed in Table 1 are already recorded automatically (surface measurements in general) and are transmitted through the Global Teleconnection System (GTS) to the meteorological centres.

Technology for continuous-automatic monitoring of the variables listed in Table 1 has been only partially developed. In Table 2 we show the consolidated technology for some of the variables.

Most of the instruments listed in Table 2 have been developed following the needs of the forecasting/modelling community. For example, sea level and wave forecasting in the ocean has prompted the development and the usage of *in situ* moored stations to monitor the surface sea state regimes in open ocean and near coastal areas. Several of these stations have been now located in crucial monitoring areas of the European shelves (Miendl, 1996, Golmen, 1997).

Table 2: Proven technologies for continuous/automatic and *in situ* measurements and for routine monitoring

Variable	Instrument/System/platform (Satellite/Buoy)
Sea level / tides	Tide gauges (pressure and acoustic), seabed echosounder (inverted echosounder) satellite altimeter
Meteorological variables, e.g.: air temperature, atmospheric pressure, humidity, wind velocity and direction, solar radiation	Land-based observation and data collection, platforms, buoys and observation towers with telemetry using VHF, HF and Satellites, shipborne deck/bridge observations
Extent of sea ice	Synthetic Aperture Radar (SAR) Self Scanning Microwave Instrument (SSMI) and shore based radar
Photosynthetically available radiation	*In situ* sensors
Wave period, height	Wave rider buoys with telemetry, satellite based SAR, altimeter
Wave direction, frequency, spectra	Shore-based radar, wave directional buoys with telemetry
Sea Surface Temperature	*In situ* sensors, satellite radiometers, drifting buoys
Vertical profile of temperature	XBT
Vertical profile of salinity and temperature	CTD, XCTD
Surface currents	Shore-based high frequency radars (e.g., OSCR, CODAR) wind-sea coupled models, ADCP, moored and drifting buoys
Vertical profile of currents	ADCP, current meters
Salinity	*In situ* sensors, discrete samplers
Dissolved oxygen	*In situ* sensors, discrete samplers
Ocean colour (surface chlorophyll)	Ocean scanner
Turbidity and suspended sediments	*In situ* sensors, bottom mounted acoustic instruments, satellite optical sensors, moored buoys
Reflectance (oil spill detection)	Satellite based radiometers
Precipitation	Radar

With few exceptions, the need for forecasting of ocean currents has not yet prompted new technological developments and the setting up of automatic data acquisition networks. A first exception to this rule is given by the military community which has developed in the past 20 years automatic profiling systems for open ocean mesoscale forecast activities. Another exception is the implementation of a Tropical Atmosphere Ocean (TAO) automatic moored set of sensors for ENSO forecasting which will be described later (McPhaden, 1995).

Even though widespread, frequent, accurate and timely *in situ* observations of marine properties such as temperature, salinity, currents, oxygen, turbidity, underwater light, nutrients, phytoplankton and zooplankton are crucial to the understanding and prediction of coastal areas biomass fluctuations and thus sea health, very little effort has been made in the past to start monitoring programs with accurate measurements in the water column for all these variables. Any forecasting system must however be based upon a reliable observing system where data can be collected and disseminated in real time or with very small time delay.

The Voluntary Observing Ship (VOS) or ship of opportunity programmes (Rossby et al., 1995) for the global ocean have offered routine meteorological and surface parameters for decades and an example of coverage is shown in Fig. 6. Subsurface temperature profiles are obtained by means of expendable bathythermographs (XBT) on board commercial vessels. The coverage is shown in Fig. 7. However, it is also necessary to expand the VOS base to commercial lines, including container ships and ferry routes, especially for the Mediterranean.

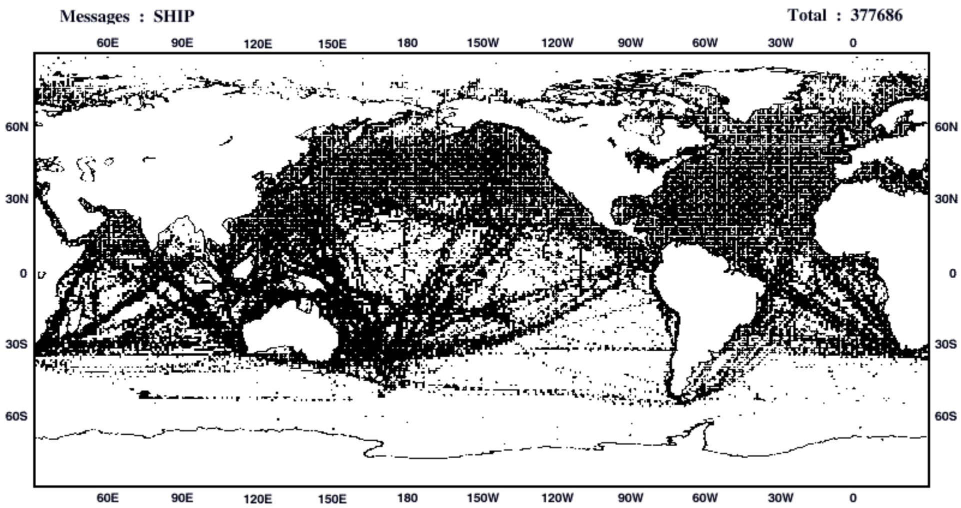


Figure 6: *Regional coverage of meteorological observations from merchant vessels, July 1993-September 1993 (Rossby et al., 1995)*

EuroGOOS has started a working group on a Volunteer Observing Ferries (VOF) for European seas and first results indicate that 13 parameters (Photosynthetic Available Radiation, sea water temperature profile, conductivity/salinity profile, geographical position, time, ship's heading, turbidity, transmissivity, fluorescence, optical properties, phosphates and nitrates) could theoretically be measured at the surface and along several ferry routes. Several ferries already carry instrument packages measuring a subset of these variables. Both for VOS and VOF the data acquisition systems need to be further developed, in the first case to add multisensor measurements and to optimise measurements strategies, and for the latter to develop sensors that can measure subsurface profiles. Telecommunication of these wider data in near real-time should be encouraged and community distribution of these data organised.

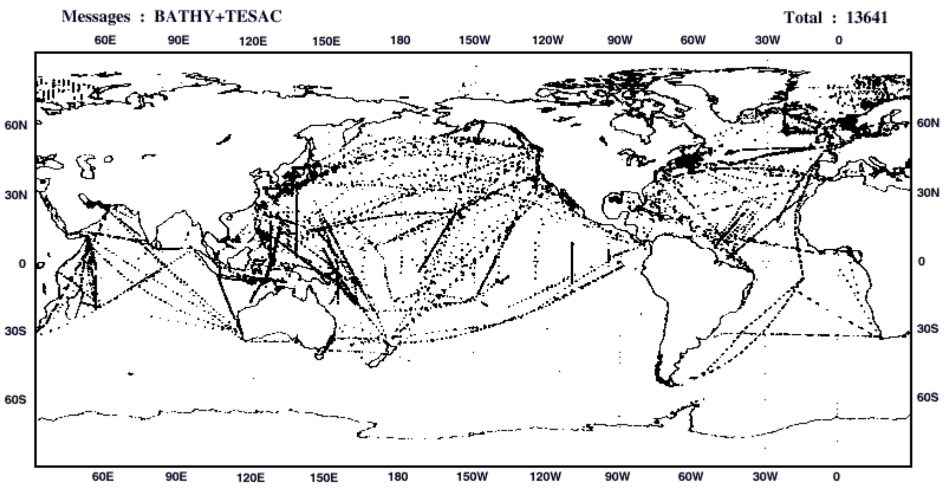


Figure 7*: Regional coverage of XBT and TESAC (temperature and salinity at the surface) messages from volunteer observing ships, July 1993-September 1993 (IOC/WMO 1993)*

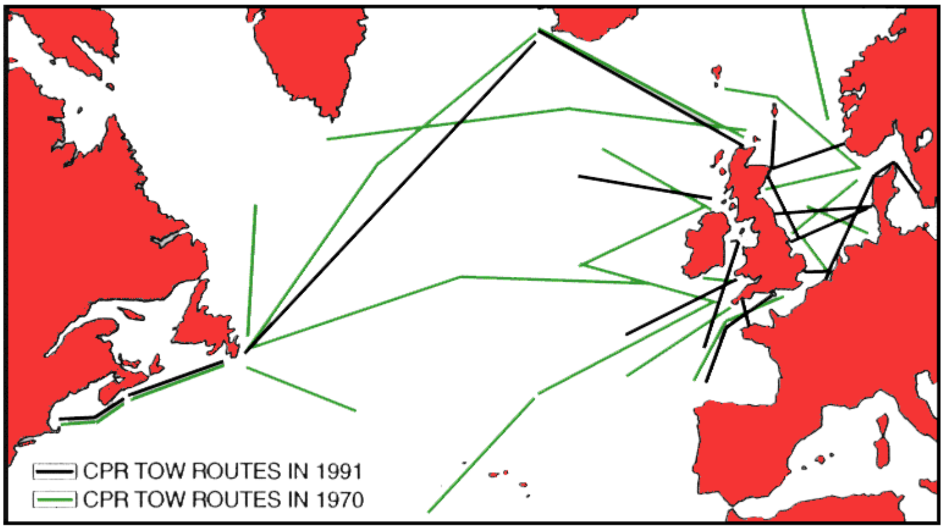
The Tropical Atmosphere Ocean (TAO) moored array developed to study and predict the ENSO phenomenon in the tropical Pacific (McPhaden, 1995) is an important open ocean global *in situ* meteorological and water column monitoring system developed since 1985. This array monitors air-sea interface parameters and subsurface temperature and current parameters at selected locations and chosen resolution along and on either side of the equator in the Pacific area. It is found in fact that such a network is essential to initialise OGCM of the Pacific and that real time data transmission and maintenance is possible without substantial loss of data continuity for several years.

The monitoring of the Sea Surface Temperature (SST) and the surface ocean currents are nowadays partially realised by remote sensing instruments, such as advanced infrared radiometers and radar altimeters. The reconstruction of SST at 9-18 km resolution for the global ocean is done from AVHRR by the Pathfinder Program (Smith et al., 1996) and analyses of SST are produced routinely but not in real time at several meteorological forecasting centres. Time resolution is about a week and the accuracy of the SST reconstruction can be as good as 0.5ºC (Reynolds, 1988). For the altimetry, which gives the sea surface height anomaly with respect to an unknown mean value, the Topex/Poseidon accuracy is now a few centimetres which makes this information useful for the Mediterranean area, where the signal is only few tens of centimetres. It has been proved that surface mesoscale signal can be reconstructed from the combined use of Topex/Poseidon and ERS-1 data (Ayoub et al., 1998) and that the large scale general circulation can be reconstructed from Topex/ Poseidon (Stammer and Wunsch, 1996) even with large geoid errors. These two remotely sensed data sets form an important basis for an observational network for operational oceanography but it is evident that they need to be complemented by subsurface measurements offered by the conventional moored stations, and the VOS or VOF or other *in situ* measurement techniques. Furthermore several questions related to almost real time analysis of sea surface topography need to be addressed before such measurements can be used in operational ocean forecasting systems.

Other promising techniques for operational ocean monitoring are drifting buoys or floats and tomographic arrays. The former have been developed for surface (surface drifters) and subsurface (SOFAR or RAFOS floats) but they have never been used in operational monitoring systems. Except for surface drifting buoys which measure surface meteorological parameters (e.g., Golmen, 1997) all the other instruments have more or less been used in proof-of-concept experiments (trying to interpret the particle trajectory with more or less theoretical models) and only very few of these data sets have been assimilated into numerical ocean models (Carter, 1992). Long range acoustic transmissions can monitor the internal state of the ocean over tens and hundreds of kilometres. Basin-wide integrals or mesoscale information can be extracted about the heat content, stratification, or flows. The feasibility of a basin-wide transmissions in the Mediterranean Sea has been demonstrated during a nine month long tomography experiment in 1994. Strait throughflow observations with cross-strait acoustic transmissions have just been tested in the Gibraltar Strait. All of these could be conducted with shore-cabled instruments and would thus ideally be suited for a real time monitoring system. In addition to all these measurements, ship-mounted Acoustic Doppler Current Profilers (ADCPs) have been proved to give a three dimensional view of the ocean currents but work is required in order to see if it will be possible to insert them in a VOS system.

Sensors for continuous monitoring of the upper ocean biochemical variables have been developed in the past twenty years especially with ship towed instruments. These sensors have the capability of measuring the temperature, conductivity, primary production levels, and components of the zooplankton biomass. The towing can be done at fixed depth, such as in the case of Continuous Plankton Recorder (CPR), or with undulating instruments in the upper hundred meters of the water column. These instruments can be equipped with multi-spectral irradiance sensors and dissolved nutrient analysers. The CPR routes already exist for VOS (fig. 8) but the collected samples are usually analysed with long delay time.

More modern sensors, usually available on the undulating packaged instruments, have not been tried yet on VOS. Overall technological development of biochemical sensors can potentially be done for a variety of measuring strategies such as depicted in Fig. 9. There is a need however for parameter and measurement strategy to be checked against usage to initialise, validate or tune a numerical model of the ecosystem more than has been done in the past.



Continuous Plankton Recorder tow routes in the north Atlantic and North Sea.

Figure 8

Why the Mediterranean Sea?

In "The Strategy for EuroGOOS" (EuroGOOS, 1996) we read:

".. Forecasts of the state of coastal Seas and oceans for days to decades into the future will add several percent to the revenue of all maritime industry...The full benefits of operational oceanography are only obtained when observations and modelling are integrated at scales from global, to regional, to local...The European sea areas of especial interest are the marginal and semi-enclosed seas, Baltic, North West European shelf seas, the Mediterranean, etc..."

The Mediterranean Sea coastal area is one of the most heavily populated regions of the world ocean and a large part of the coastal nations' Gross National Products (GNP's) are produced through fishing, transportation, recreation and other industries depending on a healthy coastal environment (Jeftic et al. 1992 and 1996). It is a strategic area for Europe, bordered by many North African countries and opening eastward to the Black Sea. Shipping in this Sea is a backbone for the international commerce and trading. The management of this area, which consists of a semi-enclosed Sea, with complex social structures and cultural heritage, is a challenge and a need for the world. The MFS is concerned with a sector of the marine environmental predictions in the Mediterranean related to four major scientific and technological problems:

1) The first is the prediction of the Mediterranean Sea water cycle and water resources. This problem is urgent since most bordering countries are adjacent to desert areas and others live constantly with limited summer water availability. The long term (seasonal) accurate prediction of precipitation, river run-off, evaporation from the sea, is an outstanding scientific problem which needs to be addressed and needs an ocean forecasting component. It has been shown in fact that sea surface temperature in the Eastern Mediterranean is correlated with Sahel rainfall (Ward M. N., 1993) and that cyclonic activity in the basin can be connected to sea surface temperature signals.

2) Coastal algae biomass fluctuations can affect the recreation industry, can favour anoxic conditions and related marine ecosystem health problems and can cause damage to fisheries in extreme events. This problem is largely connected to eutrophication of the coastal areas and anthropogenic inputs through rivers play a major role, but remote effects, due to hydrodynamics, can be of comparable importance (MTP-I, 1996). Due to the particular structure of the ecosystem in the Mediterranean and its shelf areas, the coastal regimes are intrinsically connected to the large scale ecosystem structure. In order to sustain healthy coasts and predict responses of the coastal ecosystem to human activities in the Mediterranean area one has to consider the interconnections of the shelf areas with remote parts of the basin.

3) Fish resources are of great importance for the Mediterranean economy and fisheries are affected by all the environmental problems listed above. Being at the end of the marine trophic chain and being affected by climate change phenomena (Bombace, 1992) it is a very sensitive sector of the marine research which needs to be analysed in the context of marine environmental predictions from the open ocean to the coastal areas.

4) Oil exploration and commerce activities are an important industrial and pollution problem also in the Mediterranean Sea as well as in other parts of the world ocean. Environmental predictions, from the large scale surface and deep currents structure to the different biotic components of the marine ecosystem are needed in order to control and monitor emergency events and oil pollution.

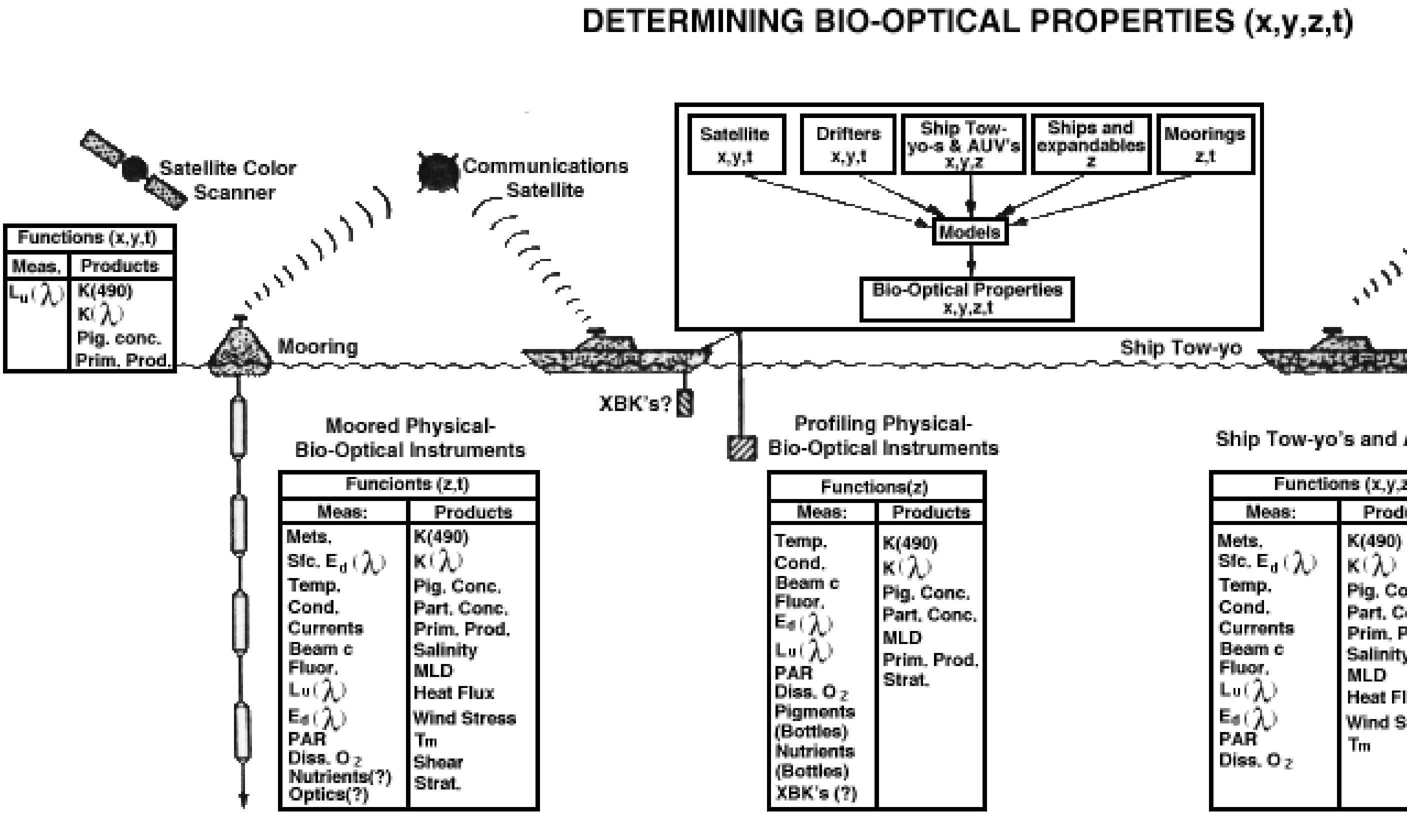


Figure 9: *A schematic illustrating a methodology for determining the variability of bio-optical properties in space an as well as in situ data sets along with appropriate models. Applications could include determinations of the subs particulate carbon fluxes, and the penetrative component of solar radiation (after Dickey et al. 1995).*

Identification of the user community

The societal impact of MFS will be felt in many sectors, from the civil engineering community, offshore oil and gas and ship operations to the managers of coastal marine resources and political authorities. For the Mediterranean in particular the user community includes:

1. coastal environmental authorities advising the management of the coastal area and its living resources. Any specific or local water quality control system should use the information coming from the MFS outputs;
2. local political, regulatory, and enforcement authorities in order to handle emergencies occurring in territorial waters. The continuous monitoring and availability of nowcasts or analyses of the 3-D state of the sea and its associated biochemical parameters would provide important inputs for decisions taken to handle emergency events (oil discharge, extreme eutrophication phenomena, sea health and pollutant dispersal and monitoring, etc.);
3. the tourist and maritime transport industries along the coastal areas of the Mediterranean and associated insurance companies;
4. the marine aquaculture community which is developing rapidly around the Mediterranean Sea and especially some of the coastal regions;
5. the meteorological agencies producing short, medium and long range predictions over the Mediterranean area;
6. the Mediterranean climate change community which needs a continuous long lasting observational network for climate scenario studies;
7. manufacturers of marine sensors involved in the monitoring of the basin, new community of forecast products disseminators, technical staff for routine MFS operations.
8. Offshore oil and gas operations, pipelaying, and cable laying operations.

Benefits

At national and European level there is a strong public demand for improved management of water quality in the sea. Politically this demand is expressed through legislation, regulations and European directives, and through the creation of new environmental services and agencies, all of which provide a strong customer group for ocean forecasting activities.

There is a global and European commitment to climate prediction which requires ocean forecasting. This has been expressed via a series of important international meetings, agreements and conventions relating to marine resources, management of the sea, marine conservation and climate control. Many European nations have a commitment to the biodiversity convention. There is a determination to maintain and preserve biodiversity which creates a demand for marine monitoring, especially the measurement and prediction of variables describing biota and the concentrations of nutrients and contaminants. Complex models are required to predict levels of disturbance or pollution which are likely to pose a threat to different ecosystems.

The MFS proposes to involve directly a large number of countries bordering the Mediterranean with an exchange of expertise in order to :

1) build a cost-effective basin wide monitoring system;

2) build capacity in local centres to model the shelf areas with state of the art hydrodynamic modelling;

3) create a network between all the nations bordering the Mediterranean Sea, including the south coast states, which will freely share observational data and model results.

The overall aims of MFS have been designed to serve marine environmental predictions in the Mediterranean Sea coastal areas. Modelling and forecasting the Mediterranean will be of great benefit to the maritime industries of the Mediterranean region, especially the control of pollution, management of fisheries, and improvement of marine conditions for tourism. Forecasting the Mediterranean Sea climatic conditions requires coupled ocean-atmosphere models and an observational network which allows to initialise the forecast, both in the ocean and the atmosphere. Although far from being solved as a problem, the MFS advances the monitoring and modelling components toward a system which can be used for regional predictions of climate. The forecasting of Mediterranean Sea climate will have a large economic and humanitarian benefit for North Africa and the Sahel regions, since rainfall is correlated to the Mediterranean Sea state.

In the preparation of implementation plans for a Mediterranean Forecasting System a specific task will be to analyse the economic and social value of the forecasts, and analyse the up-take of information by potential users.

Economic and Social Impacts

Operational Oceanography is a growing business in the world. If Europe moves fast now it will establish a lead, possibly globally, with a secure benefit also in terms of increasing sales of services, expertise and equipment. The present proposal, for example, includes an experimental buoy system for deep ocean with multiparametric sensors which, if developed adequately, could serve as a reference point for other forecasting monitoring programs.

The MFS Plan addresses the research issues required to set up ocean forecasting at the Mediterranean Sea basin scale and prepares the necessary steps to provide forecasts of primary production (algae) in the coastal areas.

The short to medium term economic benefits from this kind of activities fall into two categories :

1) economic benefits accruing to industries and services conducted at sea, beneath the surface of the sea and on the coasts;

2) economic benefits accruing on land through the prediction of climate variability (which is intimately connected to surface and deep ocean variability)

The social impact of this proposal will be first of all to promote Mediterranean wide collaboration, between the Northern and Southern Mediterranean nations. The forecasting of marine parameters outlined by the proposal will bring to a reduction of the risks, or warnings of public hazards and natural disasters impacting on maritime industries, tourism and offshore oil and gas platforms.

Overall Objectives of MFS

Scientific and pre-operational goals

The overall MFS goals are as follows:

Scientific

To explore, model and quantify the potential predictability of the marine ecosystem variability at the level of primary producers from the overall basin scale to the coastal/shelf areas and for the time scales of weeks to months through the development and implementation of an automatic monitoring and a nowcasting/forecasting modelling system, the latter called the Mediterranean Forecasting System as a whole.

Pre-operational

To demonstrate the feasibility of a Mediterranean basin operational system for predictions of currents and biochemical parameters in the overall basin and coastal/shelf areas and to develop interfaces to user communities for dissemination of forecast results

The outstanding scientific questions and technological developments required to achieve the goals outlined above are:

1. Can a real time basin wide physical and biochemical monitoring system be set up?

2. What is the impact of such an observational system and what data quality is necessary to enable useful forecast skill ?

3. What is the potential predictability of the Mediterranean upper water flow field at weekly and monthly time scales if we suppose that we know accurately the atmospheric forcing ?

4. What is the "internal" predictability of the flow system, e.g., how important is to know accurately the initial condition with respect to the external forcing parameters?

5. What is the potential predictability of the shelf areas viewed as physical components of the ecosystem?

6. What is the optimal set of intermediate and shelf model parameters (horizontal and vertical resolution, physical parameterisations) which will allow best downscaling of the OGCM simulations?

7. What is the potential predictability of phytoplankton biomass fluctuations and what are the major limiting factors, e.g., "internal nonlinearity" of the ecological system or errors in the representation of physical components of the models?

8. How do we downscale the ecosystem model from basin wide resolution to the coastal areas?

The Mediterranean Sea: scientific background

The Mediterranean Sea is a basin largely dominated by open ocean processes acting on the coastal/shelf areas and determining the coastal/shelf circulation. Thus the prediction of the coastal circulation structures and the coastal biomass evolution involves the solution of a fully three dimensional, density driven circulation problem.

The large scale general circulation of the Mediterranean Sea has been described as composed of intense coastal/boundary currents and gyres, with intense variability at the seasonal and interannual time scales (see Fig. 10a and 10b, Millot, 1987, Robinson et al., 1991, Roussenov et al., 1995, Pinardi et al., 1997). The horizontal structure of the circulation is associated with a vertical circulation connected to deep and intermediate water formation processes occurring in the basin and the inflow/outflow system at the Gibraltar Strait. This conveyor belt system is represented schematically in Fig. 11 where the traditional Levantine Intermediate Water (LIW) conveyor belt is represented following the water mass characteristics together with the meridional vertical overturning due to deep water mass sources.

The large scale current structures of the basin are driven by the wind stress typical of the region (Fig. 12) and the heat fluxes which determine the rate of deep and intermediate water formation. This general circulation flow field impinges on the coastal regions and strongly influences the local dynamics of currents. Shelf areas in the Mediterranean are rather small in extent (see Fig 13) and they are separated from the deepest regions by steep continental shelf breaks. Thus this configuration makes possible the intrusion of the large scale flow field on the coastal/shelf areas and the direct influence of the large scale currents on the coastal flows. Transport of material from the coastal areas to the open ocean will be enhanced by this mechanism with important consequences for the maintenance of the ecological cycles in the basin.

The time variability of the flow field described in Fig. 10 varies from the mesoscale (few weeks) to the seasonal and interannual scales, the latter mostly associated with the atmospheric forcing variability (Pinardi et al., 1997). Climatological estimates of the circulation parameters are then relatively bad predictors of the flow field structure since the currents can even reverse depending upon the season and the year.

The monthly average picture of surface chlorophyll for April and August from the CZCS satellite sensor shows the high productivity longitudinal and latitudinal gradients in the basin (Fig. 14). These gradients are partially maintained by the physical circulation structures described above and by the functioning of the food web which is different in various parts of the basin. On the overall basin scale, the primary production levels are maintained by fast microbial loop recycling processes occurring during the summer and by nutrient pulses from below the thermocline during the winter, especially in areas of deep water formation. However it is important to point out that the largest biomass concentration gradients are in the neighbourhood of river run-off areas (Rhône, Po, Nile, etc.). Thus for each different shelf area of the Mediterranean a careful analysis of budgets in terms of local and advective nutrient sources should be done in order to develop the appropriate nutrient monitoring system.

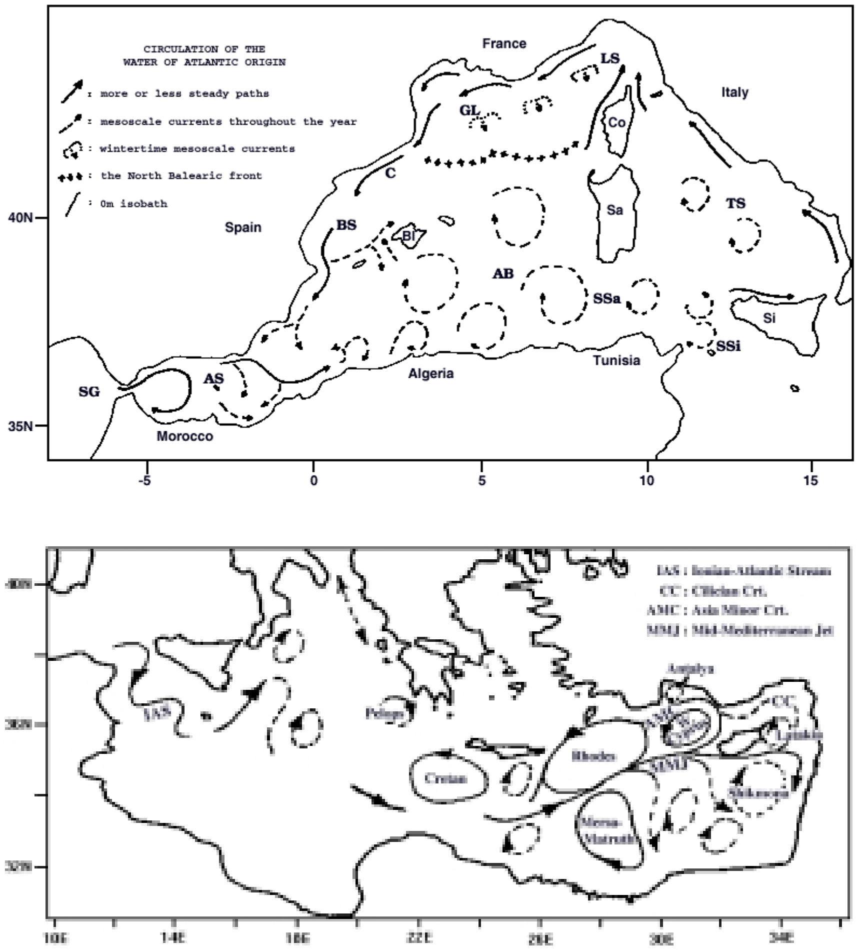


Figure 10a: *Upper panel: circulation of modified Atlantic Water (MAW) (from Millot, 1987a). The major geographical features are identified by their initials., e.g., GL is Gulf of Lions, LS is Ligurian Sea, TS is Tyrrhenian Sea, AB is Algerian-Balearic basin, Ssa is Strait of Sardinia, AS is Alboran Sea, Ssi is the Strait of Sicily, BS is the Balearic Sea, C is Catalan Sea. Lower panel: Schematic general circulation of the Eastern Mediterranean. Dashed features are recurrent or transient upper thermocline structures (from Robinson et al., 1991)*

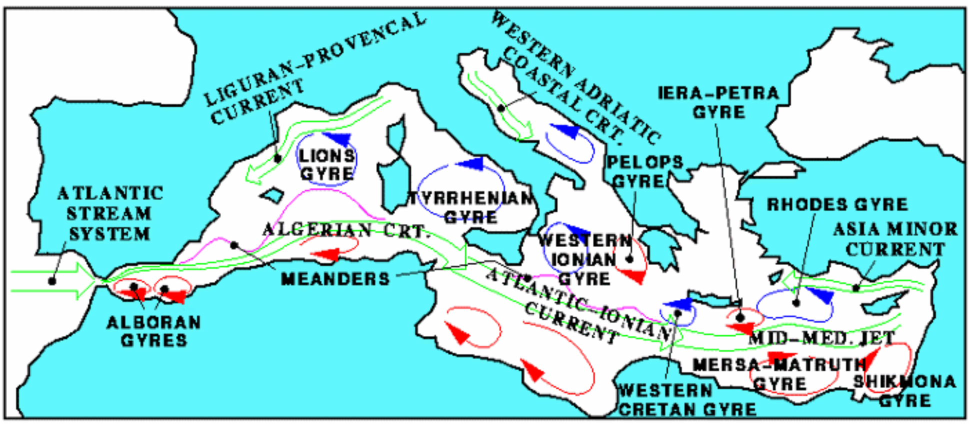


Figure 10b: *Schematic of Mediterranean Sea general circulation. Structures from both observations and model results.*

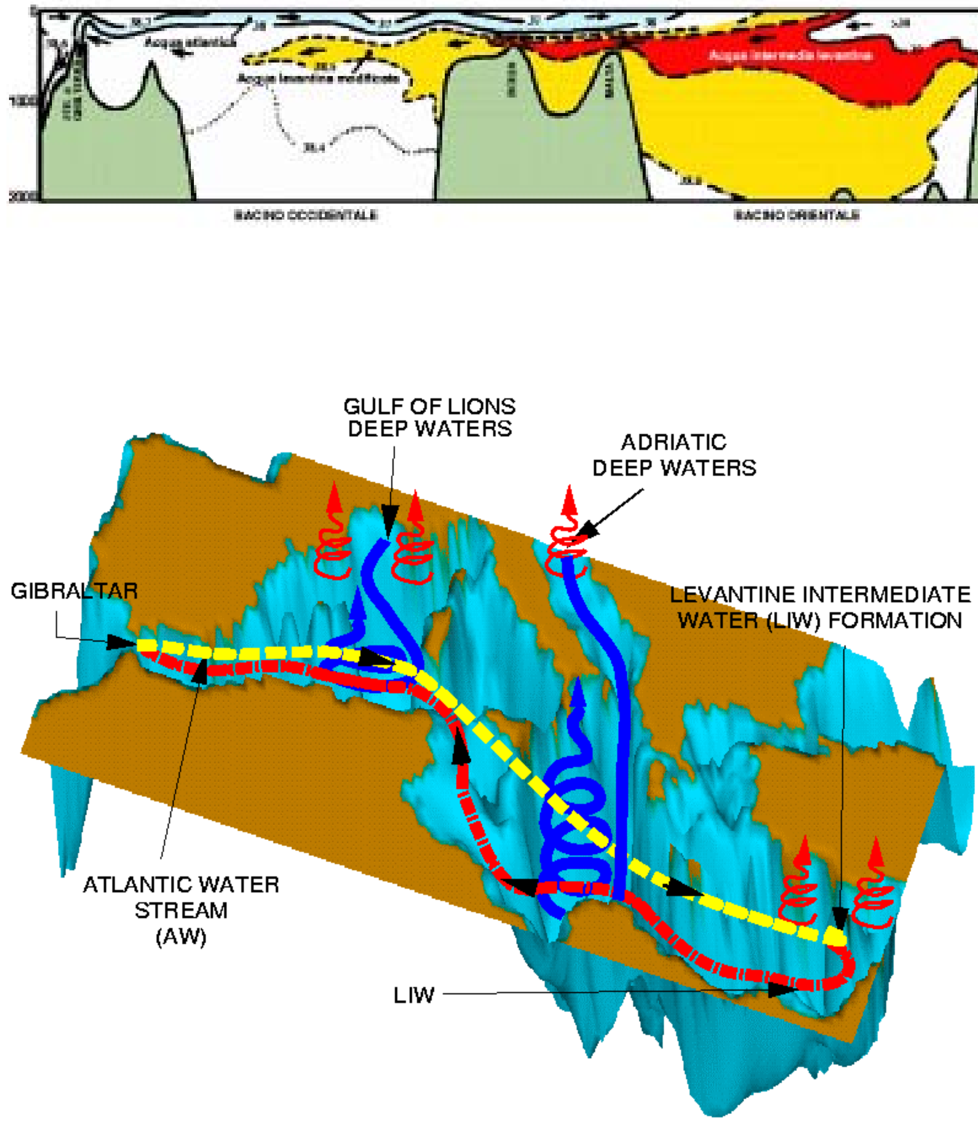


Figure 11: *The vertical water masses circulation and major conveyor belt systems of the Mediterranean. The upper panel show an along-Mediterranean section with water masses indicated by salinity values. The vertical recirculation of the Atlantic Water transformed into Intermediate Water is shown by the arrows. The lower panel shows a 3-D view of the previously mentioned Intermediate Water conveyor belt and the meridional vertical circulation introduced by the sources of deep waters located in the Gulf of Lion and Adriatic Sea regions. The meridional circulation is similar in dynamics to the meridional overturning cell of the North Atlantic.*

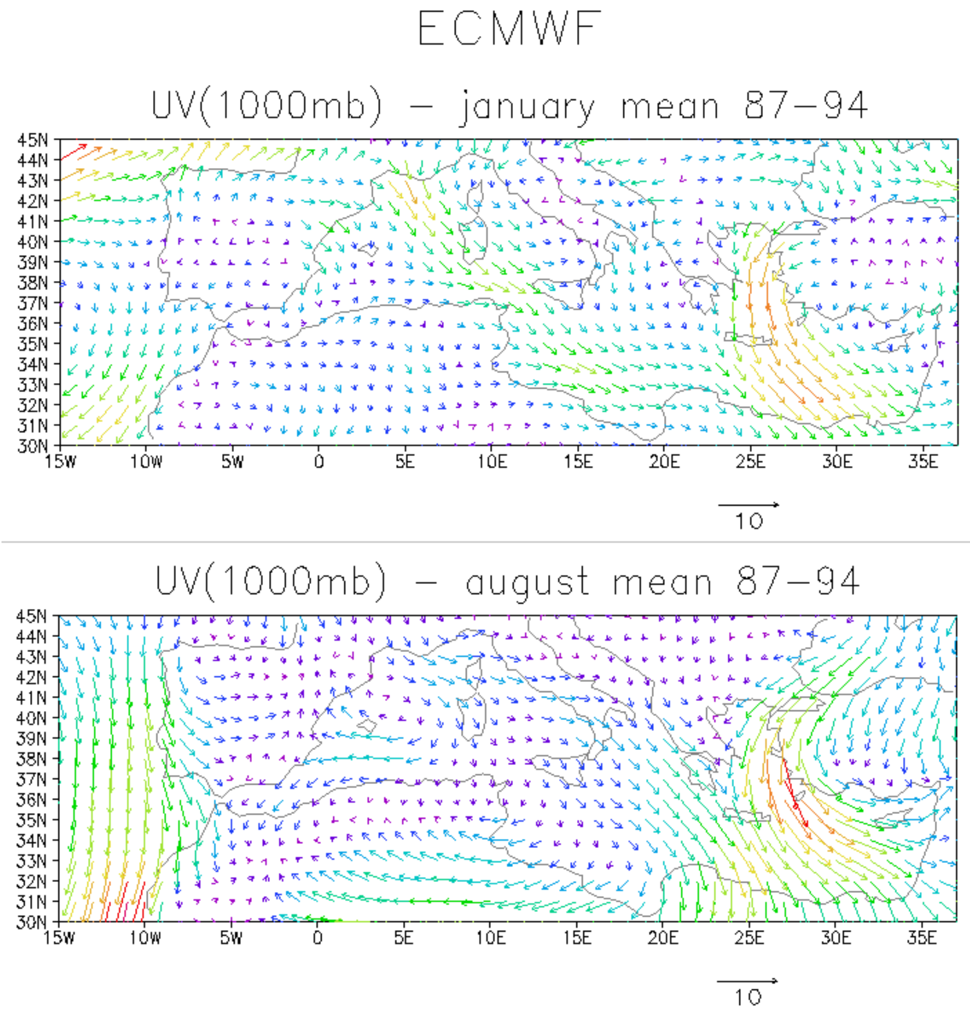


Figure 12: *ECMWF 8 years average (Jan 1987- Dec 1994) of 1000mb winds for January and August. The reference arrow indicates 10 m/sec.*

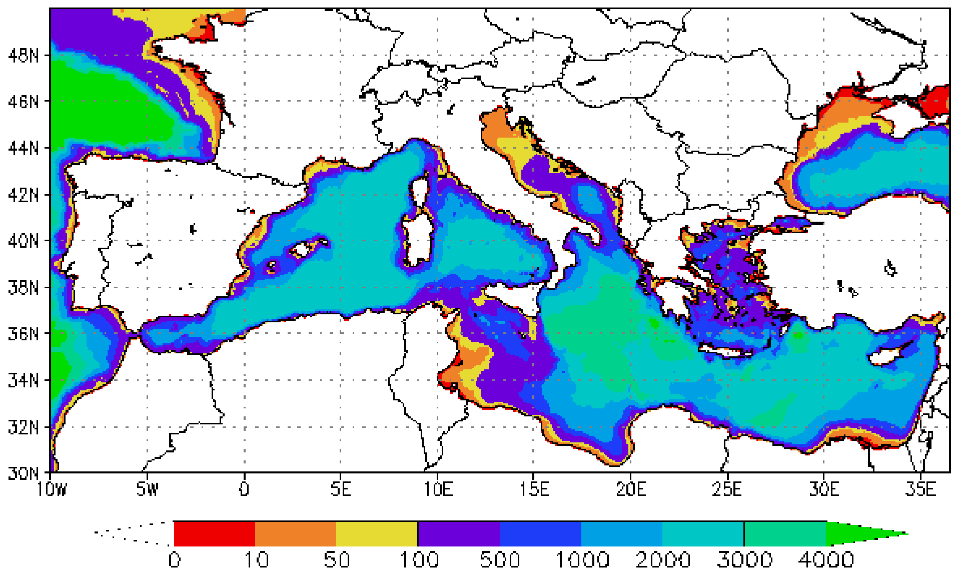


Figure 13: *coastlines and 10, 50, 100 m. contours of bathymetry over the Mediterranean area. Note the extended shelf areas only in the proximity of Northern Adriatic and Tunisian coasts.*

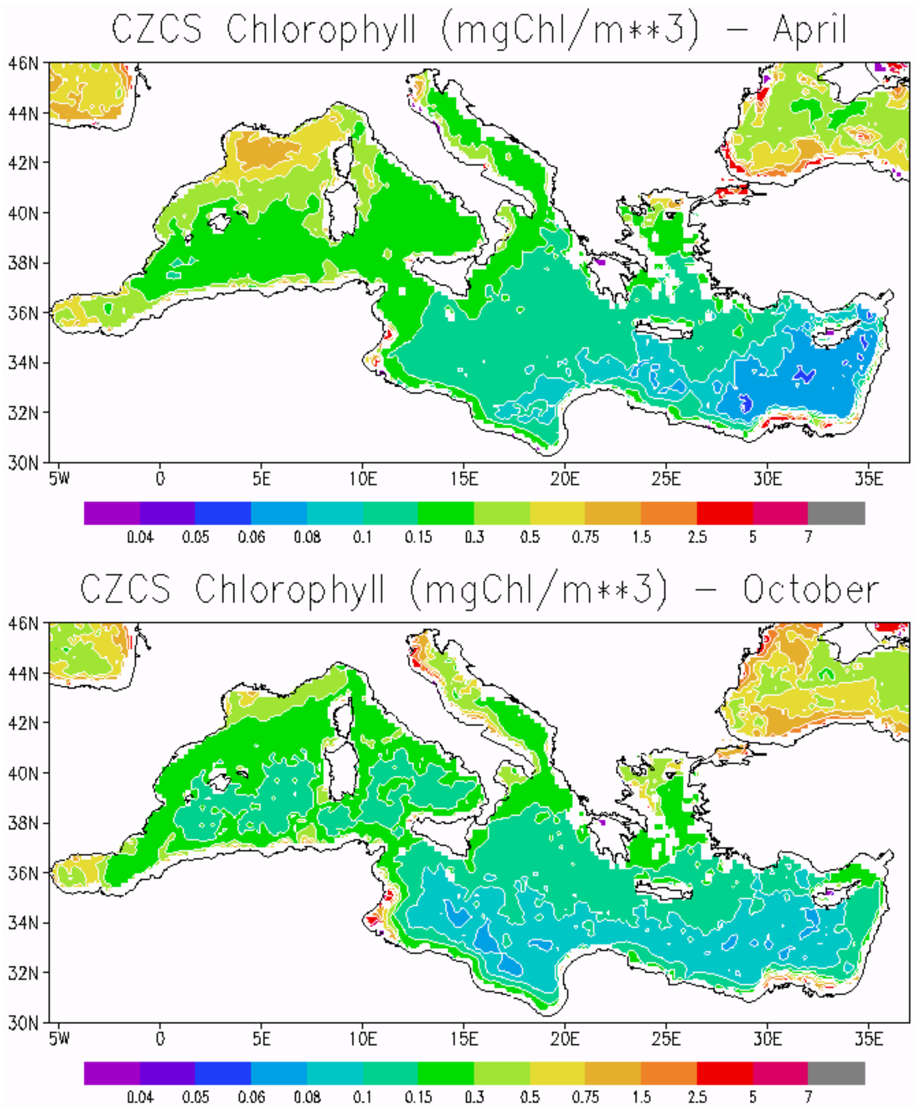


Figure 14: *Surface Chlorophyll average distribution from 1979 to 1985 for April and October. Pictures produced by the Ocean Colour European Archive Network (OCEAN) of the Joint Research Centre in Ispra, Varese, Italy.*

The monitoring system for Mediterranean forecasting

The observational system in support of the MFS should be composed of many parts, to be developed and implemented over the next ten years. A critical factor in the design of an operational observing system is to define the necessary and minimum number of observations which are needed to increase the accuracy and usefulness of the forecast. This process cannot be designed theoretically at the start, though the major elements should be considered. This is because the problem of predicting which measurement is more useful for a better forecast is theoretically not well posed. Thus we need a combination of "experimental work" and conceptual exercise to be able to set up the observational network most useful but economical for the MFS.

The following components are recommended:

Ship-of-opportunity temperature and salinity monitoring

Here a VOS and/or VOF based measuring system capable of automatic recording and transmission of upper thermocline temperatures and salinities (0-500 meters) transmitting data to land based stations is envisaged (Fig. 15). The common instrument used is the expendable BathyThermograph (XBT) developed in the seventies. The accuracy of the probe is about 5-10 meters at 700 meters, with increasing accuracy closer to the surface.

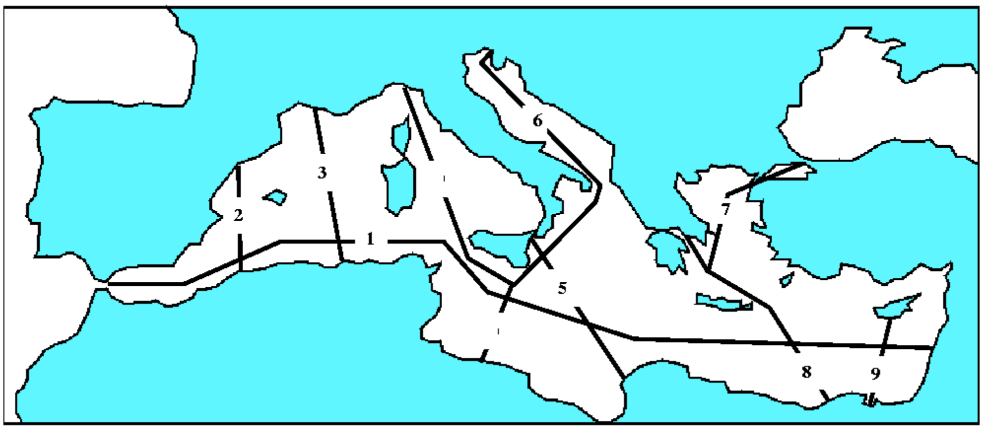


Figure 15: *Planned ships of opportunity tracks network for the first phase of strategic development*

The Mediterranean is lacking such a data set at adequate resolution which is however present elsewhere (see earlier section) and it is the basis of data assimilation and forecast experiments in other parts of the world ocean. Conductivity measurements can be done on VOS or VOF in approximately the same way as the XBTs via the expendable CTD probe (XCTD) but accuracy is still under scrutiny. Important technological developments involve: the development of an automatic system for multiple launching of XBT, the feasibility of XCTD measurements on VOS, the data transmission to Mediterranean centres, data quality control and standardisation of data collection procedures, the usage of such data sets for nowcasting and initialising model forecasts and the design and implementation of the network of ship tracks.

Ship-of-opportunity pelagic system monitoring

Here a VOS and VOF based measuring system for automatic collection of nutrient data profiles, optical parameters, primary production levels, phytoplankton and zooplankton biomass data in the first 100 meters of the water column is envisaged The continuous monitoring of nutrient, production, phytoplankton and zooplankton abundance at the basin scale is vital for the understanding of the coastal areas ecosystem response and the predictions of changes. Moreover, shelf areas can be eutrophic due to nutrient loading from rivers and coastal upwelling phenomena. An automatic VOS or VOF biochemical monitoring is again a plausible solution in order to get almost real time data for forecasting of pelagic biomass fluctuations at both basin scale and in the shelf areas. Important technological developments involve: the design of undulating towed instruments or packages on VOS or VOF, the design of the appropriate network, the determination of time delays involved in the analysis of the acquired data, the usage of these data to calibrate and initialise ecological models of the basin, standardisation of measuring methods over the whole basin areas.

Mediterranean Moored Multisensor Array (M^3A)

Here we define the *in situ* moored stations system capable of measuring air-sea interaction parameters and upper thermocline current and temperature/salinity continuous profiles together with biochemical parameters for the euphotic layer of the Mediterranean (Fig 16). These moored stations should form the basis of the long term monitoring of the basin for the validation and calibration of the hierarchy of numerical models used for forecasting. They should be located in crucial experimental areas for ecosystem model validation and in a regular network grid of stations.

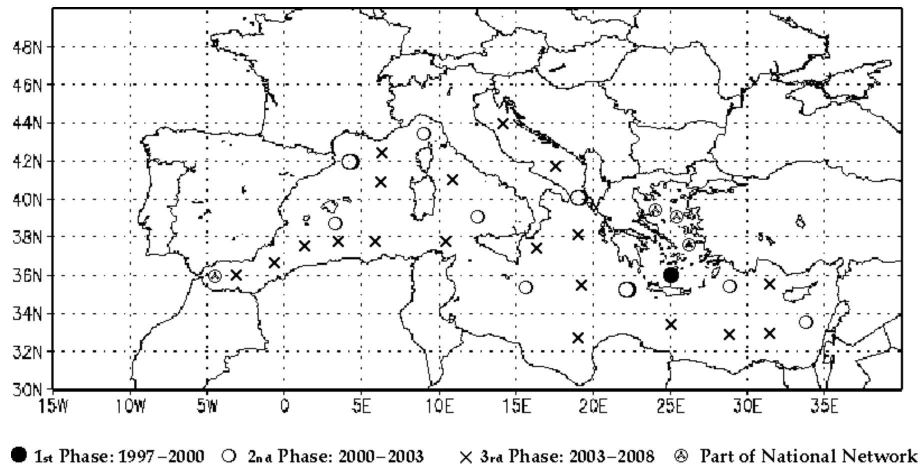


Figure 16: *Moored Mediterranean Multisensor Array (M3A). Station locations.*

There are two aspects to the M^3A array: the first is the networking of moored stations with equivalent measurements and quality control, the second is the development of reliable sensors for the profiling of biochemical parameters on a moored station. The location of the array should be decided on the basis of the usage of data in model validation exercises. This means that the array should be put outside the strongly advective regimes of the coastal/shelf areas, which are partially dominated also by terrestrial inputs of strong local nature. Furthermore, the necessarily scarce spatial coverage of the stations network excludes it from being capable of resolving the strong lateral gradients of currents and biochemical parameters along the continental shelf margins. Thus the optimal locations of such moored stations are the deep waters (depth greater than 1000 meters) outside the continental shelf area which coincides also with regions far from fishing activities. Suggested parameters for M^3A are: air-sea interaction parameters (air temperature, wind direction and amplitude, relative humidity), water temperature, conductivity, currents, primary production, photosynthetic activity, Photosynthetically Available Radiation (PAR), Oxygen, turbidity, nitrate/nitrite, particle fluxes, zooplankton biomass (acoustic), etc. The biochemical parameters should be collected in the first 100 meters while the physical parameters should be measured in the upper 500 meters or deeper.

Remotely sensed SST, colour and sea surface topography operational analyses

The data of interest consist of remotely sensed sea surface topography, sea surface temperatures and ocean colour (Fig. 17). The technological question is connected with real data analysis of these large data sets and their transmission through the network at a time frequency (from daily to weekly) useful to update forecasts. Regarding the radar altimetry, measuring the sea surface height along the satellite track, the technological question is how to produce sea surface height anomalies with a fast turnover time without loosing too much accuracy in the resulting product. The Mediterranean basin is particularly challenging since the large scale currents sea level anomaly signal is of few tens of centimetres and sophisticated retrieval algorithms are required to extract these values from the remotely sensed sea surface height signal.

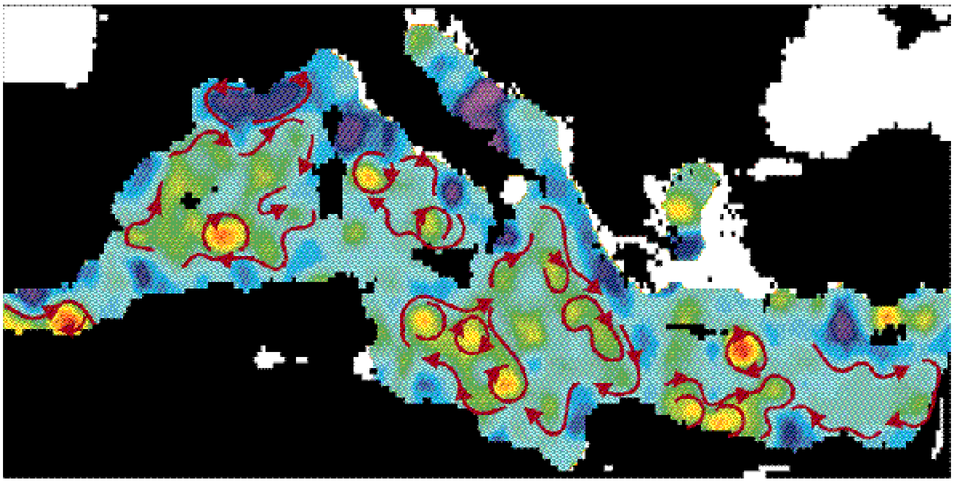


Figure 17: *Analysis of Sea Surface Height anomaly from satellite altimetry*

On the other hand the SST accuracy for the Mediterranean should be tested especially for the summer months where low ocean clouds could develop. Colour data should be analysed from the newest satellite sensors and new algorithms should be tested in order to obtain relevant parameters for assimilation in ecosystem models.

Lagrangian measurements of currents and water properties

Lagrangian data, combined with other moored or ship-based observations and with remotely sensed data, will provide the necessary information about, and monitoring of, the spatial and temporal variability of the Mediterranean sea dynamic system that will ultimately be assimilated into numerical models. The main advantage of Lagrangian measurements over other techniques is the relatively inexpensive way of obtaining broad geographical *in situ* sampling of oceanographic parameters at different water depths. The scientific aspects explored by water-following instruments range from the study of high-frequency tidal and inertial signals, on the one hand, to the investigation of seasonal and interannual variability of the mean dynamical characteristics in the different Mediterranean basins, on the other. Lagrangian sampling at the mesoscale, and most particularly in the vicinity of shelves and shelf slopes provide also crucial information on coastal processes such as deep sea and shelf interactions. The real (or quasi-) real time monitoring of currents and water properties has a variety of operational applications, such as providing the environmental sea conditions for pollution issues, commercial and military operations. The major technological question connected with such data sets is the development of data assimilation techniques capable of using the potential information of the Lagrangian instruments. The other question is the determination of the space and time sampling required in order to get useful updating and initialisation information for the forecasts.

Acoustic tomography observations

Acoustic tomography is the most likely remote sensing technique for the interior of the ocean, since the water column is opaque to electromagnetic radiation. Recent experiments have demonstrated the usefulness of tomography for observing ocean phenomena or for monitoring changes in the ocean on meso- and basin-scales. One would expect that such kind of large-scale information is a good constraint for models that are to be used for predictive purposes. It is now technically and scientifically feasible to deploy acoustic monitoring instruments with data transmission capabilities on moorings or with shore-cabled stations. The impact of acoustic observations of large-scale stratification, meso-scale information, and strait-transports in an assimilation/forecasting system could be investigated.

Numerical models and data assimilation methods

Any useful numerical modelling system of the Mediterranean coastal areas will consider the importance of the large scale flow field on the coastal currents, the high frequency atmospheric variability and the high resolution required to define topographic features. Thus a proper coastal/shelf coupling with the open ocean must be depicted in the framework of nested models which seem to be a robust tool in order to downscale the large scale currents to the required high resolution in the coastal areas. This is known to work for hydrodynamics in general but it should be true also for biochemistry where experience is lacking, and downscaling from the large scale to the small ones (shelf areas) could involve coupling of partially different ecosystem models.

To produce weekly and monthly forecasts of marine ecosystem parameters for the whole and regional/shelf areas the required modelling developments are:

1) develop direct and indirect (synchronous or asynchronous) coupling with atmospheric analyses and forecasts at short (week) and medium (months) time scales for the OGCM at basin wide scales and the nested regional/ shelf models. The indirect coupling will provide the short term forecasts and will serve as a tool for understanding the air-sea physical parameterisations needed, the predictability time scales of the oceanic flow field, the separate effect of errors in atmospheric forcing and ocean initial conditions on the short term forecast skill. The direct coupling will evaluate impact of ocean SST on atmospheric forecast and the potential of medium range predictions in the Mediterranean areas (ocean and atmosphere). This is the preliminary step toward the study of water cycles in the entire Mediterranean land-ocean area.

2) develop and evaluate the nesting procedures for the shelf models capable of interfacing the large scale high resolution OGCM and the coastal models (Fig. 18). The appropriate downscaling technique should be assessed in order to be able to achieve resolutions of 2-3 km in coastal/shelf areas, needed to resolve the physical flow field scales and processes. The goal is to be able to calibrate and verify each shelf model at the synoptic, seasonal and interannual time scale and customise the atmospheric coupling for the shelf area of interest. The predictability time scale of the coastal/shelf system should be assessed as a function of errors in lateral boundary conditions, atmospheric forcing space-time scales, and initialisation data. The forecast skill should be computed for short (week) to medium range predictions both at the regional and shelf scale.

3) develop ecological models at both basin and regional/shelf scale with the hydrodynamic components developed in 1 and 2 above. The ecological models should be able to represent the major nutrient cycling, primary production, major phytoplankton and zooplankton functional groups up to mesozooplankton. The basin ecological models should be composed of a main pelagic compartment and parameterisations for

sinking of detritus in the deep ocean. The shelf models should consider instead the effective coupling of benthic biochemistry with the pelagic food web. The computational requirements of such work could be huge and several simplifications will be necessary. The major scientific task will be to assess the predictability time scales for primary production in the coastal and open ocean areas, the development of data assimilation techniques and the actual production of forecasts.

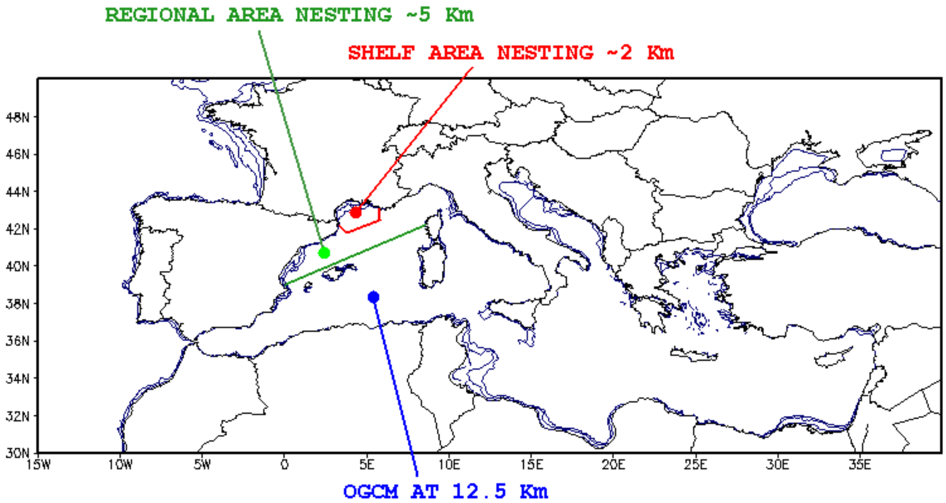


Figure 18: *Example of the nesting strategy from OGCM to shelf areas. Numbers indicate grid spacing.*

Overall Strategic Plan

The scientific and technological developments outlined in the previous sections are required to solve the many scientific questions which are at the heart of the marine forecast problem for the Mediterranean and its coastal regions. In synthesis the methodology of approach is:

1. Construction of a prototype permanent monitoring system for the physical-biochemical components of the ecosystem in the Mediterranean Sea at adequate space-time resolution for model initialisation and forecast;

2. Construction of a basin wide ocean General Circulation nowcast/forecast Model and associated data assimilation techniques, for the physical components of the Mediterranean Sea ecosystem, capable of predicting the currents on the time scales of few weeks to months, together with nested regional/coastal/shelf models.

3. Construction of a coupled atmosphere-ocean regional model over the Mediterranean area. Techniques for coupling with extended range atmospheric simulations should be assessed.

4. Construction of coupled biochemical-physical models capable of predicting the nutrients and phytoplankton biomass variability in the marine ecosystems of different coastal areas.

In the following we will outline a work time table for the scientific and technological developments outlined above. The work has been subdivided into three phases, respectively:

First Phase (1997-2000)- Short term forecasts

- A VOS for XBT, CPR, XCTD and biochemical sensors should be established through a pilot project. Technological developments should concentrate upon the development of multiple XBT launching system, check of XCTD accuracy, analysis of CPR and development of biochemical sensors for nutrients. The network of ship routes should be minimal but enough to cover the large scale flow field, and real time data acquisition and communications should be established (see fig. 15).

- M3A system should be put in place for few stations all around the Mediterranean and networking and communications should be established, together with common data analysis procedures. Maintenance costs and sensor reliability should be checked, especially for the biochemical sensors (see fig. 16).

- Near real time analysis of satellite data sets should be tried, in particular for sea surface height (SSH), SST and ocean colour. This analysis usually requires long time delays between acquisition and release of elaborated data, due to the necessity of using sophisticated algorithms for signal processing. Near real time communication with modelling centres should be tried for assimilation in the OGCM (see fig. 17).

- An OGCM at 1/8 X 1/8 degrees resolution and 30-50 levels in vertical should be developed with data assimilation components in order to start forecast experiments with atmospheric asynchronous coupling at the 5-10 days time scales. Results from these short term forecasts should be disseminated for parameters such as surface currents, SST, mixed layer depth and structure. Development and testing of synchronous coupling of OGCM with atmosphere should be done in order to prepare the medium range forecasting activities.

- Impact of different observational data sets on the quality of nowcasts and forecasts should be studied, together with the development of multivariate assimilation techniques, assimilation of novel data sets such as Lagrangian data, basin wide tomography. Observational system simulation experiments should be tried to minimise data quantity and optimise quality of forecast

- Nested regional/shelf hydrodynamic models into the OGCM should be calibrated and validated for seasonal and interannual variabilities in the different regions. Intercomparison of regional simulation skills for the seasonal cycle and interannual variability and customisation of atmospheric forcing over the regional models should be established (see fig. 18).

- Ecological models should be calibrated and checked against M3A and VOS data sets for the basin and the regional/shelf areas where they will be applied. Only simulation experiments should be tried at this stage. The goal is to understand limits of predictability of the ecosystem, the technical problems of coupling high resolution hydrodynamics to complex biochemical models, initialisation of ecosystem variables, comparison with non-synoptic data, intercomparison of different coastal/shelf regime simulations.

Second Phase (2000-2003)- Regional and medium range forecasts

- Set up a coastal monitoring system connected to the VOS system realised in phase I. A VOF system should be added and heavily instrumented with biochemical sensors. This network obviously will cover the regional areas, on or close to, the continental shelves of the basin. Furthermore, attention should be devoted to terrestrial inputs of nutrients, both by devising new automatic monitoring systems or networking with existing monitoring systems. In very shallow water areas (10-30 meters) the monitoring of benthic biochemical activity should be considered through benthic stations.

- the M3A network of stations should be increased and equipped with more biochemical sensors on all the moored stations. Further development of sensors for automatic detection of nutrients, zooplankton and primary production should be carried out (see fig. 16).

- Pilot experiments with tomography, lagrangian data and Strait throughflow observations should be established and the improvement on the forecast skill assessed.

- Development of a fully coupled Ocean-Atmosphere Mediterranean model and study of feed back mechanism between SST, water cycle and precipitation over land areas. Short term ocean forecasts should be tried with the coupled model and compared with previous asynchronous coupling forecasts.

- Assessment of short term forecast skill should continue from the first phase

- Pilot forecast experiments should be tried for the nested regional/shelf models, together with forecasts done at the overall basin and with the OGCM developed previously. Coupling of the regional/shelf models with medium term regional atmospheric forecasts should be tried.

- Simulation experiments should be tried with ecosystem models developed in the first phase of the project and data assimilation techniques should be developed for the biochemical components.

- Tighter links with a potential user community should be established, including assessment of utilisation of data, and feedback from users.

- Assessment of long (months) range forecasts in the ocean-atmosphere coupled system.

Third Phase (2003-2008)- Pre-operational

- transition of the observational network to National and International marine operational agencies

- economic impact studies and user community needs drive the operational customisation of the MFS

- release of short and medium term forecast capabilities to National authorities

- full assessment of forecast skill in the coastal areas for the hydrodynamics and parts of the ecology.

The MFS Pilot Project

Phase 1 of the MFS has been partly developed as a proposal to the DGXII MAST Programme, called the MFS Pilot Project. Some short extracts from the Project Technical annex are shown in Annexes 1-3. The Pilot Project will start its activities in September 1998 and it is funded to last 2.5 years.

The MFSPP organises the automatic collection and near real time distribution of marine data sets and implements advanced modelling and data assimilation tools to undertake the first phase of the MFS plan, as described in the overall objectives. The data sets and models are:

1) *In situ* VOS data. Nine tracks of XBT temperature profiles every two weeks covering the whole Mediterranean at 10 nautical miles resolution ;

2) *In situ* multiparametric buoy station data (M3A) . One pilot station in deep ocean which measures temperature, salinity , currents down to 500 m, biogeochemical parameters (oxygen, turbidity, chlorophyll and nutrients) down to 100 m and meteo-marine parameters at the surface (10m winds, air temperature, air humidity, air pressure, wave direction and amplitude) ;

3) Satellite sea surface height (SSH), sea surface temperature (SST) and colour (SSC). The whole basin remotely sensed data will be analysed and distributed in near real time in the same network of *in situ* collected data ;

4) a multivariate data assimilation system for combined temperature profiles and sea surface height data from altimetry ;

5) an Ocean General Circulation Model (OGCM) with 1/8 X 1/8 degree resolution and 31 levels, interfaced with : 1) 3-5-10 days forecast atmospheric forcing parameters from operational weather centres ; 2) data assimilation tools in order to initialise 3-5-days ocean forecasts ;

6) Several Intermediate and shelf nested models into the OGCM. The intermediate model will be at 5 km resolution nested within the OGCM and shelf models will be at 2 km resolution in various Mediterranean shelf regimes ;

7) Complex ecosystem models in several shelf and across shelf areas. The models will be one-dimensional in this phase, describing in detail the biogeochemical interactions at the primary production level and interfaced with realistic atmospheric forcing and water column mixing.

The tools and data sets are also schematically represented in Fig. 19

The Project has been subdivided into three different phases during which different data sets will be released. The central time period of the Project is called TOP, Target Operational Period, where Near Real Time forecast experiments will be carried out with the OGCM. The others surround the TOP. They are:

8) Period TOP-2: preparation and test. During this period, going from the start of the Project up to month 15, the observing system will be deployed, the OGCM model will be coupled with atmospheric forcing and the Mark-II data assimilation components will be tested.

9) Period TOP-1: transitional. During this period, the quality of the communication system between the data collecting centres and the forecasting centre will be evaluated. The near real time satellite data will be made available together with the *in situ* VOS and M3A data to the modelling centres and trial forecasts started;

10) Period TOP: near real time forecasting. During this time period, the collected data will be all transmitted in near real time and three, five and ten days forecast experiments will be carried out.

The Project time line and the delayed and Near Real Time data delivery system is described in Fig. 20 below.

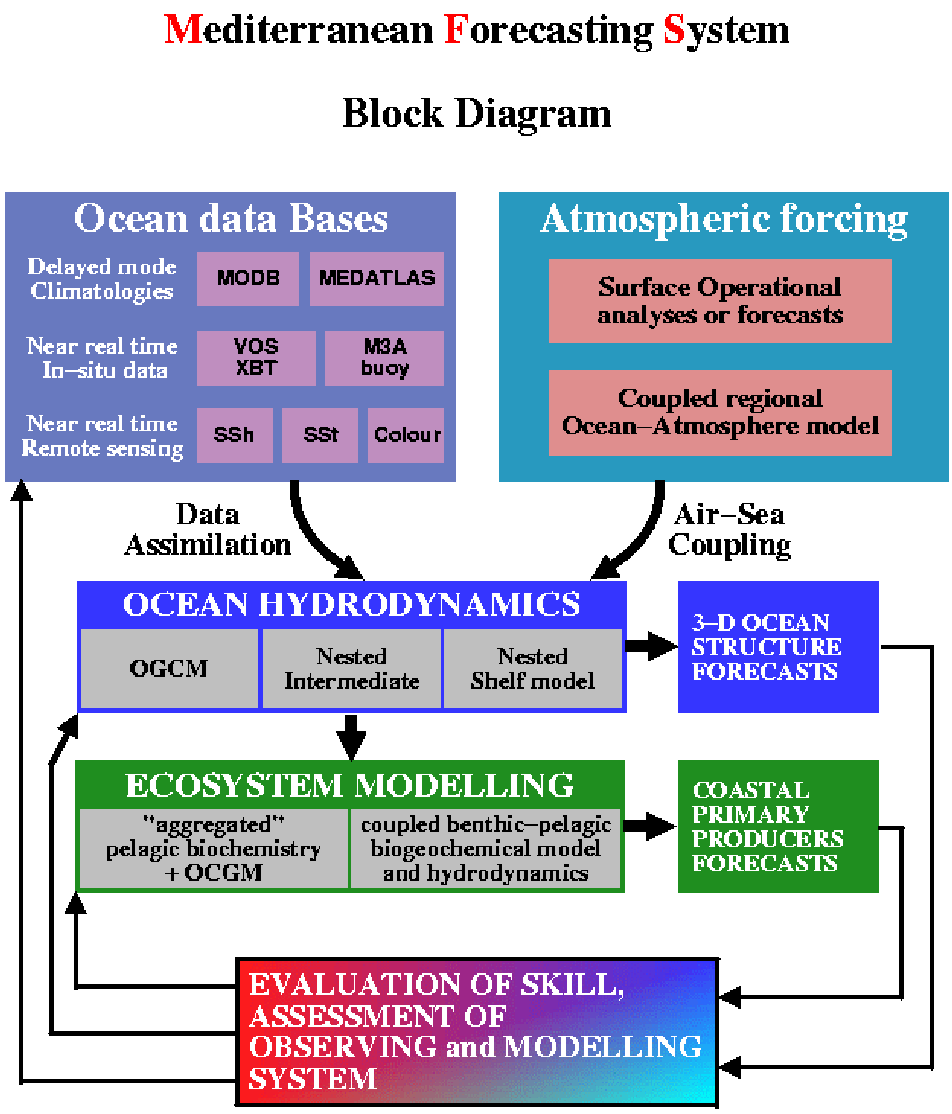


Figure 19. *Schematic of the MFSPP methods and tools*

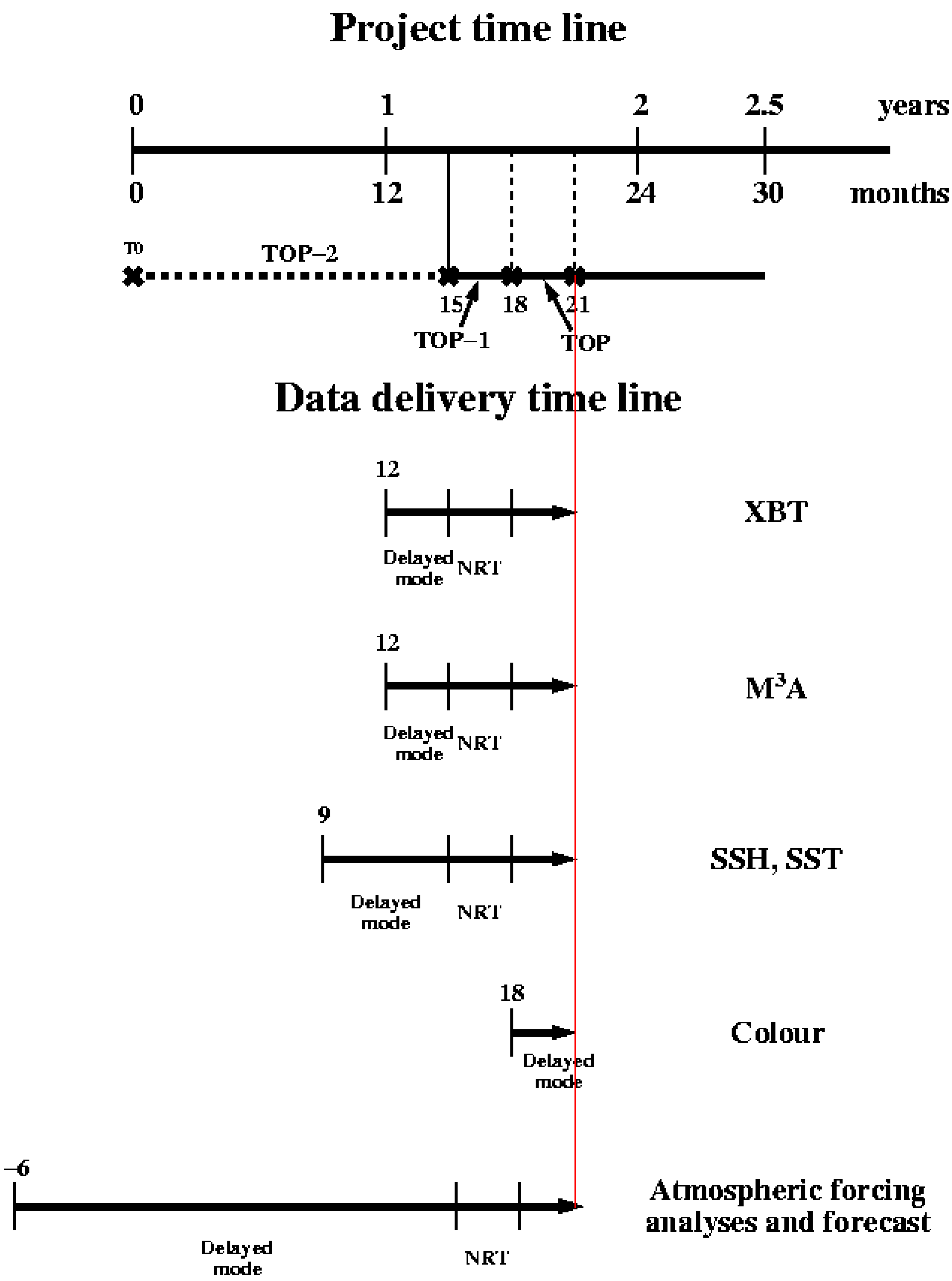


Figure 20. The MFSPP time line and data delivery time line

The EuroGOOS Mediterranean Task Team

This document is the result of the collaborative work between a large Mediterranean scientific community which hopefully will continue in the future. In order to organise future activities a Scientific Steering Committee (MFS-SST) is nominated which organises:

- Periodic discussions and workshops on themes of MFS
- Co-ordination with external activities to MFS
- Preparation of funding proposals
- Synthesis of achievements
- Contacts with EuroGOOS Office, MATER Project and other relevant projects in the area.
- Dissemination of results

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It was decided that the Chairperson should represent the MFS at the EuroGOOS annual working group meetings.

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Annexe 1 - Executive Summary of the MFS Pilot Project

This project develops a strategy for the implementation of a Mediterranean Forecasting System aimed at the prediction of marine ecosystem variability in coastal areas up to the primary producers and from the time scales of days to months. Such a predictive capability is required to sustain an healthy coastal environment and its management. A forecasting system of such kind requires two essential parts, an observing system and a numerical modelling/data assimilation component that can use the past observational information to optimally initialise the forecast. The technical rationale of the Project is based upon the hypothesis that both hydrodynamics and ecosystem fluctuations in the coastal/shelf areas of the Mediterranean are intimately connected to the large-scale general circulation. The second assumption is that, for the physical components of the ecosystem, monitoring and numerical modelling can work almost pre-operationally. A major goal of the proposal is to show that Near Real Time (NRT) forecasts of the large scale basin currents are possible.

In this project we develop and implement:

1) a pilot automatic temperature monitoring system for the overall Mediterranean Sea (Voluntary Observing Ship-VOS system) with NRT data delivery;

2) a pilot Mediterranean Multisensor Moored Array buoy system (M3A) which could automatically monitor a complete set of physical parameters, such as temperature, salinity and currents, together with relevant biogeochemical and optical measurements in order to establish the feasibility of multiparametric monitoring of the upper thermocline in the whole basin;

3) NRT satellite data (sea surface height, sea surface temperature and colour) analysis and mapping on the numerical model grid;

4) different data assimilation schemes in order to assimilate multivariate parameters, e.g., XBT from the VOS system and satellite sea surface height and sea surface temperature;

5) a strategy to carry out 3, 5 and 10 days ocean forecast experiments at the whole basin scale and for a total period of three months ;

6) techniques to downscale the hydro-dynamics to different shelf areas of the Mediterranean Sea with nested models of different resolution;

7) ecosystem models in shelf areas of the basin and a strategy for validation/ calibration with M3A data sets;

8) methods for assimilating nutrient, chlorophyll and PAR into predictive ecosystem models ;

9) realise an overall NRT data collection and dissemination network which should allow the timeliness release of data for the forecasting exercise.

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Annexe 3 - Workpackage structure of the MFS Pilot Project

The Project is organised in several Workpackages which define the major subportion of work to be carried out by the partners.

They are:

Workpackage 1: Voluntary Observing Ship (VOS) Temperature Data Collection

Task 1100: Software and hardware preparation

Task 1200: Data acquisition

Task 1300: Data quality control procedures

Task 1400: Future implementations

Task 1500: Data Management

Workpackage 2: Mediterranean Moored Multisensor Array (M3A)

Task 2100: Configuration, design and construction of the system

Task 2200: Lab testing, deployment and operation of the M^3A

Task 2300: Data quality control and analysis procedure

Task 2400: Data management

Workpackage 3: Near Real Time Remotely Sensed Data Collection and Analysis

Task 3100: Develop and test algorithms to process NRT altimeter data

Task 3200: Develop a Near Real Time SST product

Task 3300: NRT data processing before and during the TOP

Task 3400: Remote sensing data management

Workpackage 4 : Ocean Data Assimilation and Impact of Data Strategy and Accuracy

Task 4100: Assembly and test of Mark-II DAS in the OGCM

Task 4200: Impact of system components on forecast skill

Task 4300: Observing system simulation experiments

Task 4400: Dissemination of data assimilation products

Workpackage 5: Numerical Forecasting Experiments During TOP

Task 5100: Collection of atmospheric forecasts and analyses

Task 5200: Preparation and Test of OGCM (TOP-2 Period)

Task 5300: Transition to forecasting (TOP-1 Period)

Task 5400: Near Real Time forecasting (TOP Period)

Task 5500: Dissemination of ocean model results and forecasts

Workpackage 6: High Resolution Simulations in the Coastal and Shelf Areas with Nested Model Implementations

Task 6100: Intermediate model simulations and data networking

Task 6200: High resolution Shelf Models in Test Case Areas.

Task 6300: Novel implementation of shelf models and technology transfer

Task 6400: Customised (downscaled) atmospheric forcing.

Task 6500: Intermediate and shelf area models data management

Workpackage 7: Ecosystem Model Validation and Hindcasting

Task 7100: Optimising parameter sets for regional seas ecosystem models

Task 7200: Biogeochemical properties data assimilation

Task 7300: Hindcasting the M3A Buoy data

Task 7400: Testing the response of the ecosystem models to high frequency meteorological data.

Task 7500: Recommendations for the monitoring of biogeochemical variables for the second phase of the MFS

Task 7600: Ecosystem models data management

Workpackage 8 : Data Management

Task 8000: MFSPP centres

Task 8100 : Protocols and Specifications for observational and model data archiving

Task 8200 : Data Flow organisation

Task 8300: Metadata flow organisation

Task 8400 : Near Real time Quality Control

Task 8500 : Delayed time Quality Control

Task 8600 : Integration of MFSPP archived data with other archiving systems

Task 8700 : General web pages at DMC

Workpackage 9: Dissemination and Exploitation of Results

Task 9000: User identification

Task 9100: Dissemination policy for NRT data

Task 9200: Dissemination of MFSPP know-how

Task 9300 : Exploitation of results

References

Allen J., I., Blackford J.C., Radford P. J., 1998 "A 1-D vertically resolved modelling study of the ecosystem dynamics of the Middle and Southern Adriatic Sea." *Jou. Marine Sys*., in press.

Anderson D. J. L., J. Sheinbaum, K. Haines, 1996. "Data assimilation in ocean models." *Rep. Progr. Phys., 1209-1266.*

Ayoub, N., P.Y. Le Traon and P. De Mey. (1997) "Combining ERS-1 and Topex/Poseidon data to observe the variable oceanic circulation in the Mediterranean sea", *J. Mar. Sys*, (in press).

Baretta J.W., Ebenhöh W. Ruardij P. (1995). "The European Regional Seas Ecosystem Model, a complex marine ecosystem model". *Neth. J. sea res. 33 (3/4) 233-246*.

Bombace G. (1992). Fisheries of the Adriatic Sea. In: Marine Eutrophication and population Dynamics (G. Colombo Ed.), 379-389.

Carter E. F., 1989 "Assimilation of Lagrangian data into a numerical model". *Dyn. Atmos. Oceans, 13, 335-348.*

Carton J.A, B.S. Grese, X. Cao and L. Miller, 1996. "Impact of altimeter, thermistor and expendable bathithermograph data on retrospective analyses of the tropical Pacific Ocean." *Journ. Geoph. Res., 101(C6), 14147-14159*.

Derber J. And Rosati A. (1989). "A global oceanic data assimilation system." *J. Phys. Oceanogr., 19, 1333-1347.*

Dickey T., 1995. "Critical variables and their observations." *International GLOBEC Numerical Modeling Working Group Meeting, Nantes (FR)*, Unpublished manuscript.

EuroGOOS (1996) The strategy for EuroGOOS. *EuroGOOS Publ*., 1. 132pp.

Ezer T., D.S. Ko and G. L. Mellor ,1992. "Modeling and forecasting the Gulf Stream." In Oceanic and Atmosphere Nowcasting and Forecasting, D.L. Durham and J. K. Lewis ed., Mar. Tchn. Soc. Journal, 26(2), 5-14.

Ezer, T. and G. L. Mellor, 1994. Continuous assimilation of Geosat Altimeter data into a three-dimensional primitive equation Gulf Stream model." *Journ. of Physical Oceanography, 24, 832-847*.

Fasham M. J. R., 1995. "Variations in the seasonal cycle of biological production in subarctic oceans: a model sensitivity analysis." Deep Sea Research, 42(7), 1111-1149.

Fukumori I., and Malanotte Rizzoli, P., 1995 . "An approximate Kalman filter for ocean data assimilation, an example with an idealized Gulf Stream." *Journ. Geoph. Res., 100 (C4), 6777-6793*.

GLOBEC (1997) "Globec Science Plan". GLOBEC Report 9 (IGBP report 40). 82pp.

Golmen, L.G., 1997. EGOS-European Group on Ocean Stations. A continuously operating data buoy programme in the North Atlantic,, 1997. In Operational Oceanography. The challenge for European-cooperation, edited by J.H. Stel, H.W.A. Behrens, J.C. Borst, L.J. Droppert and J.v.d. Meulen, Elsevier Oceanographic series 62, Elsevier, 141-147.

GOOS, 1997. Coastal Module planning Workshop, Univ. of Miami, February 24-28, Report to J-GOOS-IV, 53 pp.

Komen J.G., Cavaleri L., Donelan M., Hasselman K., Hasselman S. and Janssen P.A.E.M., 1994. Dynamics and Modelling of Ocean Waves, Cambridge, Cambridge Univ. Press, P.532.

Lai C.-C., A. Qian, W. G. Scott, 1994. "Data assimilation and model evaluation Experiment datasets"*, Bull. Of Americ. Meteor. Soc., vol. 75, 793-809.*

Latif M., A. Sterl, E. Maier-Reimer and M. M. Junge, 1993. “Structure and predictability of El Ninõ Southern Oscillation phenomenon in a coupled Ocean-Atmosphere general circulation model.” *Journ. of Climate, 6, 700-708*.

McPhaden M.J., 1995. “the Tropical Atmosphere Ocean Array is completed.” *Bull. Americ. Meteor. Soc., vol 76, 5, 739-741*.

Miendl A., 1996. Guide to moored buoys and other ocean data acquisition systems. Data Buoy Co-operation Panel. Technical Document 8. WMO/IOC Geneva.

Millot C. ,1987. Circulation in the Western Mediterranean Sea. *Oceanol. Acta,* 10, 143-149.

Moron V., A. Navarra, N. Ward and E. Roeckner, 1998. “Skill and reproducibility in climate simulations”. *Climate Dynamics, 14,83-100.*

MTP-I ,1996. “Interdisciplinary research in the Mediterranean Sea. A synthesis of scientific results from the Mediterranean targeted Project (MTP) phase I”. *Research in enclosed Sea series-1. EUR 17787*.

Philander, S.G., 1990. “El Ninõ, la Nina, and the Southern Oscillation”. *Academic Press, Vol. 46, International Geophysics Series.*

Pinardi N., G. Korres, A. Lascaratos, V. R. Roussenov E. Stanev (1997). Numerical simulation of the interannual variability of the Mediterranean Sea upper ocean circulation. *Geophys Res.Lett,* 24(4), 425-428.

Pinardi N., P. De Mey, G. Manzella, A. Ruiz de Elvira and the EuroGOOS Mediterranean Test Case Scientific Steering Group, 1997. “The EuroGOOS Mediterranean Test Case: science and implementation plan.” *Operational Oceanography. The challenge for European Co-operation. J. H. Stel and H. W. A. Behrens, J. C. Borst, L. J. Droppert, J. V. D. Henlen, Elsevier Science B. V., 549-557.*

Reynolds, R.~W., 1988. “A real time global sea surface temperature analysis”, J. Climate, 75--86,.

Robinson A. R., 1994. “Physical processes field estimation and an approach to interdisciplinary ocean modelling”. *Earth Sci. Rev., 40, 3-54.*

Robinson A.R., Golnaraghi M., Leslie W.G, Artegiani A., Hecht A., Lazzoni E., Michelato A., Sansone E., Theocharis A., Unluata, U. (1991). The eastern Mediterranean general circulation: Features structure and variability. *Dyn. Atmos. Oceans*, 15, 215-240.

Rossby T, G. Siedler, W. Zenk, 1995.”The volunteer Observing Ship and Future Ocean Monitoring”. *Bull. Am. Meteorol. Soc.*, 76(1), 5.

Roussenov V. M., E. Stanev, V. Artale, N. Pinardi(1995). A seasonal model of the Mediterranean Sea. *J. Geophys. Res., 100(c7), 13515-13538*

Sarmiento J. L., R. D. Slater, M. J. R. Fasham, H. W. Ducklow, J. R. Toggweiler And G. T. Evans, 1993. “A seasonal Three-dimensional ecosystem model of nitrogen cycling in the North Atlantic euphotic zone.” *Global Biogeochemical Cycles, 7, 417-450.*

Smith E. et al., 1996.”Satellite derived Sea Surface Temperature data available from the NOAA/NASA Pathfinder Program”. http://www.agu.org/eos_elec/95274e.html .

Stammer D. and C. Wunsch, 1996. “The determination of large scale circulation of the Pacific Ocean from satellite altimetry using model Green’s function”. *Journal of Geophysical Research, 101(C8), 18409-18432.*

Ward M.N. (1992). Provisionally corrected surface wind data, worldwide ocean-atmosphere surface fields and Sahelian rainfall variability. *J Clim, 5, 454-475.*

Zavatarelli, M., Baretta J. W., J. G. Baretta-Bekker, N. Pinardi (1997) "The dynamics of the Adriatic sea ecosystem. Part I: an idealised model study". Submitted to *Deep Sea Research*.7