I - EXECUTIVE SUMMARY

This synthesis was written by all participants of the workshop under the coordination of Jordi Font. Frédéric Briand, the Monograph Series Editor, reviewed and edited this chapter along with the entire volume, assisted by Valérie Gollino for the physical production process.

1. INTRODUCTION

The Mediterranean, a semi-enclosed, deep and oligotrophic mid-latitude Sea of global importance, is characterized as a "miniature ocean" and an ideal model to study oceanic processes and land-ocean-atmosphere interactions (see previous volumes in CIESM Monographs Series). As known from geological records, the Mediterranean pelagic ecosystem amplifies climatologic signals, particularly temperature, well beyond the response occurring in the global ocean. This remarkable sensitivity make it an ideal test bed for climatic studies.

The Mediterranean Sea is locked into the surrounding European, African and Asian continents, and communicates with their climates. On the basis of our present understanding, it is not clear how the global climate system is projected onto this region of contrasts and transitions between marine and continental climates. There high gradients in physical characteristics and in socio-economics could lead to disproportionately large feedbacks between regional and global climate systems.

Continental shelves in the Mediterranean are non-existent along many stretches of coast, and where they exist, they are specific, such as the Gulf of Lions, Gulf of Gabes – Malta, northern Adriatic, Nile Cone, Gulf of İskenderun, and the Aegean, southern Marmara and western Black Sea regions. The majority of these wide shelf regions are also the confluence regions of large rivers. In the cases of the Black and Caspian Seas, catchments of few large rivers drain adjacent continents. In contrast, numerous catchments of small rivers are confined by mountain ranges along the northern coast of the Mediterranean, while the few rivers on the southern coast have either an episodic (sometimes dramatic) regime, or have their discharges curtailed, such as in the case of the Nile, that contributes lesser and lesser amounts of freshwater compared to the increasing volumes of salty and warmer water flowing through the Suez canal. With impending climate change favouring increased north-south gradients in temperature and precipitation, the specific distribution of water, as well as the unbalance in the rate of increase of coastal populations pose threats to balanced development and sustainable ecosystem services in the Mediterranean.

The Mediterranean Sea is a complex system that requires a multidisciplinary approach to fully understand its functioning and take adequate actions for its preservation. From the mid 1980s international programs began to gather precious time series, notably in the physical and biogeochemical fields, allowing to sketch a first broad outline of Mediterranean dynamics and ecosystems. However, these observations have remained necessarily limited, either by the specificity of the subjects addressed or by the geographical extent of the measuring program. As a result certain scientific disciplines and certain regions have been very poorly represented in this considerably large catalogue of activities.

In recent years several efforts have been done, mainly through international programs, to extend as much as possible these activities to the whole Mediterranean basin and try to answer to hot topics like the spatio-temporal variability at several scales of the interaction between the different components of the Mediterranean environment and ecosystems, or building efficient indicators of the health of our sea. Beyond the longterm, highly selective programs launched by CIESM, illustrative, non-exhaustive examples are European Union funded projects in operational oceanography like MFSTEP, MERSEA and MyOcean, as well as the observational programs like SESAME and those launched by MOON and the thematic network in the MAMA project developed under the framework of MedGOOS. Nowadays, in the context of global change challenges, the need for complete observations of the ocean both in pelagic and deep environments and in vast domains that range from meteorology to fisheries, lead to an increased coordinated activity where many kinds of strategies, from time series of coastal monitoring at marine stations to present and future high-resolution satellite measurements, and from fixed point interdisciplinary permanent observatories to autonomous high-tech sampling devices, are being put in place and considered from the point of view of integrated observing systems.

This 34th CIESM exploratory Workshop gathered specialists from different disciplines and from different regions – some involved in international programs, others running monitoring networks or working in new methodological or technical approaches – to check the state of the art and discuss the possible ways of implementing the concept of an integrated system of marine observatories in the Mediterranean area.

The need to address this subject was first discussed during the 38th CIESM Congress (Istanbul, April 2007) among members of the Committee C2 on Physics and Climate of the Ocean, and considered timely and very relevant to generate a Mediterranean added value within the integrated marine observatories approach, that is increasingly addressed at national and international levels. As a result, following further consultations, seventeen scientists from Italy, France, Spain, Belgium, Cyprus, Greece, Israel, Malta, Turkey and UK, were invited by CIESM to meet for four days, from 16 to 19 January 2008, in La Spezia, Italy.

In welcoming the participants, the Director General of CIESM, Dr Frederic Briand, first expressed his gratitude to the NATO Underwater Research Centre for providing such remarkable meeting facilities. He went on to underline the importance of the workshop theme, at a time when monitoring programs and initiatives – too often disconnected one from another – were multiplying in the region, and when national and European agencies were increasingly turning to CIESM to help develop concerted research strategies in the region. In his view, the harmonization of a multi-sites, multi-platform system of Mediterranean Observatories was not longer utopic but a necessity, as was the mutualization of Mediterranean experimentations, technology tools, and research vessels (as demonstrated by recent CIESM-SUB multidisciplinary campaigns).

Dr Jordi Font, Chair of the Committee C2, followed to present the main Workshop objectives that were two-fold: (a) to analyse from several fields of expertise how the many kinds of physical, chemical, biogeochemical and biological data can be merged to address the key scientific and environmental issues of the Mediterranean Sea relevant to operational oceanography and climate change; and (b) to design what should be the components and optimal strategy for setting up an integrated Mediterranean observatory system suitable for a wide range of scientific and management issues, including climate and global change impacts. During the first two days the workshop participants presented their views and specific examples of observatory activities and networks under implementation. During the last two days they engaged into exploratory, open discussions on the required components of a Mediterranean integrated system of systems. They proposed technical solutions and recommendations for implementation that are described in this Executive Summary.

2. The Integrated Marine Observatory concept in the Mediterranean

The Mediterranean environment, its ecosystems, services and resources are under unprecedented pressure from population explosion, climate change and overexploitation of its living and non-living resources.

Recent observations have revealed unexpected large scale changes including changes to deep ocean circulation, heat and regional climate, accelerating sea level rise, the deterioration in water quality, increasing number of harmful algal blooms and alien species, and the collapse of regional fisheries.

In addition, forecasts of global climate change over the next century are expected to impose dramatic economic, ecological and societal changes in all the 21 countries surrounding the Mediterranean. For example, changes to surface temperature, sea level, storminess, erosion, biodiversity, fisheries, seawater quality will have a profound and in some cases irreversible effects on the environment.

To date even our best observations have been of short duration, regionally confined and ecologically restricted, and thereby limiting in their diagnostic and prognostic power. Feedback mechanisms regulating the connections between climate, circulation and life in the sea, and possible alterations under future climate scenarios are not yet well understood.

From another viewpoint, marine space and resources will remain key assets for competitiveness and economic strength in the Mediterranean. The quest for sustainable development is expected to be more exigent on the intelligent management of the marine environment, to protect the marine ecosystem, minimise the impacts of climate change and anthropogenic influences, and provide wide-ranging benefits. There is an evident evolution in the way that policy undertakings, management of marine resources, coastal planning and efficient marine operations are perceived and implemented. One notes a greater understanding that actions need to be taken on the basis of informed decisions. Hence intelligent support systems, relying on real-time sensing platforms and instant data elaboration, receive increasing attention and wider application in the marine realm.

The latest developments in science and technology are called to meet these demands. Further research in methodology, equipment and analysis of observations, as well as additional, improved and cost-effective long-term monitoring systems for reliable systematic observations are required. This will allow improving the ability to detect, attribute and understand the various processes operating in the Mediterranean – including those affected by climatic changes – in order to reduce uncertainties, improve impact assessments, and predict changes down to local, coastal scales. In particular, the practice of real time monitoring and numerical modeling together with the production of reliable forecast fields needs to incorporate other environmental aspects besides the physical components. The ability to access, share, codify, re-use and transform data into information and knowledge through creation and re-creation, the use of increasingly ramified and complex networks and clusters of distributed activities is already becoming a reality in many sectors. This should also be the shape of things in the marine sector. The advent of multi-disciplinary, spatially widespread, long-term data sets is expected to trigger an unprecedented leap in the economic value of ocean data. This will bring about a radical transformation in our perception of managing marine resources, and will be critical to competitiveness, product development and enhancement of services. The future is pointing towards multi-purpose observing systems, linking marine observations across disciplines, merging data and information on the sea with economical, environmental and social parameters to provide a holistic description of systems in support of an integrated management approach and integrated service-oriented applications in key marine realms and industries as well as for security, safety and enforcement (see EU Blue Paper on an Integrated Maritime Policy, 2007; and contribution by A. Drago, this volume).

The CIESM group of experts concluded that a comprehensive Mediterranean-wide observation system composed of sub-systems to cover appropriate space and time scales, and using multi-parametric and multi-purpose platforms with a new generation of sensors and adaptive sampling capabilities, is needed to provide vital understanding of the oceanic domain. Melded into state-of-the-art 3D-models, such a system would resolve questions about the interconnectivity of ecosystem components, provide a reliable prediction of future changes, and furnish viable mitigation options to sustainably protect and manage the Mediterranean.

The concept of an Integrated Mediterranean Marine Observatory is structured as a system of systems composed of satellite platforms in conjunction with measurements performed by open sea buoys, moorings, ships, drifters profilers and gliders, and coastal systems including networked arrays of meteo-marine sensors (sea level, waves, ADCPs, HF radar beacons). Such a hierarchical design is crucial to optimally monitor and observe the marine environment at appropriate scales, as well as to target the multiple needs of users across a wide spectrum of applications.

From the scientific point of view, the generally narrow shelf areas along most of the Mediterranean basin perimeter expose the coastal hydrodynamic regimes, and subsequently the whole ecosystem dynamics, to the predominant influence and forcing by the open sea and basin scale circulation. This has implications on the ecosystem functioning that is vulnerable to both distant and local signals. On the other hand, the conditioning of water on the shelf areas is known to trigger processes that contribute to control or modify the basin water mass characteristics. Such distinctive Mediterranean features imply that observations in the coastal waters, while essential to address the different needs of customers and to support a wide range of applications in the coastal zone, need to be interconnected to larger scale processes. Indeed they need to be conducted across sub-basins, straits and national jurisdictions over a cascade of geographical scales from the coarse basin configuration, to shelf resolution, and up to coastal detail.

Such a configuration made up of a system of observational sub-systems as shown in Figure 1 will enable to capture information from the basin observations (at spatial scales of ~ Mm and time scales of years, seasons and months, and with special emphasis in the deep sea) down to mesoscale resolution and to the small scale level of deltas, estuaries and harbours (with specific scales of ~ km and time scales of days, hours or minutes). These *in situ* observing system components will be seamlessly linked through numerical models that will be used to meld in the space-derived data, and extract information from the observations to derive added value products and services to the end-users.

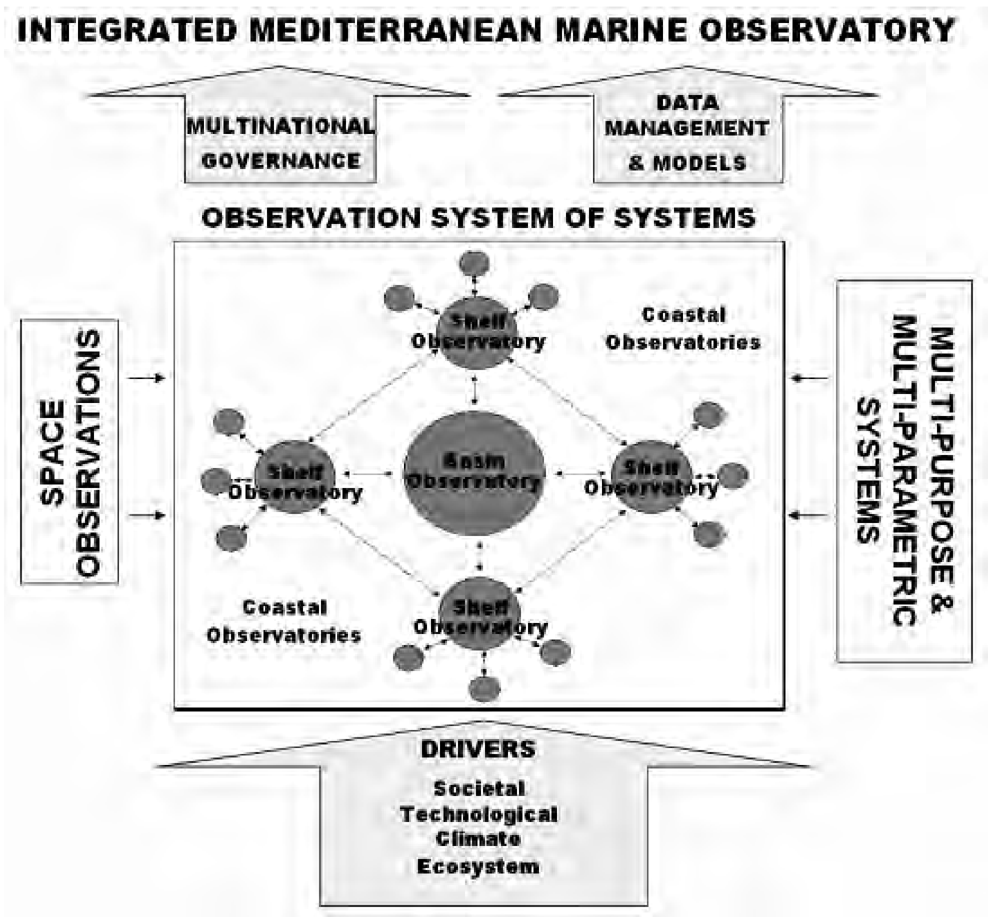

Fig. 1. Schematic design of the Integrated Mediterranean Marine Observatory.

Observations need to be tailor-made to solve problems in the coastal areas that are more often related to the ecology and environmental quality, than just the physics, of the marine environment. Responding to stakeholders' questions on geohazards, fisheries, biodiversity, pollution, etc., will require a better knowledge and understanding of the functioning of the ecosystem, and hence a denser, well-coordinated network of reliable field observations, linked to robust, predictive models.

Satellite observations targeting the coastal areas are an essential component of an integrated system. Coastal and estuarine applications of remote sensing require significantly finer temporal, spatial and spectral resolution compared to open-ocean studies. The answer comes from the use of satellite platforms with a hyper-spectral environmental suite for coastal waters and with complementary payloads of atmospheric sounding sensors. While polar orbiting satellites lack the temporal resolution, geostationary orbiting platforms with a higher number of spectral bands and higher sampling frequencies are necessary to provide the resolution levels required at coastal and estuarine scales.

Furthermore the observational component must be integrated into data management and analysis systems. These will rapidly, systematically acquire, carry out quality control and disseminate marine data with derived products describing the state of the sea in hindcast, nowcast and forecast modes. The challenge to both data providers and users will be the efficient and timely handling of high-volume flows of different types of data. Providers will have to secure the regular delivery of highest quality core data in common standard and user-friendly formats. The marine core service provision will seamlessly access and process different data sources and enable rapid integration and packaging of data sets according to user-defined requests. Reasonable requirements and standards for data applications must be set, using analysis techniques that include multi-spectral classification, geographic information systems and global positioning systems, so as to extract the information required by end-users. At the end of the chain, end-users will be able to exploit marine data and information, addressing both research and operational needs.

3. Observing strategy

The Mediterranean basin has strong peculiarities. The geology, oceanography, geochemistry and biology, the oceanic and coastal regions are intimately interconnected at basin and sub-basin scales and are impacting all forms of life – up to human activities – at short and long time scales. To develop appropriate management strategies, the observational effort has to take into consideration this specificity. In particular, an accurate description of the variability of the boundary coastal currents around the basin and of the meanders and eddies, as well as water characteristics evolution over decades, must form the basis of any observing strategy. The latter shall also integrate the regional characteristics of sub-basins and support the set up of regional observatories. A multi-scale space-resolving time series observation strategy is thus mandatory for the comprehension of the processes in the Mediterranean.

With the recent development of operational oceanography in the Mediterranean, one may expect as is now the case for meteorological products, that operational oceanic products will become routine tools to help understand complex observations of the marine ecosystems. The observing strategy should thus be linked as closely as possible to the operational observing systems, up to a complete integration when relevant (e.g. MedARGO, see below).

As a consequence, a major challenge of the observing strategy is to obtain the right technology in order to acquire all the core parameters (physical, chemical and biological) on *the basis of long time series* with the best cost-efficiency in order to better *support more dedicated observing periods or locations* for specific process-oriented or operational objectives. The Californian Current Ecosystem of the Long Term Ecosystems Research US network (CCE-LTER) is a potential example (<http://cce.lternet.edu>).

The observing strategy should link 1) fixed point long term surveys of deep basins, basin exchanges and coastal areas, 2) autonomous moving platforms, 3) remote sensing and 4) modeling tools. Specific instruments such as coastal HF radars for large area coverage of surface current, ADCP permanent stations or profiling moorings for full vertical profiles at key sites should also be considered. Routine observations and dedicated measurements (episodic campaigns) must be closely coordinated.

These observational techniques have to be considered at three scales:

1) Basin scale, where the core parameters of the water masses must be captured over decades in relation with the dense water formation areas (i.e. temperature, salinity, and a set of routine biogeochemical parameters).

2) Sub-basin/ Regional scales (see below the example "Toward a regional observatory of the North Western Mediterranean sub-basin"), where time series of the above parameters are acquired at deep stations, and where the water mass transports are monitored at mesoscale and between sub-basins.

3) Coastal scales, where the same parameters are acquired together with more specific ones devoted to thematic surveys: zooplankton (see below the example "Monitoring the meso-and macroplankton in the Mediterranean and Black seas"), pollutants, etc. At these three scales, specific attention shall be paid to straits, passages and to some large sections connecting sub-basins so as to enable the adequate temporal sampling of the exchanges between sub-basins. The monitoring of these keys sections is mandatory for keeping track of the propagation of signals and for establishing consistent budgets at basin and sub-basin scale.

Such a strategy will allow the observation of 1) the seasonal and interannual variability, the trends as well as episodic extreme events and of 2) coastal currents and mesoscale features where most of the transport occurs. It will also provide 1) the right flux of data for basin/regional scale "blue" and "green" operational models, 2) the flux of data needed to assess the interannual variability and trends of the ecosystems and 3) the data to support more specific and point observations of parameters such as geo tracers and pollutants.

Observations at the boundaries will not be ignored. Air-sea interaction and atmospheric deposition parameters are to be considered and monitored at deep sea and coastal points. Land-Sea interaction monitoring is essential and should be supported whenever possible by coastal stations. Deep sea floor processes monitoring (ESONET network) including geohazards, coastal sea level monitoring (see paper by Rosen on MedGLOSS, this volume) will also provide *inter alia* essential information to better characterize the fluxes at these boundaries.

In terms of logistics, sharing infrastructures (mainly for deployment, maintenance and data transmission) between sea level, deep sea floor and water column observatories is necessary. Overall the harmonisation of 1) national survey programs (that are already in operation at permanent stations, 2) spatial ship surveys, and 3) information exchange on projects and concerning acquired data sets is essential.

Special attention should be put on data assimilation and predictive modeling that can provide not only the synthesis of the observations on the state and evolution of the marine system but also help define optimal sampling strategies.

Since the remote sensing activity is supported by national and European centers, while *in situ* observations are mainly supported at a more regional or local level (note that the operational modeling activity is an intermediate situation), CIESM could play a most useful role by facilitating the links between the data providers at all levels, the modelers, especially in operational centers, and the various users.

3.1 Deep sites for fixed long term surveys

In the context of recent national and international programs (see for example papers by Gasparini *et al*., this volume; Delfanti, this volume; Papathanassiou, this volume), a set of deep stations, covering key areas of the Mediterranean, have been identified for long term monitoring.

a - These should be equipped with moored instruments and be visited as often as possible with shipborne instrumentation. A unifying perspective could be the profiling moorings that are now becoming technologically feasible for deep environment (Ocean Observatories Initiative, 2007). These main stations will provide the biogeochemical database characterizing the different basins and their long-term evolution. Other 'lighter' stations will provide the database on the evolution of the hydrography of deep waters (e.g. CIESM HYDROCHANGE Program, see below).

b - These stations should be also visited periodically by autonomous platforms (gliders, AUVs). Gliders are also suitable to act as virtual moorings at these fixed stations, thus providing continuous profiles, a cheap alternative to ship surveys and profiling moorings.

c - CIESM should continue to encourage the operation of deep-sea monitoring stations and the development of new stations that have been identified.

3.2 Coastal permanent stations

There is a large variety of monitoring initiatives in the coastal areas, with different objectives (research, monitoring, pollution control, etc.) and a variety of supporting institutions (research laboratories, environmental agencies, ministries, local authorities, etc.).

a - Activity of the coastal permanent sampling stations should be encouraged, standardized and networked.

b - Thematic networks should be implemented, taking advantage of the existing ones (for ex. CIESM Mediterranean Mussel Watch, Mediterranean Zooplankton Indicators). Some of the laboratories running the permanent stations could constitute nodes for specific sample treatment (i.e. zooplankton) and for the moving platform assistance.

3.3 Autonomous moving platforms

Fleets of autonomous underwater vehicles (profilers, gliders and propelled UVs) are a new promising – and relatively low cost – perspective for research in the field of ocean dynamics and marine biogeochemistry as well as for operational oceanography (see paper by Mortier and Testor, this volume).

a - Actual observational efforts using profiling floats of the MedARGO/EuroARGO program should be maintained and developed toward the acquisition of basic biogeochemical parameters (O2, turbidity and fluorescence signals). Surface drifters surveys should also be maintained as they provide very useful and low cost information on Lagrangian transport and sea surface parameters.

b - Operational use of gliders and AUVs for mesoscale studies at regional and basin scale and the integration of new sensors should be stimulated.

c - Data assimilation and modeling activities should be strongly encouraged to better dimension the profilers and gliders networks.

3.4 Remote sensing

a - Data management should rely as much as possible on existing data centers and support a better dissemination of the information.

b - The additional treatment concerning Mediterranean specificities (altimetry, ocean color, etc.) should be managed in dedicated centers, with the end products made easily available to all users.

3.5 Voluntary observing ships

a - Some basin-wide regular commercial lines should be equipped with 'FerryBox' type units for the acquisition of surface parameters. A specific effort should be made toward the acquisition of current (ADCP) along lines suitable to monitor the exchanged transport between sub-basins. Other complementary sensors (biochemistry, atmosphere, aerosols, etc.) could be added at a moderate cost.

b - Secondary lines equipped with smaller units for basic surface parameters should be developed at regional scales (see example of CIESM TRANSMED program in paper by Taupier-Letage, this volume).

3.6 Multidisciplinary cruises

a - Information on multidisciplinary oceanographic cruises should be diffused as soon as established at national levels in order to harmonise activities.

b - Transits of research vessels should be optimized, with towed bodies (CPR, etc.), continuous onboard sampling (echosounders, thermosalinometers, flow cytometers, fluorometers, etc).

3.7 General recommendations

a - Some regions are presently lacking coastal permanent or regional observatories. It is hoped that relevant projects in such areas will be initiated by concerned local laboratories, with the cooperation of foreign laboratories and the harmonization of CIESM with regard to the overall monitoring regional strategy.

Example 1: Toward a regional observatory of the North Western Mediterranean sub – basin.

This example is largely generic as similar processes occur in other sub-basins (Adriatic, Aegean, Levantine, etc.). Obviously the strategy will be adapted to the specific topology of each region.

Due to the wind and heat forcings from the atmosphere as well as to the inflow of Atlantic water (AW), the circulation in the North Western Mediterranean basin displays a permanent Northern Current (NC) flowing westward along slope from the Gulf of Genoa further than the Balearic sub-basin. Part of these water masses recirculates in the south of the sub-basin from the Balearic Islands back to Corsica. In the centre, mainly off the Gulf of Lions, deep convection occurs in winter and plays a major role in shaping the Mediterranean thermohaline circulation.

This area has been extensively investigated since the 1960s with hydrological surveys, moorings equipped with current meters and even high resolution acoustic tomography arrays. At the central part of the Ligurian sub-basin, the DYFAMED is one of the world longest biogeochemical observation time series. Despite these long-lasting observational efforts, a permanent monitoring at the sub-basin scale at the right temporal and spatial scales is still a challenge.

Coordination of some scientists, laboratories and agencies is now taking place to build this permanent observatory which provisional name is “Mediterranean Ocean Observation Site on Environment” (MOOSE) (see Figure 2). The backbone of this observatory could be two deep moorings, one at the centre of the convection area, the other at the DYFAMED point in order to maintain the continuity of this existing 25 year-long time series. Due to their operating range, gliders are perfectly suited to survey with high frequency so called “Endurance lines” between the coast and these moorings. Other glider lines would extend the hydrological survey at the scale of the whole sub-basin and monitor the exchanges through the North Balearic front south of this region. Periodic hydrographical ship borne surveys at the sub-basin scale and across the boundaries of this region should provide the missing data to better constrain budgets. This should include the monitoring in narrow passages based on moorings like in the Corsican Channel. The activity of the many coastal stations (from La Spezia in Italy to Mallorca Island) has to be harmonised as mentioned above and should in particular help to better characterise the input from land by rivers and atmospheric deposition.

Example 2: Monitoring the meso-and macroplankton in the Mediterranean and Black Seas

Zooplankton is considered a good indicator of climate related ecosystem changes because:

a- Mesozooplankton (about 0.1-2cm body length) are a key link between primary producers and larger predators;

b - They are abundant, and can be quantified by relatively simple and intercomparable sampling methods;

c - Life cycles of most species range from a few months to one year;

d - Changes in population size are rapid enough to track seasonal-to-interannual changes in environmental conditions;

e - As few zooplankton taxa are fished, most zooplankton population changes can be attributed to environmental causes;

f - Many commercial fish are dependent on a zooplankton food source during their pre-recruit life history stages.

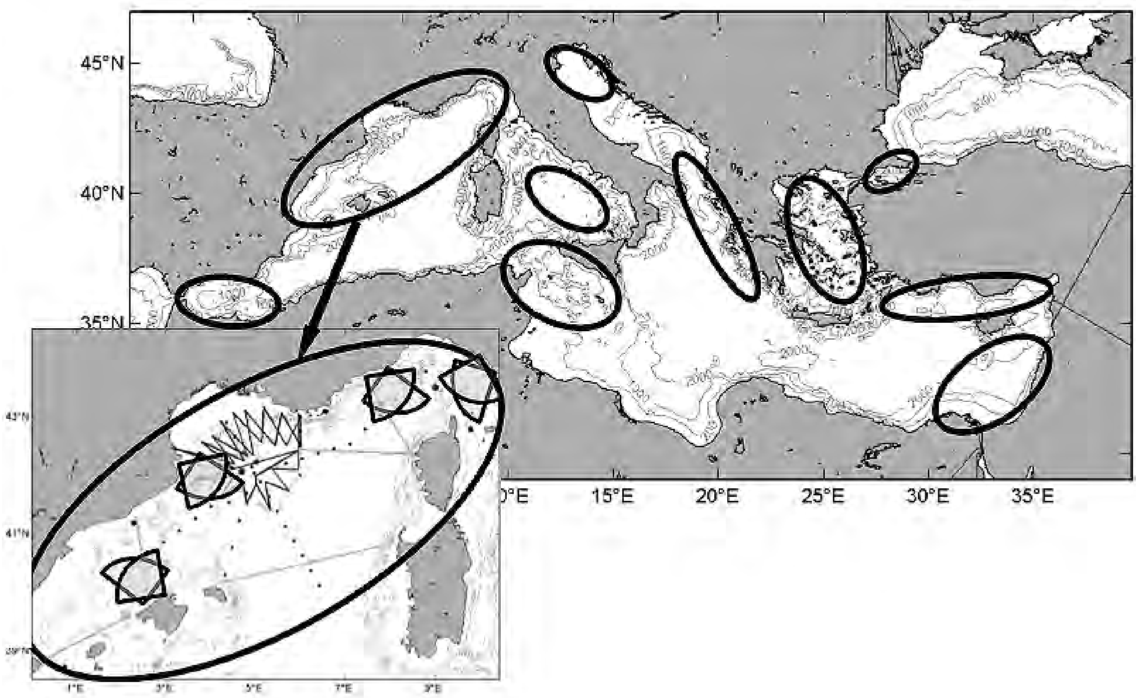

Fig. 2. Key regional components of an Integrated Mediterranean Marine Observatory: areas where integrated regional observatories are in development or that require special attention due to their significant role in the functioning of the basin-wide marine system. The box on bottom shows the sampling strategy for one of these components: Red and blue dots are permanent deep moorings, green lines are continuous gliders surveys, blue lines are gliders surveys oriented toward a specific process (here the meandering of the Northern Current and the deep water formation area), blue fan shaped symbols are HF radars stations and black dotted lines are seasonal R/V hydrographic surveys. Due in particular to tidal effects and to marine traffic constraints, observatories encompassing narrow straits may include specific components or strategies. Note that coastal stations are not shown here (see <http://www.ciesm.org/marine/programs/index.htm>), but are essential components of each regional observatory.

Consequently, anomalies in zooplankton evolution in time may be useful leading indicator for commercial fish stocks evolution (Batchelder *et al*., 2002 and Beaugrand *et al*., 2003). Furthermore, changes in zooplankton biogeography and changes in long term trends provide an important tool for examining climate-ecosystem interactions. Between-region comparisons allow a better comprehension of causal mechanisms and consequences of the physical forcing on marine food chains. In the North-western Mediterranean the long-term variability of different zooplankton functional groups seems to be linked to changes of climate forcing of the North Atlantic sector. Large-scale climate forcing has altered the pelagic food-web dynamics through changes in biological interactions, competition and predation, leading to substantial changes in zooplankton populations, which peaked in 1986-87 and are considered by some as a regime shift in the North-western Mediterranean (Molinero *et al*., 2008).

Monitoring of meso- and macroplankton should thus form an important component of the initiative to create a system of Integrated Mediterranean Observatories. The Zooplankton Indicators Program, initiated in October 2005 by CIESM (see paper by Gorsky, this volume), and now backed up by 17 laboratories from 14 countries that undertake regular zooplankton sampling with increasing use of the ZOOSCAN methodology for processing, will naturally play a structural role in this development.

4. Technical solutions

Solutions for an effective Integrated Marine Observatory concept implementation should rely on multi-purpose, multi-scale, intelligent, adaptive, automated, network enabled, inter-operable low cost, low maintenance technologies. Most criteria are mandatory in an operational oceanography framework but also translate into optimized resources for climate research on the long-term.

Operational oceanography networks are now routinely collecting *in situ* and remote sensing data. Remote sensing data offer regular depiction of the sea surface while *in situ* data provide full water column scarce spatial information. European Marine observatories are integrated within dedicated networks. Efforts should be made to integrate or harmonize as much as possible the development of observatories in other Mediterranean countries with existing networks.

To this end regional efforts on the integration of marine observations need to be consolidated through capacity building and technology transfer efforts. Numerous specific national observatories and local research institutes exist and should be better interconnected and connected into wider networks.

The scientific community is now getting organized at many levels by dedicated infrastructure developments and regular technology watch should become a standard activity of a future Integrated Marine Observatory in the Mediterranean.

The ocean environment is by definition hostile to sensors and there is room for improvements on many issues. Bio-fouling limit the period that an instrument can stay in the water and anti-fouling paints are usually not environment friendly. Except for cabled systems, usual platforms have a limited lifetime which new kinds of batteries (e.g. capacitor, fuel cells) could extend significantly. Artificial intelligent sensors may optimize idle modes, trigger specific sampling patterns, and report malfunctioning. Increased storage capacities and communications have decreased the recovery/redeployment rate of moorings. A new generation of nanonutrients detection sensors is undergoing tests. New developments on underwater positioning systems, acoustic, optical and magnetic communications, and inductive battery recharging are expected in the near future. Nanotechnologies will also decrease the energy demand of miniaturized optical and geo-chemical sensors (micro arrays, cameras, flow-cytometry, green-house gas detection, etc.). The number of expert taxonomists around the Mediterranean is rapidly decreasing, especially in some regions, and this will only partially be compensated by emerging molecular techniques.

The integration of multi-platform multi-sensor data will be critical to a successful observatory system. Cooperative behavior and fleet mission planning tools for autonomous platforms will greatly enhance the effectiveness of monitoring and require the definition of international standards to be inter-operable. Sensor inter-calibration could jeopardize a whole experiment and requires utmost attention. Data management may be centralized or distributed depending on the end-user requirements but has to cope with increased volume and diversity of data of different kind. Automatic sensor calibration, data quality check procedures and techniques with only limited human intervention should be preferred. Grid computing, data mining techniques and new multi-dimensional visualization tools will offer new ways to look at complex data sets and modeling products, which should be disseminated on the world-wide web using user-friendly tools.

Remote sensing also offers great promises with new salinity and gravimetric sensors. More sensors are to be expected in the future.

Modeling techniques allow filling in the 4D spatio-temporal box at both operational and climatic scales that are otherwise impossible with monitoring-only techniques. Interactions between modeling and monitoring must be enhanced in order to develop coupled hydrodynamic-ecosystem based management models.

Data assimilation techniques merging both *in situ* and remote sensing of information have improved prediction skills significantly in recent years but a number of critical shortfalls in our understanding of error covariances still need to be addressed. Uncertainties derived from model-data fusion may be directly exploited for cost-effective monitoring in adaptive sampling strategies.

5. Implementation of an efficient system of systems

From a practical point of view, the Integrated Marine Observatory concept will have to be implemented in the Mediterranean as a coordinated network of complementary observatories.

Conceptual design of the observatory network

The Mediterranean is a mosaic of geographical, political, social, physical and ecological sub-domains with much diversity and contrasts. The integrated marine observatory must account for these contrasts, and yet be flexible enough to address observational needs concurrently and also in sufficient detail. Only with the collective goodwill and efforts of scientists, oceanographic institutions and governments within the Mediterranean and Black Seas region will such a coordinated action be able to achieve its goals. The tightly coordinated, but non-hierarchically organized, network of observatories shall be based on existing and new facilities, taking into account the available means of countries bordering the Mediterranean. Through its multiple interfaces with riparian governments, with scientists and the research institutions of the whole Mediterranean region, CIESM is considered to be the key body to promote and facilitate this initiative.

Coordination of existing and future initiatives

Scientific objectives form the core of marine observatories but, as is the case for meteorological networks, will coexist with monitoring duties that are carried out by governments and other authorities. Thus, the contemplated structure of the Integrated System of Mediterranean Marine Observatories must draw its strength from the existing marine research community and institutions able to draw upon wide-scale public support and funding, but must also further expand and consolidate to cover modern means of concurrent, key observations spanning the entire basin.

Establishing priority actions

Among the activities required in priority for the establishment of an Integrated System of Mediterranean Marine Observatories, the participants listed:

a. Survey all Mediterranean monitoring bodies and consolidate the existing metadata bases (SeaDataNet, NODCs, etc.) for all the relevant marine fields (physical, geological, chemical and biological) for the Mediterranean and Black Seas.

b. Determine the missing or poorly covered areas, together with strategic key sites, and continue monitoring well-known key places (such as repeated transects across current or deep hydrographical stations), to detect/identify there what is anomalous, and because long term time series are the only data sets that allow evidencing climatic (weak signal) trends.

c. Prepare coordinated proposals for upgrading and/or acquiring new monitoring equipment, and for including new members (institutes or countries) that will join existing or emerging programs.

d. Identify synergies and common parameters for the monitoring activities of the system of systems, integrating relevant activities of all riparian countries.

Basin wide–involving also Southern and Eastern Mediterranean countries scientists

The basin-wide character is obviously essential to the success of an integrated system. Most of problems addressed above require coverage by a Basin-wide network of observatories, and so it is fundamental to involve scientists and institutions from all riparian countries. The participation of groups from the southern and eastern shores will need to be enhanced by logistic assistance from international organizations, and by capacity-building initiatives among the Mediterranean scientific community.

Initially the observatory system – and the actions conducted within that frame – should be focused on routine actions/measurements. Meaning that observations are basic, regular, low cost or cost-efficient. Then they will be extended to the southern and eastern countries, setting an homogeneous network at the Mediterranean scale. In parallel, observation sites or platforms better instrumented will carry on with innovative sensors/developments.

To reach full scale, the Mediterranean observatory system will require a minimum configuration for the various observation actions/fields, and a guaranty that the North African coast countries get both the instruments and capacity training to use/deploy them. They in turn should provide the manpower (and the shiptime if required), plus the recurrent cost for maintenance/turn-over.

Another example of cooperation – currently tested by the CIESM transMED Program - would be to have these countries operate a line of ferry/cargo equipped with a (nearly autonomous) thermosalinometer. The difficulty here is to find the adequate technical staff to make such installations. However, when lines link different countries, part of the maintenance work can be shared between them so as to optimize the existing human resources. An observational network runs with shared tasks

An effective cooperation at intra-Mediterranean governmental level will be the adequate framework to address current diplomatic problems, like sampling (e.g. allow for drifting autonomous instruments) in claimed Exclusive Economic Zones that can seriously handicap global monitoring activities in the Mediterranean.

Funding considerations

Funding must ensure that the overall system will run for at least 10 years – and more generally aim for a monitoring system over climatological scales (several decades minimum). It is foreseen that it should be designed similarly to that of the meteorological community.

6. Workshop recommendations

6.1. Essential features of the observatory system

The main recommendations detailed in the previous sections and arising from several of the workshop presentations included in this monograph, are summarised below in a synthesised form.

A Mediterranean marine observatory shall be an **integrated** system of systems in the sense that it will:

- Comprehend the entire Mediterranean ecosystem;
- Incorporate the distribution and time scales of processes ranging from bacteria to basins and be contiguous between Mediterranean sub-regions and boundaries;
- Apply state-of-the-art sensor technologies and numerical modeling tools;
- Focus on key strategic outcomes relevant to stakeholders;
- Adopt an open strategy to absorb the diversity of skills and facilities present in all nations;
- Federate, harmonise and exchange the most effective of existing observational activities;
- Archive past and log future observations into a common Mediterranean database to ensure sustainability of knowledge.

To attain its objectives a future integrated system must necessarily

- Cover the whole Mediterranean basin, offshore and coastal zones, surface and deep sea;
- Include as main strategic components:
    - Selected deep sites for fixed long term surveys (water column, seafloor processes);
    - Permanent coastal stations, covering the different typologies of coastal and shelf systems (deltas, eroding coasts, cities, freshwater discharges);
    - Autonomous moving platforms;
    - Remote sensing information;
    - Voluntary observing ships equipped with standard packages;
    - Coordinated multidisciplinary cruises;
    - Modeling tools to increase capabilities in optimized sampling planning, data assimilation and prediction;
    - Efficient dissemination and organisation of the information.
- Consider the basin scale, sub-basin/regional scales and coastal scales;
- Measure exchanges at Gibraltar, at the entrance of the Suez canal and with the Black Sea;
- Monitor the sites of dense water formation, major heat transfer and main straits and channels;
- Harmonise the present and future national/regional survey programs by establishing core parameters to be measured with homogenised methodologies;

- Rely on the potential of existing programs/observatories; identify main gaps, propose solutions and implement agreements with local institutions;
- Establish links with meteorological and hydrological-continental networks, as well as with operational oceanography centers;
- Be structured, and consequently funded, as a permanent activity to last for decades, including the adequate provision of technical staff.

6.2 Priority actions

From a technical and logistical perspectives the following actions are recommended:

- Technology watch on concepts, sensors, systems and modeling;
- Promote the use of autonomous devices, real-time data transmission and 2-ways communications with platforms for intelligent sampling;
- Propose robust, cost-efficient, basic sampling methodologies able to be implemented as the observatories network backbone in all countries and Mediterranean sub-basins;
- Pooling of sensors, platforms and sharing any kind of infrastructures;
- Coordination of ship time around the Mediterranean;
- Better Navy-Civilian activities coordination;
- Coordination of inter-calibration efforts. Organise a CTD calibration site in the Mediterranean;
- Identification, definition and adoption of standards (including units, accuracy) of parameters;
- Promote the consolidation and coordination of observatories technical staff (permanent formation, sharing experiences, etc.);
- User-friendly dissemination of data and adequate global data banking and quality control capability;
- Transfer of technologies to all countries of the Mediterranean basin through dedicated capacity building;
- Leverage on uncertainties from model-data fusion for cost-effective monitoring;
- Build on public awareness for efficient monitoring (e.g. alert system for jelly fish, red tides, macro algae, etc.);
- Develop coupled hydrodynamic-ecosystem based management models.

The group of experts considers that CIESM can play a fundamental role in making the Integrated Marine Observatory strategy in the Mediterranean a consolidated reality. By encouraging the continuation and harmonization of existing open sea monitoring stations. By raising awareness on missing components of the global system of systems. By proposing network priorities, supporting the standardisation of newly designed observatories, ensuring links between the different data providers (*in situ* and remote sensing) and all the Mediterranean users. By supporting training activities and the upgrade of technical capacities. By using the CIESM portal to diffuse information on the activities of the Mediterranean marine observatory system and main findings. By promoting collaboration between the coastal countries, the relevant agencies and within the Mediterranean research community, for the transfer of knowledge and efforts to key understudied areas.

I - Executive Summary

This synthesis was written by all participants of the workshop under the coordination of Jordi Font. Frédéric Briand, the Monograph Series Editor, reviewed and edited this chapter along with the entire volume, assisted by Valérie Gollino for the physical production process.

1. Introduction

The Mediterranean, a semi-enclosed, deep and oligotrophic mid-latitude Sea of global importance, is characterized as a "miniature ocean" and an ideal model to study oceanic processes and land-ocean-atmosphere interactions (see previous volumes in CIESM Monographs Series). As known from geological records, the Mediterranean pelagic ecosystem amplifies climatologic signals, particularly temperature, well beyond the response occurring in the global ocean. This remarkable sensitivity make it an ideal test bed for climatic studies.

The Mediterranean Sea is locked into the surrounding European, African and Asian continents, and communicates with their climates. On the basis of our present understanding, it is not clear how the global climate system is projected onto this region of contrasts and transitions between marine and continental climates. There high gradients in physical characteristics and in socio-economics could lead to disproportionately large feedbacks between regional and global climate systems.

Continental shelves in the Mediterranean are non-existent along many stretches of coast, and where they exist, they are specific, such as the Gulf of Lions, Gulf of Gabes – Malta, northern Adriatic, Nile Cone, Gulf of İskenderun, and the Aegean, southern Marmara and western Black Sea regions. The majority of these wide shelf regions are also the confluence regions of large rivers. In the cases of the Black and Caspian Seas, catchments of few large rivers drain adjacent continents. In contrast, numerous catchments of small rivers are confined by mountain ranges along the northern coast of the Mediterranean, while the few rivers on the southern coast have either an episodic (sometimes dramatic) regime, or have their discharges curtailed, such as in the case of the Nile, that contributes lesser and lesser amounts of freshwater compared to the increasing volumes of salty and warmer water flowing through the Suez canal. With impending climate change favouring increased north-south gradients in temperature and precipitation, the specific distribution of water, as well as the unbalance in the rate of increase of coastal populations pose threats to balanced development and sustainable ecosystem services in the Mediterranean.

The Mediterranean Sea is a complex system that requires a multidisciplinary approach to fully understand its functioning and take adequate actions for its preservation. From the mid 1980s international programs began to gather precious time series, notably in the physical and biogeochemical fields, allowing to sketch a first broad outline of Mediterranean dynamics and ecosystems. However, these observations have remained necessarily limited, either by the specificity of the subjects addressed or by the geographical extent of the measuring program. As a result certain scientific disciplines and certain regions have been very poorly represented in this considerably large catalogue of activities.

In recent years several efforts have been done, mainly through international programs, to extend as much as possible these activities to the whole Mediterranean basin and try to answer to hot topics like the spatio-temporal variability at several scales of the interaction between the different components of the Mediterranean environment and ecosystems, or building efficient indicators of the health of our sea. Beyond the longterm, highly selective programs launched by CIESM, illustrative, non-exhaustive examples are European Union funded projects in operational oceanography like MFSTEP, MERSEA and MyOcean, as well as the observational programs like SESAME and those launched by MOON and the thematic network in the MAMA project developed under the framework of MedGOOS. Nowadays, in the context of global change challenges, the need for complete observations of the ocean both in pelagic and deep environments and in vast domains that range from meteorology to fisheries, lead to an increased coordinated activity where many kinds of strategies, from time series of coastal monitoring at marine stations to present and future high-resolution satellite measurements, and from fixed point interdisciplinary permanent observatories to autonomous high-tech sampling devices, are being put in place and considered from the point of view of integrated observing systems.

This 34th CIESM exploratory Workshop gathered specialists from different disciplines and from different regions – some involved in international programs, others running monitoring networks or working in new methodological or technical approaches – to check the state of the art and discuss the possible ways of implementing the concept of an integrated system of marine observatories in the Mediterranean area.

The need to address this subject was first discussed during the 38th CIESM Congress (Istanbul, April 2007) among members of the Committee C2 on Physics and Climate of the Ocean, and considered timely and very relevant to generate a Mediterranean added value within the integrated marine observatories approach, that is increasingly addressed at national and international levels. As a result, following further consultations, seventeen scientists from Italy, France, Spain, Belgium, Cyprus, Greece, Israel, Malta, Turkey and UK, were invited by CIESM to meet for four days, from 16 to 19 January 2008, in La Spezia, Italy.

In welcoming the participants, the Director General of CIESM, Dr Frederic Briand, first expressed his gratitude to the NATO Underwater Research Centre for providing such remarkable meeting facilities. He went on to underline the importance of the workshop theme, at a time when monitoring programs and initiatives – too often disconnected one from another – were multiplying in the region, and when national and European agencies were increasingly turning to CIESM to help develop concerted research strategies in the region. In his view, the harmonization of a multi-sites, multi-platform system of Mediterranean Observatories was not longer utopic but a necessity, as was the mutualization of Mediterranean experimentations, technology tools, and research vessels (as demonstrated by recent CIESM-SUB multidisciplinary campaigns).

Dr Jordi Font, Chair of the Committee C2, followed to present the main Workshop objectives that were two-fold: (a) to analyse from several fields of expertise how the many kinds of physical, chemical, biogeochemical and biological data can be merged to address the key scientific and environmental issues of the Mediterranean Sea relevant to operational oceanography and climate change; and (b) to design what should be the components and optimal strategy for setting up an integrated Mediterranean observatory system suitable for a wide range of scientific and management issues, including climate and global change impacts. During the first two days the workshop participants presented their views and specific examples of observatory activities and networks under implementation. During the last two days they engaged into exploratory, open discussions on the required components of a Mediterranean integrated system of systems. They proposed technical solutions and recommendations for implementation that are described in this Executive Summary.

2. The Integrated Marine Observatory concept in the Mediterranean

The Mediterranean environment, its ecosystems, services and resources are under unprecedented pressure from population explosion, climate change and overexploitation of its living and non-living resources.

Recent observations have revealed unexpected large scale changes including changes to deep ocean circulation, heat and regional climate, accelerating sea level rise, the deterioration in water quality, increasing number of harmful algal blooms and alien species, and the collapse of regional fisheries.

In addition, forecasts of global climate change over the next century are expected to impose dramatic economic, ecological and societal changes in all the 21 countries surrounding the Mediterranean. For example, changes to surface temperature, sea level, storminess, erosion, biodiversity, fisheries, seawater quality will have a profound and in some cases irreversible effects on the environment.

To date even our best observations have been of short duration, regionally confined and ecologically restricted, and thereby limiting in their diagnostic and prognostic power. Feedback mechanisms regulating the connections between climate, circulation and life in the sea, and possible alterations under future climate scenarios are not yet well understood.

From another viewpoint, marine space and resources will remain key assets for competitiveness and economic strength in the Mediterranean. The quest for sustainable development is expected to be more exigent on the intelligent management of the marine environment, to protect the marine ecosystem, minimise the impacts of climate change and anthropogenic influences, and provide wide-ranging benefits. There is an evident evolution in the way that policy undertakings, management of marine resources, coastal planning and efficient marine operations are perceived and implemented. One notes a greater understanding that actions need to be taken on the basis of informed decisions. Hence intelligent support systems, relying on real-time sensing platforms and instant data elaboration, receive increasing attention and wider application in the marine realm.

The latest developments in science and technology are called to meet these demands. Further research in methodology, equipment and analysis of observations, as well as additional, improved and cost-effective long-term monitoring systems for reliable systematic observations are required. This will allow improving the ability to detect, attribute and understand the various processes operating in the Mediterranean – including those affected by climatic changes – in order to reduce uncertainties, improve impact assessments, and predict changes down to local, coastal scales. In particular, the practice of real time monitoring and numerical modeling together with the production of reliable forecast fields needs to incorporate other environmental aspects besides the physical components. The ability to access, share, codify, re-use and transform data into information and knowledge through creation and re-creation, the use of increasingly ramified and complex networks and clusters of distributed activities is already becoming a reality in many sectors. This should also be the shape of things in the marine sector. The advent of multi-disciplinary, spatially widespread, long-term data sets is expected to trigger an unprecedented leap in the economic value of ocean data. This will bring about a radical transformation in our perception of managing marine resources, and will be critical to competitiveness, product development and enhancement of services. The future is pointing towards multi-purpose observing systems, linking marine observations across disciplines, merging data and information on the sea with economical, environmental and social parameters to provide a holistic description of systems in support of an integrated management approach and integrated service-oriented applications in key marine realms and industries as well as for security, safety and enforcement (see EU Blue Paper on an Integrated Maritime Policy, 2007; and contribution by A. Drago, this volume).

The CIESM group of experts concluded that a comprehensive Mediterranean-wide observation system composed of sub-systems to cover appropriate space and time scales, and using multi-parametric and multi-purpose platforms with a new generation of sensors and adaptive sampling capabilities, is needed to provide vital understanding of the oceanic domain. Melded into state-of-the-art 3D-models, such a system would resolve questions about the interconnectivity of ecosystem components, provide a reliable prediction of future changes, and furnish viable mitigation options to sustainably protect and manage the Mediterranean.

The concept of an Integrated Mediterranean Marine Observatory is structured as a system of systems composed of satellite platforms in conjunction with measurements performed by open sea buoys, moorings, ships, drifters profilers and gliders, and coastal systems including networked arrays of meteo-marine sensors (sea level, waves, ADCPs, HF radar beacons). Such a hierarchical design is crucial to optimally monitor and observe the marine environment at appropriate scales, as well as to target the multiple needs of users across a wide spectrum of applications.

From the scientific point of view, the generally narrow shelf areas along most of the Mediterranean basin perimeter expose the coastal hydrodynamic regimes, and subsequently the whole ecosystem dynamics, to the predominant influence and forcing by the open sea and basin scale circulation. This has implications on the ecosystem functioning that is vulnerable to both distant and local signals. On the other hand, the conditioning of water on the shelf areas is known to trigger processes that contribute to control or modify the basin water mass characteristics. Such distinctive Mediterranean features imply that observations in the coastal waters, while essential to address the different needs of customers and to support a wide range of applications in the coastal zone, need to be interconnected to larger scale processes. Indeed they need to be conducted across sub-basins, straits and national jurisdictions over a cascade of geographical scales from the coarse basin configuration, to shelf resolution, and up to coastal detail.

Such a configuration made up of a system of observational sub-systems as shown in Figure 1 will enable to capture information from the basin observations (at spatial scales of ~ Mm and time scales of years, seasons and months, and with special emphasis in the deep sea) down to mesoscale resolution and to the small scale level of deltas, estuaries and harbours (with specific scales of ~ km and time scales of days, hours or minutes). These *in situ* observing system components will be seamlessly linked through numerical models that will be used to meld in the space-derived data, and extract information from the observations to derive added value products and services to the end-users.

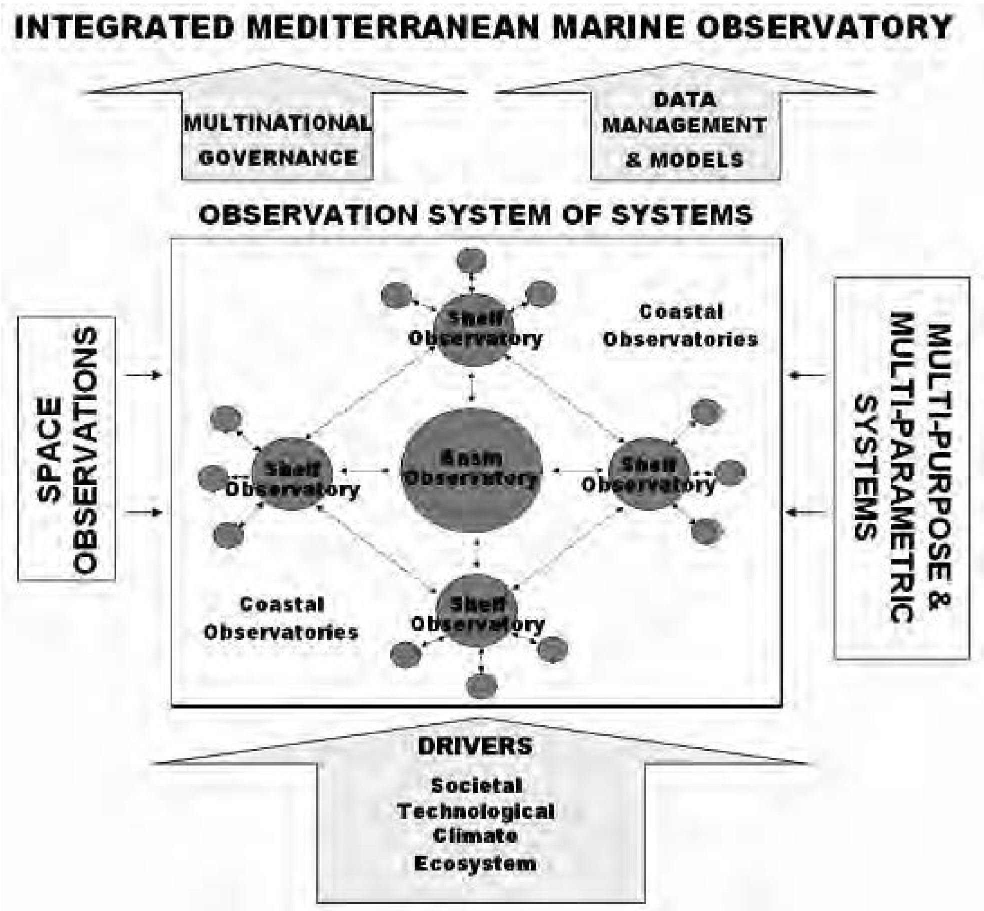

Fig. 1. Schematic design of the Integrated Mediterranean Marine Observatory.

Observations need to be tailor-made to solve problems in the coastal areas that are more often related to the ecology and environmental quality, than just the physics, of the marine environment. Responding to stakeholders' questions on geohazards, fisheries, biodiversity, pollution, etc., will require a better knowledge and understanding of the functioning of the ecosystem, and hence a denser, well-coordinated network of reliable field observations, linked to robust, predictive models.

Satellite observations targeting the coastal areas are an essential component of an integrated system. Coastal and estuarine applications of remote sensing require significantly finer temporal, spatial and spectral resolution compared to open-ocean studies. The answer comes from the use of satellite platforms with a hyper-spectral environmental suite for coastal waters and with complementary payloads of atmospheric sounding sensors. While polar orbiting satellites lack the temporal resolution, geostationary orbiting platforms with a higher number of spectral bands and higher sampling frequencies are necessary to provide the resolution levels required at coastal and estuarine scales.

Furthermore the observational component must be integrated into data management and analysis systems. These will rapidly, systematically acquire, carry out quality control and disseminate marine data with derived products describing the state of the sea in hindcast, nowcast and forecast modes. The challenge to both data providers and users will be the efficient and timely handling of high-volume flows of different types of data. Providers will have to secure the regular delivery of highest quality core data in common standard and user-friendly formats. The marine core service provision will seamlessly access and process different data sources and enable rapid integration and packaging of data sets according to user-defined requests. Reasonable requirements and standards for data applications must be set, using analysis techniques that include multi-spectral classification, geographic information systems and global positioning systems, so as to extract the information required by end-users. At the end of the chain, end-users will be able to exploit marine data and information, addressing both research and operational needs.

3. Observing strategy

The Mediterranean basin has strong peculiarities. The geology, oceanography, geochemistry and biology, the oceanic and coastal regions are intimately interconnected at basin and sub-basin scales and are impacting all forms of life – up to human activities – at short and long time scales. To develop appropriate management strategies, the observational effort has to take into consideration this specificity. In particular, an accurate description of the variability of the boundary coastal currents around the basin and of the meanders and eddies, as well as water characteristics evolution over decades, must form the basis of any observing strategy. The latter shall also integrate the regional characteristics of sub-basins and support the set up of regional observatories. A multi-scale space-resolving time series observation strategy is thus mandatory for the comprehension of the processes in the Mediterranean.

With the recent development of operational oceanography in the Mediterranean, one may expect as is now the case for meteorological products, that operational oceanic products will become routine tools to help understand complex observations of the marine ecosystems. The observing strategy should thus be linked as closely as possible to the operational observing systems, up to a complete integration when relevant (e.g. MedARGO, see below).

As a consequence, a major challenge of the observing strategy is to obtain the right technology in order to acquire all the core parameters (physical, chemical and biological) on *the basis of long time series* with the best cost-efficiency in order to better *support more dedicated observing periods or locations* for specific process-oriented or operational objectives. The Californian Current Ecosystem of the Long Term Ecosystems Research US network (CCE-LTER) is a potential example (<http://cce.lternet.edu>).

The observing strategy should link 1) fixed point long term surveys of deep basins, basin exchanges and coastal areas, 2) autonomous moving platforms, 3) remote sensing and 4) modeling tools. Specific instruments such as coastal HF radars for large area coverage of surface current, ADCP permanent stations or profiling moorings for full vertical profiles at key sites should also be considered. Routine observations and dedicated measurements (episodic campaigns) must be closely coordinated.

These observational techniques have to be considered at three scales:

1) Basin scale, where the core parameters of the water masses must be captured over decades in relation with the dense water formation areas (i.e. temperature, salinity, and a set of routine biogeochemical parameters).

2) Sub-basin/ Regional scales (see below the example "Toward a regional observatory of the North Western Mediterranean sub-basin"), where time series of the above parameters are acquired at deep stations, and where the water mass transports are monitored at mesoscale and between sub-basins.

3) Coastal scales, where the same parameters are acquired together with more specific ones devoted to thematic surveys: zooplankton (see below the example "Monitoring the meso-and macroplankton in the Mediterranean and Black seas"), pollutants, etc. At these three scales, specific attention shall be paid to straits, passages and to some large sections connecting sub-basins so as to enable the adequate temporal sampling of the exchanges between sub-basins. The monitoring of these keys sections is mandatory for keeping track of the propagation of signals and for establishing consistent budgets at basin and sub-basin scale.

Such a strategy will allow the observation of 1) the seasonal and interannual variability, the trends as well as episodic extreme events and of 2) coastal currents and mesoscale features where most of the transport occurs. It will also provide 1) the right flux of data for basin/regional scale "blue" and "green" operational models, 2) the flux of data needed to assess the interannual variability and trends of the ecosystems and 3) the data to support more specific and point observations of parameters such as geo tracers and pollutants.

Observations at the boundaries will not be ignored. Air-sea interaction and atmospheric deposition parameters are to be considered and monitored at deep sea and coastal points. Land-Sea interaction monitoring is essential and should be supported whenever possible by coastal stations. Deep sea floor processes monitoring (ESONET network) including geohazards, coastal sea level monitoring (see paper by Rosen on MedGLOSS, this volume) will also provide *inter alia* essential information to better characterize the fluxes at these boundaries.

In terms of logistics, sharing infrastructures (mainly for deployment, maintenance and data transmission) between sea level, deep sea floor and water column observatories is necessary. Overall the harmonisation of 1) national survey programs (that are already in operation at permanent stations, 2) spatial ship surveys, and 3) information exchange on projects and concerning acquired data sets is essential.

Special attention should be put on data assimilation and predictive modeling that can provide not only the synthesis of the observations on the state and evolution of the marine system but also help define optimal sampling strategies.

Since the remote sensing activity is supported by national and European centers, while *in situ* observations are mainly supported at a more regional or local level (note that the operational modeling activity is an intermediate situation), CIESM could play a most useful role by facilitating the links between the data providers at all levels, the modelers, especially in operational centers, and the various users.

3.1 Deep sites for fixed long term surveys

In the context of recent national and international programs (see for example papers by Gasparini *et al.*, this volume; Delfanti, this volume; Papathanassiou, this volume), a set of deep stations, covering key areas of the Mediterranean, have been identified for long term monitoring.

a - These should be equipped with moored instruments and be visited as often as possible with shipborne instrumentation. A unifying perspective could be the profiling moorings that are now becoming technologically feasible for deep environment (Ocean Observatories Initiative, 2007). These main stations will provide the biogeochemical database characterizing the different basins and their long-term evolution. Other 'lighter' stations will provide the database on the evolution of the hydrography of deep waters (e.g. CIESM HYDROCHANGE Program, see below).

b - These stations should be also visited periodically by autonomous platforms (gliders, AUVs). Gliders are also suitable to act as virtual moorings at these fixed stations, thus providing continuous profiles, a cheap alternative to ship surveys and profiling moorings.

c - CIESM should continue to encourage the operation of deep-sea monitoring stations and the development of new stations that have been identified.

3.2 Coastal permanent stations

There is a large variety of monitoring initiatives in the coastal areas, with different objectives (research, monitoring, pollution control, etc.) and a variety of supporting institutions (research laboratories, environmental agencies, ministries, local authorities, etc.).

a - Activity of the coastal permanent sampling stations should be encouraged, standardized and networked.

b - Thematic networks should be implemented, taking advantage of the existing ones (for ex. CIESM Mediterranean Mussel Watch, Mediterranean Zooplankton Indicators). Some of the laboratories running the permanent stations could constitute nodes for specific sample treatment (i.e. zooplankton) and for the moving platform assistance.

3.3 Autonomous moving platforms

Fleets of autonomous underwater vehicles (profilers, gliders and propelled UVs) are a new promising – and relatively low cost – perspective for research in the field of ocean dynamics and marine biogeochemistry as well as for operational oceanography (see paper by Mortier and Testor, this volume).

a - Actual observational efforts using profiling floats of the MedARGO/EuroARGO program should be maintained and developed toward the acquisition of basic biogeochemical parameters (O2, turbidity and fluorescence signals). Surface drifters surveys should also be maintained as they provide very useful and low cost information on Lagrangian transport and sea surface parameters.

b - Operational use of gliders and AUVs for mesoscale studies at regional and basin scale and the integration of new sensors should be stimulated.

c - Data assimilation and modeling activities should be strongly encouraged to better dimension the profilers and gliders networks.

3.4 Remote sensing

a - Data management should rely as much as possible on existing data centers and support a better dissemination of the information.

b - The additional treatment concerning Mediterranean specificities (altimetry, ocean color, etc.) should be managed in dedicated centers, with the end products made easily available to all users.

3.5 Voluntary observing ships

a - Some basin-wide regular commercial lines should be equipped with 'FerryBox' type units for the acquisition of surface parameters. A specific effort should be made toward the acquisition of current (ADCP) along lines suitable to monitor the exchanged transport between sub-basins. Other complementary sensors (biochemistry, atmosphere, aerosols, etc.) could be added at a moderate cost.

b - Secondary lines equipped with smaller units for basic surface parameters should be developed at regional scales (see example of CIESM TRANSMED program in paper by Taupier-Letage, this volume).

3.6 Multidisciplinary cruises

a - Information on multidisciplinary oceanographic cruises should be diffused as soon as established at national levels in order to harmonise activities.

b - Transits of research vessels should be optimized, with towed bodies (CPR, etc.), continuous onboard sampling (echosounders, thermosalinometers, flow cytometers, fluorometers, etc).

3.7 General recommendations

a - Some regions are presently lacking coastal permanent or regional observatories. It is hoped that relevant projects in such areas will be initiated by concerned local laboratories, with the cooperation of foreign laboratories and the harmonization of CIESM with regard to the overall monitoring regional strategy.

Example 1: Toward a regional observatory of the North Western Mediterranean sub – basin.

This example is largely generic as similar processes occur in other sub-basins (Adriatic, Aegean, Levantine, etc.). Obviously the strategy will be adapted to the specific topology of each region.

Due to the wind and heat forcings from the atmosphere as well as to the inflow of Atlantic water (AW), the circulation in the North Western Mediterranean basin displays a permanent Northern Current (NC) flowing westward along slope from the Gulf of Genoa further than the Balearic sub-basin. Part of these water masses recirculates in the south of the sub-basin from the Balearic Islands back to Corsica. In the centre, mainly off the Gulf of Lions, deep convection occurs in winter and plays a major role in shaping the Mediterranean thermohaline circulation.

This area has been extensively investigated since the 1960s with hydrological surveys, moorings equipped with current meters and even high resolution acoustic tomography arrays. At the central part of the Ligurian sub-basin, the DYFAMED is one of the world longest biogeochemical observation time series. Despite these long-lasting observational efforts, a permanent monitoring at the sub-basin scale at the right temporal and spatial scales is still a challenge.

Coordination of some scientists, laboratories and agencies is now taking place to build this permanent observatory which provisional name is “Mediterranean Ocean Observation Site on Environment” (MOOSE) (see Figure 2). The backbone of this observatory could be two deep moorings, one at the centre of the convection area, the other at the DYFAMED point in order to maintain the continuity of this existing 25 year-long time series. Due to their operating range, gliders are perfectly suited to survey with high frequency so called “Endurance lines” between the coast and these moorings. Other glider lines would extend the hydrological survey at the scale of the whole sub-basin and monitor the exchanges through the North Balearic front south of this region. Periodic hydrographical ship borne surveys at the sub-basin scale and across the boundaries of this region should provide the missing data to better constrain budgets. This should include the monitoring in narrow passages based on moorings like in the Corsican Channel. The activity of the many coastal stations (from La Spezia in Italy to Mallorca Island) has to be harmonised as mentioned above and should in particular help to better characterise the input from land by rivers and atmospheric deposition.

Example 2: Monitoring the meso-and macroplankton in the Mediterranean and Black Seas

Zooplankton is considered a good indicator of climate related ecosystem changes because:

a- Mesozooplankton (about 0.1-2cm body length) are a key link between primary producers and larger predators;

b - They are abundant, and can be quantified by relatively simple and intercomparable sampling methods;

c - Life cycles of most species range from a few months to one year;

d - Changes in population size are rapid enough to track seasonal-to-interannual changes in environmental conditions;

e - As few zooplankton taxa are fished, most zooplankton population changes can be attributed to environmental causes;

f - Many commercial fish are dependent on a zooplankton food source during their pre-recruit life history stages.

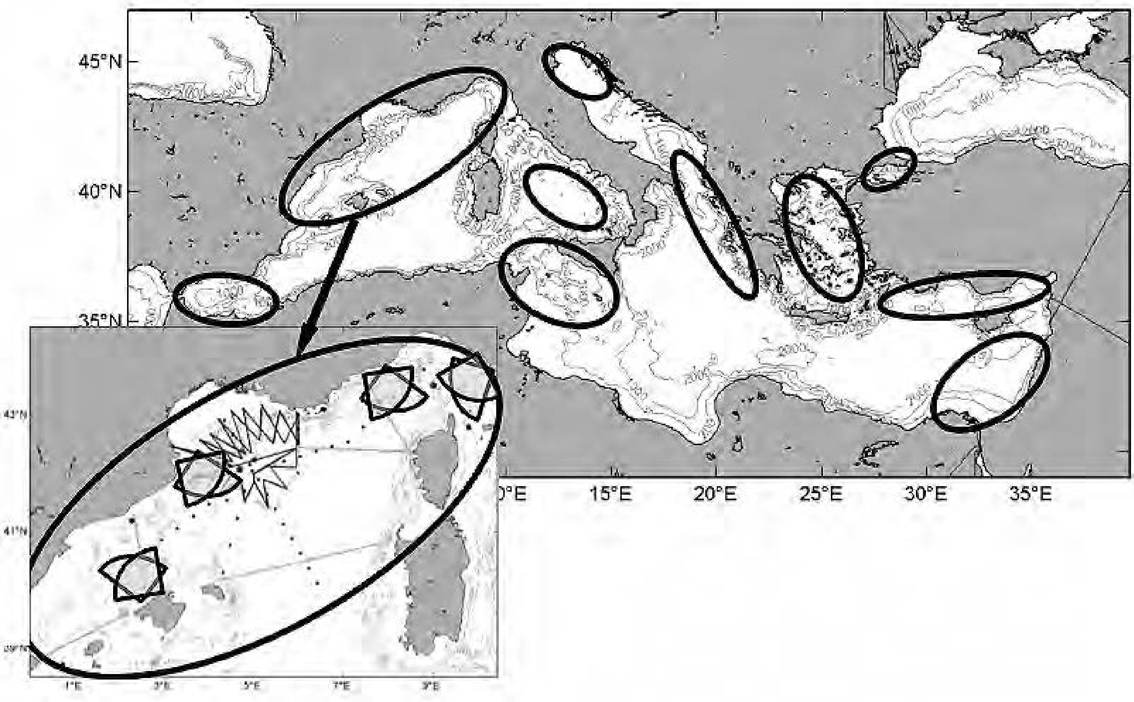

Fig. 2. Key regional components of an Integrated Mediterranean Marine Observatory: areas where integrated regional observatories are in development or that require special attention due to their significant role in the functioning of the basin-wide marine system. The box on bottom shows the sampling strategy for one of these components: Red and blue dots are permanent deep moorings, green lines are continuous gliders surveys, blue lines are gliders surveys oriented toward a specific process (here the meandering of the Northern Current and the deep water formation area), blue fan shaped symbols are HF radars stations and black dotted lines are seasonal R/V hydrographic surveys. Due in particular to tidal effects and to marine traffic constraints, observatories encompassing narrow straits may include specific components or strategies. Note that coastal stations are not shown here (see <http://www.ciesm.org/marine/programs/index.htm>), but are essential components of each regional observatory.

Consequently, anomalies in zooplankton evolution in time may be useful leading indicator for commercial fish stocks evolution (Batchelder *et al*., 2002 and Beaugrand *et al*., 2003).
Furthermore, changes in zooplankton biogeography and changes in long term trends provide an important tool for examining climate-ecosystem interactions. Between-region comparisons allow a better comprehension of causal mechanisms and consequences of the physical forcing on marine food chains. In the North-western Mediterranean the long-term variability of different zooplankton functional groups seems to be linked to changes of climate forcing of the North Atlantic sector. Large-scale climate forcing has altered the pelagic food-web dynamics through changes in biological interactions, competition and predation, leading to substantial changes in zooplankton populations, which peaked in 1986-87 and are considered by some as a regime shift in the North-western Mediterranean (Molinero *et al*., 2008).

Monitoring of meso- and macroplankton should thus form an important component of the initiative to create a system of Integrated Mediterranean Observatories. The Zooplankton Indicators Program, initiated in October 2005 by CIESM (see paper by Gorsky, this volume), and now backed up by 17 laboratories from 14 countries that undertake regular zooplankton sampling with increasing use of the ZOOSCAN methodology for processing, will naturally play a structural role in this development.

4. Technical solutions

Solutions for an effective Integrated Marine Observatory concept implementation should rely on multi-purpose, multi-scale, intelligent, adaptive, automated, network enabled, inter-operable low cost, low maintenance technologies. Most criteria are mandatory in an operational oceanography framework but also translate into optimized resources for climate research on the long-term.

Operational oceanography networks are now routinely collecting *in situ* and remote sensing data. Remote sensing data offer regular depiction of the sea surface while *in situ* data provide full water column scarce spatial information. European Marine observatories are integrated within dedicated networks. Efforts should be made to integrate or harmonize as much as possible the development of observatories in other Mediterranean countries with existing networks.

To this end regional efforts on the integration of marine observations need to be consolidated through capacity building and technology transfer efforts. Numerous specific national observatories and local research institutes exist and should be better interconnected and connected into wider networks.

The scientific community is now getting organized at many levels by dedicated infrastructure developments and regular technology watch should become a standard activity of a future Integrated Marine Observatory in the Mediterranean.

The ocean environment is by definition hostile to sensors and there is room for improvements on many issues. Bio-fouling limit the period that an instrument can stay in the water and anti-fouling paints are usually not environment friendly. Except for cabled systems, usual platforms have a limited lifetime which new kinds of batteries (e.g. capacitor, fuel cells) could extend significantly. Artificial intelligent sensors may optimize idle modes, trigger specific sampling patterns, and report malfunctioning. Increased storage capacities and communications have decreased the recovery/redeployment rate of moorings. A new generation of nanonutrients detection sensors is undergoing tests. New developments on underwater positioning systems, acoustic, optical and magnetic communications, and inductive battery recharging are expected in the near future. Nanotechnologies will also decrease the energy demand of miniaturized optical and geo-chemical sensors (micro arrays, cameras, flow-cytometry, green-house gas detection, etc.). The number of expert taxonomists around the Mediterranean is rapidly decreasing, especially in some regions, and this will only partially be compensated by emerging molecular techniques.

The integration of multi-platform multi-sensor data will be critical to a successful observatory system. Cooperative behavior and fleet mission planning tools for autonomous platforms will greatly enhance the effectiveness of monitoring and require the definition of international standards to be inter-operable. Sensor inter-calibration could jeopardize a whole experiment and requires utmost attention. Data management may be centralized or distributed depending on the end-user requirements but has to cope with increased volume and diversity of data of different kind. Automatic sensor calibration, data quality check procedures and techniques with only limited human intervention should be preferred. Grid computing, data mining techniques and new multi-dimensional visualization tools will offer new ways to look at complex data sets and modeling products, which should be disseminated on the world-wide web using user-friendly tools.

Remote sensing also offers great promises with new salinity and gravimetric sensors. More sensors are to be expected in the future.

Modeling techniques allow filling in the 4D spatio-temporal box at both operational and climatic scales that are otherwise impossible with monitoring-only techniques. Interactions between modeling and monitoring must be enhanced in order to develop coupled hydrodynamic-ecosystem based management models.

Data assimilation techniques merging both *in situ* and remote sensing of information have improved prediction skills significantly in recent years but a number of critical shortfalls in our understanding of error covariances still need to be addressed. Uncertainties derived from model-data fusion may be directly exploited for cost-effective monitoring in adaptive sampling strategies.

5. Implementation of an efficient system of systems

From a practical point of view, the Integrated Marine Observatory concept will have to be implemented in the Mediterranean as a coordinated network of complementary observatories.

Conceptual design of the observatory network

The Mediterranean is a mosaic of geographical, political, social, physical and ecological sub-domains with much diversity and contrasts. The integrated marine observatory must account for these contrasts, and yet be flexible enough to address observational needs concurrently and also in sufficient detail. Only with the collective goodwill and efforts of scientists, oceanographic institutions and governments within the Mediterranean and Black Seas region will such a coordinated action be able to achieve its goals. The tightly coordinated, but non-hierarchically organized, network of observatories shall be based on existing and new facilities, taking into account the available means of countries bordering the Mediterranean. Through its multiple interfaces with riparian governments, with scientists and the research institutions of the whole Mediterranean region, CIESM is considered to be the key body to promote and facilitate this initiative.

Coordination of existing and future initiatives

Scientific objectives form the core of marine observatories but, as is the case for meteorological networks, will coexist with monitoring duties that are carried out by governments and other authorities. Thus, the contemplated structure of the Integrated System of Mediterranean Marine Observatories must draw its strength from the existing marine research community and institutions able to draw upon wide-scale public support and funding, but must also further expand and consolidate to cover modern means of concurrent, key observations spanning the entire basin.

Establishing priority actions

Among the activities required in priority for the establishment of an Integrated System of Mediterranean Marine Observatories, the participants listed:

a. Survey all Mediterranean monitoring bodies and consolidate the existing metadata bases (SeaDataNet, NODCs, etc.) for all the relevant marine fields (physical, geological, chemical and biological) for the Mediterranean and Black Seas.

b. Determine the missing or poorly covered areas, together with strategic key sites, and continue monitoring well-known key places (such as repeated transects across current or deep hydrographical stations), to detect/identify there what is anomalous, and because long term time series are the only data sets that allow evidencing climatic (weak signal) trends.

c. Prepare coordinated proposals for upgrading and/or acquiring new monitoring equipment, and for including new members (institutes or countries) that will join existing or emerging programs.

d. Identify synergies and common parameters for the monitoring activities of the system of systems, integrating relevant activities of all riparian countries.

Basin wide–involving also Southern and Eastern Mediterranean countries scientists

The basin-wide character is obviously essential to the success of an integrated system. Most of problems addressed above require coverage by a Basin-wide network of observatories, and so it is fundamental to involve scientists and institutions from all riparian countries. The participation of groups from the southern and eastern shores will need to be enhanced by logistic assistance from international organizations, and by capacity-building initiatives among the Mediterranean scientific community.

Initially the observatory system – and the actions conducted within that frame – should be focused on routine actions/measurements. Meaning that observations are basic, regular, low cost or cost-efficient. Then they will be extended to the southern and eastern countries, setting an homogeneous network at the Mediterranean scale. In parallel, observation sites or platforms better instrumented will carry on with innovative sensors/developments.

To reach full scale, the Mediterranean observatory system will require a minimum configuration for the various observation actions/fields, and a guaranty that the North African coast countries get both the instruments and capacity training to use/deploy them. They in turn should provide the manpower (and the shiptime if required), plus the recurrent cost for maintenance/turn-over.

Another example of cooperation – currently tested by the CIESM transMED Program - would be to have these countries operate a line of ferry/cargo equipped with a (nearly autonomous) thermosalinometer. The difficulty here is to find the adequate technical staff to make such installations. However, when lines link different countries, part of the maintenance work can be shared between them so as to optimize the existing human resources. An observational network runs with shared tasks

An effective cooperation at intra-Mediterranean governmental level will be the adequate framework to address current diplomatic problems, like sampling (e.g. allow for drifting autonomous instruments) in claimed Exclusive Economic Zones that can seriously handicap global monitoring activities in the Mediterranean.

Funding considerations

Funding must ensure that the overall system will run for at least 10 years – and more generally aim for a monitoring system over climatological scales (several decades minimum). It is foreseen that it should be designed similarly to that of the meteorological community.

6. Workshop recommendations

6.1. Essential features of the observatory system

The main recommendations detailed in the previous sections and arising from several of the workshop presentations included in this monograph, are summarised below in a synthesised form.

A Mediterranean marine observatory shall be an **integrated** system of systems in the sense that it will:

- Comprehend the entire Mediterranean ecosystem;
- Incorporate the distribution and time scales of processes ranging from bacteria to basins and be contiguous between Mediterranean sub-regions and boundaries;
- Apply state-of-the-art sensor technologies and numerical modeling tools;
- Focus on key strategic outcomes relevant to stakeholders;
- Adopt an open strategy to absorb the diversity of skills and facilities present in all nations;
- Federate, harmonise and exchange the most effective of existing observational activities;
- Archive past and log future observations into a common Mediterranean database to ensure sustainability of knowledge.

To attain its objectives a future integrated system must necessarily

- Cover the whole Mediterranean basin, offshore and coastal zones, surface and deep sea;
- Include as main strategic components:
    - Selected deep sites for fixed long term surveys (water column, seafloor processes);
    - Permanent coastal stations, covering the different typologies of coastal and shelf systems (deltas, eroding coasts, cities, freshwater discharges);
    - Autonomous moving platforms;
    - Remote sensing information;
    - Voluntary observing ships equipped with standard packages;
    - Coordinated multidisciplinary cruises;
    - Modeling tools to increase capabilities in optimized sampling planning, data assimilation and prediction;
    - Efficient dissemination and organisation of the information.
- Consider the basin scale, sub-basin/regional scales and coastal scales;
- Measure exchanges at Gibraltar, at the entrance of the Suez canal and with the Black Sea;
- Monitor the sites of dense water formation, major heat transfer and main straits and channels;
- Harmonise the present and future national/regional survey programs by establishing core parameters to be measured with homogenised methodologies;

- Rely on the potential of existing programs/observatories; identify main gaps, propose solutions and implement agreements with local institutions;
- Establish links with meteorological and hydrological-continental networks, as well as with operational oceanography centers;
- Be structured, and consequently funded, as a permanent activity to last for decades, including the adequate provision of technical staff.

6.2 Priority actions

From a technical and logistical perspectives the following actions are recommended:

- Technology watch on concepts, sensors, systems and modeling;
- Promote the use of autonomous devices, real-time data transmission and 2-ways communications with platforms for intelligent sampling;
- Propose robust, cost-efficient, basic sampling methodologies able to be implemented as the observatories network backbone in all countries and Mediterranean sub-basins;
- Pooling of sensors, platforms and sharing any kind of infrastructures;
- Coordination of ship time around the Mediterranean;
- Better Navy-Civilian activities coordination;
- Coordination of inter-calibration efforts. Organise a CTD calibration site in the Mediterranean;
- Identification, definition and adoption of standards (including units, accuracy) of parameters;
- Promote the consolidation and coordination of observatories technical staff (permanent formation, sharing experiences, etc.);
- User-friendly dissemination of data and adequate global data banking and quality control capability;
- Transfer of technologies to all countries of the Mediterranean basin through dedicated capacity building;
- Leverage on uncertainties from model-data fusion for cost-effective monitoring;
- Build on public awareness for efficient monitoring (e.g. alert system for jelly fish, red tides, macro algae, etc.);
- Develop coupled hydrodynamic-ecosystem based management models.

The group of experts considers that CIESM can play a fundamental role in making the Integrated Marine Observatory strategy in the Mediterranean a consolidated reality. By encouraging the continuation and harmonization of existing open sea monitoring stations. By raising awareness on missing components of the global system of systems. By proposing network priorities, supporting the standardisation of newly designed observatories, ensuring links between the different data providers (*in situ* and remote sensing) and all the Mediterranean users. By supporting training activities and the upgrade of technical capacities. By using the CIESM portal to diffuse information on the activities of the Mediterranean marine observatory system and main findings. By promoting collaboration between the coastal countries, the relevant agencies and within the Mediterranean research community, for the transfer of knowledge and efforts to key understudied areas.

Observing the Mediterranean variability from meso- to decadal scales: how can we get the right picture?

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Abstract

The overall functioning of the Mediterranean Sea, which transforms Atlantic Water (AW) into Mediterranean Waters (MW), has been comprehended for decades now, and so is the process of dense water formation (DWF), which leads AW to sink in specific offshore northern zones of both basins. However, some circulation features are still being debated, as are the impacts of climate change. This is mainly due to the lack of adequate data, especially of long-term time series. Indeed, the intense mesoscale activity of the Mediterranean requires a fine coverage in both space and time, and the variability over decadal (and more) scales requires monitoring over a long period to achieve an actual description, a proviso for a correct understanding. Adequate monitoring is only within the reach of an integrated system of Mediterranean marine observatories.

1. Introduction

One of the main scientific challenges of the 21st century will be to answer societal demand about climate change issues, such as trends in temperature, sea level rise, occurrence of high impact weather events (flash floods, hurricanes, droughts, etc.) etc.[1]. While meteorologists can rely on long enough observations to test and validate forecasting models, climatologists must rely mostly on proxies. Although the time scales accessible (for instance with ice cores) are well within climatic range, the potential variability in both space and time may raise questions about the generalization and validity of the proxies (e.g. Wunsch, 2006; Toggweiler and Russel, 2008). It is even worse in the field of oceanography *s.l.*, where only a few data sets of observations (in and above the sea) are longer than a few decades. It is thus impossible to test and validate the models dealing with changes in the circulation at climatic scale. Efforts have yet to be made, hence, to present the results (scenarios) with the errors and uncertainties estimated at best (e.g. Wunsch, 2007; Wunsch *et al*., 2007). Moreover, climatic changes in the ocean are most often apprehended through the study of the changes of the ocean circulation, taken as the Meridional Overturning Circulation[2] (MOC, also Mediterranean Overturning Circulation in Tsimplis *et al*., 2006). But recent works tend to show that eddies affect the mass and volume transport too, at a time scale of ~ 4 years: since the MOC also reacts on such time scale, impact of mesoscale activity on climate simulations should be considered (Stammer *et al*., 2006; Wunsch, 2008).

[1] Most of these items will be addressed for the Western Mediterranean in the framework of the HyMEx program (2010-2020): <http://www.cnrm.meteo.fr/hymex/>

[2] Also known as the “conveyor belt”

Satisfying outcomes to these issues rest for a large part on a concerted effort to collect comprehensive observations on the long term (see GOOS and other global observing efforts and networks). The Mediterranean is no exception. The functioning of the Mediterranean is basically known and established for decades (for a review see e.g. Millot and Taupier-Letage, 2005a). However several points remain to be either refined or definitely settled, as adequate observations (both remote and *in situ*) are lacking yet. First we review briefly the main processes and scales of variability that hinder our forecasting ability. Then we sketch, for discussion purposes, the outlines of a Mediterranean-wide concerted observing strategy.

2. Sources of variability

a. Mesoscale activity

The mesoscale activity is represented mainly by meanders and eddies. Horizontal dimensions range from ~ 50km up to 150km, vertical ones from ~ 100-1,000m (often reaching the bottom: ~ 3,000m), with lifetimes from few weeks to one year (up to three). This activity is ubiquitous in the Mediterranean (Figure 1), while more intense in the southern parts of both western and eastern basins. It generates a high variability in both space and time, and thus such a complexity that it requires for instance at least four altimeter missions to monitor the mesoscale circulation. Its importance must be considered, since it can modify locally and temporally the circulation of the water masses (e.g. Taupier-Letage, 2008), for instance by entraining water off its normal path, up to reversing the mean circulation at depth (Millot and Taupier-Letage, 2005b). It is also likely that it contributes to the variability of the basin-wide mass and volume transport.

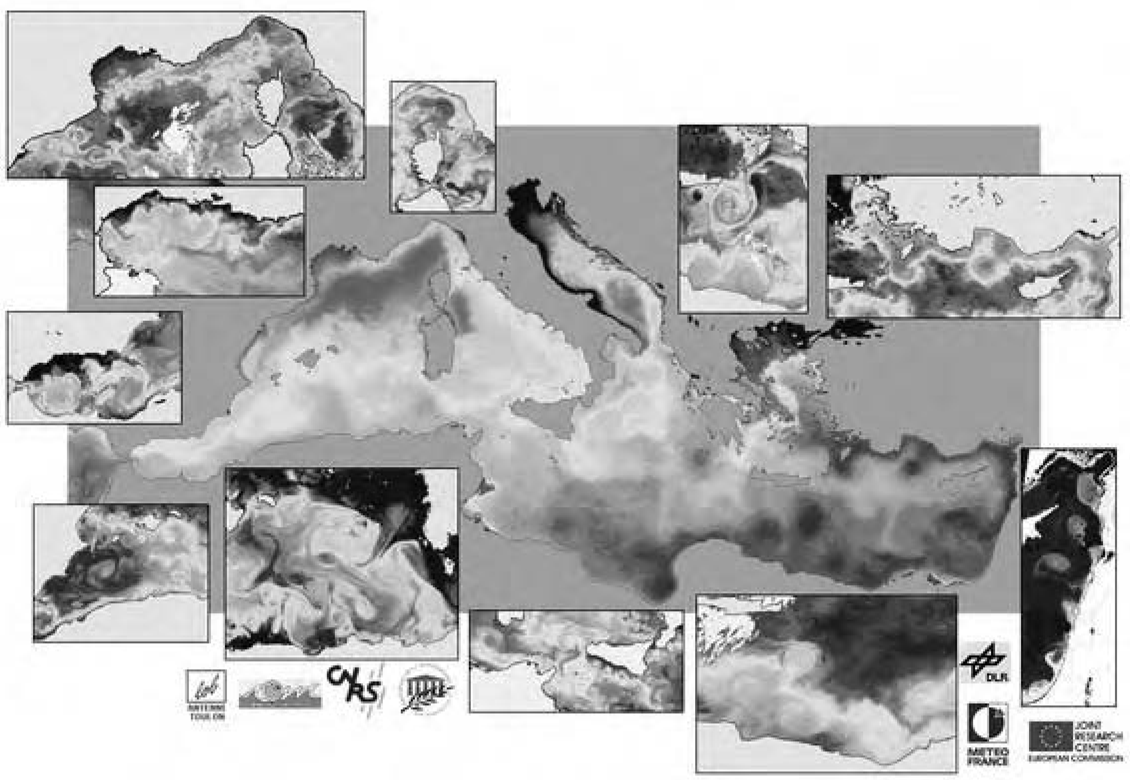

Fig. 1. Illustration of the mesoscale dynamics in the Mediterranean with thermal NOAA/AVHRR images from SATMOS/MétéoFrance and DLR (but *g:* ocean colour/chlorophyll content from SeaWiFS, from *ies*). Images have been selected at different dates. **a:** the monthly composite of January 1998 for the whole Mediterranean. **b:** the Alboran, in its classic situation of two gyres filling the sub-basin. **c:** the jet of AW on the western half of the eastern Alboran gyre reaches the Algerian slope near 0° and continues as the Algerian Current, which can be seen (lighter gray signature) propagating alongslope as far as ~ 4°E (south of Menorca), where it veers offshore (due to eddies interactions, not shown). An Algerian eddy (mid-gray) can be seen south of Ibiza. **d:** Algerian eddies interacting strongly in the eastern part of the Algerian sub-basin, the accumulation zone ΣA_E. The strong shear between 2 close anticyclones creates small cyclonic shear eddies. Upwelling cells (dark gray tongues) are generated on the southwestern side of the AEs, where the current is directed

offshoreward. **e:** the channel of Sardinia with an AE (blocked) at the entrance, and the channel of Sicily (the upwelling cells along the southern coast of Sicily are typical of summertime conditions). **f:** The western Levantine, with Libyo-Egyptian eddies (accumulation zone ΣL_W). **g:** The Middle-East, with coastal instabilities revealed by their chlorophyll content (SeaWiFS "ocean colour" image; situation not characteristic of the accumulation zone ΣL_E). **h:** The Northern Current off Turkey, showing sharp meanders and an eddy pinching off. **i:** Most of the Northern Current is feeding the wind-induced Ierapetra eddy, east of Crete. **j:** The Ligurian subbasin, with a vortex dipole (mushroom-like structure) north of Corsica; the cold (darker) patch east of the strait of Bonifacio reveals the divergence induced by a strong (past) mistral wind event. **k:** the Liguro-Provencal subbasin: the Northern Current flows close to the coast since the slope is steep east of the gulf of Lions; there it skirts the continental shelf along the ~ 200m isobath, and thus crosses the gulf; the cold (darker) area off the gulf of Lions (and probably the one east of the strait of Bonifacio too) reveals the area where wintertime deep convection occurs, forming dense water (image typical of wintertime situation). **l:** Upwelling cells in the gulf of Lions induced by strong Mistral events.

When overlooked, the interpretation of identical data sets can diverge, as in the case of the debated existence of a westward vein of Levantine Intermediate Water (LIW) circulation off Algeria (compare Millot and Taupier-Letage, 2005a and Figure 79 of Tsimplis *et al.*, 2006), or in the case of the much debated schema of the surface circulation in the Eastern Basin (compare circulations schemas in Figure 1 of Hamad *et al.*, 2006).

On a much shorter scale, a CTD moored ~ 10m above the bottom at 3,200m deep off Libya revealed episodes few-day long when the temperature dropped by a tenth of a degree C (Figure 2). Whatever its origin[3] such a variability must be properly described when addressing climatological issues, and searching for a signal/trend that is only 1/100 of a degree °C/year (e.g. Salat and Pascual, 2002).

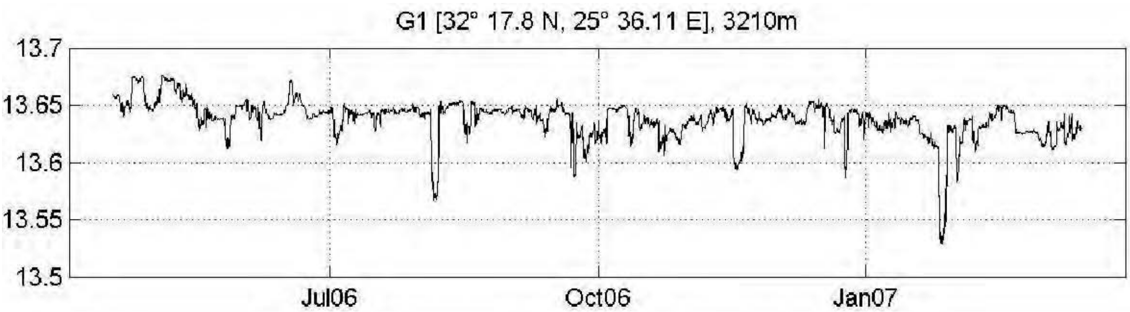

Fig. 2. Time series of temperature recorded off Libya at ~ 3,200m, about 10m above the bottom. The high variability shows that it is irrelevant to use the deepest layer to intercalibrate CTDs, that isolated measurements are likely not to be representative of the mean value –and that a mean value may be delicate to use (relevancy?). This Hydro-Change[4] autonomous CTD was put on the mooring G1 of the EGYPT (Eddies and Gyres Paths Tracking) experiment (<www.ifremer.fr/lobtln/EGYPT>).

b. Seasonal variability

Seasonal variability is generally well understood, if not well described. It is more marked in the northern parts of both basins, by an intensification of the Northern Current and an increase of its mesoscale activity (meanders), in relation to Dense Water Formation (DWF) processes.

Note however that in the southern part of the Ionian sub-basin the surface circulation has yet to be preciced. It is strongly dependant on the wind regime, and seems to be reversed during summertime. Because of its complexity (two circulation cells), the recent efforts with surface drifters (Gerin *et al.*, 2007) do not provide definitive results yet.

[3] Most probably mesoscale phenomena, but data analysis is still underway.

[4] Hydro-Changes CIESM program: <http://www.ciesm.org/marine/programs>

c. Inter-annual variability

Dense water formation (DWF) is the process to monitor especially. During mild winters (no long-lasting intense episodes of northerly dry winds) only the formation of intermediate water occurs. Otherwise deep convection occurs, mixing surface and intermediate waters, resulting in a denser water that can reach the bottom. In the Eastern Basin the formation of Levantine Deep Water has yet to be described and fully observed. In the Western Basin, besides the well-known DWF sites in the Gulf of Lions, intense episodes (e.g. Puig *et al.,* this volume) have been recently described, i.e. in the Ligurian and the eastern Catalan subbasins (Smith and Bryden, 2007). This raises the question of the real frequency and geographic extent of the DWF in the northwestern Mediterranean.

d. Multi-year up to decadal variability

This is for instance the case of the Eastern Mediterranean Transient (EMT: the main source of deep water suddenly switched from the Adriatic to the Aegean; see e.g. Tsimplis *et al.,* 2006). Due to the scarcity of quasi-decadal scale data, this phenomenon (event?) was not predicted, and there was no dedicated monitoring. As the EMT signal propagates in the Western Basin, it also progressively modifies the characteristics of the dense water formed there (e.g. Schröder *et al*., 2006; Gasparini *et al*., this volume). In some places a definitive increase of temperature was observed, based on available long time series. This was for instance evidenced by a ~ 30-year long record of the surface temperature around the Medes Islands (NW Mediterranean, Pascual and Salat, 2005), as well as downstream close to Cartagena (Plaza *et al*., 2008).

In the same way, our knowledge of the connexions between the Mediterranean and the Atlantic needs improvement. While it is mostly discussed in terms of the Mediterranean overflow water (MOW) fluxes and impact on the Northern Atlantic (for a review see e.g. Artale *et al*., 2006), the acquisition of time series in the Strait of Gibraltar within the framework of the CIESM Hydro-Changes program recently showed that the temperature of MOW had increased as a result of the modification of its composition (Millot *et al*., 2006). Most importantly, while modifications in the Mediterranean are most generally ascribed to internal (Mediterranean) forcings, these time series evidenced a continuous increase in salinity of the Atlantic Water (AW) entering at Gibraltar of ~ 0.05 /year in 2003-2007: the AW yearly trend is a dozen times larger than the Mediterranean waters (MWs) decadal one (see Millot, 2007, and references therein).

3. Outlines of a Mediterranean-wide concerted observing strategy

a. Required components:

- Cover the whole Mediterranean: both basins, offshore and coastal zones;
- Sample from the surface to the bottom (several layers and/or water column);
- Consider the exchanges at Gibraltar and with the Black Sea;
- Consider the exchanges between the sub-basins (Channels of Sicily, Sardinia, Corsica, Otranto (see Gasparini *et al*., this volume);
- Consider the exchanges with the Suez Canal to determine their significance (see Rosen, this volume);
- Be designed from the beginning to have a lifetime of 10 years at least (aiming at the century);
- Include both remote and *in situ* observations;
- Have core parameters homogeneously measured in both space and time, that will be the backbone for other parameters observation (multidisciplinarity);
- Resolve time scales ranging from the hour to inter-annual and decadal;
- Resolve space scales ranging from the km to the basin scale;
- Encompass networks of platforms (e.g. gliders, gliders, moorings, ferries, drifters, etc.) and specific programs of observation at fixed stations;
- Have links (2-way communications) with meteorological and hydrological-continental networks and observatories;

- Have links (2-way communications) with operational oceanography centers (operational oceanography, assimilation).

b. Main bottlenecks

- Legal issues: for now the restrictions to sample off the 12 miles of the territorial waters of many countries, even without taking samples (e.g. drifting buoys), prevent a truly Mediterranean-wide system of observations to develop;
- Undersampled areas (mainly southern parts of the Eastern Basin);
- Lack of dedicated staff: the regular activity of data acquisition cannot be that of a scientist trained for data analysis;
- Data exchange (time embargo if network is run by scientists);
- Lack of recurrent funding for long term (target is usually ~ 3 years);
- Management for rescuing platforms (funding, staff, shiptime, etc.).

c. Some solutions

- Perennial funding of the observation activity and means (for the sake of debate see some perspectives by Baker *et al*., 2007);
- Develop and promote autonomous platforms and devices (e.g. a moored profiler for high-frequency CTD casts);
- Increase and combine complementary networks[5] (improve synopticity and spatial coverage), see Figure 3:
    - network of moored CTDs (see CIESM program Hydro-Changes) and other sensors;
    - networks of multi-instrumented buoys;
    - network monitoring the surface with thermosalinometers (+ meteorological sensors) installed on ferries[6] (see CIESM program TRANSMED[7]);
    - network of gliders;
    - network of periodic CTD and XBT transects (e.g. across the straits and DWF);
    - periodic releases of ARGO CTD profiler and surface drifters.

  Whenever possible, additional measurements and/or samples must be taken to insure the multidisciplinarity (e.g. towed plankton recorders, etc, see Executive Summary). Beside these routine networks, “networks of opportunity” should be considered, such as CTD profiles or transects in key places (Figure 3).
- Promote the use of homogeneous devices/installations;
- Periodic (yearly?) meetings of technical staff for training and “recipes” exchanges;
- Develop 2-ways communications with platforms for intelligent sampling (event-triggered);
- Develop/fund real-time communication of data whenever relevant;
- Develop structures hiring staff dedicated to “observation”;
- Improve the data banking capability: increase/create centers for QA/QC, improve requests functions etc. (more dedicated staff).

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[5] This list doest not pretend to be exhaustive, and disregards the regional observatories, considered in the executive summary.

[6] Contribution of southern riparian countries to a concerted effort could especially take advantage of the ferries (more generally Volunteer Observing Ships), which offer a highly cost-efficient platform.

[7] See the figure representing the potential network on <http://www.ciesm.org/marine/programs/transmed.htm>

4. A FIRST SKETCH

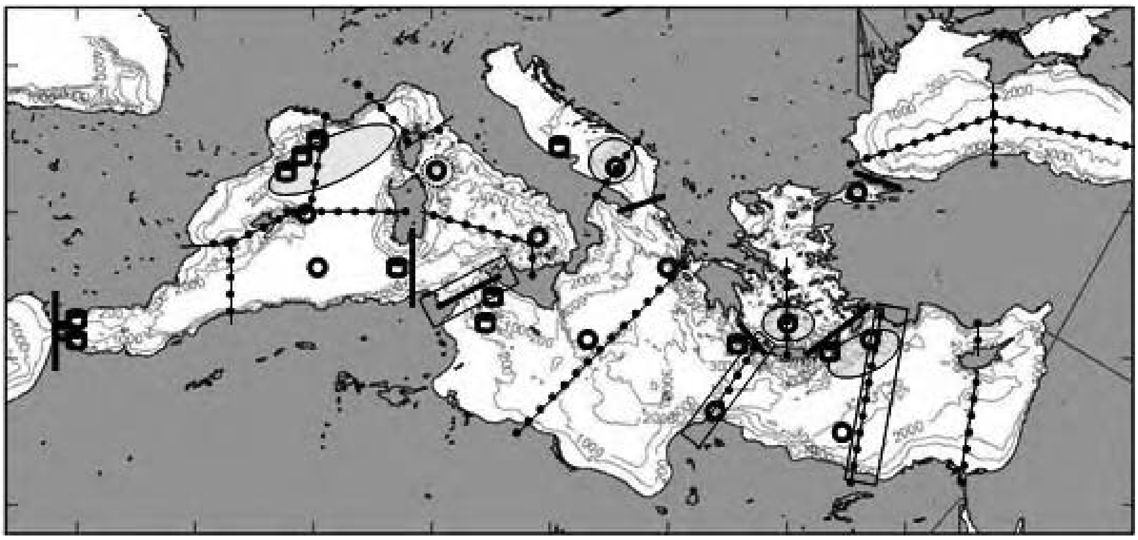

Fig. 3. Key transects suggested for regular observations.

5. CONCLUSION

Considering the lack of (long) time series and the numerous places where *in situ* data are simply lacking (southern part of the Eastern Basin), one can only conclude that the data bases constructed with measurements isolated in both space and time and pooled for climatological studies need at least to be improved. This effort must be conducted along with an analogue effort to collect and analyse meteorological and continental hydrological observations.

There is now a general agreement about the need to improve the monitoring of the marine domain, from the global ocean to the coastal seas, and many efforts are being done at the international level (e.g. GMES, GOOS, etc.). Setting up an integrated system of marine observatories in the enclosed Mediterranean may seem in theory easier than at global scale, but this task faces many national and trans-national challenges, not least the financial ones. Our understanding and forecasting abilities depend on it.

Acknowledgements

This paper has been fueled by collaborative work and discussions, especially with J.L. Fuda, G. Rougier and C. Millot.

On the added value of integrated multi-disciplinary observing and prediction systems

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Abstract

Ocean prediction is inherently limited by the chaotic nature of the environment. Compared to the atmosphere, Monitoring the ocean on a persistent and regular basis poses a number of additional challenges to obtain accurate and reliable predictions. Detailed analyses of multivariate covariances may help alleviating this limitation to improve prediction skills, reduce uncertainty and optimize our monitoring effort accordingly. The concept of multi-model data fused predictions illustrates the added value of integrated multi-disciplinary observing and prediction systems.

1. Introduction

Whilst numerical weather prediction relies on regular and intense observing systems over land, the ocean is still lacking robust, diverse, dense and sustained monitoring capabilities. Satellites allow for regular remote sensing of some of the ocean surface properties like temperature, ocean colour, sea surface anomaly, significant wave height, etc., and will also provide e.g. salinity measurements in the very near future. Ocean *in situ* data collection is however much more cumbersome. The sea is by definition a hostile environment for sensors and platforms. High salinity induces corrosion; primary production induces bio-fouling; heavy sea states induce structural damages on platforms, etc.

Traditional ship-based oceanographic field experiments are expensive, time-consuming and pose a series of logistic (and political) hurdles. Even when focusing on small areas of interest for a targeted period, they cover at best a small portion of the spectrum of ocean processes.

2. Covariances to compensate for poor monitoring

This *a priori* admission of failure is however omitting a crucial property of nature. Certain variables are inherently correlated over specific time and spatial scales, i.e. there is no need to measure everything every time because of significant redundancy of information. Temperature in the mixed layer is strongly correlated (if not almost identical) to Sea Surface Temperature (SST) which is also strongly correlated on the horizontal through advection processes (Figure 1).

Under careful assumptions, the assimilation of one measurement may have a positive impact both on the horizontal and the vertical. Different variables may also be strongly correlated. For example, sea surface height and temperature are usually well correlated (Figure 2). This translates our physical understanding that, according to geostrophy, if the sea surface is lifted, the water column must become lighter to avoid pressure and velocity changes at the level of no motion.

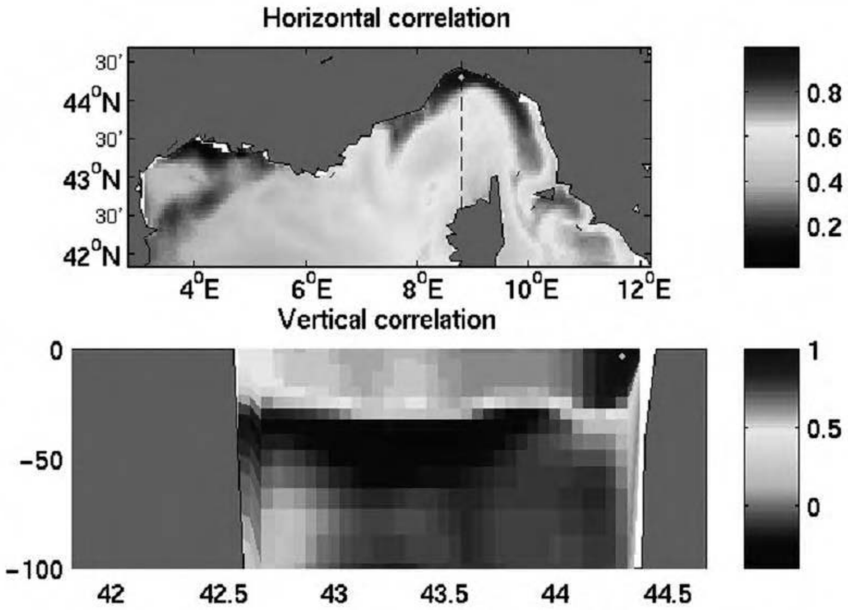

Fig. 1. Horizontal and vertical correlation between the surface temperature at 44°20N and 8°48E with the temperature at other positions in the Provençal Basin (after Barth *et al.*, 2007).

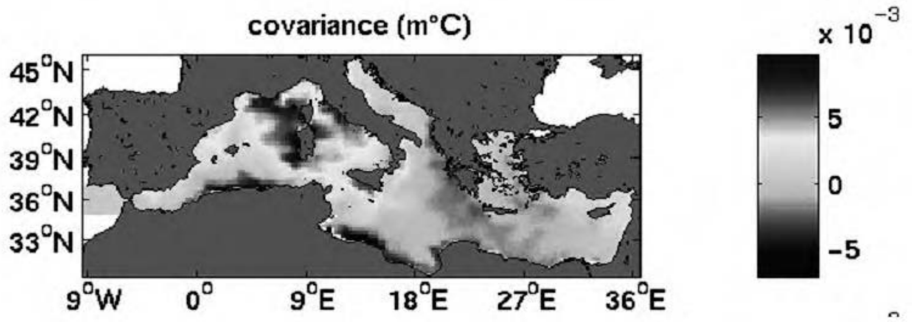

Fig. 2. Covariance between the sea level anomaly of a point in the Provençal Basin at 42° 30N and 8°E and the sea surface temperature in the Mediterranean Sea (after Barth *et al.*, 2007).

Along the same line, models at different resolutions like nested models also exhibit useful correlations which may further improve prediction skills through two-way data assimilation (Barth *et al.*, 2007). Other examples include high covariances between chlorophyll and temperature, currents and sediment concentration, etc.

3. Integration monitoring and prediction systems

The Mediterranean has been the focus of several climate and operational oceanography international research efforts and hosts a wide series of observing and modelling systems, yet to be integrated.

The use of Multi-model Super-Ensembles (Krishnamurti *et al.*, 1999) (SE) which optimally combine different models, has been shown to significantly improve atmospheric weather and climate predictions (Krishnamurti *et al.*, 2000a,b). In the highly dynamic coastal ocean, the presence of small-scales processes (Figure 3c,d), the lack of real-time data and the limited skill of operational models at the meso-scale have so far limited the application of SE methods (e.g. Rixen and Ferreira-Coelho, 2005; 2007). Here, we report results from state-of-the-art super-ensemble techniques in which SEPTR (de Strobel and Guladesi, 1997; Perkins *et al*., 2000; Grandi *et al*., 2005) [a trawl-resistant bottom mounted instrument platform transmitting data in near real-time, Figure 3a,b] temperature profile data are combined with output from a group of eight ocean models run in a coastal area during the Dynamics of the Adriatic in Real-Time (DART) experiment in 2006.

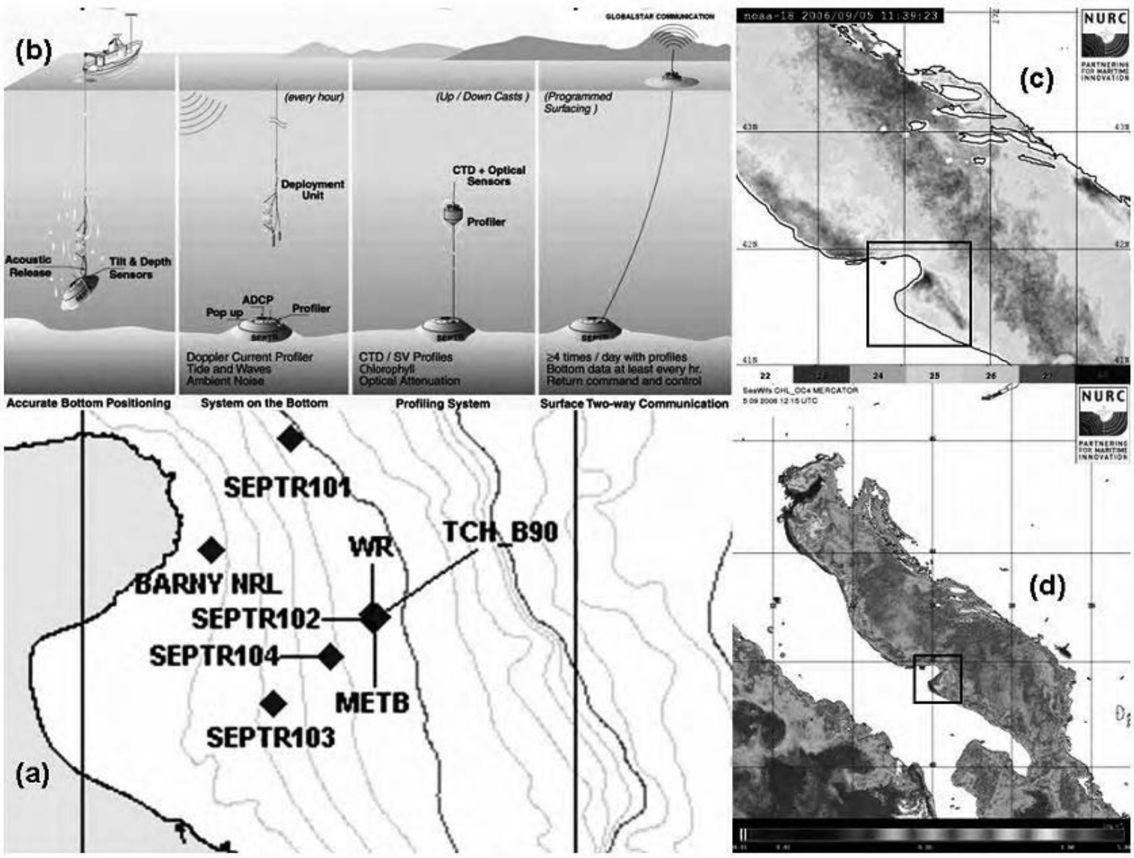

Fig. 3. Area of interest of the DART06 experiments: a) location of moorings in the Gulf of Manfredonia including SEPTR 104 b) SEPTR operations sketch: deployment, profiling and data transmission c) illustration of small-scale instabilities along the Western Adriatic Current as seen from an infrared NOAA AVHRR Sea Surface Temperature image (ºC) around noon on 5 September 2006 d) same as (c) but for chlorophyll A (mg m^{-3}).

SE methods based on Kalman filter (Kalman, 1960; Evensen, 2006) and Particle filter (Doucet *et al*., 2000; 2001; van Leuw, 2003), which allow for dynamic evolution of weights and associated uncertainty, show increased skill (a minimum of 8%, Figure 4) as compared to the best single models.

Particle filter methods cope with non Gaussian error statistics and provide robust and reduced (by 40%, Figure 5) uncertainty estimates (Lermusiaux *et al*., 2006).

The collection of models from the various home institutions and those run onboard RV ALLIANCE was ensured through continuous mirroring of the NURC and NRV ALLIANCE FTP servers over a dedicated, high-bandwidth satellite-link system (a standard 2-way SATCOM connection complemented by a Digital Video Broadcasting System (DVB-S) asymmetric link) (Figure 6). This allowed the SE predictions to be computed onboard NRV Alliance on a daily basis.

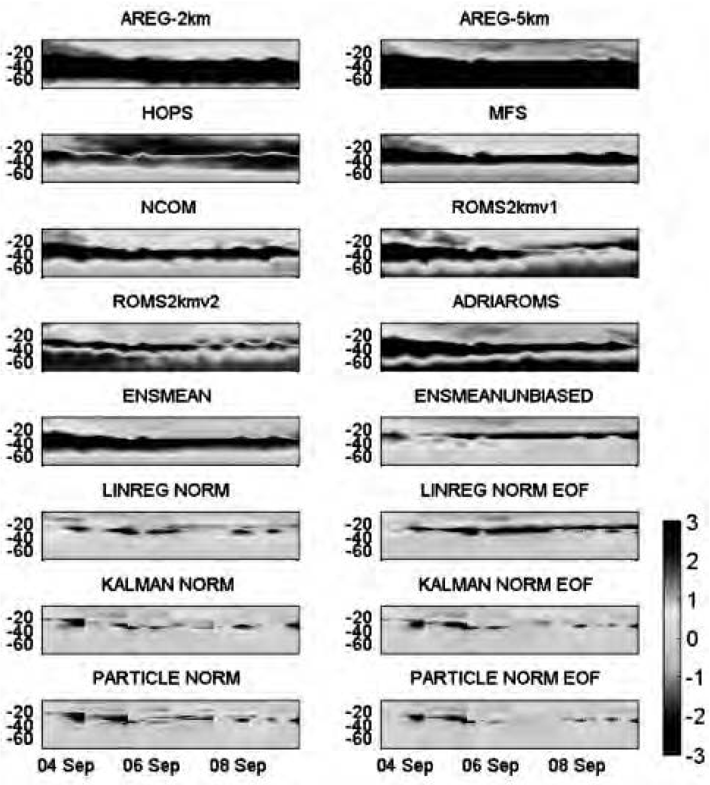

Fig. 4. Time series of 24-hr temperature (ºC) forecast errors versus depth (m) of individual models and super-ensemble predictions: (from left to right and top to bottom) the eight individual models, ENSMEAN, UNENSMEAN, LINREG_NORM, LINREG_NORM_EOF, KALMAN_NORM, KALMAN_NORM_EOF, PARTICLE_NORM and PARTICLE_NORM_EOF. Methods with EOF suffix have additional EOF-based regularization for improved generalization skill.

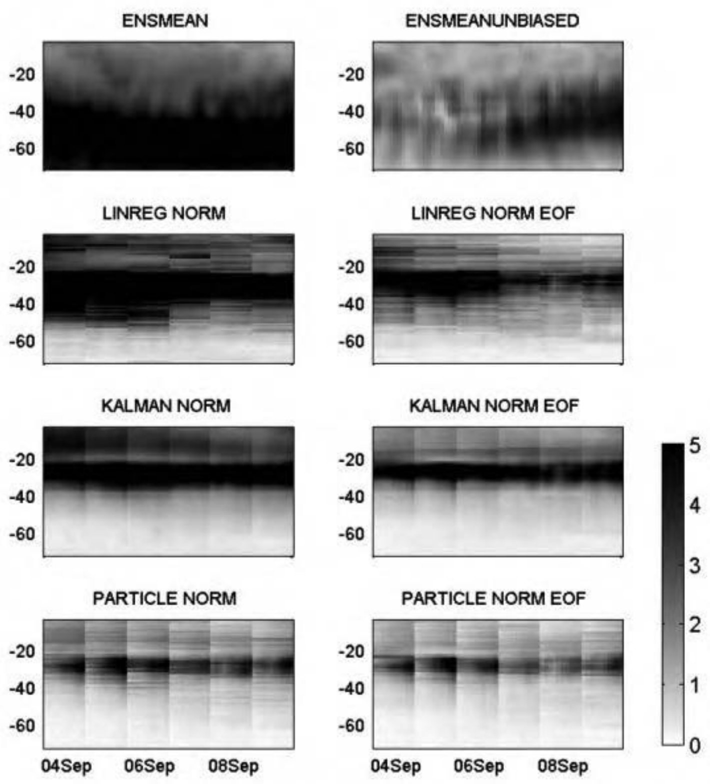

Fig. 5. Time series of uncertainty (99.7% confidence interval) of 24-hr temperature forecast (ºC) versus depth (m).

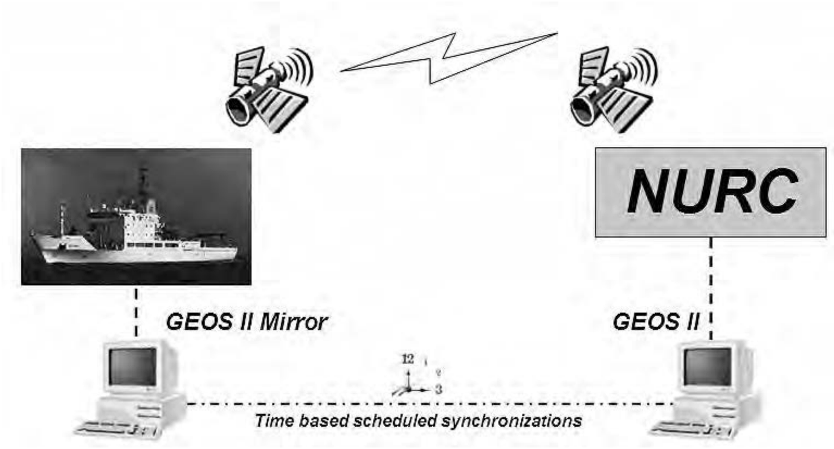

Fig. 6. High bandwidth satellite-link system for 2-way mirroring of http/ftp server between NURC and NRV Alliance.

4. Conclusions

The added value of integrating monitoring and modelling systems has been illustrated. Covariances between environmental variables may be exploited for multiple purposes. On the one hand, information redundancy and correlations may be used to optimize sampling efforts and data assimilation on specific spatio-temporal ranges. Multivariate covariances may compensate for poorly sampled variables, areas and events. On the other hand, multiple models may be combined to improve joint prediction skills and better assess underlying uncertainties, which allows for cheaper and targeted monitoring efforts.

In the framework of operational oceanography, the success of this approach relies on real-time data and in-depth understanding of covariances. A wide diversity of multi-disciplinary platforms will increase the robustness of this assessment. Persistent *in situ* observing systems whether moored or autonomous should be cost-effective. The latter option offers the additional advantage of being cost-effective, limited risk, low-maintenance, scalable, adaptive and real-time.

The same conclusions hold for climate research, but at wider spatio-temporal scales. Persistent real-time monitoring efforts for operational oceanography provide the basis for climate research. The SE approach is potentially valid for a wide range of multivariate monitoring and prediction systems and should be further investigated through multi-institutional collaborative efforts.

Integrated observatories in the Seas of the Old World

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Abstract

The history of climate observation is relatively recent. We provide a glimpse of the requirements and developing activities in the "Seas of the Old World", where an integrated network of sustained observations is needed.

1. Introduction

The Mediterranean, Black and Caspian Seas, i.e. the "Seas of the Old World" (Figure 1) comprise an interconnected climatic unit in communication with climates of the surrounding continents of Europe, Africa and Asia and the Atlantic and Indian Oceans. On the basis of our present understanding, it is not clear how the global climate system is projected onto this region. Yet, high gradients in physical characteristics as well as in socio-economics make the region prone to impacts of climate change, especially with respect to changes in hydrology and eco-systems. Feedbacks between regional and global climate systems could be disproportionately large in this region of contrasts and transitions between marine and continental climates (Özsoy, 1999).

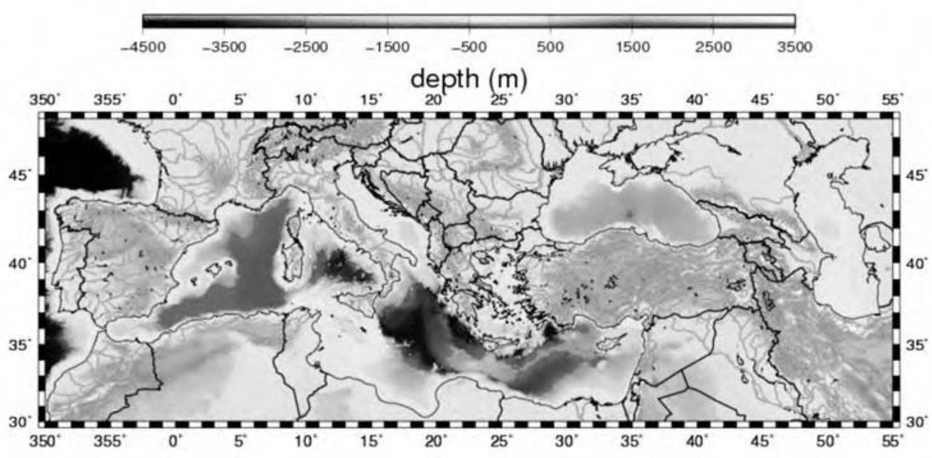

Fig. 1. The bathymetry and land topography of the Seas of the Old World, with superposed major rivers and country borders.

The complexity of climate processes and the scarcity of some resources in the region call for integrated scientific investigations. Networks of observing systems, shared data bases and models, integrated through supporting institutions in the region are essential to enable environmental prediction and management within a global change perspective. The keywords for such a long-term, sustained activity should be 'integration' and 'continuity': both are difficult to achieve but they must be attempted to ensure continued peace and stability in the region.

The climates of the Seas of the Old World are closely interconnected. It is imperative to eventually extend the integration of observing systems from the North Atlantic, downstream to the Black and Caspian Seas, so that the proposed Mediterranean observatory will be connected with a larger regional system. Episodes of past exchanges between the Black Sea and the Mediterranean (Ryan *et al*., 1997; Eriş *et al*., 2007) and recent thermo-haline adjustments in the Eastern Mediterranean (Özsoy and Latif, 1996; Roether *et al*., 1996) are reminders of regional extreme events. Often the cooling is connected to the entire region (Özsoy, 1999; 2001; 2005). The Mediterranean is known to be at the crossroads of distant atmospheric circulation systems and pollution sources that affect the entire region (Lelieveld *et al*., 2002) and there is ample evidence that the region is under the influence of large scale climate patterns such as the NAO, NCP regimes and the monsoons (Gündüz and Özsoy, 2004; Lionello *et al*., 2006), which impact ecosystems (Oğuz, 2003; 2005). In the age of climate changes favoring increased meridional gradients and extreme events (IPCC, 2007), expected changes in river fluxes (Arpe and Roeckner, 1999) can impact ecosystems as they have done in the past (Schilman *et al*., 2001).

Focusing on the Levantine and Aegean basins of the Eastern Mediterranean and the Black Sea (Figure 2), we observe that shallow continental shelves in the region are confined to the Nile Cone, the Gulf of İskenderun, some areas of the Aegean Sea, southern Marmara Sea and western Black Sea. Some of these wide shelf regions are also the confluence regions of large rivers. In the cases of Black and Caspian Seas a few large rivers have large catchments draining continental areas. In the Mediterranean, the catchments of many small rivers are confined by mountain ranges along the northern shore, and rivers on the southern shore are either non-existent or their discharges curtailed by the need for water, such as in the case of the Nile.

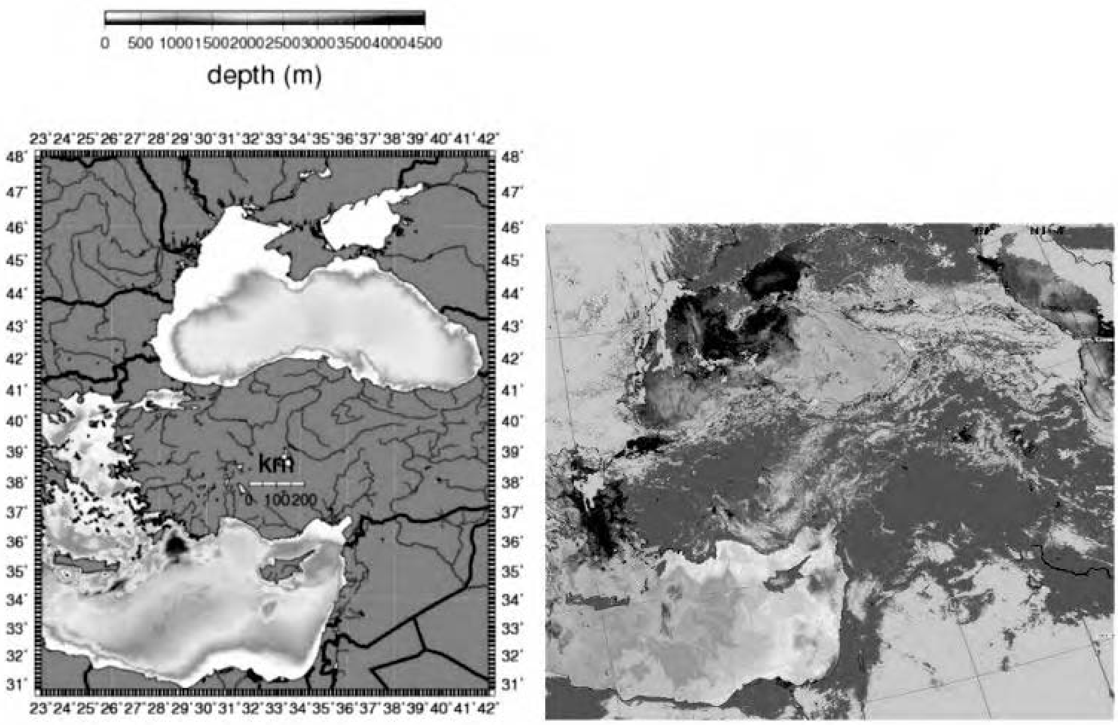

Fig. 2. (a) Bathymetry of the Levantine, Aegean and Black Seas; (b) satellite image.

2. Regional characteristics and observation need

The Black, Aegean and Levantine Seas are connected through the Turkish Straits. These basins have contrasting hydrological regimes. One is a dilution basin with an excess of fresh water from precipitation as well as large rivers such as Danube draining large continental catchments and bringing in large nutrient loads. The other is a concentration basin where evaporation is excessive, the river discharges are limited and confined to narrow catchments around the basin. The effects are immediate on the hydrography and ecosystems of each basin. While the Black Sea is eutrophic, especially near continental shelves, the Levantine Sea is mostly oligotrophic, with enhanced niches of production especially near rivers. Where river inputs of fresh water coincide with wide, shallow continental shelves, e.g. the Danube in the western Black Sea, the Nile in the southern Levantine, and Seyhan, Ceyhan and Göksu in the northeastern Levantine, local ecosystems are supercharged with nutrients, creating special conditions in their vicinity and contrasts with the deep sea ecosystems.

Physical characteristics and driving forces determine the state of the ecosystem in each basin resulting in various eco-zones. Riverine and atmospherically supplied nutrients provide the fuel for the marine ecosystems, but the internal machinery or 'weather' of each region determines the transport, mixing, deposition and new production characteristics. While the Black Sea (Özsoy and Ünlüata, 1997) and the Eastern Mediterranean (Figures 3 and 4) have their own dynamics, the Turkish Straits System (Figures 3b and 5) serve as a buffer between them and has its own regime, with a fjord-like two-layer stratification, mixing and ecosystem mechanisms controlling the exchange of materials between the adjacent seas (Ünlüata *et al.*, 1990; Beşiktepe *et al.*, 1993; 1994). A delicate machinery of transition and complex topographic and hydraulic constraints of flow (Figure 5) operate through the Dardanelles and Bosphorus Straits (Gregg *et al.*, 1999; Gregg and Özsoy, 1999; 2002).

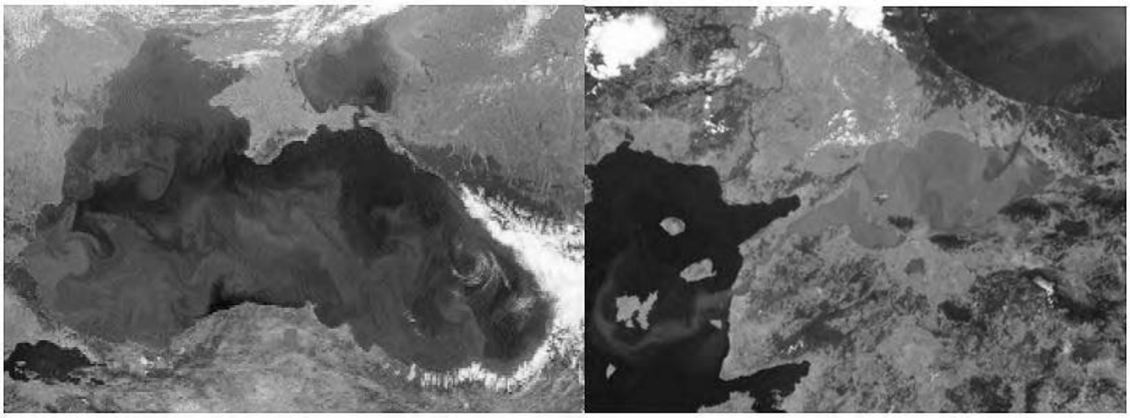

Fig. 3. (a) Black Sea MODIS image showing plankton blooms; (b) *Emiliana huxleyi* bloom in the Turkish Straits in the absence of a concurrent Black Sea bloom.

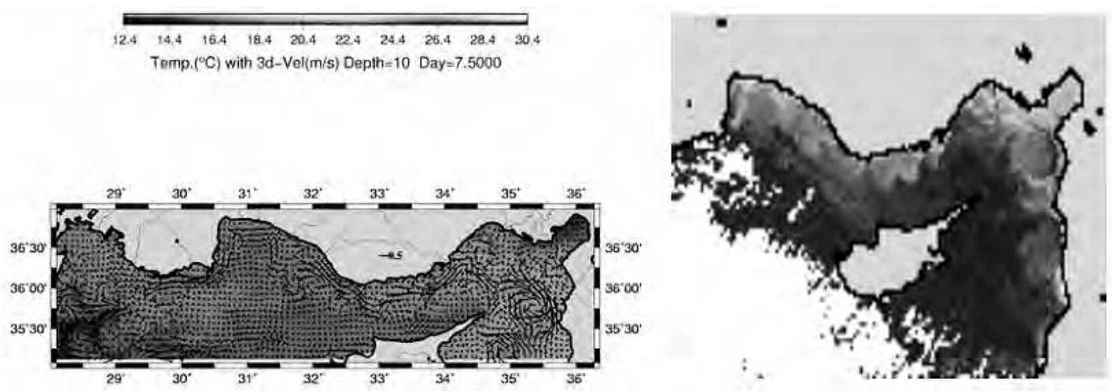

Fig. 4. (a) Daily forecasts of currents and surface temperature and (b) satellite chlorophyll distribution.

3. Observing and forecasting systems and infrastructures

Observation systems are too fragmented right now to speak about 'integration' and 'continuity' of measurements across a given region. Continuous ocean measurement is a task sparsely carried out by marine institutes and national agencies throughout the region. In the Levantine, Aegean and Black Seas region, there are a number of regional alliances for networking of observations (e.g. www.bo.ingv.it/mfstep, www.poseidon.hcmr.gr, isramar.ocean.org.il, medgloss.ocean.org.il, etc.) notably within the Mediterranean Operational Oceanography Network (MOON, www.moon-oceanforecasting.eu). These activities help, but do not ensure networking throughout the entire Seas of the Old World. Increased availability of satellites and real-time data transmission technologies add significant value but do not diminish the need for classical observations (Figure 6) for assessment of long term all-encompassing effects such as climate change and ecosystem stability. These efforts are further limited by the need to increase numbers, and add new types, of observations.

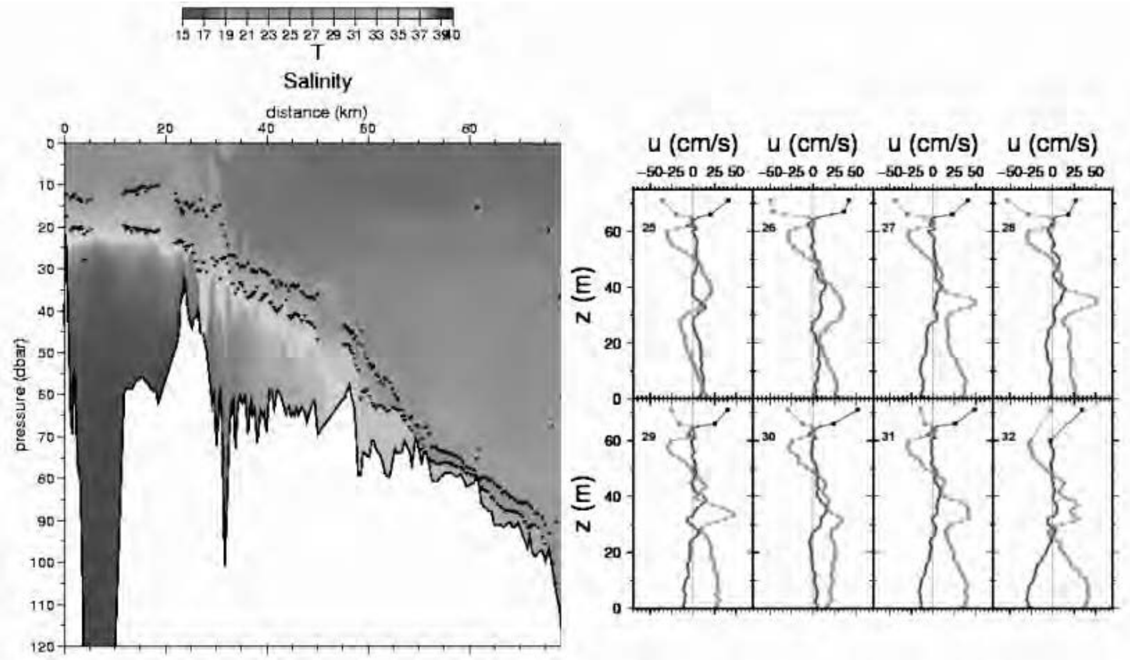

Fig. 5. (a) Salinity section from the Marmara Sea, through the Bosphorus Strait and across the Black Sea continental shelf (Özsoy *et al.*, 2001); (b) repeated current velocity profiles (u,v components) from bottom mounted real-time ADCP system in the Bosphorus.

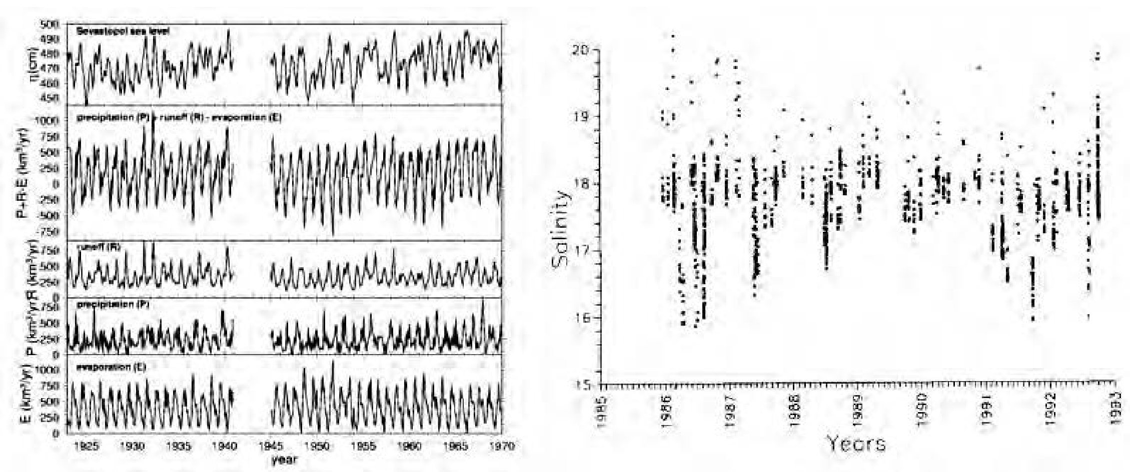

Fig. 6. Examples of time-series observations: (a) the components of the water budget for the Black Sea (Özsoy *et al.*, 1998); (b) surface salinity at the Black Sea entrance to the Bosphorus from hydrographic station data (Sur *et al.*, 1994).

IMS-METU recently participated in EU integrated projects such as the MFSTEP, MERSEA and in the currently running ECOOP and SESAME efforts as well as in the MAMA, MedGOOS, Black Sea GOOS and MOON alliances, to count a few. A number of other international projects have been carried out in the Black Sea and Caspian Sea with similar emphasis on collaboration. These activities help in establishing networks and maintaining the necessary infrastructure. In addition to these various national activities carried out with the support of Turkish Scientific and Technical Research Council (TÜBİTAK), through a local effort entitled the 'Meteorology and Oceanography Network' (MOMA, http://144.122.146.136), a number of observation stations are being established and predictive tools developed through cooperation of IMS-METU with government and research institutions. The stations include sea-level, meteorological, sea water properties measurements at a number of coastal stations, networking of existing stations, acoustic Doppler current profiling, automated nutrients, chlorophyll and plankton measurements at the straits and automated moisture and carbon dioxide eddy correlation atmospheric measurements at a coastal station. The observations are supplemented by the development of predictive modeling adapted to coastal seas and to the Turkish Straits System.

These efforts largely rely on individual institutions or initiatives. Although networking of these capabilities can help address some of the 'integration' and 'continuity' aspects, it does not guarantee sustained observational capacities in the age of global change. It is necessary and urgent to maintain and build up the underlying infrastructures, institutions and personnel, with the formulation of a new organizational model: the establishment of a regional network of 'integrated observatories' with long-term objectives and organization.

Observing System Simulation Experiments (OSSEs) for an integrated Mediterranean Observatory

Annalisa Griffa

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1. Introduction

A central problem in the setting of a marine observatory is to define the criteria for "an optimal strategy suitable for a wide range of scientific and management issues". Often inputs into the design of marine observing systems, in terms of spatial and temporal resolution and measurement locations, are mostly qualitative and based on general previous knowledge of the natural system. The Observation System Simulation Experiments (OSSEs) provide a more systematic and quantitative approach, originated in dynamic meteorology and early recognized as an important tool in oceanography (Malanotte Rizzoli, 1996; Robinson *et al.*, 1998).

While the effectiveness of a sampling strategy depends on how accuratly it can reconstruct the state of the system, its evaluation is usually elusive since the actual characteristics of the ocean are not known with sufficient precision. The OSSEs approach offers an attractive alternative, where the naural system is approximated with the numerical simulation results that are regarded as the "truth" and are entirely known. The truth is then subsampled according to a given sampling strategy, to produce a simulated data set and the data are used into an analysis or assimilation scheme to reconstruct reality. The reconstructed field is then quantitatively compared with the truth, therefore providing an objective evaluation of the sampling strategy. It should be noticed that there is a caveat in this approach, i.e. the fact that the simulations are assumed to provide a satisfactory representation of the natural system. This is not always the case, and therefore the scope of the OSSES have to be carefully evaluated and restricted to the aspects of the models that are realistic.

2. Previous OSSEs results in the Mediterranean Sea: the MFSTEP project

The overall objective of the Mediterranean Forecasting System project (MFSTP, http://www.bo.ingv.it/mfstep) was to explore, simulate and quantify the potential predictability of the marine ecosystem variability (Pinardi and Flemming, 1998), which requires, among other elements, the support of an observational system to monitor the relevant parameters in the water column. An important role in the implemented observing system of MFSTEP, which included *in situ* and satellite observations, was played by the fleet of profiling floats MedArgo. They drift at the nominal depth of 350m., providing information on temperature and salinity (TS) profiles and on positions (**r**) at intervals Δt of approximately five days. These information can be assimilated in the numerical model system to improve prediction of water mass structure and velocity.

In the framework of MFSTEP, the Observing System Simulation Experiments (OSSE) approach has been applied to investigate MedArgo sampling strategies and to quantify their impact. Various types of tests have been made including a) assimilation of TS profiles from MedArgo taken in isolation as well as taken together with information from other *in situ* platforms (Griffa *et al*., 2006); b) mapping of TS MedArgo profiles, in isolation and together with satellite SST and altimetric information; and c) assimilation of positions from MedArgo (Taillandier and Griffa, 2006; Taillandier *et al*., 2006b).

The assimilation OSSEs are performed by means of identical twin experiments, in which data extracted from a Control run that represents the "true ocean" are assimilated in another run obtained with the same model but with different initial conditions. The convergence of the Assimilation run towards the Control run is measured to quantify the data assimilation effectiveness in driving the model with 'wrong' initial conditions towards the truth. Each twin experiment includes: a Control run, which represents the 'true' ocean and provides the simulated data to be used in the assimilation; an Assimilation run, with different initial conditions from the Control run and including the assimilation of the data extracted from the control run; a Free run, initialized as the Assimilation run but without data assimilation. All runs are driven by the same external forcing. The convergence of the Free run towards the Control run is used for reference, since it shows the ability of the model to converge towards the Control run due to the atmospheric forcing.

Data assimilation for TS (Griffa *et al*., 2006) is performed by means of the System for Ocean Forecasting and Analysis (SOFA) (De Mey, 1994; 1997; De Mey and Benkiran, 2002). The assimilation was performed in the general circulation model MOM. SOFA includes a reduced-order multivariate optimal interpolation scheme, where the order reduction is achieved by projecting the state vector onto vertical EOFs, that represent the eigenvectors of the error covariance matrix for the forecast. The scheme is multivariate in terms of both data input and corrections on the model output. For position information, since no methodology was available at the beginning of MFSTEP, a new method based on a variational approach was developed, aimed at correcting the model velocity state variable (Molcard *et al*., 2005; Taillandier *et al*., 2006a), and then used in the OSSEs. The method was implemented and tested in the framework of the general circulation model OPA.

Results from the MFSTEP OSSEs are contained in several papers (Raicich and Rampazzi, 2003; Raicich, 2006; Taillandier and Griffa, 2006; Taillandier *et al*., 2006b; Griffa *et al*., 2006). The main points can be summarized as follows:

- The accurate but sparse MedArgo *in situ* TS data can be effectively merged with other platforms such as Voluntary Observing Ships (VOS) T profiles or lower accuracy but high-resolution data derived from satellite altimeter and sea surface temperature observations. The merging provides a much better estimation of the 50m T fields. Results show, in particular, that the optimal combination is instrumental in reducing the aliasing due to the mesoscale variability and in adjusting the analyzed fields to the *in situ* fields.
- Regarding sampling strategies, the most effective trajectories for TS assimilation appear to be the ones in frontal areas dividing different water masses, since even small differences in the mesoscale structure of the fronts can account for a significant correction (Figures 1 and 2). For the intermediate layer, the most prominent and permanent fronts are observed in the Ionian Sea close to the Otranto Strait (dividing the Levantine Intermediate Water (LIW) from the Adriatic water) and West of the Sardinia Channel, (dividing the modified LIW from the water of Atlantic origin). For the position assimilation, regions of high velocity variability are the most effective, such as for instance the meandering Liguro-Provencal-Catalan Current.
- On the basis of the OSSEs results it is recommended that the number of MedArgo floats is increased with respect to the MFSTEP coverage corresponding to a total of 23 floats released over the whole Mediterranean Sea. Results show that when the coverage is doubled, the corresponding correction in TS and in velocity is more than doubled, going from a marginal correction (10% or less) to a consistent correction of 25-30%. Global convergence is not reached with the sparse data distribution while it is reached when doubling the coverage, Also mapping results show a significant improvement when doubling the coverage. Increase in the coverage is especially recommended in the present phase, given the uncertainty in the future of altimeter measurements in the next few years, implying that prediction might rely more heavily on *in situ* data.

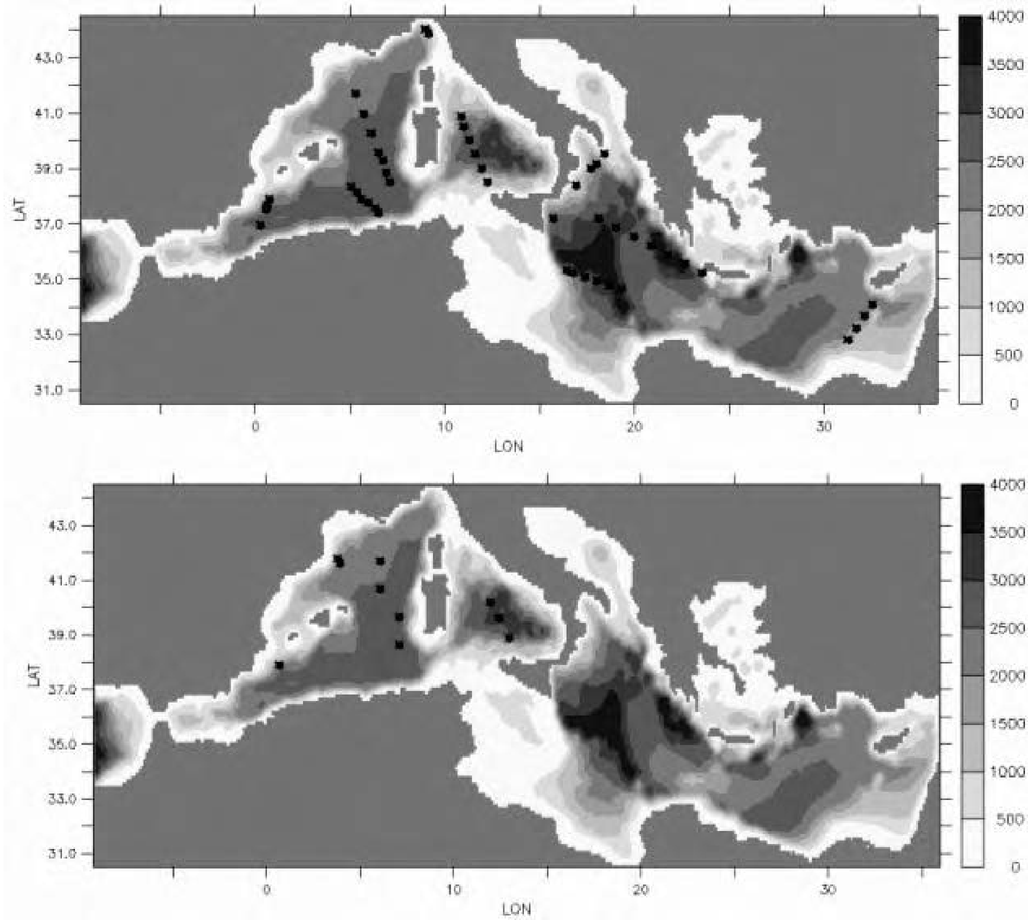

Fig. 1. Examples of launching sites for the synthetic MedArgo floats used in the OSSE assimilation experiments: experiments with 47 floats (upper panel) launched along VOS tracks, and with 10 floats (lower panel) with realistic launches. Shades indicate bottom depth in meters.

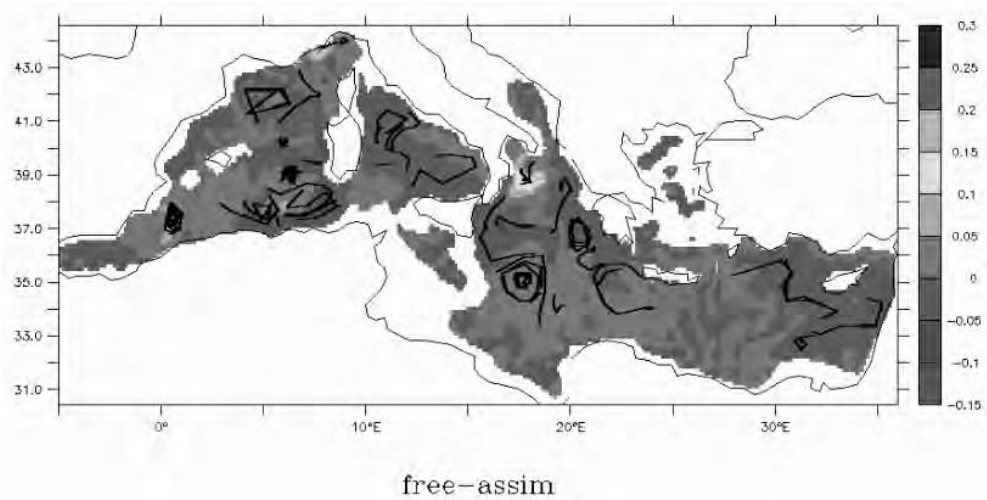

Fig. 2. Trajectories (computed over the whole integration period of 40 d) superimposed to salinity misfit maps for the winter experiment with 47 floats at 400m and at time t=35d. The misfit is computed between the Assimilation and Free run (Free minus Assim).

3. Future OSSEs and planning of a new Integrated Mediterranean Marine Observatory

While the MFSTEP experience with OSSEs have been very positive and it has shown the potential of the approach, several methodology improvements can be foreseen and developed in the future.

First of all, while the MFSTEP OSSEs were based on reconstruction of TS or velocity fields using assimilation or mapping, new methodologies can be explored based on variational methods and sensitivity analysis (Baker and Daily, 2000). In particular the adjoint of the tangent linear model is extremely suitable for sensitivity analyses because it allows to determine how a certain metric representative of a physical aspect of interest, evolves due to linear variations of the system variables. The observing system design question is addressed directly because we quantitatively determine which system variables should be observed, where and at what time to have the greatest influence on the property we wish to know.

Another important aspect to be further developed is the OSSE's application to ecosystem dynamics. While pioneering works are available in the Mediterranean Sea (Crispi *et al*., 2006), further refinements are needed, especially considering the crucial role played by bio-geochemical measurements in future observing systems. Improvements in several directions can be foreseen, from improvements of assimilation and sensitivity techniques, to even more basic studies focused on modelling approaches able to embrace, for instance for the large scale problem, the complexity of the ecosystem "community structure" (Follows *et al*., 2007).

Finally, the nature of the metrics used to quantify the effectiveness of the observing system should be further investigated. In the MFSTEP a very simple type of metrics was used, i.e. the reconstruction of the same variables as measured. T, S and velocity maps were reconstructed through assimilation over time scales of the order of weeks to month, i.e. time scales relevant to operational oceanography. Different metrics, more complex and of climatic value, can also be considered for further applications. As an example some key features of the thermohaline circulation can be considered, such as water mass formation or strength of conveyor belts.

The general plan for the future Integrated Mediterranean Marine Observatory (IMMO) will likely include various components and platforms. A multi-scale monitoring strategy can be foreseen, composed of:

a) a large scale component with basin wide measurements from satellite, Argo floats and/or VOS XBT, complemented by a few fixed point measurements in key areas such as the main straits;

b) a high resolution component (similar to the ORION array) in one or two selected regions to address fundamental processes related to enhanced biological productivity and cross-frontal exchanges at the shelf break. They will include a mooring array complemented by glider sections.

c) a near coastal component (in few demonstrative sites), addressing specific coastal management problems and including HF radar, gliders and drifters. Inclusion of bio geochemical sensors in fixed and moving platforms will be of great importance.

In this complex multi platform and multi parametric framework, the OSSEs will be most important to help selecting the most effective strategies, at least from the scientific/oceanographic point of view. They can provide indications on questions such as how many instruments are needed, what is their best location or tracks, which time or space resolution is more appropriate for given parameters.

Deep seafloor observatories: a new tool for monitoring geohazards, climate change, ecosystem life and evolution

Pierre Cochonat and Roland Person

Ifremer, France

Abstract

To better understand geophysical, biogeochemical, oceanographic and biological active phenomena it is now recognized that we need long time series of data coming from the seafloor at key provinces. Major advances in our understanding of environmental processes require us to identify temporal evolution and cyclic changes and to capture episodic events relative to oceanic circulation, deep-sea processes and ecosystems evolution. Long-term monitoring will allow the capture of episodic events such as earthquakes, submarine slides, tsunamis, benthic storms, biodiversity changes, pollution and other events that cannot be detected and monitored by conventional oceanographic sea-going campaigns. Sea-floor observatories are needed to collect long time series of simultaneous data relative to: seismology, geodesy, sea level, fluid and gas vents, physical oceanography, biodiversity imaging at different scales. Several sites have already been selected in the Mediterranean sea for the study of environmental processes in the geosphere, biosphere and hydrosphere in the framework of the EU supported initiatives such as ESONET NoE ("European Seas Observatory Network" Network of Excellence) and EMSO (European Multidisciplinary Seafloor Observatory) recently listed in the European Strategy Forum on Research Infrastructures (ESFRI). These may provide the scientific basis and technical infrastructure of an Integrated Mediterranean Marine Observatory.

1. The challenge of the deep-sea floor observation

Oceans cover 71% of planet earth, at least 40 % of the EU territory is underwater. The understanding of this "hidden world" requires a better exploration of new frontiers. The study of the oceans would enable an entire new class of scientific experiments and studies that are impossible if we are limited to ships, satellites, single moorings and individual autonomous vehicles. Episodic events such as earthquakes, submarine slides, tsunamis, benthic storms, biodiversity changes, pollution and other events cannot be detected and monitored by conventional oceanographic sea-going campaigns. New observatories will improve the rate and scale of ocean data collection. These observatories, including relocatable systems, will be deployed on specific sites characterized by active processes and be linked in a network at European level. They will also provide platforms to support new kinds of instruments and autonomous vehicles.

The scientific need for long time series of data coming from the seafloor at key provinces providing continuous surveillance in relation to geophysical, biogeochemical, oceanographic and biological active phenomena, is now demonstrated in several disciplines. This refers to the need of establishing long term monitoring of environmental processes which can be related to ecosystem life and evolution, global changes and geohazards. Major advances in our understanding of the oceans require to measure cyclic changes and to capture episodic events relative to such deep-sea processes and ecosystems. Seafloor instrumentation are needed to acquire simultaneously long time series of data relative to: seismology, geodesy, sea level, gas vents, physical oceanography, biodiversity imaging at several scales, particle dynamics, slope failure, turbitidy currents, pollution, etc. Most of these processes interact and should be measured for modelling and forecasting natural events.

The development of deep water scientific observatories for scientific purposes is in its infancy. Technology today allows to build sophisticated systems, but the cost of these systems is high and, funds usually attributed to oceanography are not related to such investments. We have to demonstrate the importance for humans of such infrastructures so that governments will invest in their development as they did in space systems: it is more critical today for humanity to save the Ocean than to walk on Mars ! (Person, 2007)

2. Past and current initiatives

European state-of-the-art on seafloor observatories. During the 5th FP the EU has developed an array of preliminary seafloor observatories, thanks to an effective synergy among research institutes, industries and SMEs. This fleet includes single-frame multi-parameter observation platforms, developed and validated during EU projects (e.g., GEOSTAR, GEOSTAR 2, ASSEM, ORION-GEOSTAR 3,) for a total of eight units and an Italian seafloor multi-parameter platform (SN-1, one of the ESONET key-sites). The nine units of the fleet have compatible communication protocols, have the required seafloor observatory specifications (e.g., multidisciplinary, long-term operability, capability of [near]-real-time data transmission, possibility to be integrated with on-land networks) and can be integrated with both offshore and on land monitoring systems, as demonstrated for instance in the ASSEM-ORION joint experiment in Corinth (2004). Other EU projects have developed complementary sub-marine systems (such as “landers”) which, even lacking “observatory” capabilities, are important and effective for specific scientific objectives, as demonstrated in any experiments.

ESONET, CA (European Seafloor Observatory NETwork, Concerted Action). “The European Sea Floor Observatory Network” thematic network established the basis for a network of long-term, seafloor and multi-disciplinary observatories at key locations on the European margin providing continuous vigilance in relation to geophysical, biogeochemical, oceanographic and biological phenomena. The concerted action ESONET have identified natural processes that require long time series to detect because they are hidden by noise of higher frequency processes. The most important ones are: (1) the episodic release of methane from the seabed affecting climate change, (2) the relationship between earthquakes, tsunami generation and submarine slope failures, and (3) the short term biogeochemical processes affecting the marine ecosystem. These processes are of fundamental importance for European society, because we need to devise sensible climate change policies, protect our coastal population and infrastructure, and manage our marine resources.

ESONIM. The “European Seafloor Observatory Network Implementation Model” (ESONIM) specific support action is currently working to identify the best technical solution, to provide the economic justification and suggest the appropriate legal structures to establish a seafloor observatory that conforms to the model defined within the ESONET thematic network.

ESONET Network of Excellence. The “European Seas Observatory Network” (ESONET) Network of Excellence is now working towards creating an organization capable of implementing, operating and maintaining a network of multidisciplinary ocean observatories in deep waters around Europe from the Arctic Ocean to the Black Sea. The goal of the ESONET NoE is the lasting integration of European research on deep sea multidisciplinary observatories. Over the next four years, the approach will be to merge the programmes of member Organisations through research activities addressing the scientific objectives and networking activities specially designed for integration and spreading excellence.

ESONET observatories constitute a sub-sea segment of the GMES and GEOSS initiatives and are linked to the EU INSPIRE initiative. Twelve key areas around Europe have been identified from which specific targets are selected for relevant science programmes of potential hazards, geo hot spots and ecosystem processes (Figure 1). Sea floor infrastructure will provide platforms for instrumentation deployed throughout the water column and the geosphere below.

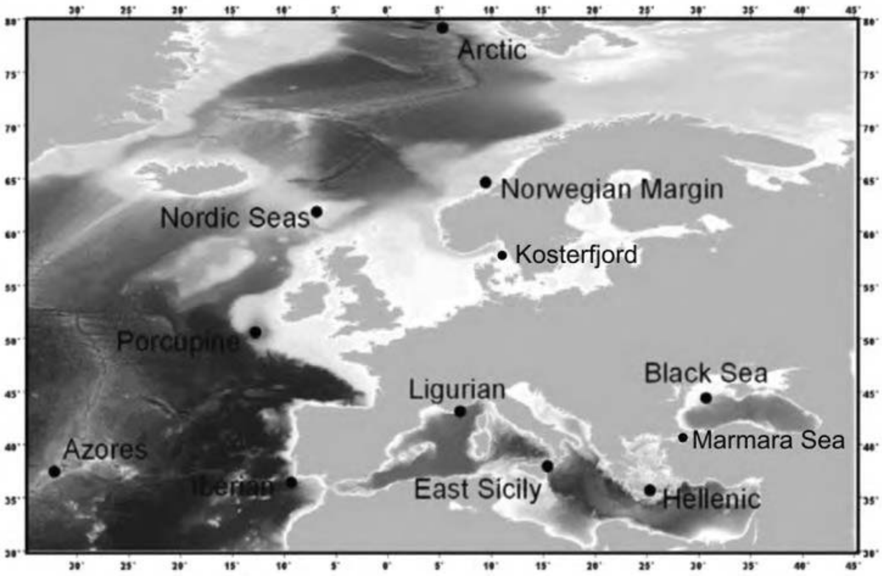

Fig. 1. Sites planned by ESONET NoE.

EMSO (European Multidisciplinary Seafloor Observatory). The NoE ESONET will construct the scientific framework. In parallel, The EMSO projects will prepare and provide the infrastructures at European and National levels. The European Strategy Forum on Research Infrastructures (ESFRI) noted that the European deep-sea observatory community has matured and is ready to establish a multi-disciplinary seafloor observatory network (EMSO). ESFRI has identified EMSO as a candidate research infrastructure that could be supported during FP7.

Implementation of EMSO is based on evolution of existing systems by connecting previously autonomous systems, and providing power and long-term real-time data capability, integrating in the wider system of mobile and re-locatable seafloor lander platforms. Establishing the network of seafloor observatories requires a fulfillment of a critical mass at European level overcoming national fragmentation, and the involvement of state members. This major issue is the purpose, and the challenge of the present-day EMSO Preparatory Phase.

KM3net is a future deep-sea research infrastructure hosting a neutrino telescope with a volume of at least one cubic kilometre to be constructed in the Mediterranean Sea in deep water. The Preparatory Phase of the infrastructure will start in 2008. The design, construction and operation of the KM3NeT neutrino telescope will be pursued by a consortium formed around the institutes currently involved in the ANTARES, NESTOR and NEMO pilot projects. Based on the leading expertise of these research groups, the development of the KM3NeT telescope is envisaged to be achieved within a period of three years for preparatory R&D work plus three years for construction and deployment. Oceanographic measurements will be associated to neutrino telescope.

International: considerable development work has been done by NEPTUNE-MARS projects in the North America and the VENUS – ARENA projects in Japan. NEPTUNE Canada is implementing a first network.

3. Objectives

3.1 Scientific objectives

Fieldwork approach: observation at different time and space scales. The concept of deep sea observation must be seen as mainly devoted to field work approach. That means that (1) the selected area representative for the occurrence of deep sea processes are studied thanks to seafloor and water column systems, cabled or not cabled, allowing acquisition of long time series data but (2) acquisition should also be carried out by recurrent "conventional" scientific cruises operating any modern survey technologies, including multi-parameter acquisitions. The overall objectives remain to understand the dynamics of the ocean and especially its seafloor. Major advances across a range of scientific disciplines are expected:

Geosciences and sea floor interface: geo-hazards (earthquakes, slope instability and sediment failures, tsunamis); transfer from the Earth's interior to the crust, hydrosphere and biosphere; plate tectonics; sedimentary processes; sediment transfer to the deep sea and climate change; fluids seeps and vents, gas hydrates.

Physical oceanography and global change: deep circulation; water masses; ice cover; climatology; physical oceanography processes.

Biology of marine ecosystem: biogeography; ocean productivity; biodiversity and hot spots; ecology of photo-synthetically and chemo-synthetically driven benthic ecosystems, dynamics of deep seafloor vents ecosystems (hydrothermal and cold seeps); coral reefs and carbonate mounds; living resources.

Non-living resources: energy-hydrocarbons; renewable and $C0_2$ sequestration; mining/deposition.

A few points are detailed below:

Geohazards/Seismic activity resulting from the convergence of the European and African plates represents a major hazard for the populated, southern margins of Europe. According to the Red Cross/Red Crescent report on world disasters, earthquakes have proved the deadliest of all Europe's disasters over the past decade, and cost the continent 25 billions € in damage alone. It is recognized that earthquakes such as those that occurred in the recent past in Europe [e.g. Lisbon, 1755; Messina, 1908] would certainly result in tens or hundreds of thousands victims and billions of Euros in damage. Seismicity is also evident in the Eastern Mediterranean Sea and along the Algerian Margin. There is therefore a clear need for stations at strategic locations along these plate boundaries to monitor seismic events in the Earth's crust which may become geo-hazards. Combined with borehole instrumentation, sea-floor observatories, integrated with land-based networks, will advance the fundamental understanding of plate tectonics and seismogenic zones around Europe.

"Despite recent advances, there is at present no unified theory of fault slip to account for earthquake nucleation and propagation, nor to explain the mechanisms of strain across the spectrum of observed deformation rates ranging from seconds to years. Consequently, the question of whether precursor signals exist for major earthquakes, even in theory, remains under discussion. Progress on these topics is severely limited by a lack of information on ambient conditions and mechanical properties of active faults at depth." (NatroSeize programme)

Ocean circulation and climate evolution. Ocean circulation connects all basins around Europe. There are several locations of global significance within the ESONET area where sustained *in situ* observations need to be monitored. Change in water mass properties in terms for example of temperature, salinity, oxygen, carbon and major nutrients is important for marine resources around Europe. Change in large scale circulation in terms of transport of heat and matter that is influencing and important for regional and global climate.

Geo-biology. Studies at the sea floor interface have become multi-disciplinary as the interaction between venting of fluids and specialised biological communities living on the sea floor has been elucidated. Oceanic areas around Europe comprise a remarkable variety of such vent habitats, from mud volcanoes, pockmarks, seeps, and carbonate mounds, to hydrothermal hot vents at the mid-ocean ridge. It is thought that the biodiversity of related ecosystems and of the deep waters around Europe, still being discovered (e.g. HERMES), exceeds that of the total European land biomass. Sea-floor observatories will allow for decadal monitoring of these biodiversity hotspots, setting up for groundbreaking discoveries on issues such as microbial biodiversity, life in extreme environments, and the importance and role of the subsurface biosphere. A prerequisite to answer the forgoing question is to first understand the spatial and temporal variability of benthic ecosystem structure over large areas subject to a broad range of environmental conditions. This will require fixed and mobile imaging as well as *in situ* sampling for ground truth. Understanding the functionality of benthic communities (e.g., respiration, reproduction, and bioturbation) is just as important; this will require intensive studies at key representative locations. Models will play a key role in understanding the coupling of the variability of the upper water column with the benthos.

Fluid fluxes and geophysical processes in the sediments and crust. Sustained time-series recordings by instruments sealed within boreholes will be required to investigate active processes such as pore-water flow, thermal and chemical advection and crustal deformation. Boreholes will also be used for perturbation experiments to investigate *in situ* physical properties of sediments and/or crust, and their associated microbial communities. In Gas-hydrate provinces, the variability driven by different forcing must be monitored.

3.2 Technical objectives

Standardisation and interoperability. In contrast to terrestrial systems, underwater observatories are not easily accessible and servicing can prove difficult. A similar planning and logistic effort, as seen in space sciences, needs to be implemented for these observatories. This is the main reason for having standards, as instruments can be tested and integrated in a defined procedure before deployment. Standards make interoperability possible, which not only means interchange-ability of instruments but that the collected information is comprehensible for all subsequent data processing units. The sensor information must be accompanied by an exhaustive description of the data in the form of standardised metadata schemes. In other words the standards on a lower level should be translatable to a higher level as for instance has presently been set up with Sensor ML and IEEE-1451. This will then provide a base to make the data available for automated information retrieval. On top of that, schemes of sensor information metadata will facilitate the interoperability in particular under the aspect that information from different observatory sites has to be integrated into a common system.

Last but not least the standardisation processes are expected to generate added value and benefits in an economic context (enhanced product quality and reliability; reduction in costs; increased efficiency and ease of maintenance; simplify and improve usability; greater compatibility and interoperability of goods and services; improved health, safety and environmental protection).

In the industrial community, standardisation is a normal step, typically (almost inevitably) occurring when the industry has reached a sufficient level of growth and maturity.

Sensors. To the extent possible, these instruments should possess the following characteristics: 1) be long-lived, 2) require little or no *in situ* calibration, 3) measure unaliased integral quantities more representative of larger scales, and 4) be useful for multiple disciplines. The first requirement probably calls for bottom-mounted instruments with few or no moving parts. Candidate sensors included broadband pressure, temperature, salinity (conductivity), dissolved oxygen, optical transmission and backscatter; fluorometer, broadband acoustic hydrophones and transceivers (ambient sound, inverted echosounder, acoustic profiler, fish sonar, geodesy, navigation, and communications); electrometer (for barotropic velocity), acoustic Doppler current profiler, seismometer, geophone; broadband formation pressure, seep or vent-flow monitor, continuous fluid sampler, and sediment trap. Video imagery was also requested. It was recognized that there may be different combinations of these and other sensors that may constitute a “basic suite” depending on the particular location. There are clearly many other sensors that will be used for more specific experiments.

Industrial impacts. The development of new technologies, including standards on sub-sea equipments, must be considered as a new challenge for European industry. For this purpose the European experts in this field, from industry as well as from research institutions, have to closely interact to come up with a sustainable concept. On the hardware side dedicated developments as for instance the branching of seafloor cables have to be stimulated where SMEs and telecommunication companies will contribute with existing components. The long term deployment of instrumentation in the harsh ocean condition is a major obstacle to be solved. Problems include bio fouling, corrosion and physical damage. Here observatories will offer a unique opportunity to develop new concepts as, by inter-comparison of different sensor signals additional information can be derived. The offshore oil and gas industry make great use of remotely operated vehicles (ROVs) but only a few scientific institutes in Europe have deep water ROVs capable of servicing deep sea observatories: compatible methods are required.

3.3 Socio-economical objectives

Data end-users. The ESONET Consortium (with representatives from UK, Norway, France, Netherlands, Germany, Ireland, Greece, Italy, Portugal and Sweden) in the framework of a Concerted Action sponsored by the EC as a sub-sea component of the European initiative for Global Monitoring for Environment and Security (GMES) has previously identified data end-users in a sample 11 countries Belgium, Bulgaria, France, Germany, Ireland, Italy, Netherlands, Portugal, Romania, Spain and UK. Potential user category, user area of interest and policy issues are summarized below:

User category	User interest	Policy issue
Government, Departments, Public institutes, State sponsored bodies, Research bodies, Private consultancy, Private industry, Industry organisations, Charitable organisations, Nature protection organisations, Public	Climate change studies, Geo-hazard identification, Education and training, Ecosystem, Biodiversity assessment, Environmental protection and conservation, Pollution, Waste prevention regulation policy, Administration, Civil security and defense, Offshore oil industry, Mineral extraction, Biotechnology, Industrial accidents, Renewable energy, Tourism	Climate change, biodiversity, decline/habitat destruction, environmental security, geo-hazards, oil pollution/ hazardous substances, water quality, pollution, waste, recreation.

Socio-economic impacts. The transfer of knowledge to users will allow the EU and governmental bodies to make significant contributions to the world effort to define mitigation strategies to confront global change, and to manage marine resources and ecosystems. The socio-economic users of EMSO knowledge include (a) assessment bodies, their scientists and policymakers, e.g. IPPC, (b) Intergovernmental organisations, e.g. IOC, FAO, ICES, CIESM, (c) International agreements on exchange of data related to hazards such as global seismographic networks like GSN, FDSN and GEOSS related tasks (d) International Conventions, e.g. CBD, OSPAR Convention, (e) Non-governmental Organisations, (f) National fisheries assessment and climate change agencies, (g) Relevant European Commission directorates, e.g. MARE Directorate General.

Public outreach. The spreading of knowledge to the European public will be achieved through the use of a network of public outreach standpoints. Transfer of knowledge will specifically target the young age groups in order to favour general orientation towards science, foster scientific careers and most importantly shape an environmentally sensitive European society. The joint public relations can provide a wide range of new opportunities to explore and investigate the dynamics of the marine world using real-time data flow to classrooms and living rooms coupled with cutting-edge visualization techniques. Collaborators within the informal educational community will include museums, science centers, aquariums, media, and youth programs. All these restructuring activities will lead to higher scientific excellence of the new generation of scientists and engineers of the EU.

Environment and security operational issues. A network of seafloor observatories is fundamental to complete the GMES system with a sub-sea segment. This segment will fill a gap of the monitoring of those processes occurring in the sea, like hazards for the environment and humans. The sub-sea segment will be linked to the sea-surface and land segments of GMES through [near]-real-time communications (acoustics, radio, satellite and cable). The network can thus provide immediate warning of short and medium-term hazard events (e.g., tsunamis, sub-sea landslides, gas leakage, pollution from ship-wreck). The sub-sea segment of GMES shall provide the necessary data to complete the picture on the status and evolution of the environment including all the Earth domains (seafloor interface and solid Earth below, water column, sea surface, land, atmosphere). This vision is essential for the decision makers to set-up effective strategies for risk and security management.

4. Potential sites in Mediterranean Sea (from ESONET EMSO projects)

- Iberian

This region outside the Strait of Gibraltar is at the point of interaction of the Mediterranean outflow with waters of the NE Atlantic. Geologically there is the junction of the Eurasian and African plates with doming of the sea floor, mud volcanoes and other features including the putative origin of the great 1755 Lisbon earthquake and tsunami which was the most catastrophic ever to occur in Western Europe. ESONET would provide permanent sub-sea seismic stations in this area as well as oceanographic and water column sensors in 3,000-4,000m water depth requiring 130km of cable.

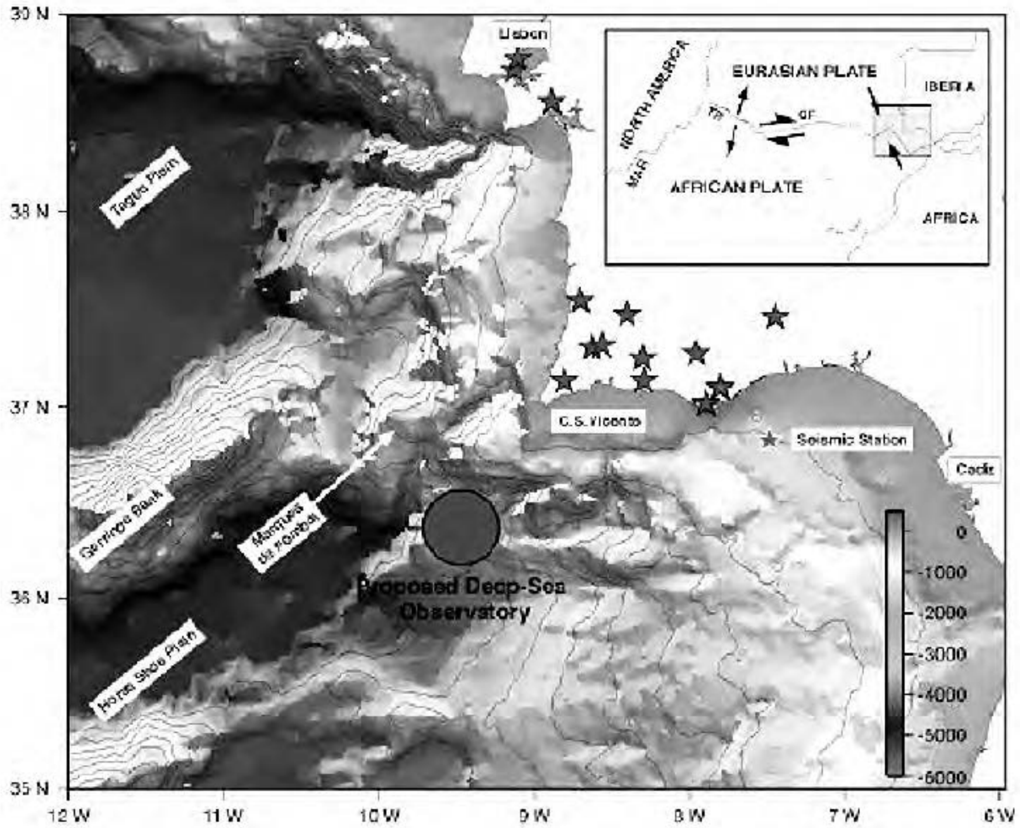

Fig. 2. Location of proposed Deep-Sea observatory off Gibraltar.

- Ligurian Sea

The Ligurian Sea site (2,300m deep, 25km off Nice) is of multidisciplinary scientific interest with seismic activity near dense human habitation areas, slope instabilities with turbidity currents in canyons, past tsunamis, long term studies on biological and physical oceanography (DYFAMED). The Ligurian margin site is close to a neutrino net Antares offering existing infrastructures (cables, land fall station, etc.), is already cabled and has been used to test sea-floor installations. It will be enhanced to provide an international facility for testing marine sea-floor and bore-hole installations. Bore-holes are planned as part of an IODP project in 2007-2008. The development will be carried out in close synergy with Nemo (East Sicily) and NESTOR (South West Peloponissos). This is the site for addressing the question of geohazard. The experiment developed in Ligurian site would be efficiently applied on other sites in a further step, such as the Marmara Sea. Ideally, three stations are proposed with broadband seismometers, biogeochemical sensors and physical sensors, a local acoustically networked array to monitor slope stability and moorings to monitor dynamic fluxes with 180km of cable.

This site may be considered as the basis for a N-W Mediterranean Sea observation system, including for instance, possible link with the Algerian Margin especially for seismic aspects and particularly tsunami warning system. Multinational networks or initiatives are presently ongoing for the monitoring of geological hazards in the Euro-Mediterranean area, for instance the Unesco Intergovernmental Coordination Group for the North Eastern Atlantic and Mediterranean Sea Tsunami Warning System in (ICG/NEAMTWS).

- East Sicily – NEMO-SN-1

This is a multidisciplinary observatory located in the Ionian Sea off East Sicily, close to Mount Etna (Figure 3), in an area which has experienced disastrous seismic events, some of them accompanied by tsunamis such as the 1693 and 1908 earthquakes which completely destroyed the cities of Catania and Messina respectively. An underwater electro-optical cable owned by the Italian Istituto Nazionale di Fisica Nucleare (INFN) has been deployed for pilot experiment of the NEMO (NEutrino Mediterranean Observatory) project. The SN-1 (Submarine Network-1) deep seafloor multi-parametric observatory is connected to shore via this cable. SN-1 focuses on geophysical, mainly seismological data, and also provides oceanographic and environmental measurements which are all uniquely time referenced. A modular design allows additional sensors to be added as required. SN-1, equipped with a junction box for the connection to the cabled interface-device, was deployed and connected to the cable at the end of January 2005 when real-time acquisition started.

The NEMO SN-1 site is an open underwater laboratory for demonstration and integration activities. A total length of over 130km cable is envisaged.

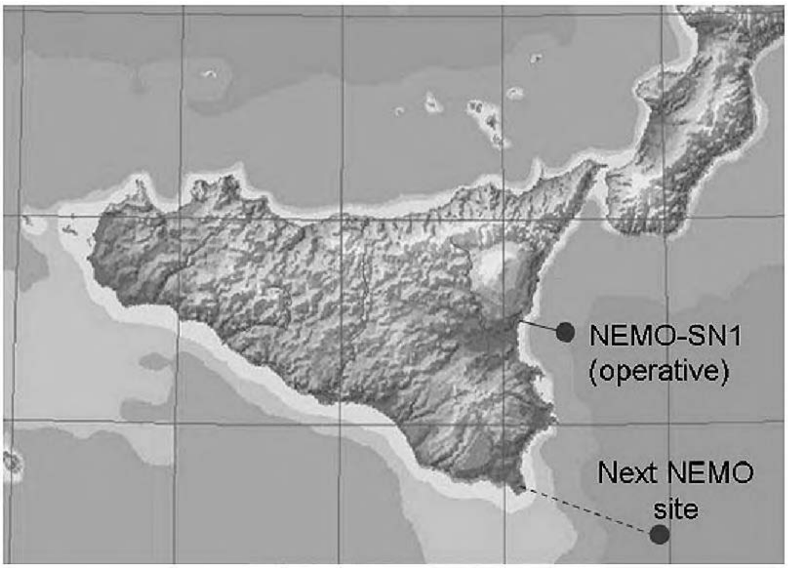

Fig. 3. Location of NEMO existing and future observatories.

- Hellenic

The eastern Mediterranean is characterised by significant seismicity, special habitats in deep basins and a very steep drop off in depth from the coastlines. The Hellenic region will comprise four separate cables. 1. NESTOR (NEutrino experimental Submarine Telescope with Oceanographic Research) which has an existing cable off the Peloponnese. 2. IODP (Integrated Ocean Drilling Program) deep borehole location on the accretionary complex south of Crete in 2,486m water depth. 3. Cretan basin in the southern Aegean. 4. The Rhodos basin, one of the deepest large basins in the eastern Mediterranean. The combined system will require 220km of cable.

- *Marmara Sea*

The Marmara Sea could be seen as the more appropriate site for addressing the huge problem of seismic risks in a dense human habitation area and in an area prone to high earthquake in the future. The interest for a Marmara Sea observatory is related to the rapidly growing research efforts on the mechanics and dynamics of faulting processes that integrate rock mechanics, seismology, geodesy, frictional physics, and fluid-fault interactions. The link between fluid and seismicity should be investigated there in terms of monitoring pore-fluid pressure as a possible precursor of earthquake.

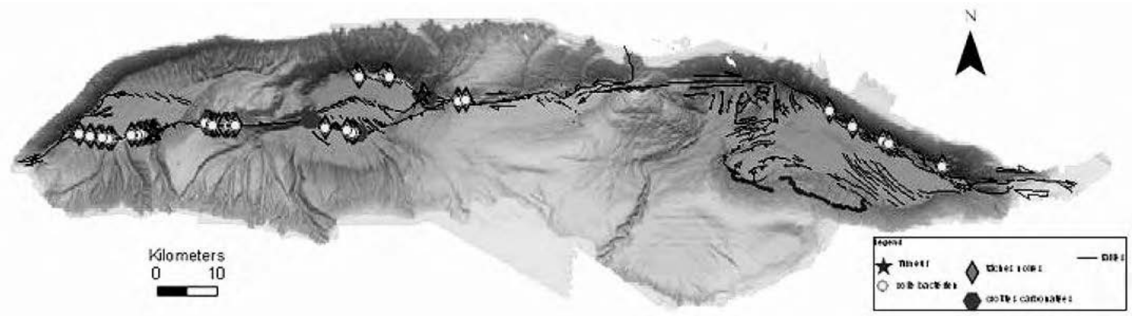

Fig. 4. Cold seep distribution in the Marmara Sea mostly based on ROV observations during Marmarascarps cruise (Armijo *et al.*, 2005). Note that all known seeps are on strike-slip fault traces and that most, but not all, fault segments explored have cold seeps.

5. Strategy

Multi-disciplinary, multi-site, cooperation aspects. It is clear that there are needs of common infrastructure for different scientific objectives: multi-disciplinary projects will be the new paradigm.

Establishing a network of seafloor observatories requires the fulfilment of a critical mass at European level overcoming national fragmentation. The development shall be based on synergic collaboration between the academic community and that of industry for technology. This synergy allows each partner to increase its own know-how, to improve marine technology and set strategies to be competitive with countries such as the USA and Japan. The question of the integration in a global network may arise (GEOSS).

More specifically, the proposed research multi-site infrastructure will greatly facilitate common definition of requirements for continuous data acquisition on decadal time scales at fixed locations in the seas around Europe. This requirement brings together scientific disciplines that would otherwise have little contact with one another. Geo-sensors may be deployed in bore holes beneath the sea floor to monitor fluid flow with the earth's crust. Ocean bottom seismometry is focussed on signal processing from arrays, rather than specific sampling of the seafloor. Within the water column, oceanographers study movements of water masses and their influence on the transfer of heat and matter across the planet with little reference to biology or solid Earth sciences. There is little communication between remote sensing scientists and those specialising in development of sea floor instrumentation. Initiatives in progress such as ESONET NoE and EMSO Pp will facilitate generation of links across these separated disciplines in order to build a joint infrastructure. A further development is the link with the astronomy community in the joint use of their deep sea facility in the Mediterranean for neutrino astronomy (Km3NeT-Design Study project financed under FP6).

Implementation. It will be based on evolution from existing systems by connecting previously autonomous systems to junction boxes, providing power and long-term real-time data capability. The development of a networked system will require organisational schemes for huge amount of data flows. The fundamental underlying principle is the full and open exchange of data and information for scientific and educational purposes (GEOSS data sharing principles). Among other activities, we will have to facilitate and organize:

- Interoperability between infrastructures, based on the implementation of globally accepted information standards (Sensor ML, ISO family of standards, SOAP/WSDL) and existing Spatial Data Infrastructures (SDI). This activity will take care of the INSPIRE proposal directive for spatial information in Europe.
- Long-term archiving, publication, and dissemination of observatory data, metadata, and data products using European and international data centres. For all these activities, We will rely on SeaDataNet pan-European infrastructure for marine data (FP6 financed project) and also benefit from the results of other integrated projects like MERSEA, Carbocean or NoE Eur-Oceans.

Links with international observatory programmes. Close links with other long term observatory projects in both US, Canada and Asia will allow cross fertilization of ideas and technological approaches. Technology transfer to less developed countries will be the next step of dissemination. The development will allow establishing formal links with extra-European programmes addressed toward the establishment of seafloor observation networks. The links will be aimed at setting about the European experience, at stimulating the technological and scientific debate, compare adopted techniques/methodologies and try to face together technical and scientific problems in the development of seafloor networks. Profitable links will be maintained with the principal extra-European seafloor multiparameter real-time networks under development within the framework of ORION (NSF programmes), NEPTUNE (USA-Canada) and ARENA (Japan).

Both the ICDP[1] and the IODP[2] have shifted their attention towards long-term instrumentation of their boreholes. Depending on the scientific goals at the site, certain depth intervals are instrumented under “corks” with sensors, in cases down to several kilometres and temperatures in excess of 100°C. Teaming up with such programmes, and having instrumented boreholes near ESONET “nodes” in the Ligurian Sea and in the vicinity of Crete/Greece is envisaged. For example a proposal has been submitted to propose that IODP drill three ~300-m cased re-entry boreholes in the Ligurian Sea, to establish a borehole instrument test facility and to develop borehole-to-submarine-cable technologies.

6. Conclusion

The scientific need for long time series of data coming from the seafloor at key provinces is clear to measure cyclic changes and to capture episodic events relative to such deep-sea processes and ecosystems. It is now time to proceed, taking advantages of existing projects and initiatives to go further towards an integration and opening to non-European countries, such as ESONET NoE. Many scientific questions have to be addressed and are specifically relevant in the Mediterranean Sea, such as the response to climate change, the deep ecosystems associated to specific and active geological environments and the natural hazards related to plate tectonics and numerous sediment accumulation prone to failures. The geology, biogeochemistry, oceanography and biology are intimately interconnected through several natural process interacting; all these phenomena should be measured for modeling and forecasting natural events.

[1] ICDP = International Continental scientific Drilling program

[2] IODP = Integrated Ocean Drilling Program

Monitoring the meso-and macroplankton in the Mediterranean and Black Seas

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Introduction

The coastal Mediterranean is under strong demographic pressure and is the site of important socioeconomic activities, which may be strongly impacted by Global Change. Resilient social-ecological systems may be built on the basis of reliable information on the different elements of the 'Global Change'. The change in the marine ecosystem is one of them and the phyto- and zooplankton constitute the basis of this ecosystem.

Zooplankton are the animal members of the marine planktonic community. They range in size from microscopic protozoans to jellyfish of over 10m long. These herbivores and carnivores play an exceptionally important role in marine foodwebs and their population dynamics make them particularly suitable for analysis of interannual ecosystem changes.

Zooplankton is considered as a good indicator of climate related ecosystem changes because:

1) mesozooplankton (about 0.1-2cm body length) are a key link between primary producers and larger predators;

2) they are abundant, and can be quantified by relatively simple and intercomparable sampling methods;

3) the life cycles of most species range from a few months to one year;

4) changes in population size are rapid enough to track seasonal-to-interannual changes in environmental conditions;

5) as few zooplankton taxa are fished, most zooplankton population changes can be attributed to environmental causes;

6) many commercial fish are dependent on a zooplankton food source during their pre-recruit life history stages.

Consequently, anomalies in zooplankton evolution in time may be useful leading indicator for commercial fish stocks evolution (Batchelder *et al*., 2002; Beaugrand *et al*., 2003).

On the other hand, changes in zooplankton biogeography and changes in long term trends provide an important tool for examining climate-ecosystem interactions. Between-region comparisons allow a better comprehension of causal mechanisms and consequences of the physical forcing on marine food chains.

Change in plankton populations impacts other trophic levels (e.g. fish, mammals) through bottom-up control. In the North Atlantic both phytoplankton and zooplankton species and communities have been associated with Northern Hemisphere Temperature (NHT) trends and variations in the North Atlantic Oscillation (NAO) index. These have included changes in species distributions and abundance, the occurrence of sub-tropical species in temperate waters, changes in overall phytoplankton biomass and season length, changes in the North Sea ecosystem, community shifts, phenological changes and changes in species interactions. It is thought that temperate marine environments are particularly vulnerable to phenological changes caused by climatic warming because the recruitment success of higher trophic levels is highly dependent on synchronisation with planktonic production. The rapid changes in plankton communities observed over the last few decades in the North Atlantic, related to regional climate changes, have enormous consequences for other trophic levels and biogeochemical processes (Beaugrand *et al*., 2003).

In the North Sea, the cause of the regime shift is related to pronounced changes in large-scale hydro-meteorological forcing. The term 'regime shift' is now widely used to describe pronounced and prolonged climate-linked changes in biological systems. Changes (increase in sea surface temperature and change in wind intensity and direction) at the end of the 1970s in the west European basin triggered a change in the location of a biogeographical boundary along the European continental shelf, initiating the regime shift after 1982.

Work done by SAPHOS (Sir Alister Hardy Foundation for Ocean Science) has shown that the extensive changes in plankton production, biodiversity and species distribution, associated with hydroclimatic changes, have had effects on fisheries production. Climate warming has triggered changes at the bottom of the marine pelagic foodweb, with a significant decrease of the zooplankton and a change in the biodiversity of the dominant copepod species due to the northwards shift of taxa characteristic of warmer waters (Beaugrand *et al*., 2002; Beaugrand *et al*., 2003; Pitois and Fox, 2006). Changes in the abundance of herbivorous zooplankton have followed closely those of their phytoplankton prey, as did carnivorous zooplankton with their prey (bottom-up control of the marine pelagic environment, Richardson and Schoeman, 2004). The rising temperature has affected the phenology of many zooplankton taxa whose seasonal peak has moved forward (Edwards and Richardson, 2004). The changes in phenology have varied between different species, functional groups and trophic levels, leading to a potential poor temporal synchrony between fish larvae and their prey (i.e. the zooplankton).

Increasing records of Harmful Algal Blooms (HAB) taxa have been reported in the North Sea. Anomalous high frequencies of HAB blooms over the last four decades have been recorded in the late 1980s in the Norwegian coastal region and in the Skagerrak (Edwards *et al*., 2006). Such changes were related to regional climate change, in particular changes in temperature, salinity and the NAO.

In the North-western Mediterranean the long-term variability of different zooplankton functional groups seems also to be linked to changes of climate forcing of the North Atlantic sector. Large-scale climate forcing has altered the pelagic foodweb dynamics through changes in biological interactions, competition and predation, leading to substantial changes in zooplankton populations, which peaked in 1986-87 and are considered as a regime shift in the North-western Mediterranean (Molinero *et al*., 2008).

There is an increasing public focus on how climate variability affects marine ecosystems (see also the ToRs of SCOR 125 Working Group at http://www.jhu.edu/scor/wg125.htm). Important questions include the qualitative character of the ecosystem responses ("what changes"), their amplitudes ("by how much"), and their timing and spatial and temporal scales ("when and where are rates of change strongest"). There is much evidence that living marine resources undergo strong and sometimes abrupt changes in stock size and productivity. This variability is associated with corresponding atmospheric, hydrologic and biologic changes.

There is no global strategy for a long term multidisciplinary monitoring of the Mediterranean basin. Therefore, the creation of an Integrated Mediterranean Observatory oriented toward scientific and management issues is a necessity. Monitoring of meso- and macroplankton should be considered as important components of this initiative.

Historical recall

During the 37th CIESM General Assembly in Barcelona the Mediterranean zooplanktonologists agreed that a global comparison of zooplankton time series and biogeography would be timely, and extremely useful. In response, CIESM initiated the Zooplankton Indicators Program. During the October 2005 workshop in Villefranche sur mer, entitled 'Impact of the climate change on the Mediterranean zooplankton', it appeared that the comparative studies can be technically feasible. 17 laboratories from 14 countries members of the MedZoo group that was formed by the Zooplankton Indicators Program (see http://www.ciesm.org/marine/programs/zooplankton.htm) undertook a regular zooplankton sampling. Discussions with other laboratories are ongoing.

The MedZoo group was recognized by SESAME Integrated Project funded by the European Commission's Sixth Framework Program, under the contract No. GOCE-2006-036949. The project started in November 2006. Most of the members of the MedZoo group are contributing to the SESAME project by their historical databases and by acquisition of new data. An important international sea-going activity planned by SESAME for 2008 will provide a synoptic multidisciplinary view of the Mediterranean and Black seas.

Monitoring Mediterranean mesozooplankton

Regular net zooplankton monitoring is ongoing in different laboratories in the Mediterranean and Black seas. Comparisons of biogeographical variations in the different sub-basins depend on the intercomparability of the data. Workshops were and will be conducted through international co-operation and through networks of institutes and experts to harmonize the taxonomic approaches. Re-processing of older archived liquid samples and of new samples through the ZOOSCAN methodology (Figure 1a) is proposed for the Mediterranean and Black seas (see www.zooscan.com). This method developed in France allows a rapid (45 min) treatment of a subsample (~1000 organisms).

The treatment comprises:

1. Image acquisition and electronic storage of the sample (Figure 1b);
2. Abundance estimation;
3. Size spectrum determination;
4. Measurement of the different morphological features of each object;
5. Organisation of all the data in a table that may be easily completed by the environmental parameters or used by other softwares.

The data tables of time series can be automatically merged and analysed for trends. Training sets for automatic recognition of faunistical groups may be constructed and/or manual on-screen taxonomic determinations rapidly performed. The system is particularly adapted for collaborative work through internet, for rapid database building and for comparative analyses, since the instruments are intercalibrated.

The aim of the mesozooplankton monitoring is the comparative study of interactions between climate change and changes in plankton community structure, abundance, distribution and phenology over recent decades. We also consider the crucial roles that plankton might have in dictating the future pace of climate change via feedback mechanisms responding to elevated atmospheric CO2 levels. The ongoing plankton monitoring programmes worldwide will act as sentinels to identify future changes in marine ecosystems and the Mediterranean scientific community will be helpful in this context.

Monitoring Mediterranean macroplankton

One of the key issues facing coastal managers at present is to understand, adapt to, and anticipate the effects of complex linkages between the environmental variables and their importance for the functioning of marine ecosystems. Dynamics of the macroplankton and in particular of its gelatinous components in relation with global warming is one of them.

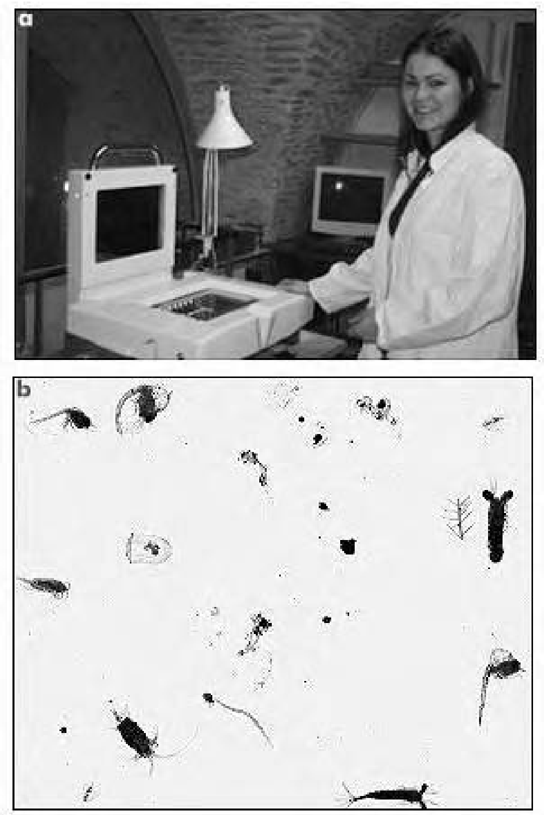

Fig. 1. a) L. Voarino, MSc student, using ZOOSCAN for net zooplankton imaging, quantification and measure (www.zooscan.com); b) A small portion of a net sample digitized by the ZOOSCAN.

Among the important representatives are medusas, ctenophores, siphonophores, salpes and krill. The most important are the ctenophores in the Black sea and the medusas in the Mediterranean (Molinero *et al*., 2005). They may become the local food chain's dead end. They may bloom and constitute swarms, devastating fish farms, causing damage to tourism and to the commercial fishery. In addition, their nutritional behaviour decreases the vertical transport of the organic matter and thus the carbon sequestration in the deep layers.

Periodically swarms of the medusa *Pelagia noctiluca* (see Figure 2) invade the coastal zones of the Mediterranean, strongly impacting the local tourist industry. Landing of populations of *Pelagia* are at present neither predictable nor avoidable (Goy *et al*., 1989). Therefore, a monitoring program seems to be the best way to learn and anticipate invasions of this species.

In the North Sea, data obtained since 1958 from the continuous plankton recorder show that that the occurrence of jellyfish is positively related to the North Atlantic Oscillation (NAO) and that the jellyfish frequency is also significantly negatively correlated with mean annual pH. The projected climate change suggests that the trend of gelatinous predator populations' occurrence will be increasing during this century (Attril *et al*., 2007).

Fig. 2. Adult *Pelagia noctiluca* and a swarm of young stages near the shore in Villefranche/mer, France (photo D. Eloire).

Monitoring of macroplankton is therefore the first step to be undertaken. It can be done by a large community of motivated participants under scientific control and guidance.

The detection of swarms (patchiness) by scientific and volunteer observers should be accompanied by the application of hydro-climatic models in order to forecast the landings. The sampling of zooplankton (potential food) and stomach contents will be analysed by scientists. Drifters should be released in the patches in order to follow and record the environmental conditions of the patch. Population dynamics and success of reproduction will be studied *in situ* and in the laboratory. New technologies (gliders, AUVs, free-drifting hydrographic profilers, Underwater Vision Profilers) should be applied for detailed studies of the different patches. Modelling studies should synthesise and improve the prediction of the response of macroplankton to environmental changes.

CONCLUSIONS

In order to develop management strategies for sustainable use and conservation in the marine environment, reliable, meaningful and integrated ecological information is needed. An Integrated Mediterranean Marine Observatory may constitute the missing framework for long term monitoring of the Mediterranean basin. It is necessary both for scientific and social reasons in the light of the ongoing Global Change. Only structured international efforts can propose answers to the question: how the Mediterranean will be impacted by climate changes in the future? The mesozooplankton is a useful indicator of these changes, whereas the impact of gelatinous macroplankton is one of their consequences. Both should be monitored by adapted and harmonised methodologies in a multidisciplinary framework in order to get a synoptic view and a good dissemination of the concepts to the socioeconomic actors and decision-makers.

In situ remote sensing with autonomous platforms: a new paradigm for observing the ocean interior

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Abstract

Gliders are autonomous underwater vehicles with a huge potential for research in the field of ocean dynamics and marine biogeochemistry as well as for operational oceanography. Coordinated deployments of gliders should make it possible to monitor, continuously and at a moderate cost, the whole range of ocean scales characterizing a given region. However, the glider technology is still under development and needs improvements regarding essentially its applicability to ocean uses and the design of adequate networks for optimal sampling.

Introduction

In order to understand how our climate and our marine environment will evolve in the next few decades under the influence of human activities, one has to better characterize and model the evolution of the ocean's stratification, ventilation and circulation. They control the oceans heat, freshwater and tracer transports (including important dissolved gases such as oxygen and carbon dioxide) and can influence fundamental changes of the marine ecosystems. A particular focus on coastal environments is justified as one finds there some of the world's most productive ecosystems. One little understood aspect concerns the interactions of the large-scale circulation with the generation and evolution of eddies, filaments, and fronts. It is critical to better characterize these mesoscale (10-100km) and sub-mesoscale (1-10km) processes over the whole water column because in many areas they play a critical part in the oceans's energy and matter budget. Mesoscale processes are in some regions the prime mechanism for the transport of dissolved matters, playing a key role in the marine ecosystems since they control the distribution of nutrients and oxygen. Mesoscale can even influence the climate system through interaction with the mean circulation over entire basins.

During the last two decades of the 20th century, remote sensing from space has almost been the unique source of information for such a problem: satellites have offered a synoptic regional and global view of the sea surface temperature and sea surface height. They revealed that surface mesoscale structures were ubiquitous and thanks to a relatively high spatial and time coverage, it became possible to study into details mesoscales and their role in shaping the ocean circulation. At the same time, data assimilation techniques made possible to use these data in numerical models of the ocean circulation: this was the birth of operational oceanography. Remote sensing of ocean colour also showed a huge potential to study the phytoplankton at surface. Nowadays routine products are available the map surface chlorophyll at very high resolution and even to separate the signal into several functional phytoplankton classes. It must be noticed here that operational satellites differ from the classical oceanographic instrumentation because there are completely managed by space agencies. Oceanographers mainly use the routinely processed product delivered by the agencies and have only moderate influence for their use or for the development of sensor packages they carry.

But, if satellites can provide a quasi-synoptic view of the surface ocean, they can only sense a limited number of parameters, as some areas are not covered (presence of clouds, dust, ice, or the vicinity of the coast for altimetry, etc.). Overall, they cannot directly give detailed information along the vertical (the ocean is opaque to electromagnetic waves and dynamic height brings information on surface currents only). Indeed for this reason among others, it is clear that observations of the ocean interior are still needed and will rely on ships, moored instruments and some autonomous platforms. However, with ships and moorings, the resolution of observations of the ocean has and will remain very coarse. It is the development during the nineties of relatively low cost autonomous platforms for *in situ* measurements that started changing this picture. By collecting around 3,000 profiles from 2,000m to the surface over the global ocean every 10 days with low cost automated profilers, the ARGO program (Figure 1) which started a few years ago, now provides an operational *in situ* monitoring array that is suitable for the large scale global circulation (Gould *et al*., 2004). Temperature and salinity Argo profiles are assimilated into global and regional operational models in order the correct the large scale distribution of hydrological properties (Balmaseda *et al*., 2007). But due to its configuration and to the technology of the profilers, ARGO can only marginally monitor the mesoscales and the circulation over continental shelves and margins.

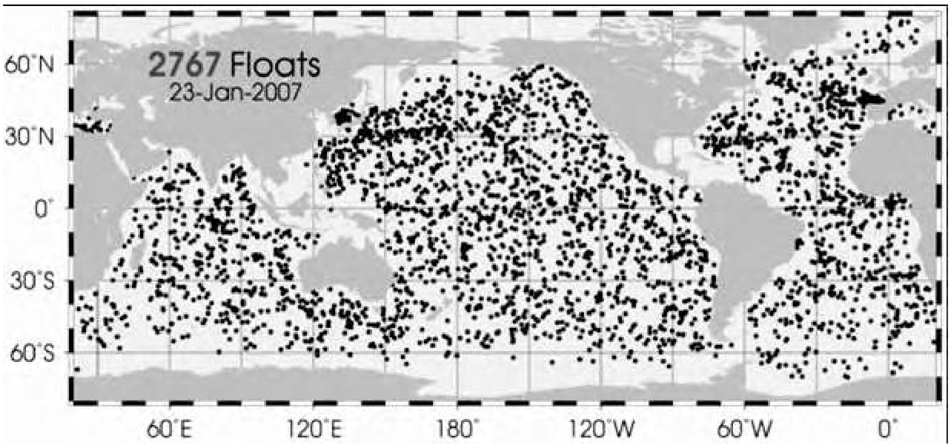

Fig. 1. The position of the 2767 ARGO profilers on 23 January 2007 (3,000 profilers have been reached in September 2007). Note the relatively homogeneous coverage except in the Southern ocean and in the Arctic seas.

Indeed, it was already envisioned by Stommel (1989) that a kind of "steered" profiling floats, the so-called "gliders" deployed as fleets at both regional and large scale could allow going a step further toward the smaller scales. Coordinated fleets of gliders could offer such a controlled spatio-temporal coverage that it could be really called "*in situ* remote sensing". It became now clear that gliders could efficiently complement the ARGO array with great benefits for both the operational oceanography and the process-oriented studies at regional, coastal, mesoscale, and submesoscale, including "green ocean" objectives. Based on the existing types of gliders developed in the USA, some pioneering groups of engineers and scientists are now trying to demonstrate this vision through several pilot projects (Schofield *et al*., 2002). In Europe, the "European Gliding Observatories" group (EGO site at http://www.locean-ipsl.upmc.fr/gliders/EGO) gathers several laboratories in order to share the corresponding effort and to provide support to people operating gliders. EGO also makes possible coordinated deployments of enough gliders for dedicated exercises in targeted areas (Testor *et al*., 2007).

GLIDER TECHNOLOGY

At the moment, three groups in the USA have developed gliders which are operational (Davis *et al.*, 2003): the Slocum by Webb Research Corporation, the Seaglider by APL-University of Washington and the Spray by Scripps Institution of Oceanography (Figure 2). Although the designs are different, they have many features in common. They all have a small size (weighing around 50kg in air and +/-200g in water) and they can "fly" underwater on slightly inclined paths, using only their buoyancy for propagation. No propeller is required. A typical dive/ascent to 1,000m depth moves the glider horizontally by around 2-4km at horizontal speed of about 40cm s^{-1}. The glider steers itself autonomously, but can also be controlled remotely (via satellite or radiowaves when at surface) to change its mission programming or to command it back to the base. Gliders collect measurements with a very high spatial resolution and can last for a reasonably long time. Today their endurance has been proven to reach 7 months (Eriksen *et al.*, 2001). The glider can measure temperature, salinity, and biogeochemical parameters (such as dissolved oxygen, fluorescence, and turbidity, etc.) along its trajectory. Data are transmitted via satellite in real-time while the glider is at surface. It should be noted that depth-averaged and surface currents can be measured via the drift of the vehicle during its dive cycle and the drift during surface procedures, respectively. The vertical velocity of the water can be also retrieved from the measurements. They can be equipped with an altimeter, this is primarily a safety precaution to avoid grounding. A glider can also carry an acoustic transducer and/or hydrophone to allow underwater localisation via triangulation and/or acoustic data telemetry with other subsurface systems. The previous comparison between gliders and profilers has only been made for referring to instruments that readers know better, but pushing it too far is sterile, since these instruments are inherently complementary in observing systems. In terms of cost, the gliders Spray and Slocum are nowadays an important investment (about 80,000 euros, while a profiler costs about five times less). However, one might expect collecting at least 800 profiles during the typical deployment of a glider –i.e. 5 times more than a classical profiler– but only down to 1,000m depth at most, while profilers are conceived for 2,000m deep profiles. Since the gliders are recovered after each deployment, they can be refurbished and made ready for other deployments as well. It must be kept in mind than running a glider is now expensive in communication and batteries, but it is proportional to its usage (about 2-4K€ per month while in survey). However, part of this cost could benefit from a national or international coordination.

Fig. 2. From left to right, the SEAGLIDER, the SPRAY and the SLOCUM.

GLIDERS SAMPLING POSSIBILITIES

Because gliders can be steered, even in relatively high currents, a fleet of gliders can be assigned to specific complex and remotely controlled missions opposite to profilers that can only drift freely with the current at 2,000m during their 10 days cycles. There are several operating modes that can given to a fleet:

- Follow an *a priori* fixed network. To some extent, this is similar to the repeated hydrological surveys carried out by R/V. This is suitable for example to monitor a coastal current with more or less a fixed path whose simplest version is the so-called "endurance line".
- Virtual mooring mode. The gliders are assigned to profile at given fixed points and must be compared to a classical mooring with only a few fixed instruments. Such a profiling mode is a

flexible and low cost alternative to sophisticated moored profilers (from bottom trawlers or surface platforms).

- They can be redeployed from a given mission to sample a particular event of interest. This is possible because data are available in real time which allows the detection of interesting features in the vertical. Surface imagery from satellite also allows this kind of redeployment, for example to sample an eddy having a thermal surface signature.
- Adaptative sampling. This features takes advantage of the fact that the information delivered in real time by the glider can be analysed to reconstruct the paths of the gliders themselves, for example to follow a front or an eddy (Fiorelli *et al*., 2004). Figure 3 illustrates how a fleet of three gliders can be automatically controlled to a moving structure whose path is *a priori* unknown.

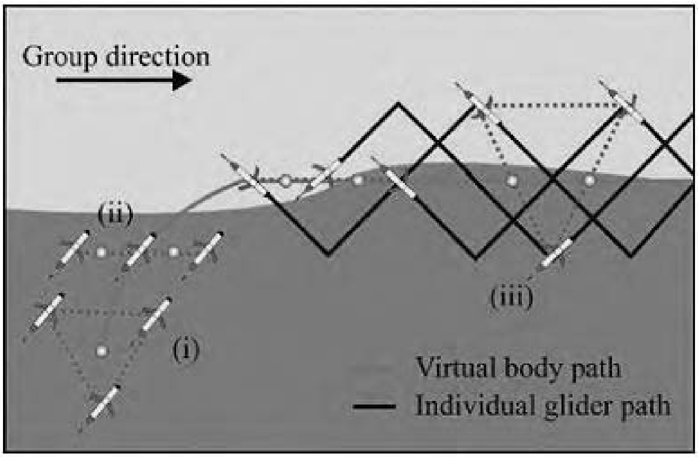

Fig. 3. How does adaptive sampling work? The diagram shows how a group of three gliders can change formation to monitor an oceanic front (a meeting of two different water masses). Initially (i) the gliders move in a triangle formation until they intersect the front. After they reach the frontal boundary they move in line with each other (ii). Finally they move along the frontal boundary in a zig-zag pattern to collect data across the front. Courtesy: J. Bellingham, MBARI.

This last operating mode is brand new and considerable efforts have been deployed in recent years to design algorithms suitable to operate a fleet able to adapt to its mission. The strong interest of this structure is follow the evolution of the whole system as for example in the following scenario often observed in the Western Mediterranean: instabilities of the inflow of Atlantic water along the Algerian coast can generate eddies which may block the current and divert it offshore toward the Balearic Island preventing the current to flow along the coast for several months (Puillat *et al*., 2002).

Gliders in the Mediterranean: first coordinated deployment in winter 2007

The Mediterranean Sea is very well suited for this kind of operations: in most places, the circulation is a basin scale cyclonic gyre dominated by unstable coastal currents, fronts and associated strong mesoscale and submesoscale events. This is especially the case in the basins where deep convection occurs in winter like in the North Levantine or in the North Western Mediterranean. For example, in the latter case the Northern current flows over the shelf break: it separates the shallow Gulf of Lions, where it partly controls the circulation, from the deep basin where convection occurs in winter. These patterns strongly shape the bloom events during the winter and spring periods. Some ARGO floats are drifting there but they are struggling to provide the relevant *in situ* profiles needed to depict the whole picture.

As a first EGO demonstration, six 1,000m and two 200m SLOCUM gliders and one SPRAY glider were deployed between January and June 2007 to collect temperature, salinity and oxygen profiles. Backscattering, Chla and CDOM fluorescence were measured as well since some gliders were equipped with WETLABs "pucks" (Testor *et al*., 2007). The SPRAY was devoted to the large scale monitoring of the gyre in its longitudinal extension from the Balearic Islands to the Gulf of Genova (Figure 4) while a 1,000m SLOCUM should have crossed the basin in the meridional direction. Unfortunately, this glider soon had pump failure and so this transect was interrupted. A 200m SLOCUM was devoted to cross the Ibiza Channel closing the Balearic Sea and a 1,000m SLOCUM the Ligurian offshore Villefranche s/mer to monitor an upstream section on the Northern Current. Finally, three 1,000m and one 200m SLOCUM were devoted to the investigation of the mesoscale and submesoscale associated with the Northern Current and the convection area in the Gulf of Lion.

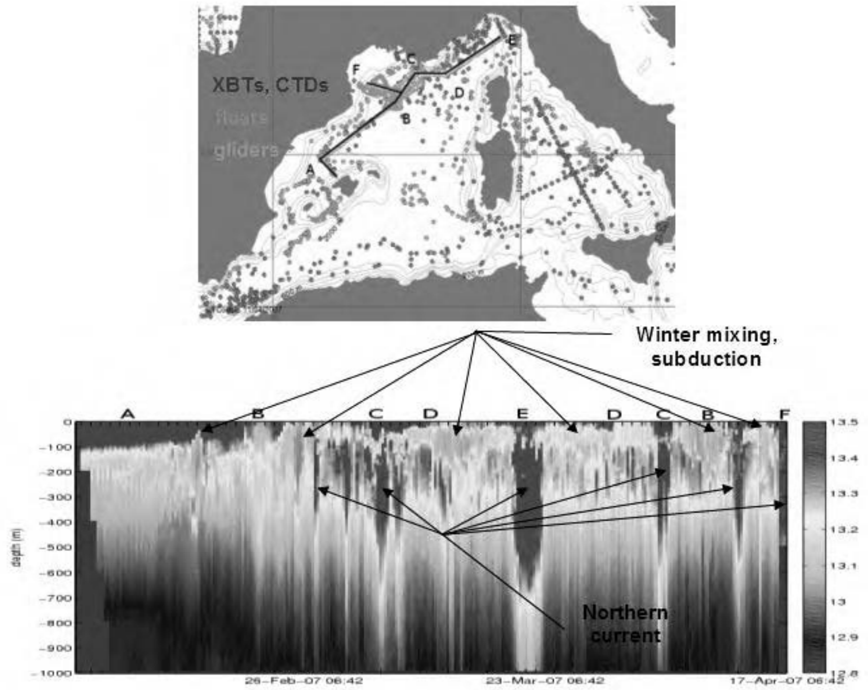

Fig. 4. Top: distribution of data collected and delivered by the CORIOLIS-IFREMER data centre during the gliders deployments (some trajectories are missing). The black line is the trajectory of the SPRAY glider. Bottom: temperature section along the black line showing a very detailed picture of the water mass distribution between the Palma de Mallorca Island to the gulf of Genova and back to Banuls s/mer.

The gliders have been deployed and recovered from small boats from the "gliderports" hosted by the marine stations around the basin: Palma de Mallorca, Banyuls s/mer, La Seyne s/mer and Villefranche s/mer. Remote operation of the gliders was conducted by the partners from any internet access. Some of the gliders equipped with alkaline batteries were recovered to change their batteries and were immediately sent back at sea.

In parallel, forecasts of the trajectories of the fleet based on the currents forecasted weekly by the French operational oceanographic agency MERCATOR, were published on the web both to help the pilots reshape the network periodically and also to deliver the information on the position to the Spanish and French marine security agencies.

Despite extremely strong mistral events impeding efficient remote control of the gliders due to bad communications, and several gliders failures, the network was maintained over this period with a peak of six gliders simultaneously at sea. A total amount of 5,000 profiles were collected and delivered in real time to CORIOLIS (Figure 4).

A first technological and scientific assessment is now being established. A first obvious conclusion is that to operate and maintain several gliders over long periods a multi-site coordinated facility to remotely pilot the gilders is needed: operators are needed

- to evaluate the actual trajectories of the gliders and modify them if needed,
- to modify some parameters (speed, sampling rate, etc.) or to correct small disfunctioning of the gliders,
- and in case of major failures needing an emergency recovery.

This first EGO deployment of a glider fleet was a very successful technological demonstration. It was somewhat disappointing because the very mild air temperature condition –despite strong winds– only triggered a 500m deep convection. For this reason, the gliders operated by NOCS failed to catch convective plume as expected. These mild weather conditions could not be anticipated with the seasonal forecast. But this is part of the game!

Needs and evolution of the glider technology

As presented before, gliders are teenagers with a huge potential! In the next years, the main objective for oceanographers using glider technology would be to develop ways to deploy them in larger numbers. So, developing intelligent software interfaces for managing fleets of gliders as well as minimizing costs are important aspects to be considered. Two kinds of technological developments could be done also on gliders.

First, one could imagine increasing the performances of the glider itself, as an oceanographic platform, such as speed, endurance, and maximum dive depth. The development of smaller, rechargeable or even expandable gliders could ease the deployments from a logistical point of view.

Then, one must consider the payload. Small, low energy, low cost, robust, biogeochemical sensors should be developed for deployment on gliders. Many sensors have been developed based on the measurements of electrical or optical properties but one has to go one step forward. Such sensors can actually respond to some monitoring requirements to the assessment of environmental and climate change but other parameters are still missing and needing the adequate sensor. Gliders equipped with a camera could help characterizing and counting organisms to support marine biological research. Finally, heterogeneous systems where gliders are messengers between deep systems (acoustic communications with moored instruments, for instance) and the surface (satellite communications) for data telemetry are in development.

The use of gliders is most efficient when done to complement more classical means of measurements (floats, moorings, ships, etc.) as each kind of platform (Lagrangian, Eulerian, point measurements) can give different and complementary information. Gliders cannot replace them (water samples, depth reached, accuracy of measurements allowed by large size instruments, etc.) but can significantly increase the spatio-temporal coverage for a number of parameters, and give a better view of the oceanic variability if deployed simultaneously.

In particular they could help to set up regional/coastal observatories as they can be deployed from small boats, steered, and operated in a region of particular interest. Repeat-sections perpendicular to the coast could provide a continuous monitoring of the along-slope circulation and seawater properties in the coastal/open-sea area. Sophisticated deployments could be envisaged such as adaptive sampling allowing a good description of particular oceanographic features, such as eddies or filaments, by a fleet of gliders.

Although it is often seen as a constraint to recover the glider after its mission, one has to keep in mind that it has some advantages. First, sensors are more easily calibrated since we can perform a calibration before and after a mission that lasts typically three months. In this way we can reach a precision that is intermediate between CTD and profilers for physical and oxygen data. Second, it is a "cleaner" vector, as long as it is not lost at sea, which unfortunately is often the fate of this instrument sooner or later. We might expect however to refurbish the glider several times before it actually happens, since most of the time, failures or accidents lead to an abort mode and an emergency recovery can be organized.

The data stream to use the data collected by gliders in operational forecasting systems is already established. An infrastructure set at international level to organize the recovery of gliders via R/Vs or Navy ships in case of failure would be very valuable. Concerning the legal framework for gliders, it is very similar to the one set for profiling floats. However, since these new platforms can be steered remotely, this introduces new legal issues especially when dealing with sampling in national waters, that have still to be addressed.

Integration of Lagrangian observations into a Mediterranean Marine Observatory

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Abstract

The use of Lagrangian instruments freely moving with the currents, such as surface drifters and profiling floats, to measure currents and water mass properties in the Mediterranean Sea is reviewed. A recent example of drifter measurements in the Ligurian Sea and an update on the MedArgo float program are presented. Recommendations for the implementation of Lagrangian observations in an integrated Mediterranean Marine Observatory in support of scientific studies and operational needs are given.

Introduction

Since the advent of satellite tracking and telemetry systems in the late 1970s, near-surface drifters and profiling floats have been used worldwide to monitor marine currents, temperature, salinity and other water mass properties. In the Mediterranean Sea, near-surface drifters have been deployed as part of national and international scientific projects since the 1980s. Their data have been archived in several databases (e.g., Poulain *et al*., 2004) and exploited to study the dynamics of the Mediterranean with particular focus on specific areas such as the Algerian Current (Salas *et al*., 2001), the Sicily channel (Poulain and Zambianchi, 2007), the Adriatic Sea (Poulain, 1999; 2001; Ursella *et al*., 2006), the Aegean Sea (Olson *et al*., 2007) and the Eastern Mediterranean (Gerin *et al*., 2007). Profiling floats have been deployed in most ocean basins and marginal seas since the turn of the 21st century as part of the international Argo program (Gould *et al*., 2004). The worldwide float population has recently achieved its target of more than 3,000 operating units. In the Mediterranean, more than 70 profiling floats have been used since 2000 and have provided more than 5,500 CTD profiles (Barbanti and Poulain, 2007). These data have already been used to explore the variability of the Mediterranean temperature and salinity (Emelianov *et al*., 2007; Barbanti and Poulain, 2007; Poulain *et al*., 2007a) and to study the deep water formation in the western Mediterranean (Smith and Bryden, 2007).

The objective of this note is to give the current status of the drifter and profiling float programs in the Mediterranean and to discuss how these Lagrangian observations could be integrated in a future Mediterranean Marine Observatory. Recent drifter observations in the Ligurian Sea are described to demonstrate the importance of Lagrangian measurements to study the surface circulation at scales ranging from small bays and gulfs (tens of kilometres) to the basin size (hundred of kilometres) and to investigate the dispersion of contaminants or floating objects transported by the surface currents. The Argo program in the Mediterranean Sea, referred to as MedArgo, is also reviewed. Its future developments and sustainability are discussed.

Recent example of Mediterranean drifter studies in the Ligurian Sea

Surface drifters were deployed in the open Ligurian Sea and the Gulf of La Spezia in May and June 2007 in the framework of Maritime Rapid Environmental Assessment (MREA) experiments. The objective of this drifter program was twofold: (1) to measure the surface circulation in both study areas and to study the related dispersion of particles; and (2) to provide ground truth for VHF coastal radar measurements of the surface currents in the Gulf. The drifters were CODE designs (Figure 1) which measure the currents in the first meter under the sea surface and the sea surface temperature. In the open sea, they transmitted their GPS positions and the data at 30 min intervals to the Argos system onboard the NOAA polar-orbiting satellites (Ursella *et al*., 2006). In the Gulf of La Spezia, they transmitted their GPS positions via the GSM/GPRS network (sampling every five min and transmissions every 15 min, Poulain *et al*., 2007b).

Fig. 1. Photograph of a CODE drifter in the Gulf of La Spezia. Only the GPS and GSM/GPRS antenna and four small spherical floating balls protrude above the sea surface.

A total of 15 drifters were released in the vicinity of the CNR meteo-marine ODAS buoy in the central Ligurian Sea. Deployments were organized in three clusters of five units separated by less than 1km on 14 May, 17 June and 22 June 2007. The drifters provided data until 20 October 2007, i.e., for about five months. The low-pass filtered (cut-off period of 36 h) drifter tracks (Figure 2) show the basin scale mean cyclonic circulation extending in the Liguro-Provençal basin and Ligurian Sea, with a pronounced Northern Current flowing to the south-west along the Italian and French coasts and some indication of the Western Corsican Current (northward and northeastward flow). Other features of interest include the offshore southward motion of the drifters at the level of the Gulf of Lions and their subsequent eastward drift towards Corsica, and the anticyclonic eddy in the Corsican Channel around the Capraia Island sampled by two drifters. Due to this eddy, there is no indication of a northward Eastern Corsican Current.

In order to focus on the Northern Current which is striking along the coast between Genova (Italy) and Toulon (France), drifter velocities have been averaged in 5km x 10km bins oriented in the along and across-shelf directions (Figure 3). Most of the strong (~50cm/s) bin-averaged velocities occur within less than 20km from the coast. The area near Imperia has the strongest currents limited to about 10km from the coast. It is actually there that the maximum low-pass filtered drifter speed was observed (near 90cm/s). In contrast, the Northern Current is weaker and broader off Fréjus ($x \approx -50$km in Figure 3).

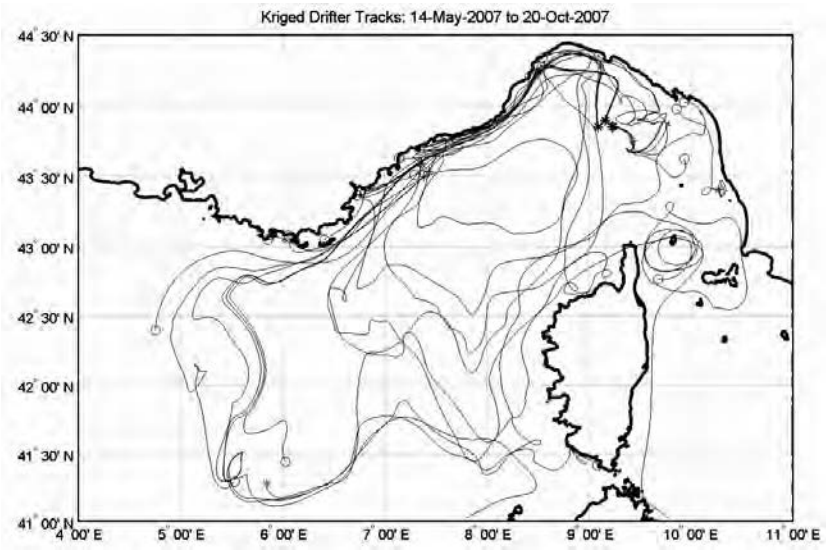

Fig. 2. Low-pass filtered drifter trajectories in the Liguro-Provençal basin for the period spanning 14 May to 20 October 2007. Deployment and last fix locations are depicted with star and open circle symbols, respectively.

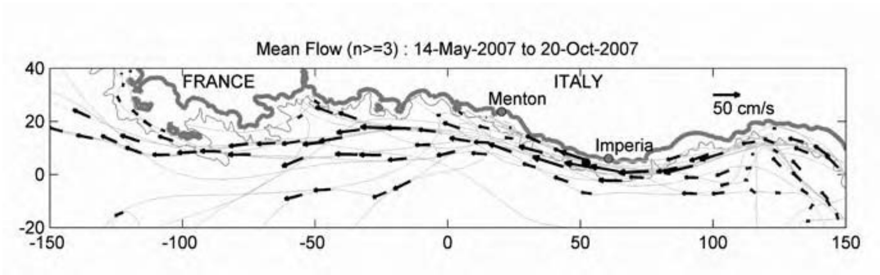

Fig. 3. Coastal currents off the Riviera di Ponente (Italy) and Côte d'Azur (France). Mean currents (black arrows), calculated in bins of 10km (along-shore) by 5km (across-shore), are only shown if the number of 6-hourly observations is larger or equal to 3 in the bins. Low-pass filtered trajectories are depicted with light grey curves. A black dot near Imperia indicates the location of the maximum speed experienced by the drifters, reaching about 90cm/s.

Clusters of two to six drifters were deployed in the Gulf of La Spezia in five dispersion experiments between 18 and 25 June 2007 (Figure 4). They were tracked for short time periods (4 to 65 h). The deployment sites were chosen with the help of VHF radars operated simultaneous with the goal to obtain as many and as diverse observations as possible in the Gulf. Data telemetry with GSM/GPRS was possible as far as 4 nm from shore (Poulain *et al.*, 2007b). The comparison of the drifter data with the VHF radar measurements reveals an excellent agreement between both types of velocity measurements. Indeed, the drifter speeds in the direction of the radar sites were compared to the radar-inferred radial currents. Negligible bias and a standard difference less than 5cm/s were found. The drifter trajectories (Figure 4) show a significant variability of the dispersion properties in the Gulf. For instance, during the first experiment, the drifters remained together until they eventually escaped in the open sea after about 15 hours of drift. In contrast, the drifters deployed at approximately the same positions two days after experienced significant dispersion within the Gulf only after about five hours.

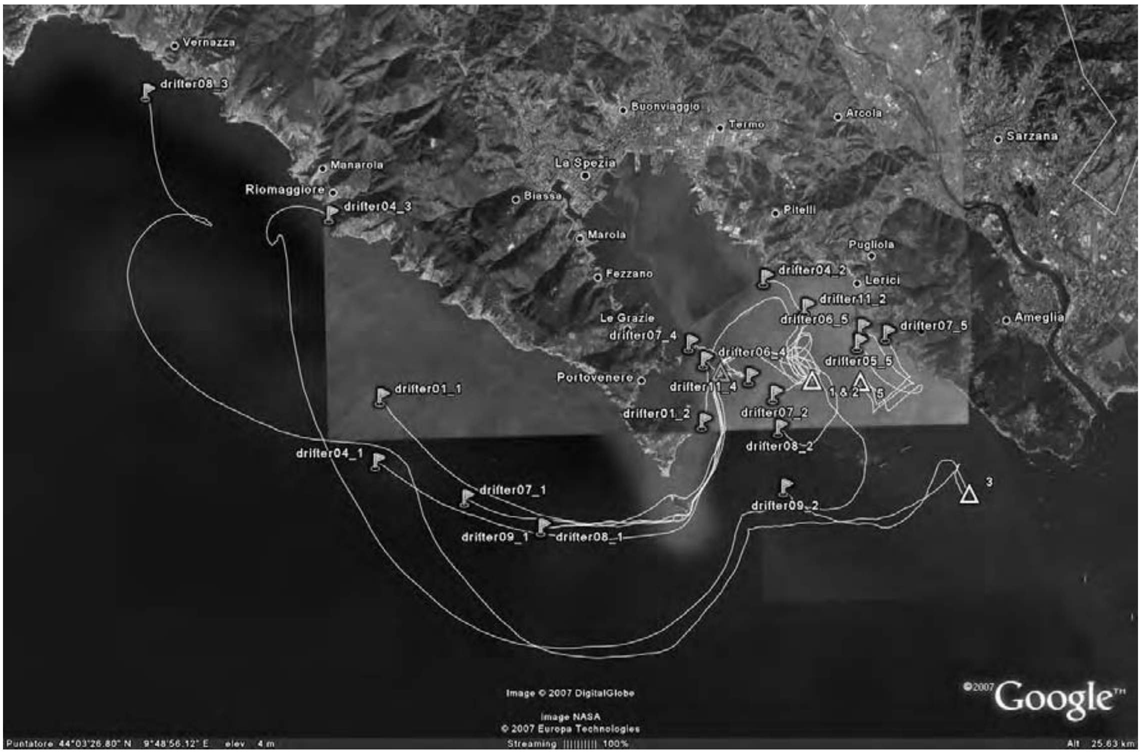

Fig. 4. Edited and smoothed (15-min running average) trajectories of the drifters deployed in the Gulf of La Spezia in June 2007. The diversity of drifter motions within the Gulf is evident. The drifters that eventually moved out of the Gulf on its western flank were entrained to the northwest with the strong coastal currents. Triangles indicate the deployment locations, whereas the last fixes are shown with flags.

Update on the MedArgo program

Profiling floats provided by several countries (France, Spain, Greece, USA) and by the European Union (as part of the MFSTEP project, fifth framework programme) have been used in the Mediterranean since 2000 (Barbanti and Poulain, 2007). At the end of 2006, a total of 71 units had been deployed and about 5,530 CTD profiles had been acquired.

Two types of profiling floats were operated, the Apex and the Provor (Figure 5). All floats were equipped with Sea-Bird CTD sensors. Most of them were programmed in the "Park and Profile" configuration with a neutral parking depth of 350m (near the salinity maximum of the Levantine Intermediate Water - LIW) and a maximum profiling depth of 700m, with a cycling period of five

Fig. 5. Argo profiling floats (Apex to the left and Provor to the right) ready to be deployed in the Eastern Mediterranean.

days. Every ten cycles, the floats were programmed to profile between 2,000m and the surface in order to sample deep water mass properties. When at surface, the floats were located by, and transmitted data to, the Argos system. The sampling intervals for the vertical profiles are 5m (above 100m), 10m (between 100 and 700m) and 50m (below 700m). Most floats were successfully deployed from ships-of-opportunity with minimal logistical problems and reduced costs.

The majority of the Mediterranean float data is processed and archived in near-real time at the CORIOLIS Data Centre (at IFREMER in Brest, France) and is distributed on the GTS following the standards of the international Argo program. Float trajectory plots and tabulated/graphical data summaries are also produced in near-real time at the Mediterranean Argo Regional Centre -

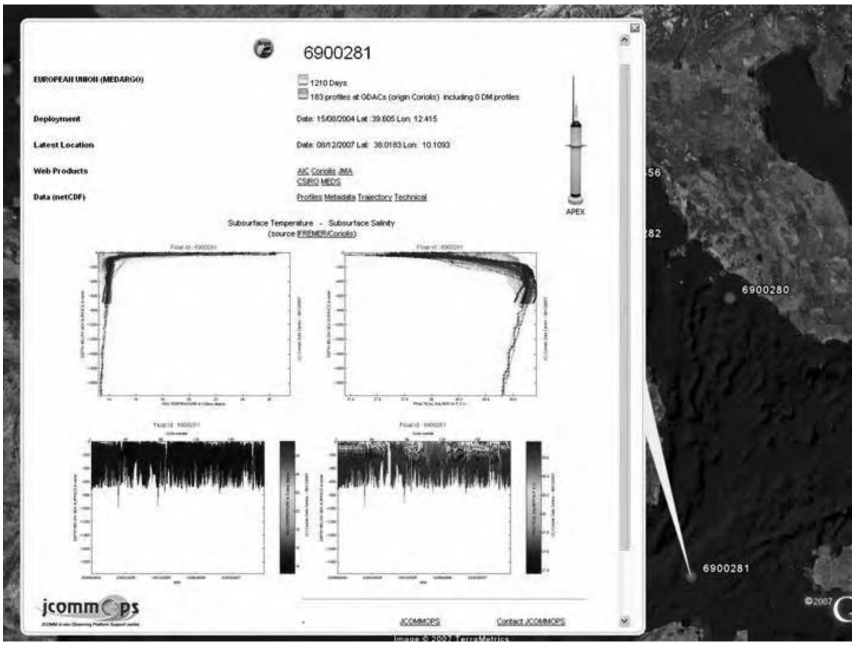

Fig. 6. Latest position (as of 8 December 2007) and graphical summaries of data provided by Apex float WMO 6900281 (Argos ID 50763). This float was deployed in the Tyrrhenian Sea in August 2003 and has performed more than 200 CTD profiles in more than three years. This is an example of graphical displays accessible via Google Earth and updated in near real time by the Argo Information Centre (jcommops).

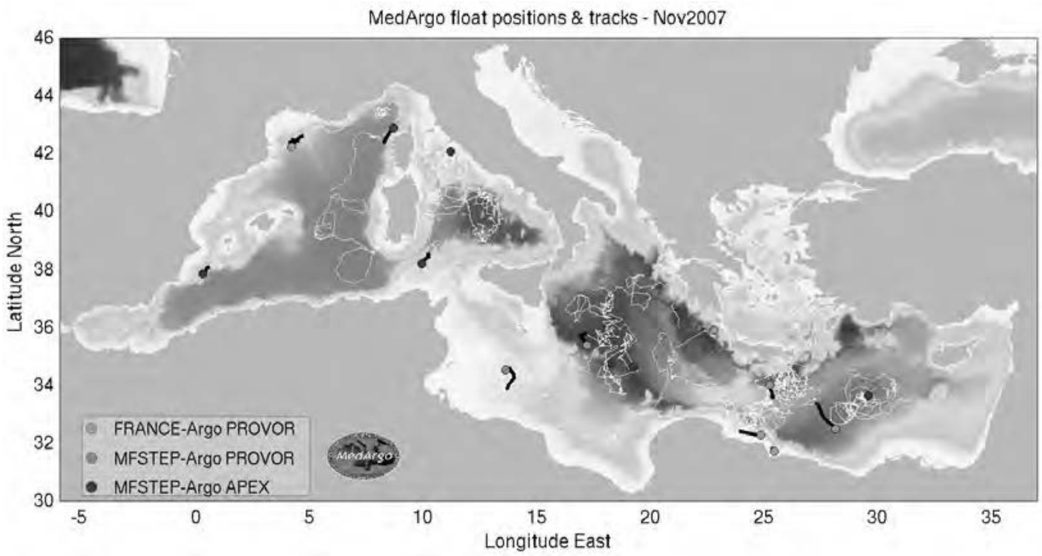

Fig. 7. Positions of Argo floats in the Mediterranean at the end of November 2007 (coloured circle symbols) and their trajectories in November 2007 (black) and since their deployment (white). This is an example of the graphical products produced by the Mediterranean Regional Argo Centre (MedArgo) in support of operational oceanography (MOON).

MedArgo (at OGS in Trieste, Italy) and at the Argo Information Centre (jcommops in Toulouse, France). Examples of near real time products publicly available via internet are displayed in Figures 6 and 7. A Google Earth map with position and information corresponding to an Apex float that operated more than three years in the Tyrrhenian Sea is displayed in Figure 6 (produced by jcommops). The seasonal evolution of the upper sea thermal structure is obvious. A graphical example of MedArgo products is shown as Figure 7, representing the active Mediterranean float tracks and positions in November 2007.

The near real time Mediterranean Argo float temperature and salinity data are assimilated in operational forecasting models of the Mediterranean circulation, such as MFS and MERCATOR (Griffa *et al*., 2006; Taillandier and Griffa, 2006; Dobricic *et al*., 2007; Griffa, this volume). The assimilation of the float's displacements at their parking depth is currently under development (see for example Taillandier *et al*., 2006). Hence drifter and float observations contribute to the Mediterranean Operational Oceanography Network (see Drago, this volume).

As of the end of February 2008, 21 Argo floats are still operational in most basins of the Mediterranean, including 13 units with the above-mentioned sampling and cycling characteristics corresponding to floats from the MFSTEP and French EGYPT (Taupier-Letage, this volume) projects. The mean age of the Mediterranean float population is, however, about two years. Consequently, if new deployments are not organized in the near future, the Mediterranean Sea will be mostly depleted of floats beyond 2008.

Implementation of drifters and floats in an integrated Mediterranean Marine Observatory

The monitoring of the Mediterranean circulation and water properties by means of drifters and profiling floats is crucial to be able to study the long-term variability of the Mediterranean as related to global warming processes. In addition, the free use of near real time drifter and float data, in conjunction with nowcasting and forecasting models in which they have been assimilated, can be essential for operational purposes such as the optimization of ship routing, the tracking of oil spills, search and rescue operations, military exercises, etc. High-quality drifter and float data should also be coordinated and used in concert with other *in situ* measurements (hydrographic surveys, moored instruments, gliders, etc.). As such the MedArgo (poseidon.ogs.trieste.it/sire/medargo) and MedSVP (poseidon.ogs.trieste.it/sire/medsvp) Centres have been created to promote drifter and float observations in the Mediterranean, to organize their operation in the most optimal way, also in relation to other *in situ* measurements and satellite data, making sure that their data are processed, archived, widely and freely disseminated to end-users in near real time.

For scientific purposes, it must be stressed that if real time drifter and float data are not calibrated they may yield erroneous results. Indeed sensors, such as the electrodes for measuring conductivity, can be affected by bio-fouling or other degradation during prolonged (multi-year) operations at sea. The possible sensor drifts might not be detected by near real time data quality control. Delayed-mode processing is therefore necessary. This can be done by analysing the variability of the dataset within itself and by comparing the Lagrangian observations with other *in situ* data (moorings, CTD surveys, etc.) approximately collocated and co-temporal. For instance, the float salinity measurements could be validated using potential temperature – salinity climatologies and the methodology proposed by Wong *et al*. (2003).

The sustainability of the Mediterranean Argo fleet is a major objective of the new EuroArgo Preparatory Phase (PP) project funded by the European Community 7th Framework Programme. EuroArgo is one of the pan-European projects of the European Strategy Forum on Research Infrastructures (ESFRI) 2006 roadmap, along with EMSO (Cochonat and Person, this volume). The goal is to organize the political governance, obtain member states funding commitments, improve some crucial technical aspects (such as satellite telemetry) and the data processing, archiving and dissemination, in order to implement a significant and sustainable European contribution to Argo by 2010. The project also includes outreach programs and divulgation/demonstration activities.

We propose the following recommendations for the future integration of Lagrangian observations in a Mediterranean Marine Observatory:

1. To coordinate the drifter and float operations at the Mediterranean level;
2. To seek national and international support to maintain a minimum number of operating units in the Mediterranean. For the surface drifters, a minimum of 30 units throughout the sea is proposed. For the Argo floats, a minimum of 20 floats is proposed to be mostly contributed by European member states through EuroArgo;
3. To improve near real time data processing, archiving and dissemination. Develop ad-hoc Mediterranean validation procedures, similar to those adopted by Argo, for delayed-mode calibration of float data. Create high-quality drifter and float databases to be used for scientific studies;
4. To promote technological developments (improve satellite telemetry, implement new sensors such as optical instruments, oxygen sensors, etc.);
5. To integrate the drifter and float measurements with other *in situ* data and satellite observations.

Straits and Channels as key regions of an integrated marine observatory of the Mediterranean: our experience on their long-term monitoring

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Abstract

The monitoring of Mediterranean straits and channels demonstrated its ability to detect the propagation of important anomalies at basin scale, for what concerns the transport of mass heat and salt. The new available technologies are able to significantly improve the present monitoring both in term of space/time resolution and extending the coverage to biogeochemical parameters. The important task of data transmission needs to be evaluated to permit a real time monitoring and the consequent possibility to make the acquired data available for forecasting purposes.

1. Introduction

The Mediterranean is a semi-enclosed basin, connected with the Atlantic Ocean through the Gibraltar Strait. Inside it we can distinguish two main basins, which communicate through the Sicily Channel. Both the western and the eastern Mediterranean are characterized by several sub-basins, with reciprocal exchanges controlled by straits and channels of different sizes and depths. For their occurrence and uniform distributions, straits and channels are able to give satisfactory quantitative estimates of transport inside the Mediterranean and provide important information on the propagation of perturbation around it (Astraldi *et al*., 1999). Strait and channels constitute noteworthy observation points for what concerns dynamics, heat, salt and biogeochemical characteristics present in adjacent basins, the Black Sea and the Atlantic Ocean (Briand, 1996). They are also able to furnish early warning of anomalous event propagation along the basin.

2. Observational activity

For a long time, CNR-ISMAR of La Spezia concentrated its attention on straits both for what concerns their internal dynamic and as privileged locations to understand the Mediterranean circulation. Specifically, a continuous monitoring of the Sicily Channel and the Corsica Channel was maintained since the second half of the 1980s.

The Sicily Channel, controlling the east-west exchanges in the Mediterranean, is the most important Mediterranean passage, after Gibraltar. The Corsica Channel, connecting the Tyrrhenian and the Ligurian Seas, appears sensitive to the winter cooling of the Ligurian-Provencal basin.

In both channels, the monitoring consists in sub-surface moorings, which measure currents and temperature at different depths, in order to permit the detection of the exchanges both in the surface and the deep layers. In the deep layer, moorings are also equipped with a high quality CTD probe, to detect the hydrographic variability in correspondence to the LIW layer. Furthermore, hydrographic campaigns, with water sample detection, are planned in both sites approximately twice per year (every six months).

2.1 Sicily Channel

The Sicily Channel is a complex region, delimited by two sill systems and an intermediate basin between them. Both the eastern and the western sill systems are approximately 500m deep, while the internal portion reaches a depth of 1,700m, and plays a role as a buffer intermediate basin. Our monitoring is composed of two currentmeter moorings, positioned in correspondence to the two western sills (along the Mazara del Vallo – Cape Bon section). From measurements of the deep currents, a mean transport of 1.0±0.25 Sv (1 Sv = 10^6 m^3/s) has been estimated, evidencing that the mean value prevails on its variability, even if a weak seasonal cycle is present with transports higher in February and lower in August. However, the seasonally averaged transport is always greater than 0.7 Sv along the year (Figure 1).

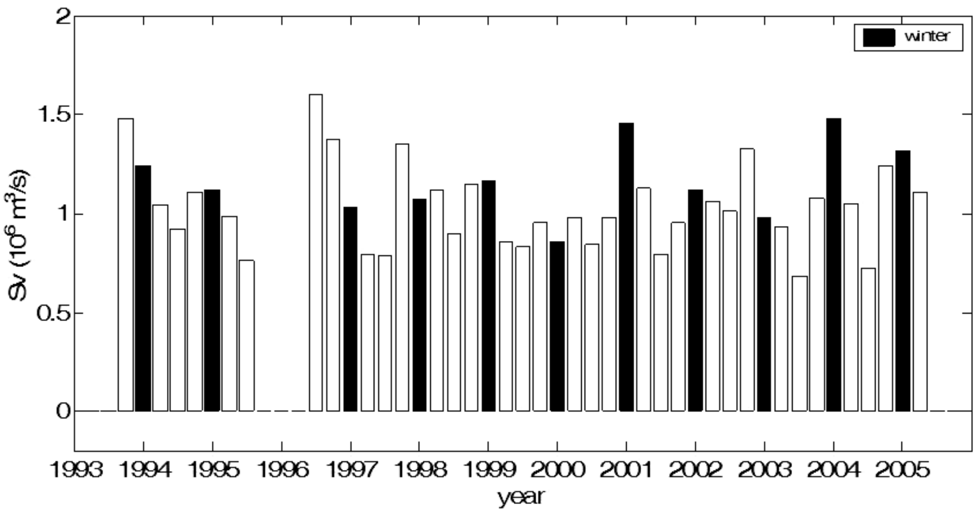

Fig. 1. Seasonal evolution of the LIW transport in the Sicily Channel. Black bar indicates the winter transport.

The monitoring the hydrographic properties, which started in the second half of the 1980s, permitted to observe the evolution of water masses under the influence of the "Eastern Mediterranean Transient" (EMT). The EMT signature in the Channel corresponds to a marked oscillation of hydrographic properties which lasted for about 10 years and which propagated toward the western Mediterranean (Figure 2). It was possible to estimate that, due to the density increase related to this oscillation, a significant percentage of the Sicily outflow sank in the deep layers of the western Mediterranean. Changes induced from this event significantly modified the hydrographic structure of the western Mediterranean. The increasing trend, detected since the 1960s both in temperature and salinity, has been sensibly accelerated by this event (Gasparini *et al.*, 2005), while the new stratification was able to significantly influence the deep water formation in the Ligurian-Provencal basin (Schroeder *et al.*, 2006).

2.2 Corsica Channel

The transport in the Corsica Channel has been monitored since July 1985. It is representative of the exchanges between the Tyrrhenian and the Ligurian Seas and it is particularly sensitive to the unbalance of the winter air-sea exchanges, significantly different in the two subbasins. While the Ligurian-Provencal basin is characterized by intense air-sea fluxes, which may induce deep water formation processes, the Tyrrhenian Sea, less concerned by the Mistral events, experiences significantly lower air-sea interactions. The mean transport through the channel and its variability have the same order of magnitude (0.49±0.42 Sv).

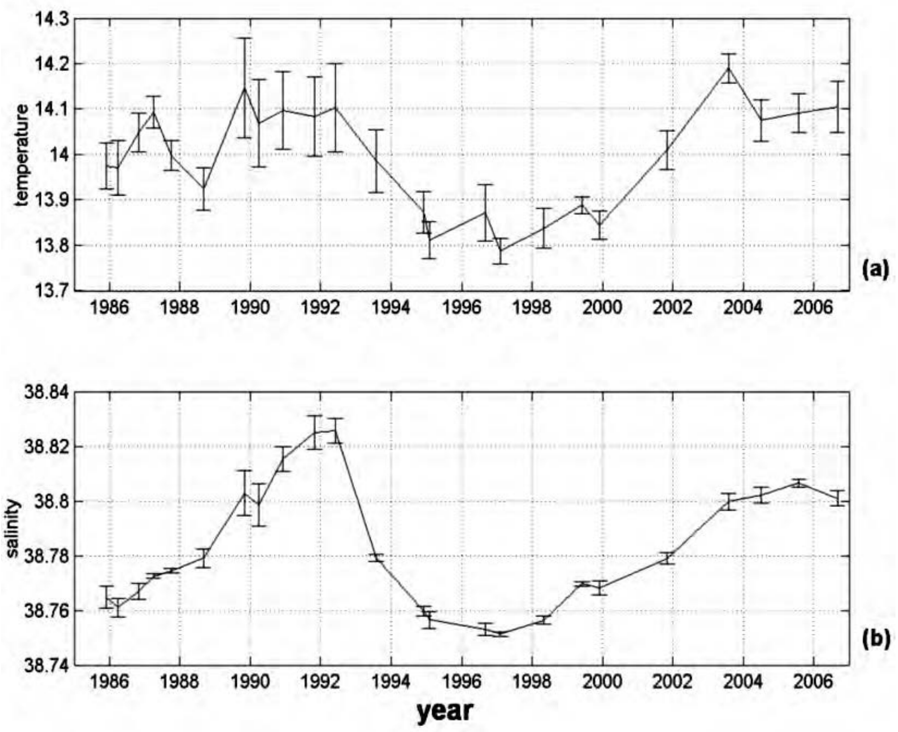

Fig. 2. Time evolution of LIW characteristics in the Sicily Channel. (a) Potential Temperature and (b) Salinity. LIW characteristics are computed averaging over a water column of 100m. Bar indicates the standard deviation. (updated from Figure 3 in Gasparini *et al.*, 2005).

The current, flowing almost permanently from the Tyrrhenian to the Ligurian Sea, has a clear seasonal cycle, with high values in winter and almost negligible values in summer (Figure 3). The seasonal cycle is quite regular and explains a large percentage of the observed variability. The interannual variability related to the winter periods (the colder the winter, the higher the transport) is remarkable: the higher transports observed during the 1980s were significantly reduced during the 1990s.

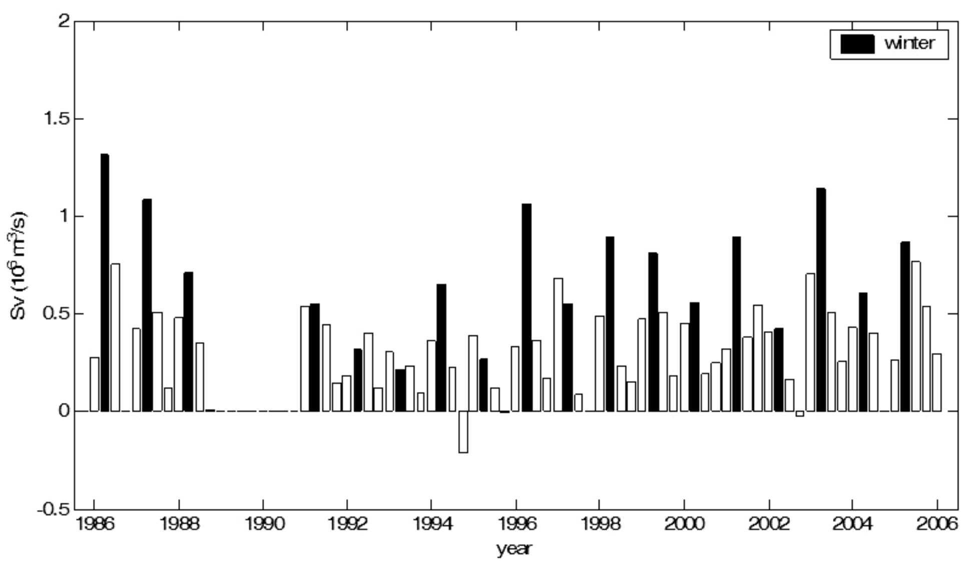

Fig. 3. Seasonal evolution of the transport in the Corsica Channel. Black bar indicates the winter transport.

While the influence on the European climate of the NAO is a consolidated result, its effects on the Mediterranean are still under discussion. Several studies showed that the Mediterranean is under the influence of several large-scale atmospheric systems (Hurrel, 1995; Raicich *et al*., 2001) and that the NAO influence seems more evident in the western Mediterranean. Recently Rixen *et al*. (2005) showed how the NAO could be responsible of a large part of the interannual Mediterranean variability.

Our group was one of the first to evidence a possible influence of the NAO on the Mediterranean circulation (Vignudelli *et al*., 1999), through its influence on winter atmospheric conditions in the Ligurian-Provencal basin and then on the air-sea exchanges, which are very active in this region. A comparison between the winter transport in the Corsica Channel and the NAO winter index shows that to higher values of the transport from the Tyrrhenian to the Ligurian Sea correspond negative NAOI values (Figure 4). Conversely, if the NAOI is very positive, the transport through the channel records the lowest values. On the other hand, going back to the Sicily Channel, we did not find any evident relation between its transport and the NAOI. There are major difficulties to detect possible relations in the Sicily Channel both for the reduced seasonal cycle and interannual variability. We have also to observe that the eastern Mediterranean is influenced by different atmospheric systems and that the interactions between the eastern and the western Mediterranean, which reflect on the Sicily Channel exchanges, are very composite and far to be understood.

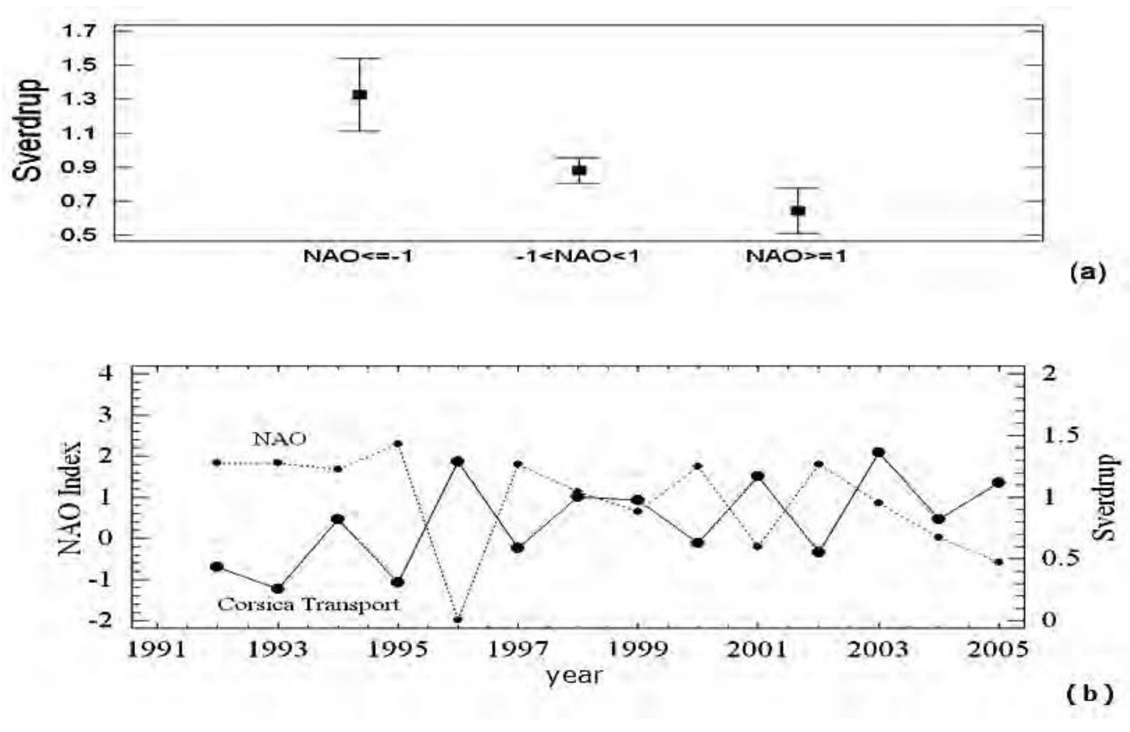

Fig. 4. (a) Mean monthly winter transport, ranked for three NAOI levels; (b) Comparison between the Corsica winter (JFM) transport (continuous line) and the corresponding NAOI (dashed line). The NAOI is the Gibraltar-Reykjavik index.

3. Future perspectives

The interannual variability of the hydrographic conditions, which we are now observing in the western Mediterranean, evidences how the influence of the EMT in the Mediterranean is far to be concluded. Recent observations (since 2006) in the Sicily Channel suggest the arrival of new dense waters from the eastern Mediterranean. The experience of the propagation of the EMT from the eastern Mediterranean demonstrates that straits and channels are suitable points to provide early warning of anomaly propagation.

Mediterranean passages are often coastal regions, usually with very peculiar and relevant ecosystems. It might be important to extend the monitoring to the local ecosystem, the first to be interested by possible anomaly propagation through contiguous basins.

It is important to capitalize the existing time series continuing the monitoring, while the new technology offers innovative instrumentation to integrate the present observations. The possible deployment of ADCP instruments on each mooring, will provide a detailed vertical structure of the current, while multiparametric self-recording probes (CTD, fluorimeter, dissolved oxygen, photosynthetically available radiation - PAR, fluorescence and turbidity), positioned at least at three depths: surface, intermediate and bottom, will guarantee the necessary hydrographic information. Non-conventional advanced sensors (nitrate sensor, automated plankton detector, other acoustical and optical instrumentation) may be considered in experimental way.

A typical passage becomes narrower with a more coherent dynamics going deeper. This behaviour makes the monitoring of deep layers with fixed moorings relatively easy. The same strategy appears inadequate to describe the surface characteristics. The reason is related to the greater width of the passages close to the surface but, above all, to the high short scale variability present in the surface layer. New promising instruments, as gliders, periodically crossing the passage and providing a cross-channel distribution of hydrographic conditions, would be of great help in the transport estimates.

The important task of a real time data transmission would be evaluated to permit a real time monitoring with the consequent possibility to assimilate the acquired data in forecasting systems. If in real-time intervention would be too expensive, periodic visits to the monitored positions might permit a download of recorded data by means of an acoustic modem.

Monitoring dense shelf water cascades: an assessment tool for understanding deep-sea ecosystems functioning

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Abstract

Cascading of dense shelf water from continental shelves is a global phenomenon whose effects have been largely underestimated. The north-western Mediterranean is one of the regions of the world where massive dense water formation occurs because of cooling and evaporation of surface waters during winter-time. Concurrent with the well known open-sea convection process over the MEDOC region, coastal surface waters over the wide shelf of the Gulf of Lions also become denser than the underlying waters and cascade downslope until reaching their equilibrium depth. Through this climate-driven phenomenon, dense shelf waters carrying large quantities of particles in suspension are rapidly advected hundreds of meters deep, mainly through submarine canyons. Recent observations within the frame of several research initiatives conducted in the north-western Mediterranean found that major dense shelf water cascades from the Gulf of Lions have a direct effect on the deep water (i.e. WMDW) thermohaline properties and on the long-term fluctuations of deep-sea fisheries, notably the shrimp *Aristeus antennatus*. Because of the flushing and recurrent behaviour of such cascading events, a continuous monitoring of this phenomenon under a system of Integrated Mediterranean Marine Observatories initiative could be conducted by means of establishing permanent real-time deep-sea observatories at specific key sites in the Mediterranean, in places where this process has been clearly identified (i.e. Gulf of Lions, southern Adriatic and Aegean shelves). Such infrastructures will allow studying this phenomenon using a trans-disciplinary approach to assess in detail its effects and implications in the Mediterranean deep-sea ecosystem and living resources.

Introduction

Dense shelf water cascading is a global climate-driven oceanographic phenomenon common not only on high latitude continental margins, but also on mid latitude and tropical margins (Ivanov *et al*., 2004). The Gulf of Lions is one of the three known regions in the Mediterranean where this phenomenon occurs almost every year, together with the southern Adriatic and Aegean shelves (Durrieu de Madron *et al*., 2005). Winter heat losses and evaporation induced by persistent, cold and dry northerly winds (Tramuntana and Mistral) cause densification and mixing of coastal waters. Despite the buoyancy gain induced by freshwater inputs, once denser than surrounding waters, surface waters over the Gulf of Lions' shelf sink, overflow the shelf edge, and cascade downslope until they reach their equilibrium depth (Fieux, 1974; Person, 1974). Through this phenomenon, dense shelf waters carrying large quantities of dissolved and particulate matter are rapidly advected hundreds of metres deep at speeds >85cm/s, mainly through submarine canyons (Palanques *et al*., 2006), acting as a significant natural carbon sequestration and as a potential deep-sea ecosystem fuelling mechanism (Canals *et al*., 2006). In very dry, windy and cold winters, such as in 2005, cascading is exceptionally intense, lasting for more than a month. Under these circumstances, dense shelf waters propagate along and across the continental slope (Font *et al*., 2007), reaching depths >2,000m where they merge with dense waters formed off-shelf, in the MEDOC area, by a typical open-sea convection process (MEDOC group, 1970). The mixing of these two dense waters generates a thermohaline and turbidity anomaly in the Western Mediterranean Deep Water (WMDW) that spreads throughout the entire north-western Mediterranean basin (López-Jurado *et al*., 2005; Schröder *et al*., 2006). Previous severe winters with anomalous dense water formation (i.e. those with major cascading events reaching the basin) were identified after the analysis of historical hydrographic data and took place at decadal intervals in winter 1971, 1980, 1988 and 1999 (Béthoux *et al*., 2002). Figure 1 schematizes the spreading of dense shelf waters and the formation of the WMDW thermohaline and turbidity anomaly, inferred from published data.

Although in terms of water and particle transport this process is at present relatively well known, many scientific questions arise now on how the large fluxes associated with this phenomenon may determine the functioning of deep-sea ecosystems. A recent study by Company *et al*. (2008) demonstrates that dense shelf water cascading from the Gulf of Lions have a direct effect on the long-term fluctuations of deep-sea fisheries, with the striking example of the rose shrimp *Aristeus antennatus*. This contribution will summarize some of the major findings obtained by time series observations conducted from October-November 2003 to April 2007 in the north-western Mediterranean, highlighting the effects of major dense shelf water cascades from the Gulf of Lions on the WMDW thermohaline properties and on the temporal evolution of *Aristeus antennatus* landings.

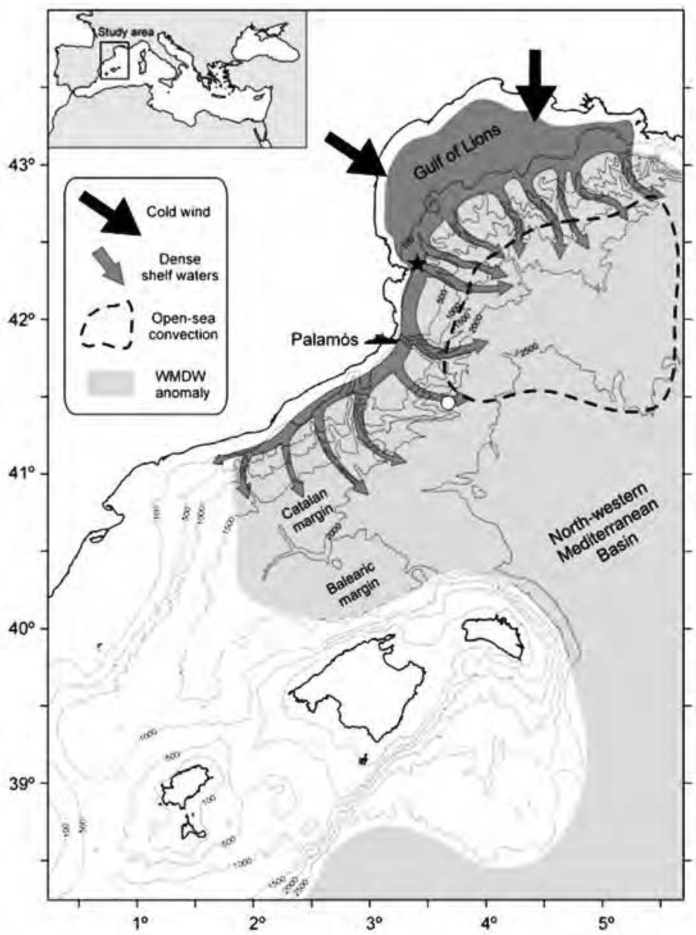

Fig. 1. Bathymetric map of the north-western Mediterranean showing the pathway of the dense shelf water cascading mechanism extending from the Gulf of Lions along and across the Catalan continental slope, the open-sea convection region (MEDOC area) and the region affected by the thermohaline and turbidity anomaly observed in the Western Mediterranean Deep Water after the 1999 and 2005 major cascading events (inferred from published literature). The location of the dense shelf water cascade monitoring site at the head of the Cap de Creus submarine canyon (black star), the HydroChanges ICM mooring (white circle) and the Palamós fishing harbour (black ship) are also shown.

Time series observations

The occurrence and effects of dense shelf water cascades from the Gulf of Lions have been continuously monitored since November 2003 under the frame of several research projects. Previous to that, since October 1993 the Centre de Formation et de Recherche sur l'Environnement Marin of Perpignan (CEFREM) has been maintaining two long-term mooring deployments in the Planier and Lacaze-Duthiers submarine canyons at 1,000m depth, which have been also recording the effects of major cascading events in the north-western Mediterranean (see Canals *et al*., 2006 and Heussner *et al.,* 2006 for details). In winter 2003-04, during the EU EuroSTRATAFORM project, seven Gulf of Lions' submarine canyon heads were instrumented with moorings deployed at 300m water depth, with sediment traps placed at 30m above the bottom (mab) and Aanderaa RCM9/11 Doppler current meters with temperature, conductivity, pressure and turbidity sensors placed at 5 mab (see Palanques *et al*., 2006 for details). Similar observations were conducted in winter 2004-05 during the NA EuroSTRATAFORM project only in the Cap de Creus Canyon – since the largest water and particle fluxes during the preceding year were observed in its canyon head– and three instrumented moorings were deployed along the canyon axis at 200, 500 and 750m depth (see Canals *et al*., 2006 for details). In winter 2005-06, during the HERMES project, a focused and larger observational effort following the same type of near-bottom mooring configuration was conducted on the western Gulf of Lions continental margin. Particle fluxes and current meter measurements were obtained in the Lacaze-Duthiers Canyon at 300, 1,000 and 1,500m depth, in the Cap de Creus Canyon at 300, 1,000, 1,500 and 1,900m depth, and on the adjacent southern open slope at 1,000 and 1,900m depth in order to follow the course of the dense shelf water cascades along and across the slope. Later on, in winter 2006-07, only the Cap de Creus canyon head remained instrumented with an Aanderaa RCM9 Doppler current meter with temperature, conductivity, pressure and turbidity sensors placed at 5 mab, as a key site to monitor the occurrence of dense shelf water cascades from the Gulf of Lions (Figure 1).

Contemporary with the above mentioned time series observations, since October 2003 and as part of the HydroChanges (HC) pilot program launched by CIESM (http://www.ciesm.org/marine/programs/hydrochanges.htm) (CIESM, 2002), the Institut de Ciències del Mar of Barcelona (ICM) has been maintaining an instrumented mooring in the lower Catalan continental slope (hereafter named HC-ICM), which has proved very valuable in identifying the effects of the dense shelf water cascading process on the NW Mediterranean deep water (see Font *et al*., 2007 for details). The HC-ICM mooring is located at 1,890m depth, downstream from the Gulf of Lions margin and south of the Palamós (also known by the fishermen community as Fonera) submarine canyon (Figure 1). This location was chosen because it was previously used in 1993-94 for a study related to the spreading of the deep water formed in the NW Mediterranean (Send *et al*., 1996), from where background information existed. The mooring is equipped with a SeaBird 37 model CTD recorder at 15 mab and an Aanderaa RCM8 mechanical current meter at 11 mab, and since March 2007 an additional Aanderaa RCM11 Doppler current meter equipped with a turbidity sensor has been installed on it.

Since 2001, daily landings of commercial species from all the fishing harbours on the Catalan coast are being recorded automatically by Direcció General de Pesca i Afers Marítims of the Autonomous Government of Catalonia. To investigate the relationship between the occurrence of cascading events and the population characteristics of commercial species, this detailed historical database is currently under study and compared with the time series observations from the instrumented moorings deployed at the head of the Cap de Creus Canyon and in the lower Catalan continental slope. For the purpose of this contribution, only daily landings of one of the most valuable Mediterranean deep-sea living resources, the rose shrimp *Aristeus antennatus* (Risso 1816), will be shown. Data from the Palamós fishing harbour have been chosen as it is one of the main fishing harbours in the north-western Mediterranean under the influence of the dense shelf water cascading process, and the one that obtains the highest yields of this highly priced deep-sea living resource (see Figure 1 for location). This first approach will allow assessing the direct effects of the cascading phenomenon in this monospecific fishery, paying special attention to the consequences derived from major cascading events (i.e. those reaching the north-western Mediterranean basin).

Results and Discussion

Results obtained during several consecutive winter deployments in the Cap de Creus submarine canyon have allowed to monitor and identify the occurrence and magnitude of dense shelf water cascades from the Gulf of Lions (Figures 2a and 2b). Cascading events are easily recognizable since they are characterized by abrupt decreases in water temperature associated with increases in current speed (up to 80cm/s). In winter 2003-04 several single (i.e. minor) cascading events that lasted for few days occurred from January to May, which were generally associated to eastern storm events (Palanques *et al*., 2006). In winter 2004-05, the lower air temperatures, the more persistent northerly cold and dry winds, and the reduction of river discharges (not shown) contributed to decrease the buoyancy of the coastal waters dramatically enhancing the intensity of the shelf water cascading mechanism. Under these weather conditions, cascading in the Cap de Creus Canyon head (200m depth) began in early December 2004, a month an a half earlier than in the preceding year. During the first events, this process only affected the canyon head, but in late January 2005 a major cascading event reached down to 750m depth. From late January to early March 2005 cascading occurred continuously and maintained cold temperatures and down-canyon steady currents between 40 and 80cm/s, showing periodic fluctuations that lasted between 3-6 days (Canals *et al.,* 2006; Font *et al*., 2007). In winter 2005-06, another major cascading event took place, with strong negative near-bottom temperatures and increased current speeds recorded in most of the moored arrays deployed during HERMES. Dense shelf water cascades begun in mid December 2005 at the head of the Cap de Creus Canyon and ocurred almost continuosuly from early January until mid April 2006. In winter 2006-07, only some isolated minor cascading events lasting for few days occurred, which started in late January 2007 and ended in mid April 2007.

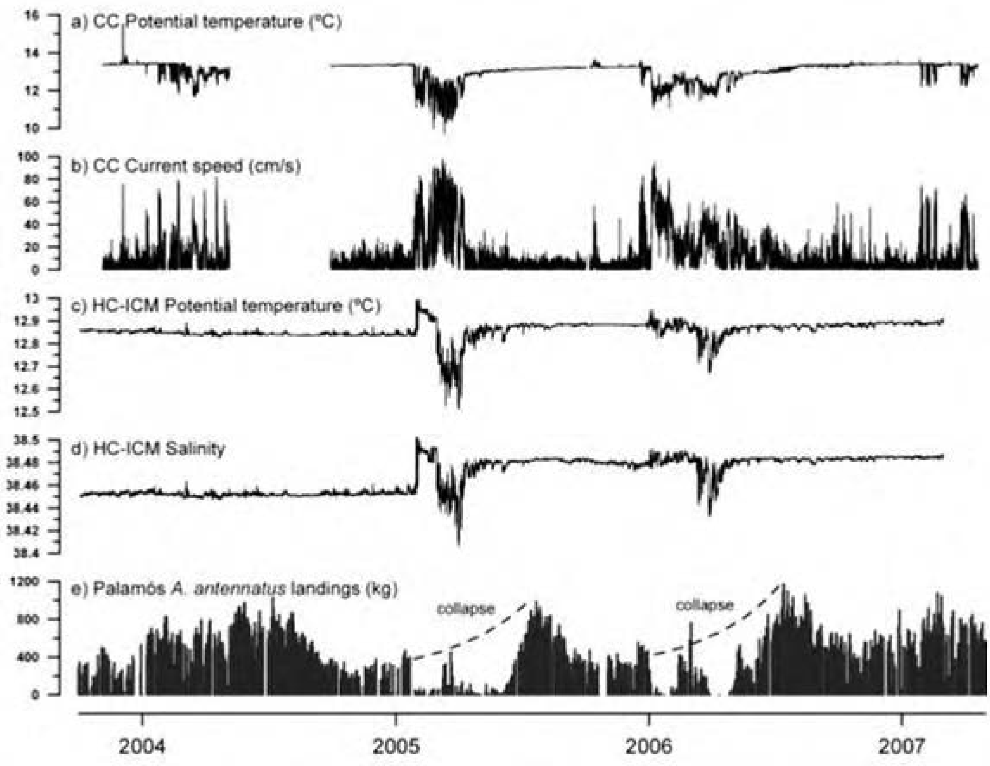

Fig. 2. Time series observations from the north-western Mediterranean showing: a) potential temperature and b) current speed at the head of the Cap de Creus (CC) submarine canyon (at 300m depth except measurements during 2004-05 that were collected at 500m depth, always 5 mab); c) potential temperature and d) salinity recorded at the HC-ICM site (at 1,890m depth, 15 mab) and e) daily landings of *Aristeus antennatus* at the Palamós fishing harbour from October 2003 to April 2007. See moorings and harbour locations in Figure 1. Dashed lines represent the intra-annual trend of *Aristeus antennatus* landings and illustrate the temporary fishery collapse associated to major cascading events.

The time series of data recorded at the HC-ICM mooring indicates a clear difference between winters characterized by minor or major cascading events (Figures 2c and 2d). The potential temperature (12.84-12.86ºC) and salinity (38.45-38.46) values at 1,980m depth in the lower Catalan continental slope remained almost unchanged from October 2003 until the end of January 2005, indicating a stable water mass situation that corresponds to typical WMDW characteristics (θ 12.8-12.9, S 38.43-38.46, σ_θ 29.09-29.10, depending on the specific conditions that occurred during its formation in winter). However, from this last date, and simultaneously with the initiation of the major 2005 cascading event in the Cap de Creus Canyon, θ and S rapidly increased to 12.99ºC and 38.50 respectively, and then for one month fluctuated between 12.90-12.95ºC and around 38.49 (σ_θ = 29.11). Such increases were attributed by Font *et al*. (2007) to the arrival at the HC-ICM site of dense waters formed or pre-conditioned by the offshore convection process, which had a large contribution of an unusually warm and salty LIW/TDW. By early March 2005, potential temperature and salinity suddenly decreased by more than 0.2ºC and 0.04, respectively, as a consequence of the arrival of colder and fresher dense shelf waters, which cascade from the Gulf of Lions to the lower Catalan continental slope (Font *et al*., 2007). The signature of these dense shelf waters remained during one month in a range of low values (with peaks down to 12.51ºC and 38.41, σ_θ = 29.14), lasting for almost the same period as the continuous cascading was recorded within the Cap de Creus Canyon, and was followed by a period of gradual θ and S increase until reaching quite steady values of 12.88ºC and 38.48 (σ_θ = 29.12) by mid June 2005. In late December 2005, potential temperature and salinity sharply increased by 0.06ºC and 0.01 respectively, presumably as a consequence of the arrival of newly formed dense waters by winter offshore convection, and afterward, θ and S fluctuated between 12.82-12.95ºC and 38.47-38.49 until early March 2006. At that time, a sudden drop of 0.16ºC and 0.04 took place, associated to the arrival of dense shelf waters to the HC-ICM site exported during the major 2006 cascading event. Similar to what occurred in the preceding year, the signature of the dense shelf waters could be detected at 1,890m depth for more than a month, with minimum values of 12.66 and 38.43 (σ_θ = 29.13). Progressively, θ and S values reached the same new (i.e. after 2005) steady values of 12.88 and 38.48 (σ_θ = 29.12) by mid May 2006, although both variables showed after that date a subtle but persistent increasing trend with periodic fluctuations of several days. The HC-ICM mooring was recovered (and reinstalled again) in early March 2007 without showing any evidence of termohaline changes in the WMDW associated to the several minor cascading events occurring in winter 2006-07.

Daily landings of *Aristeus antennatus* from the Palamós fishing harbour also reflect a clear difference between winters characterized by minor or major dense shelf water cascades. During the major 2005 and 2006 cascading events, near-bottom currents associated with the propagation of dense shelf waters reached sustained speeds >85cm/s inside de Cap de Creus Canyon (Figure 2b) and the advected dense shelf waters affected the entire northern Catalan continental slope, reaching depths ~2,000m (Figures 2c and 2 d). Landings of *Aristeus antennatus* revealed that the potential dragging capacity of such energetic flows coincided in time with the disappearance of this deep-sea living resource from the fishing grounds (located at 400-800m depth), causing a temporary fishery collapse of this species and disrupting the intra-annual variability of its landings (Figure 2e). This evidence was first reported by Company *et al*. (2008) during the major 2005 cascading event, and was noticed in all the main fishing harbours on the northern Catalan coast (i.e. Roses, Palamós, Blanes and Arenys de Mar). The disappearance of this species from the fishing grounds was gradually delayed in the harbours located down current and towards the southwest, in agreement with propagation of the cascading event (Figure 1). Landings at Palamós progressively recovered 2-3 months after cessation of the cascading observed in the Cap de Creus Canyon, indicating that effects on this deep-sea population can last for longer than the event itself. The same disappearance pattern of *Aristeus antennatus* happened in 1999, during the previous major cascading event (Company *et al*., 2008), and was observed again during the one occurring in 2006 (Figure 2). Landings at Palamós dropped in early January 2006, at the time that the cascading process was observed to occur uninterruptedly in the Cap de Creus canyon head, and similar to what occurred in the preceding year, progressively recovered their usual values in July 2006. The spatio-temporal co-occurrence between major cascading events and the temporary fishery collapse of *Aristeus antennatus* suggest that the physical disturbance by such strong deep currents of cold and turbid dense water probably displaces the individuals of this species from the fishing grounds, presumably towards greater depths. Despite this initial negative effect, Company *et al*. (2008) also conducted a long-term analysis of this fishery using historical databases and found that total landings of *Aristeus antennatus* show an increasing trend and a peak of captures between three and five years after major cascading events, preceded by an increase of juveniles. These authors concluded that the large transport of dissolved and particulate organic matter associated with this phenomenon appears to enhance the recruitment of this deep-sea living resource, apparently mitigating the general trend of overexploitation. Following this recurrent behaviour, it is expected that the beneficial effects after the 2005 and 2006 major cascading events will be seen in the landings of *Aristeus antennatus* after 2008.

Conclusions

The time series of data recorded at the head of the Cap de Creus Canyon and in the lower Catalan continental slope have allowed documenting the sequence of changes experienced by the WMDW during the major 2005 and 2006 cascading events. The mixing of dense waters generated by offshore convection in the MEDOC area and by cascading from the Gulf of Lions during winter 2004-05 seems to be the reason for a sudden transition from the typical WMDW to a saltier and warmer deep water after spring 2005. This increase was not altered by the arrival to the north-western Mediterranean basin of fresher and colder dense shelf waters originated during the major cascading event in winter 2005-06.

These observational data further provide evidence that the physical disturbance originated by strong currents during major cascading events co-occur with the disappearance of the deep-sea shrimp *Aristeus antennatus* from the fishing grounds on the north-western Mediterranean. These findings provide a new understanding of the inter-annual landings fluctuations of this highly valuable deep-sea living resource, which are linked to a climate forcing. Such knowledge will contribute to improve the management of this fishery, since the occurrence of major cascading events can be monitored and used as a tool for managing this living resource. Additional monitoring efforts could be conducted in other Mediterranean regions where dense shelf water cascades have been identified, since similar interactions with deep-sea ecosystems might be expected.

Acknowledgements

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An observational array at the western exit of the Gulf of Lions

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Abstract

An array of fixed stations, strategically located at the western exit of the Gulf of Lions, proposed as an example for an integrated system of stations. This site is focused on the monitoring of microbial systems (viruses, bacteria and phytoplankton), as they are relevant indicators of modifications in the carbon sequestration. It is also focused on particulate transfer from the coastal zone to the basin via canyon export. First results from the recorded long term, high frequency and spatial variability in hydrological conditions are presented. The integration within a single database of meteorological, hydrodynamics, biogeochemical and microbial parameters is discussed as the way to facilitate validation and development of coupled hydrodynamic-ecosystem based management models. Marine observational networks need to be flexible enough to accommodate new fields of study and emerging technology and sensors during their operational lifetime.

Introduction

The oceanic system operates over a wide range of temporal scales, from centuries-long periods, in the case of climate change, to higher frequency variations related to tidal stirring or turbulent mixing, for example. The ocean is also characterised by a large spatial variability depending on global to local forcing. Consequently, observational data in concert with oceanographic models must constitute the basic tools for identification, validation and quantification of changes in the ocean environment, either from human and natural origin.

In addition to describing seasonal or inter-annual variability, the impact of extreme events that control fluxes and budgets in marine ecosystems should be characterised. Hence, integrated and multi-scale observation networks must include both long-term monitoring and near real-time measurements capabilities in order to precisely document the broad spectrum of temporal and spatial scales involved. Measurements at high vertical and temporal resolutions can be performed by eulerian observatories and the deployment of an array of stations may lessen the impact of their poor spatial resolution. Hence, to meet all these requirements, three main objectives should be achieved:

i) the deployment of a fixed stations network, adapted to rough sea conditions and equipped with high frequency sensors, capable of transmitting measurements in real-time. Regular access to oceanographic vessels plays a key role in the maintenance and any complementary samplings at the stations.

ii) accounting for the air-sea interface which affects the environmental conditions in the euphotic zone, as well as the water-sediment interface, which channels the particulate fluxes and integrate processes at a larger time scale. In addition to hydrological and meteorological parameters, complementary measurements (e.g. chemical and biological parameters) should be measured, accounting for the variability of the processes considered.

iii) the automatic integration of the measurements into databases. After validation, data are often needed rapidly, for example those needed for assimilation in numerical models. Interconnections with databases from other locations are important for contributing to a global approach in studies of environmental change.

These requirements have been progressively implemented at an integrated system of fixed stations located at the western exit of the Gulf of Lions. This station network will be a component of the MOOSE (Mediterranean Ocean Observation multiSites on Environment) French observational network currently in progress. Building *in situ* observation networks which meet these needs will facilitate validation of operational oceanographic models, as defined by the European initiative GMES (Global Monitoring for Environment and Security), for example.

1. Station network

As indicated in the Figure 1, the Northern Current, river inputs and wind influence all control the major processes in the Gulf of Lions:

- coastal to offshore transfers on the shelf,
- benthic transfer from the shelf to the basin (canyon export),
- exchanges and transfers with the Northern Current, and
- mixing of coastal and Rhone River inputs.

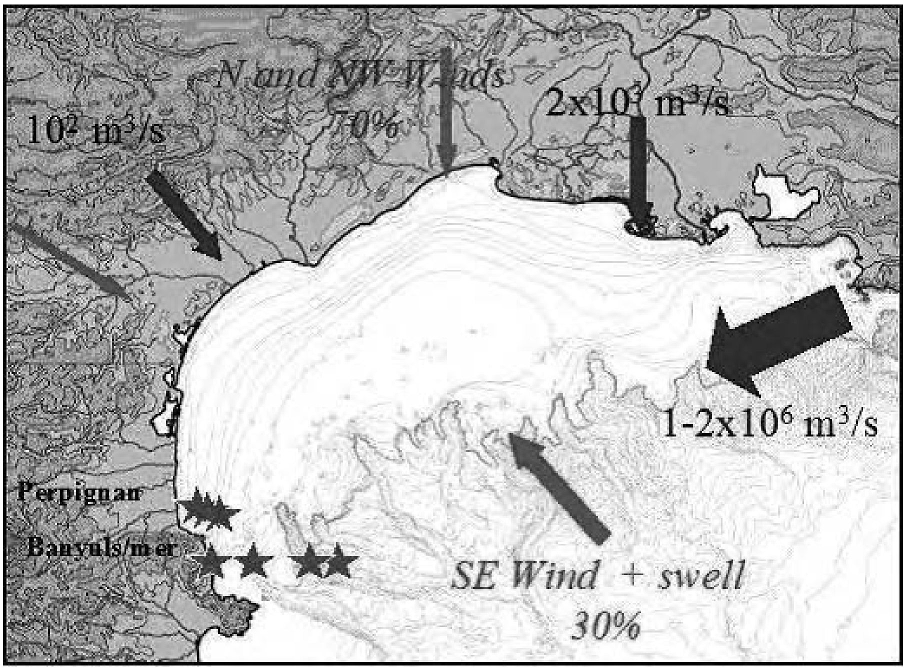

Fig. 1.

This results in a broad spectrum of variability influencing both the diversity and functioning of coastal and offshore ecosystems. The western exit of the Gulf of Lions, where advective processes predominate, is a strategic location for monitoring these processes.

Stations

The station network implemented by CEFREM (Perpignan) and the Banyuls/mer Oceanological Observatory is composed of the following units (indicated by the stars in Figure 1):

1. An automated station to measure the inputs of a coastal river (Têt River).
2. An instrumented buoy (POEM as "Plate-forme d'Observation de l'Environnement Méditerranéen du Littoral Languedoc-Roussillon") for the marine monitoring off the Têt River (Bourrin *et al*., 2007).
3. A station for the measurement of atmospheric inputs (rain and dust).
4. A station for weekly seawater sampling in the Banyuls Bay (SOLA, "Station d'Observation du Laboratoire Arago"), for long term monitoring (Charles *et al*., 2005; Joux *et al*., 2006). This station also belongs to the French national coastal observation network (SOMLIT, Service d'Observation en Milieu Littoral).
5. A station for weekly seawater sampling on the continental shelf (POLA, "Plateau Observatoire Laboratoire Arago), 5 nautical miles offshore, for the monitoring of dense water formation (Estournel *et al*., 2005; Puig *et al*., this volume).
6. A station for monthly seawater sampling on the northern flank of a canyon, 600m deep and 19 nautical miles offshore (MOLA, "Microbial Observatory Laboratoire Arago"), for microbial diversity studies (Obernosterer *et al*., 2005).
7. An instrumented mooring (sediment traps, current meters) in the canyon axis, 1,000m deep, with the BILLION (as BILan golfe du LION") monitoring program for the particulate flux transferred to the basin (Heussner *et al*., 2006).

While monitoring operations started in 2003, all these stations have been operational as a network since 2005, except for the BILLION program initiated 15 years ago, and the SOLA monitoring which began in 1997.

Results

Long term monitoring

Based on the monitoring results at SOLA, the Banyuls Bay site has typical seasonal thermal variations (dashed smoothed curve) and its variability is influenced by N-NW local winds. As shown in Figure 2, the seasonal salinity signal (solid curve) is disturbed by episodic low salinity water masses that can be related to riverine influence. There is a tight coupling between surface and bottom layers.

High frequency variability

At the MOLA site, hourly CTD profiles were performed as part of a study on the bacterial diversity at this location. During this high frequency sampling, it was shown that the thermocline could deepen more than 5m within three hours, due to the propagation of an internal wave that mixed water from the two layers. Particulate settling is controlled by the thermocline (-40m) and the deep chlorophyll maximum (-80m).

Spatial variability

SOLA (-25m, bottom row), POLA (-90m, middle row) and MOLA (-600m, upper row) stations are located along a coast-to-offshore transect monitored since May 2005. In the Figure 4, the coupling between surface and bottom layers at SOLA is confirmed. Apart from the stratification period during summer (April to October), coupling is also observed at the POLA shelf station. Three major salinity events (<38.2) were recorded at MOLA on June 2005, May 2006 and May-July 2007. Similar events were also recorded during the same periods at the two inner stations. The freshwater volume necessary to produce such diluted water masses probably originated from Rhone River discharges. The high variability observed both at the shelf site (POLA) and the nearshore site (SOLA) is related to coastal rivers' inputs.

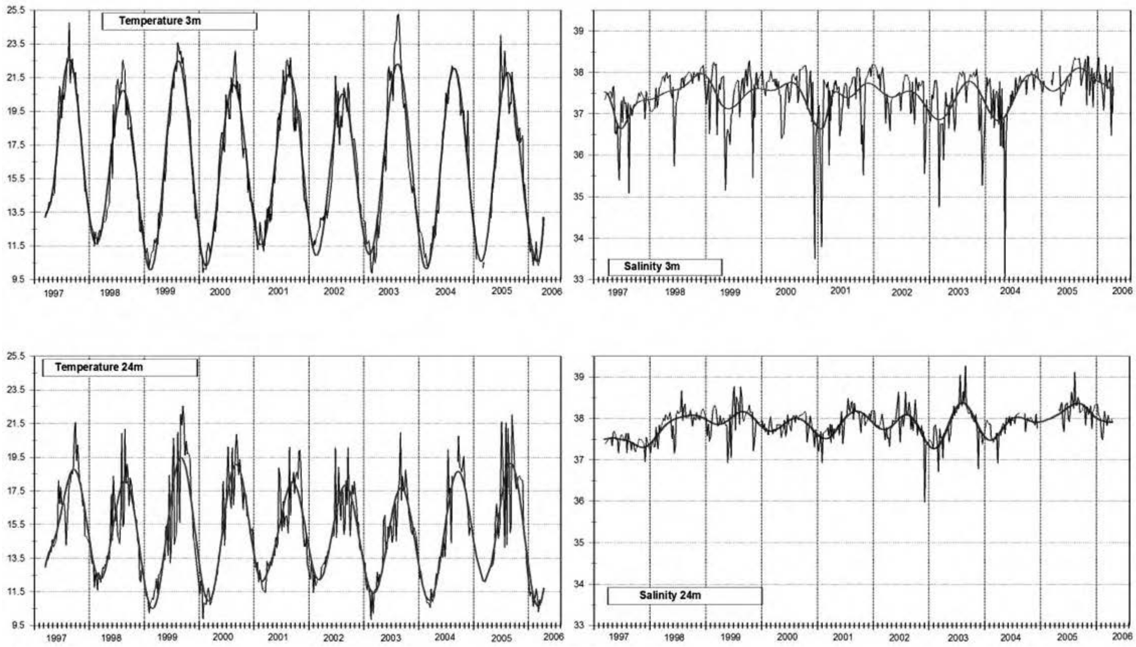

Fig. 2. Pluri annual variability (1997 – 2006) of temperature (left) and salinity (right) at 3m (upper) and 24m (lower) depth at SOLA site in Banyuls Bay.

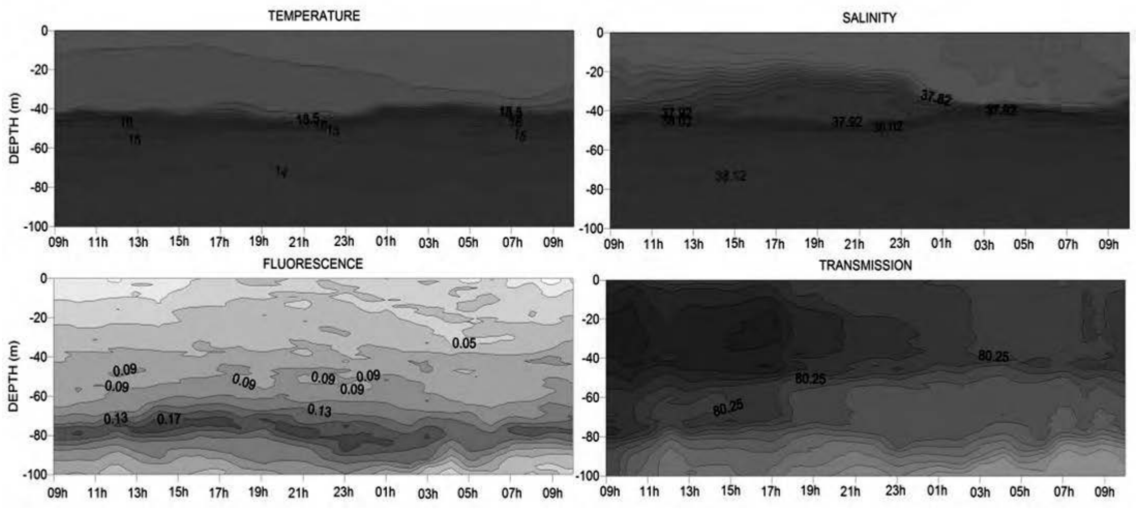

Fig. 3. Hourly variability in temperature (upper left), salinity (upper right), fluorescence (lower left) and turbidity (lower right) at the MOLA site from July 15 to 16 2004.

These initial results show that river contributions are transported along the coast-to-midshelf zone via episodic low salinity structures from 20 to 30m thick. An along slope transfer of diluted water from the Rhone River (cf. SeaWiFs images, Bosc *et al*., 2004), is also evidenced at the periods mentioned above.

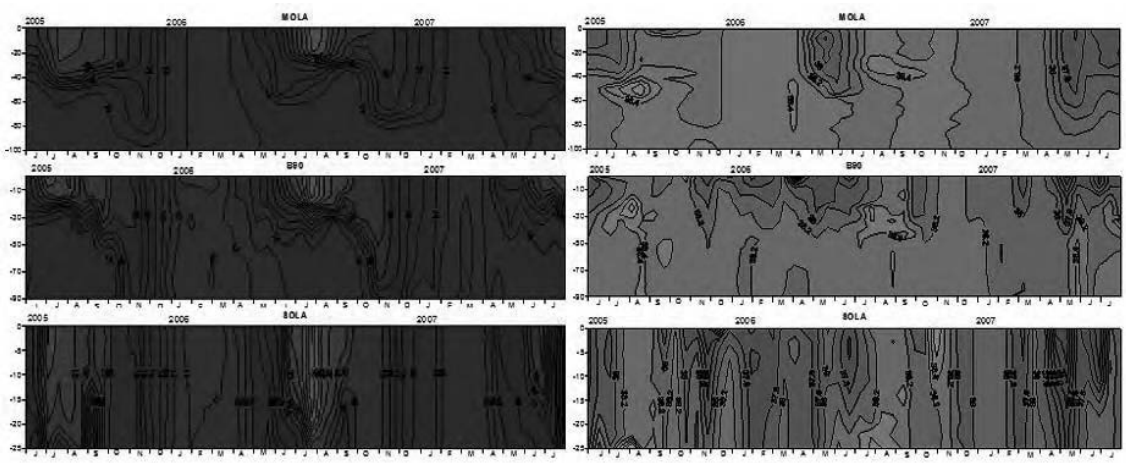

Fig. 4. Temporal monitoring of temperature (left) and salinity (right) at three stations of the observational array at the western exit of the Gulf of Lions. Please note the different vertical scales for each site: 0-100m at MOLA (upper), 0-90m at POLA (centre), 0-25m at SOLA (lower) (contribution to SESAME – WP3).

Planned improvements

The monthly sampling periodicity at the MOLA station is often disturbed due to bad weather conditions. The opportunity to reuse a moored platform (Lourenco *et al*., 2000) previously developed by the LODyC-LOCEAN laboratory (Paris, France) not only solved this problem, but also allowed the project to benefit from LOCEAN's expertise in this domain. This platform's size (6m in diameter and more than 6m in height) has a dissuasive effect with respect to the high trawling activity in the region. Six solar panels provide sufficient energy to host meteorological and hydrological instruments and to transmit in near real-time the measurements.

The immersed part of the platform has a central ring, 5m in diameter, for fixing at 35m and 80m depth, two inductive CTDs (each also has a fluorometer and transmissometer) on a weighted 120m long pendular cable. An extension to 580m long is also planned for observing the bottom nepheloid layer. All the electronic equipment for data acquisition, power supply management, storage and transmission of data is managed by a computer system protected by a waterproof box. A RDI ADCP from the CEFREM will also be added at 100m depth.

The emerged portion hosts all the meteorological sensors (anemometer, air temperature, air pressure), a GPS, a pitch and roll sensor, signalling, batteries solar panels and data transmission through the FreeWave system (2.4 à 2.4835 GHz). Ongoing testing of the data management and telemetry uses the following specifications: data about system functioning and from the sensors is collected continuously for each sensor; data is dumped to an embedded database each minute, and every 10 minutes a package is transmitted to the Observatory; data are made available to users less than 15 minutes after acquisition.

2. Parameters

The results above show both a seasonal variability and episodic variations at local or larger scales in the Gulf of Lions. Owing to rapid turnover and growth rates, microbial systems (viruses/bacteria/phytoplankton) respond relatively quickly (in terms of abundance and diversity) to environmental changes. Because the functioning of the microbial loop plays a fundamental role in the efficiency of the biological pump, incorporating meteorological, hydrodynamic and biogeochemical measurements at time scales relevant for the processes related to the functioning of the microbial loop is of primary importance. Creating integrated databases is a necessary and fundamental advance for the improvement and validation of coupled hydrodynamic-ecosystem based management models. Specifications in meteorological, hydrodynamics, biogeochemical and microbial parameters are reviewed.

Meteorological measurements

Sensor technologies are now mature, being relatively inexpensive and allowing high frequency acquisitions. The main remaining problem is to transmit in real-time the measurements from offshore stations. To account for the spatial heterogeneity at the western exit of the Gulf of Lions (Pyrenees mountains), a second site will be installed, on land, at the Observatory. This site will be equipped with the same sensors as those from the MOLA platform GPS (timing), anemometer, air temperature and pressure), as well as the receiving antenna of the FreeWave modem and a light sensor (UV-PAR).

Hydrodynamics

At this time, only the stations at either end of the monitored array are equipped with current meters (POEM buoy and BILLION mooring). An ADCP will be installed on the MOLA platform for the euphotic layer initially, and a second unit to monitor the deep layer is planned. The POLA site on the shelf is not practical because of the high trawling activity in the sector. Real-time access to the current measurements is not possible at present, and ship time is required to recover the data.

Hydrologic measurements are now collected at different time intervals (monthly to continuous) and spatial scales (profiles and at fixed depths). The heterogeneity of these existing data collection strategies is not ideal in the context of an observational network. A unified, consistent measuring strategy is an important objective for obtaining 3D (distance, depth, time) representations of the region monitored. The ultimate goal for this network is the acquisition of hourly profiles, transmitted in real-time, from all stations. A suitable profiler has already been tested for several years in Canada (http://www.brooke-ocean.com/s_horse1.html).

In collaboration with "Direction Régionale de l'Equipement", a directional Waverider operates 1 nautical mile offshore from the Observatory. Real-time measurements are freely accessible (Candhis network from CETMEF and the regional technical confederation, Gladys) for the users of the observational data.

Biogeochemical measurements

Currently, the analytical protocols established for the national network SOMLIT (http://www.domino.u-bordeaux.fr/somlit_national/methodProtocolesCom.php) are used at all the observation stations presented here. Analyses from water samples at fixed depths concern 15 parameters (temperature, salinity, pH, dissolved oxygen, ammonium, nitrite, nitrate, phosphate, silicate, particulate carbon and nitrogen, total suspended matter, chlorophyll *a* and phaeopigments). Depending on the parameters, analyses are pooled and the database is updated every three months.

This delay, acceptable for a long-term monitoring study, is not suitable for the near real-time survey required for observing the rapid biological and chemical changes precipitated during an instantaneous event, such as a storm, a phytoplankton bloom, or an oil spill. At the beginning of a phytoplankton bloom, for example the use of optical or chemical sensors with high frequency acquisition rates (profiling) and able to achieve data transmission in real-time would represent a significant progress over the more traditional analytical methods currently used for the SOMLIT protocols. For example, *in situ* analysers for ammonium and nitrate are now commercially available.

Microbiological parameters

Molecular and cellular tools are now available that rapidly provide accurate results on abundance, diversity and activities of viruses, bacteria and phytoplankton. These analyses integrated into the existing observational network can be used to expand the applicability of the monitoring program.

With regard to molecular techniques, SSCP (Single Strand Conformation Polymorphism) can provide rapid results about the structure (DNA) and the activity (RNA) of bacterial communities (Zemb *et al*., 2007). A one-year monitoring study at the SOLA station has already shown that specific OTUs (Operational Taxonomic Units) have a seasonal pattern, corresponding to the thermal stratification and homogenisation periods previously shown (April – October). Moreover, particular bacterial communities are identified either at the beginning and the end of each period and changes in the structure of bacterial communities may occur within only a few days (Ghiglione *et al.*, 2005). Tracking microbial functioning relative to biogeochemical cycles requires that bacterial activity and community structure are sampled either at daily time scale during rapid thermal changes (Dubelaar *et al.*, 2004), or at a monthly time-scale to follow seasonal trends.

With respect to cellular techniques, flow cytometry allows routine measurements of the number, relative size and fluorescence of bacterioplankton and nanophytoplankton (Troussellier *et al.*, 1995). This technology is planed as an addition to the SOMLIT protocol. However for bacteria community studies, cell counts alone are of little use since they do not vary a lot. These data must be coupled with taxonomic or functional parameters to monitor the long-term dynamics of different phylogenetic and/or functional groups. FISH (Fluorescence *in situ* hybridization) techniques along with Micro-FISH (incorporation of radiolabelled compounds) can even identify specific enzyme activities at the single cell level for specific communities. Finally, an important aspect of microbial observatories may also lie with the future development of microarrays for detecting specific genes of interest.

In the absence of proven *in situ* instruments to collect these types of microbiological data (although flow cytometer and plankton counters are in development, see Dubelaar and Geerdersl, 2004), a campaign of intensive samplings could be triggered based for example on real-time transmitted fluorescence values. In that case, estimation of biological parameters would remain dependent on ship availability and meteorological conditions.

3. Database

For long term monitoring of coastal zones, the SOMLIT program protocols are adequate (weekly surface and near the sea bottom samplings) and the reliability of this database is high as CTD profiles, intercalibrations, coding checks and quality assurance have been integrated.

With respect to near real-time measurements, the objectives and constraints are quite different. The amount of generated data is high, and some parameters (meteorology, hydrology) should be released almost immediately. In that case, the database must be updated at the site of acquisition. After transmission and an automated quality control check, data are then made available to specific users (for example, Météo-France, Coriolis) on a dedicated server.

With regard to the entire observational system, all acquired data should be registered on a temporal basis and on a single server. After quality control checks and data validation, multiple parameter requests could be submitted by researchers, modellers or other users at regional, national and/or European levels. Using a web site interface will allow real-time display of the database parameters for users. Such a system would contribute to the networks currently in use at the European level (MEDAR/MEDATLAS).

Eventually, the database may also include access to earlier data from the same region of the Gulf of Lions which is archived at the observatory.

4. Conclusions

Microorganisms play a central role in the functioning of biogeochemical cycles. Their efficiency in the carbon sequestration, for example, depends on seasonal variations in light intensity and availability in nutrients, dissolved carbon and other chemical compounds. Due to their reactivity, microbial populations are not only good indicators of these seasonal changes, but, in case of chemical limitation, could also contribute to modifications in the CO2 concentration or pH value of the sea, and thus on the climatic evolution. Hence, analyses of the processes affecting the long-term variability of the environmental conditions have to be made in concert with the monitoring of the marine microbial diversity in order to develop and validate coupled hydrodynamic-ecosystem based management models.

These objectives supported the initial studies completed during our 10 years of experience in monitoring environmental conditions in the western Gulf of Lions. Our results have been used to improve the design and integration of a new type of observatory specialised in microbiological parameters and to develop a collection of environmental strains for the long-term preservation of microbes.

In addition to contributing to studies on global change, the data collected also have a strong potential for generating new services and partnerships. Hence, the objectives of microbial observatories could be extended to:

- understand the cell biology and biogeochemical activities of the major bacterioplankton groups,
- discover as yet undescribed microorganisms and microbial consortia from diverse habitats,
- isolate large numbers of bacterial species with a specific focus on the development of innovative technologies for culturing the uncultured species,
- characterise the properties and activities of newly described and poorly understood microbes and microbial communities,
- study the genome, activities of microbes and the microbes' interactions.

Finally marine observational networks need to be flexible enough to accommodate new fields of study during their operational lifetime. For example, the recent explosion of interest in documenting marine microbial diversity is due in large part to the availability of new techniques for rapidly detecting the presence of these groups at different taxonomic levels, as well as their relative abundance in marine waters.

The VECTOR project carbon cycle observatory

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Abstract

The Italian programme VECTOR has established a national carbon cycle observatory combining coastal and pelagic time series stations and ship-based surveys at basin and regional scale for a better understanding of the mechanisms controlling time and space variability of the physical and biological pump. The strategy adopted for defining the observatory and the characteristics of the time series stations are illustrated, along with some preliminary results. VECTOR's experience is discussed in the framework of an integrated Mediterranean marine observatory.

1. Introduction

The oceans play an important role in climate variability and change, both transporting 'health' and freshwater through their general circulation and substracting CO_2 from the atmosphere through their biogeochemical cycles. Changes in the physical state and circulation can strongly affect this buffer function. In recent years marked changes have been observed in the thermohaline properties of the Mediterranean Sea: temperature and salinity of the deep waters are increasing, due in part to decreased precipitation and anthropogenic reduction of freshwater and also to a large shift in the thermohaline circulation, the Eastern Mediterranean Transient (see CIESM, 2000). These changes might have significant consequences on the biogeochemical cycles and thus on marine resources, coastal areas are subject to increasing pressures, due to intense urbanization. A series of monitoring activities have started in the marine and coastal environment, for different purposes: survey of the coastal areas, pollution control, early warning and research related to climate change. On this last subject Italy has funded the VECTOR project, a national initiative aiming at assessing the impact of climate change on the Italian coastal ecosystems and the role of the Mediterranean Sea in the global carbon cycle. Through this project a national carbon cycle observatory has been set up, which can become a module of a larger, integrated Mediterranean marine observatory.

2. The VECTOR Project

VECTOR (Vulnerability of the Italian coastal area and marine Ecosystems to Climate changes and Their role in the Mediterranean carbon cycle) has been funded as part of the Italian National Research Programme 2001-2005, Objective Climate Change and sustainable development by the Ministries of University and Research, Economy and Finance, Environment and Agriculture and Forestry. It began in 2006 and will last until 2009. It is the only marine project funded in this framework and it involves ten Partners: the Consorzio Nazionale Interuniversitario per le Scienze del Mare – CoNISMa (coordinator), three Institutes of the National Research Council (ISMAR, IAMC, and IDPA), the Italian National Agency for New Technologies, Energy and the Environment – ENEA, the Istituto Centrale per la Ricerca Scientifica e Tecnologica Applicata al

Mare – ICRAM, The Centro Euromediterraneo per i Cambiamenti Climatici (CMCC), l'Istituto Nazionale di Oceanografia e Geofisica sperimentali (OGS), la Stazione Zoologia di Napoli. The overall objective of the Project is to assess the impact of climate change on the Italian coastal ecosystems and to define the mechanisms controlling CO_2 sequestration in the Italian Seas and the role of the Mediterranean Sea in the Global Carbon Cycle. More specifically, the project aims at:

- Improving our understanding of the biogeochemical and carbon cycles;
- Quantifying sources and sinks of CO_2;
- Defining the sensitivity of the Mediterranean ecosystem to global change;
- Predicting the ocean CO_2 cycle in the next 100 years;
- Providing data on the ability of the Italian Seas in carbon sequestration to be used in international negotiations.

The activities are organized in 10 Work packages. The fist 5 WPs are related to the vulnerability of the Italian Coastal Ecosystems to climate change and in particular to assess changes in wind-wave dynamics, on coastal dynamics in estuaries/lagoon systems, sea level rise, and the impact of the different factors on biodiversity and resources. Special attention is devoted to the case study on the Venice Lagoon. Four WPs are devoted to the Mediterranean carbon cycle, and in particular to the role of the northern Adriatic shelf area in transferring carbon to the deep sea, time and space variability of the biological carbon pump, carbon fluxes between basins and the role of shelf organisms in C sequestration. The study will be carried out through observations and numerical simulations. An entire WP is dedicated to the development of a global ecosystem model, able to describe the mechanisms of exchange, transformation and transport of carbon and to simulate the climatic variability of the system atmosphere-ocean-biosphere in the next 100 years under different scenarios.

3. The VECTOR Carbon cycle observatory

VECTOR is an example of integration of coastal and deep sea observation systems, combined with ship-based surveys at basin and regional scale to derive a coherent picture of the mechanisms controlling carbon fluxes and their spatial and temporal variability. Figure 1 shows the areas selected for the national carbon cycle observatory:

- The North Adriatic Sea, for the characterization of the continental shelf pump. The objective will be matched through the analysis of historical information combined with data currently collected by fixed coastal stations and during two contemporary sampling campaigns focused on hydrology and sedimentology;
- Two pelagic stations with different dynamic conditions and trophic regimes, in the Southern Adriatic and the South Tyrrhenian Sea, for physical and biogeochemical time series data, allowing the characterization of the seasonal and interannual variability of the biological pump;
- The Straits of Otranto and Sicily, for carbon fluxes between basins;
- The time series station of the Gulf of Naples, where a long time series of physical, chemical and biological data already exists, allowing information to be derived on the impact of changes on biodiversity and resources;
- The Trans-Mediterranean sampling campaign to characterize the biogeochemical fluxes in different Mediterranean bio-provinces analyzing the kinetics of the transfer of CO_2 from the atmosphere to epipelagic and meso-pelagic waters, to food webs and the storage in deep waters and burial in sediments has been studied in detail.

4. The pelagic fixed stations

The pelagic fixed stations are the main long-term component of the VECTOR carbon cycle observatory. They have been positioned in areas characterized by different dynamic conditions and trophic regimes:

- VECTOR-AM (Figure 2a,b) in located in the S. Adriatic Sea, in the central part of a permanent cyclonic gyre (about 1,200m depth), where winter convection takes place, followed by intense

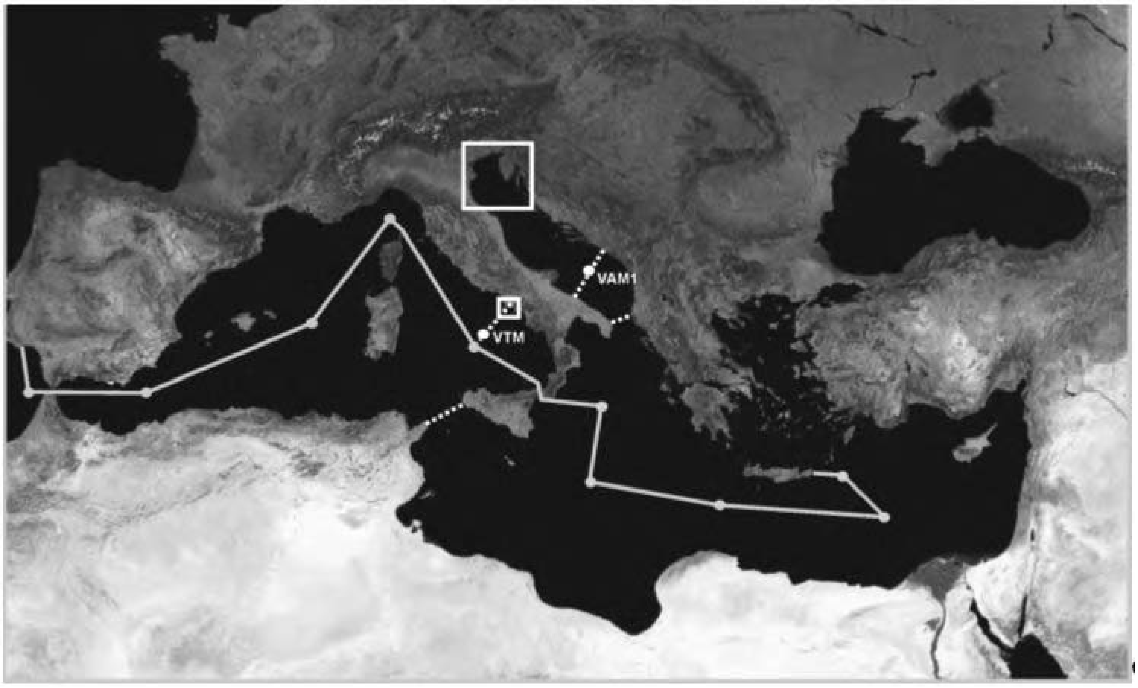

Fig. 1. The VECTOR carbon cycle observatory. Squares: coastal/shelf areas; continuous line: track of the trans-Mediterranean cruise (June-July 2007); dotted lines: transects periodically visited; white circles: pelagic fixed stations.

spring blooms; this area has been monitored in the framework of different national and international projects since 1985. A good coverage is available for physical and chemical data (O_2 and nutrients), but biological data are relatively scarce.

- VECTOR-TM (Figure 2a,b) is about 80nm SW of Naples, at a depth of 3,500m in the Southern Tyrrhenian Sea, characterized by mixing and diffusion of water masses coming from the Eastern and Western Mediterranean, the most oligotrophic area of the western basin.

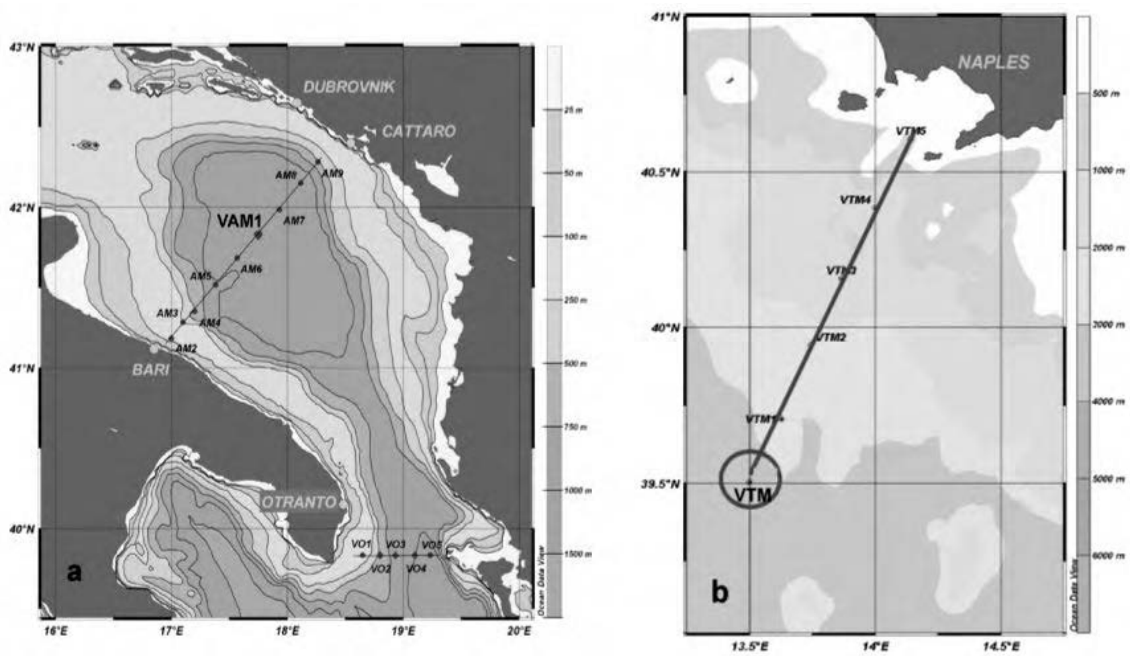

Fig. 2. The pelagic times-series stations in the Southern Adriatic (a) and South Tyrrhenian Sea (b).

The stations are visited 4 times a year, twice in the period from February to early April, once in summer and once after the fall mixing period. To better characterize the hydrological and biogeochemical conditions, CTD casts and hydrological parameters are measured along the transect Bari-Dubrovnic in the Adriatic and Gulf of Naples – Station TM0 in the Tyrrhenian Sea. At the fixed stations a set of physical, chemical and biological parameters and tracers are measured, to characterize the water dynamics, the carbon transfer through the food chain in the epipelagic and meso-pelagic layers and to quantify the rate of export and burial of particulate organic carbon.

An instrumented mooring is positioned at each station. The Adriatic one is equipped with ADCPs, CT sensors and sediment traps to determine the current profile in the water column between 300m and the surface and near the bottom, the mass transport along the water column and the particle flux from the photic zone and near the bottom. The Tyrrhenian mooring includes current meters and sediment traps for particle fluxes out of the photic zone and out of the meso-pelagic layer.

The first results confirm the suitability of the sites selected for time series acquisitions.

The Adriatic station has already been monitored, although with some discontinuity, for almost 20 years and some of the mechanisms controlling the biological cycles and the response to changes in the adjacent basins have already been identified. The new production does not seem to have been affected by the increase of the extra-input of nutrients from the Ionian Sea deriving from the new deep circulation pattern in the Eastern Mediterranean. The local winter climatic conditions act as year-to-year controlling mechanisms in determining the magnitude of the convective mixing and the amount of new nutrients available to the autotrophs (Gacic *et al*., 2002; Civitarese and Gacic, 2001). The VECTOR project has allowed a larger set of parameters to be measured, to better characterize the mechanisms controlling carbon transfer through the food web and along the water column.

In contrast, little information is available, particularly for the biogeochemical part, in the Tyrrhenian Sea. Significant changes in the hydrological characteristics were illustrated by Gasparini *et al*. (2005) following the Eastern Mediterranean Transient. The measurements carried out during VECTOR show that the changes detected at the Sicily Channel in 2005-2007 (Gasparini, this volume) are also clearly identifiable at station VTM0, where an increase of the salinity at the salinity maximum is evident. During the first year of activity POC flux from the photic zone ranged between 1 and 5 mmol C $m^{-2}d^{-1}$, and was highest in late spring (Figure 3). The station is definitely oligotrophic and shows a seasonal cycle different from the other time series stations in the

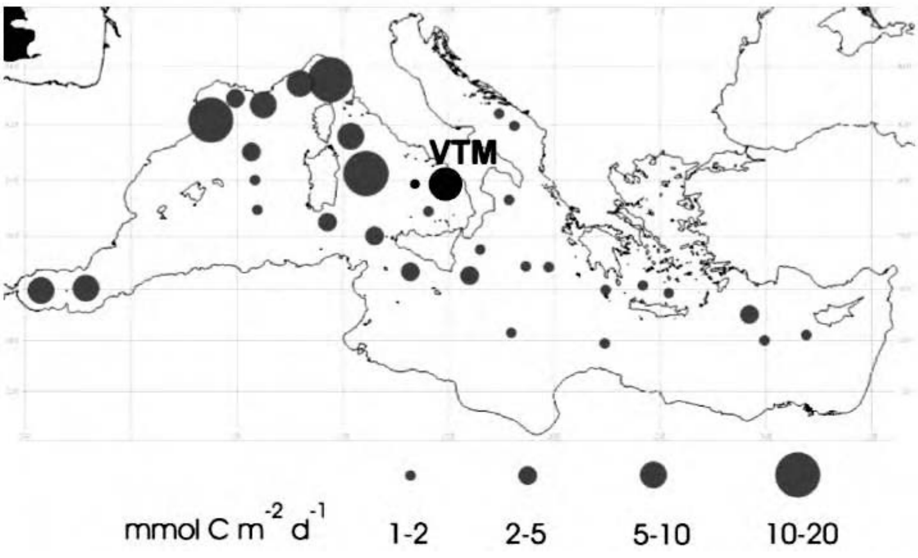

Fig. 3. POC flux from the photic zone obtained by sediment traps and 238U/234Th method in the Mediterranean Sea (Speicher *et al.*, 2006, modified) and, in black, preliminary data at the VECTOR Station VTM in 2006-2007.

Mediterranean (Dyfamed, VAM1) (Conversano *et al*., 2007; Brunet *et al*., 2007), confirming the usefulness of long time monitoring in this position.

5. Future

The VECTOR carbon cycle observatory has been funded for only two years and field activities will last until the end of 2008. Similarly, fixed stations/sections were established in key areas of the Mediterranean in the framework of international programmes (ex. EU MATER, ADIOS, etc.) and operated for the duration of the project(s) only. Basin-wide oceanographic campaigns (WOCE-type or focused on process studies) have been carried out in recent years or are already planned for 2008. All the elements for a Mediterranean climate observatory are already in place, but the different initiatives are often not contemporary and are funded for relatively short periods (typically three years). Climate change studies require instead long term observations with good sampling resolution in space and time. It is then important to define a common long-term strategy/framework at Mediterranean level, clearly stating objectives, activities and benefits to the scientific community and to the general public, able to attract funding from different sources and generating synergy among the national and international initiatives.

It is essential for the future to find common/integrated ways to overcome the main difficulties related to the operation of a long term observatory: continuity of observations and funding, presence of experienced, dedicated personnel, availability of shiptime. New technology can at least partly help overcome the problem, with automated/remotely operated systems. This technology is already mature for physical parameters but the problem of biogeochemical parameters to be determined in the whole, deep water column for relatively long periods has not been solved yet. One of the scopes of the observatory could be to test and demonstrate new technologies.

Sub-regional forecasting and observing system in the Eastern Mediterranean Levantine Basin: the Cyprus Coastal Ocean Forecasting and Observing System (CYCOFOS)

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Abstract

A sub-regional operational coastal ocean forecasting and observing system for the Eastern Mediterranean Levantine Basin has been operationally since early 2002.

The CYCOFOS marine core service consists of several operational modules: ultra high resolution coastal flow forecasts in the south coast of Cyprus, high-resolution coastal-ocean flow forecasts in the NE Levantine, regional, sub-regional and coastal wave forecasts for the Mediterranean Sea, Levantine Basin and offshore Cyprus, satellite remote sensing for the Eastern Mediterranean, the Levantine Basin and offshore Cyprus, coastal and offshore stations for continuous *in situ* observations and autonomous gliders for long range near real time observations in the Levantine Basin.

1. Introduction

The operational ocean monitoring and forecasting systems on global, regional, sub-regional and local scales are recognized nowadays that support the improvement of the management of the marine environment and assist the decision makers to response timely in environmental incidents that may arise from various activities affecting the marine system.

The Cyprus coastal ocean forecasting and observing system (CYCOFOS) was developed within the broad frame of EuroGOOS (European GOOS) and MedGOOS (Mediterranean GOOS), to promote the operational oceanographic forecast and monitoring on local and sub-regional scales in the Eastern Mediterranean Levantine Basin. The CYCOFOS has been operational and constantly improved and upgraded since early 2002 (Zodiatis *et al*., 2002; 2003a,b). CYCOFOS consists of several forecasting and observing modules and end user modules, that respectively compose its marine core and downstream services. The CYCOFOS products are accessible electronically via internet at http://www.oceanography.ucy.ac.cy/cycofos. CYCOFOS is part of the Mediterranean operational oceanography network (MOON), aimed to sustain the operational ocean forecasts in the Mediterranean, in collaboration with other basin, sub-basin and coastal ocean forecasting systems.

The development and the continuous improvement of the CYCOFOS modules is carried out following the objectives and the methodology of several EU initiatives (e.g. MFSPP, MFSTEP, MAMA), the European sea level service research infrastructure (ESEAS-RI), the CIESM Mediterranean network of global sea level observing system (MedGLOSS), the Marine environment and security in the European areas (MERSEA) and the European coastal-shelf sea operational observing and forecasting system (ECOOP).

2. Description

2.1 Forecasting

2.1.1 Flow forecasts

In CYCOFOS the operational flow forecasts are carried out by CYCOM—the Cyprus Coastal Ocean Model (Zodiatis *et al*., 2003c; 2007). CYCOM is based on the Princeton Ocean Model (POM) and is forced and initialized from lower resolution oceanic forecasts and medium and high frequency atmospheric forecasts. At present in CYCOFOS three flow forecasting models are running operationally with different horizontal resolution, initial, boundaries and forcing data (Figure 1). The first one, that has been implemented for the NE Levantine Basin with medium resolution of 2.5km, uses the MFS basin model as the parent model, along with the ECMWF forecasts. This mode of operation is allowing daily averaged 10-day forecasts to be completed every day. The second one, that has been implemented for the NE Levantine Basin with high resolution of 1.5km, uses the ALERMO sub-basin model (which is in turn nested within the MFS basin model) as the parent model, along with the SKIRON high-frequency (hourly) meteorological forecasts (Kallos and SKIRON group, 1998). This mode of operation is allowing 6 hourly averaged 5-day high resolution flow forecast to be repeated daily. The third one, that has been implemented recently for the southern coastal areas of Cyprus with ultra high resolution of 600m, use the CYCOM high resolution flow model as the parent model, along with the SKIRON high-frequency (hourly) meteorological forecasts. This mode of operation is allowing daily averaged 5-day forecasts to be completed every day.

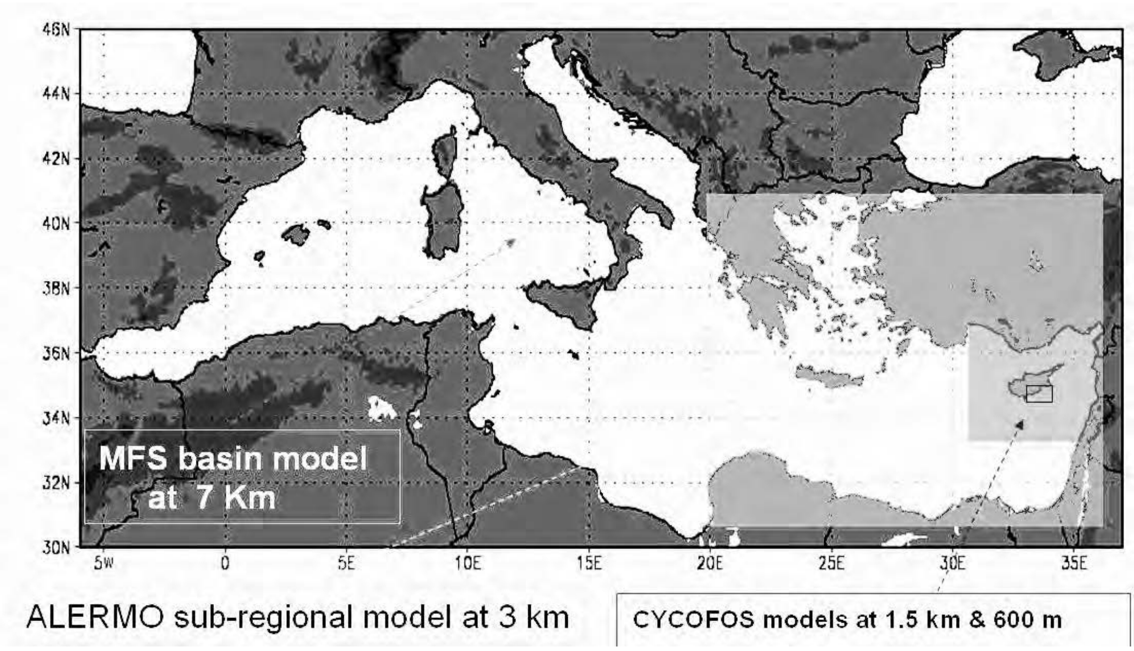

Fig. 1. CYCOFOS model hierarchy. MFS basin model of 7km resolution is produced by the Mediterranean Forecasting System (MFS). The regional model, ALERMO, of 3km resolution is nested within the MFS model. CYCOM 1.5km high resolution model is nested within the ALERMO model and CYCOM 600m ultra high resolution model at the south coastal areas of Cyprus is nested within CYCOM high resolution model.

A variational interpolation method, Variational Initialization and FOrcing Platform—VIFOP (Auclair, 2000a,b), has been implemented for the CYCOM high resolution flow forecasting model, in order to more accurately downscale the ALERMO sub-basin initial and boundary fields to the

CYCOM high resolution grid. In particular, spurious gravity waves due to interaction of the interpolated flow field and the high resolution land mask are minimized. It should also be noted that the MFS basin model includes temperature (XBT) and conductivity-temperature (CTD) profiles into its assimilation scheme, as well as satellite-based sea level anomaly, while the satellite sea surface temperatures are used for the correction of the surface heat fluxes.

2.1.2 Wave forecasts

In CYCOFOS the operational wave forecasts are carried out by WAM (WAMDI group, 1988) and SWAN models (Holthuijsen *et al*., 1997). Offshore wave forecasts with resolution 14km and 7km, respectively for the Mediterranean Sea and the Levantine basin are produced by WAM model, along with the SKIRON high-frequency (hourly) forecasting winds. The Levantine model domain is nested within the Mediterranean wave forecast (Figure 2). This mode of operation produces 3 hourly wave height and wave direction forecast every day for the coming 60 hours. Near coastal wave forecasts around Cyprus with resolution 3.5km are produced by SWAN model, along with the SKIRON high-frequency (hourly) forecasting winds.

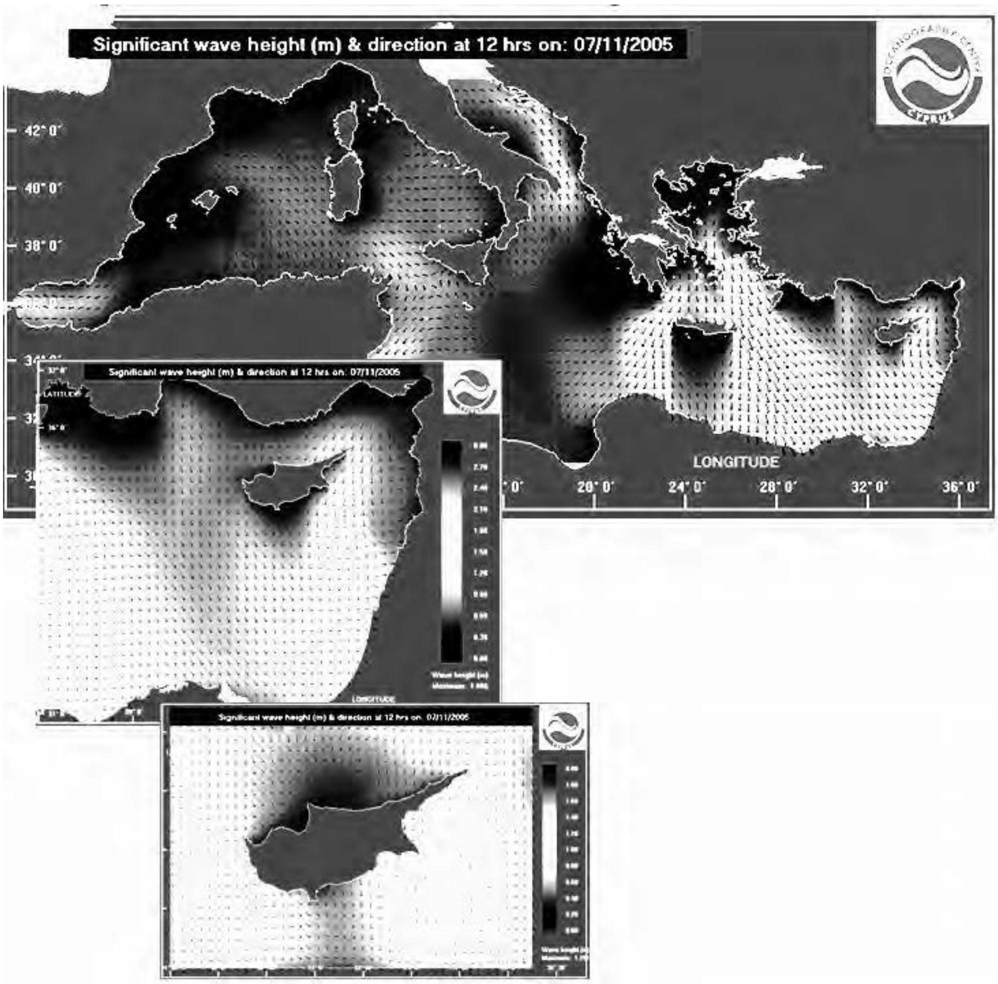

Fig. 2. The Cyprus Wave Model forecasts wave height and direction for the entire Mediterranean. Nested within that model is the wave forecast for the Levantine basin (inset 1). Nested within the WAM is a high-resolution SWAN model (inset 2).

2.2 Observing

In CYCOFOS, operational observations consist of four types: routinely satellite remote sensing of various sea surface parameters, periodic *in situ* XBT measurements from short field campaigns using VOS-volunteer observing ships, continuous *in situ* remote sensing measurements at fixed coastal and offshore locations in the Levantine Basin, *in situ* remote sensing measurements from autonomous underwater vehicles- gliders.

2.2.1. Satellite remote sensing

In CYCOFOS the satellite remote sensing module includes a satellite ground receiving station also described in Zodiatis *et al*. (2002; 2003a,b), which has been operating successfully since 2001. It collects images of SST from NOAA-AVHRR satellites. Moreover, higher horizontal resolution SST, chlorophyll *a* and light attenuation images are routinely processed using MODIS (Moderate Resolution Imaging Spectroradiometer) Aqua or Terra satellites data. Cloud cover is generally not persistent in the Eastern Mediterranean, so remote sensing images from the CYCOFOS satellite ground receiving station either from MODIS Aqua or Terra satellites are collected and processed almost daily. This mode of operation provides single passages SST, chlorophyll *a* and light attenuation images of the Eastern Mediterranean or of the Levantine basin and of the sea areas around Cyprus at the CYCOFOS web page (Figure 3). For the detection of oil spills CYCOFOS, processes MODIS images and added values SAR images to dedicated by EMSA end-users.

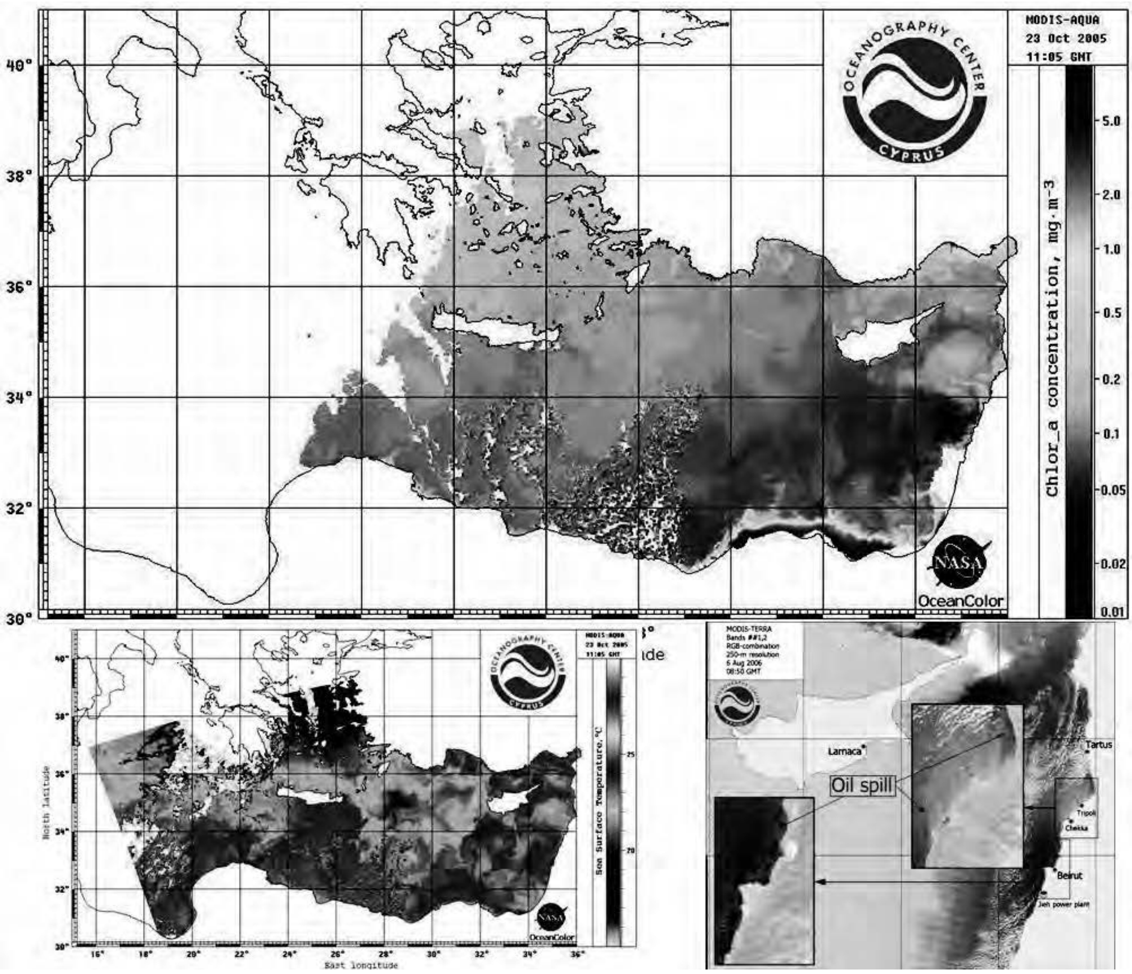

Fig. 3. MODIS surface Chlorophyll *a*, SST and oil slick detection images of the Eastern Mediterranean processed within the CYCOFOS remote sensing module.

2.2.2. In situ remote sensing

An offshore buoy has been included to the CYCOFOS observing module, which measures conductivity and temperature at five levels in the deepest part of the SE Levantine Basin. The deepest sensor also measures pressure. The sensors are SBE-37 MicroCAT C-T recorders which communicate with the surface using an inductive modem. The data are collected every 30 minutes, and retrieved every 24 hours via satellite communication. They are processed and posted on the CYCOFOS web site daily. There are plans to extend the observing depth of the buoy beyond the present water depths with additional CT sensors. Data on buoy attitude (heave, pitch, roll) will be used to calculate wave height and direction in near real time, in order to contribute in the planned Mediterranean early warning system for tsunami.

The CYCOFOS coastal station, at Paphos harbour, for sea level, water temperature, and air pressure measurements continues to operate, as it has since 2001 (Zodiatis *et al*., 2002; 2003a,b), as part also of the CIESM MedGLOSS network. Future similar coastal stations are planned to be operated by CYCOFOS.

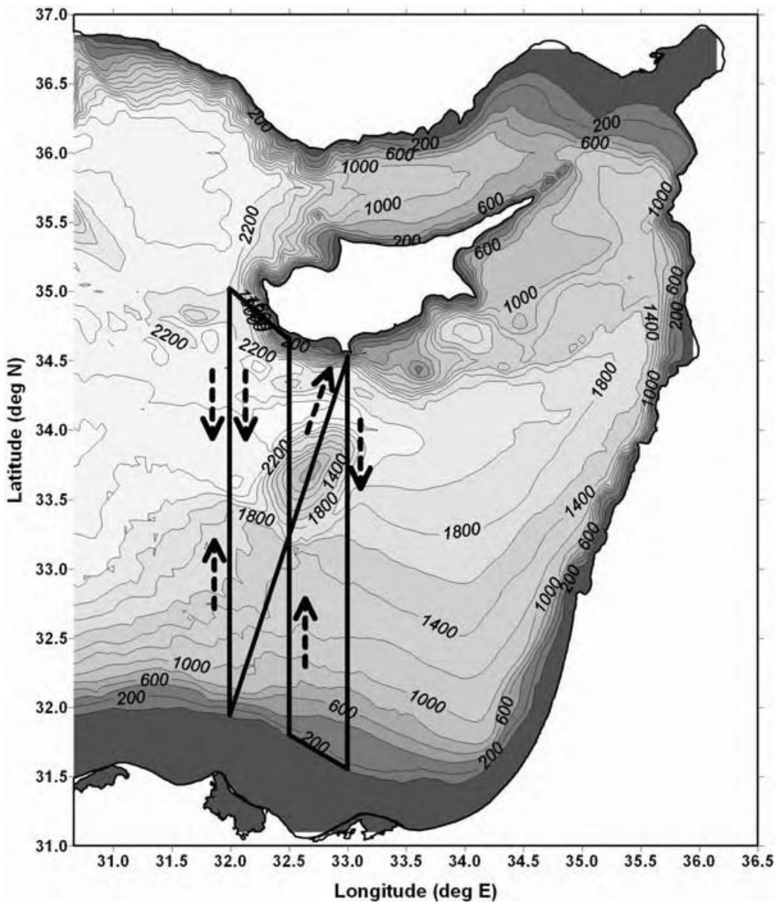

Fig. 4. Proposed glider track in the Eastern Mediterranean Levantine Basin for operational data collection and near real time data transmission, arrows indicate the direction of the glider movement starting from Limassol, Cyprus. Transit time for this mission is approximately six months.

Near real time *in situ* profiling of temperature, salinity, currents, oxygen, fluorescence and optical backscatter in the Eastern Mediterranean Levantine Basin will be carried out by using the most recent technological developments in oceanography, i.e. long-range autonomous underwater vehicles-gliders (Figure 4).

2.2.3. In situ observations

Periodic monthly XBTs measurements are carried out in the open sea areas of the Levantine Basin by the CYCOFOS team using the VOS-volunteer observing ships, along the ship track Limassol-Port Said or Limassol-Alexandria. These type of data jointly with other similar data from other parts of the Mediterranean are assimilated in the parent MFS model.

3. Conclusions

CYCOFOS is a well-rounded operational system consisting of both ocean forecasting and observing components. Most components are fully operational, they produce results every day and provide them to the general public and to dedicated agencies via the internet (http://www.oceanography.ucy.ac.cy/cycofos). CYCOFOS during the biggest so far oil pollution crisis in the Eastern Mediterranean, that of the Lebanese oil pollution crisis, did show in practice the benefit of having an ocean forecasting and observing system in place. The CYCOFOS components are constantly improved by providing higher resolution and more frequent oceanic flow forecasts, near-coastal wave forecasts, more *in situ* observations from gliders, more coastal sea level/temperature stations, and satellite images of SST frontal zones and surface zooplankton estimations.

Acknowledgements

The new developments and improvements of the CYCOFOS modules have been carried out in the framework of several European Union and other related international and national projects including: MFSTEP, MERSEA-IP, ECOOP. The authors acknowledge the support of: CIESM for providing the equipment for the Cyprus MedGLOSS station; the MFS, ALERMO and SKIRON forecasting systems; Prof. Nadia Pinardi coordinator of MFS forecasting system; Prof. George Kallos coordinator of SKIRON system; Prof. Alex Lascaratos coordinator of ALERMO forecasting system and his scientific team from the University of Athens; Dr. Sarantis Sofianos and Dr. Nicos Skliris. We are also grateful to Dr. Dov Rosen, coordinator of the CIESM MedGLOSS network and his scientific team from IOLR, Dr. Isaac Gertman and Lazar Raskin for their valuable support and all CYCOFOS collaborators: Dr. Dimitry Soloviev, Dr. Vladimir Fomin, Tommy Eleftheriou, Andria Karaolia, Iacovos Constantinou, Gregory Konnaris, Xenia Panayidou, Costantin Vrionis, Chrysovalantis Costa, Sotiris Savva, Marinos Ioannou for their contributions and to the system's modules and the system's operation, and Dr. Andrew Clark of MCS, USA for support of the CYCOFOS offshore Ocean Observatory.

Monitoring boundary conditions at Mediterranean Basin – Key element for reliable assessment of climate change, variability and impacts at Mediterranean basin shores

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Abstract

Among the major predicted physical impacts of climate change by global warming are sea level rise, increased frequency and strength of storm events and accelerated coastal erosion and increased risk of flooding. These have been assessed globally by the Intergovernmental Panel for Climate Change. It is shown that present forecasts of the rate and extent of change of these impacts in the Mediterranean are not yet sufficiently clear, with sometimes contradictory results and that further monitoring and investigations are necessary. It is of primary importance to properly monitor in a coordinated way the boundary conditions along the Mediterranean coasts, namely the sea level, waves, flows and beach erosion. Without a proper representation of the initial conditions and boundary conditions, no numerical model/s can reliably forecast future Mediterranean basin changes at its coasts, where the major part of the population activity takes place. A comprehensive and reliable assessment of future trends and rates of changes and impacts requires the synergy of all the monitored parameters data in an integrated Mediterranean marine observatory as soon as possible.

Introduction

The impacts of climate change due to the greenhouse effect have been studied by the Intergovernmental Panel for Climate Change (2001, 2007) at the global level, but with quite limited detail for the Mediterranean basin. Among the major predicted physical impacts of climate change by global warming are sea level rise, increased frequency and strength of storm events and accelerated coastal erosion and increased risk of flooding (European Union Parliament Directive 2007/60/EC, 2007). The forecast of the rate and extent of change of these impacts, as well as their implications to marine biogeochemical processes, are not yet reliably determined for the Mediterranean basin. Integration of the existing monitoring stations in the Mediterranean into a basin-wide marine observatory, further strengthened by upgrading or installation of new stations at key sites, can enable a comprehensive assessment of the state of the Mediterranean and derive a reliable assessment of the expected climate change impacts. This will also enable to plan the optimum strategy of coastal and marine management for the Mediterranean. Furthermore, coordination and integration is also needed among existing basin-wide meteo-marine monitoring by various international activities such as CLIVAR, GCOS (the climate component of the GEOSS), GMES, MedGLOSS (regional element of GLOSS), MEDGOOS (regional element of GOOS), MOON (regional element of EUROGOOS) and NEAMTWS (the Mediterranean and Black sea part of the tsunami warning system).

In the following we will concentrate on three elements which must be monitored and that should be included in the envisioned integrated Mediterranean marine observatory and we will provide some suggestions regarding how to do it.

Sea level – MedGLOSS

Sea level rise and variability constitutes a major factor affecting shore erosion, flooding and biogeochemical processes. Monitoring of the Mediterranean sea level has been done in the past by tide gauges, and since the early 1990s also by satellite altimetry. In response to the forecasted global climate change and sea level rise in 1997 CIESM and IOC/UNESCO established jointly MedGLOSS programme of sea level monitoring network in the Mediterranean and Black seas upon a bi-lateral agreement. The major objectives of MedGLOSS are: (a) regional long-term relative and absolute sea-level changes trends and acceleration rates; (b) monitor plate tectonic movements, (c) provision of real time data to the tsunami warning system developed in the Mediterranean basin as part of NEAMTWS. These objectives have been implemented by the creation of a densified regional GLOSS network subsystem for long-term, systematic sea-level monitoring in the Mediterranean and Black Seas. All MedGLOSS stations have to measure and provide sea level data according to the international standards defined for GLOSS stations. Also, for those integrated in NEAMTWS the gathered data must comply to NEAMTWS additional requirements for real time data transmission every one minute. Minimum data include hourly averaged values of sea-level and atmospheric pressure for delayed mode stations and higher rates of 5 or 6 minutes averaged values updated hourly for the near real time stations. Also, all near real-time stations should have their reference benchmarks monitored by continuous GPS stations. Since 2000 the MedGLOSS focal center has been established and maintained by IOLR. The focal center assisted, with CIESM financial support, the installation of new or upgraded sea level stations. It also has been providing operational training and assistance in the maintenance of sea level stations in regard to both software and hardware aspects.

Results of sea level rise have been derived based on both satellite altimetry and *in situ* tide gauges. The satellite data provide basin-wide coverage but are less accurate, while the tide gauge stations provide localized coverage of higher accuracy. The latter are also directly linked to the local geoid, whereas the satellite data suffer yet of inaccuracies due to the rough accuracy of the determined geoid (available based on Grace mission only at one degree grid, to be further improved by future European gravimetry satellite mission) as shown by Stammer *et al*. (2007).

Present rates and future assessments of sea level change globally and in the Mediterranean have been published by a number of bodies and investigators. The leading global assessment has been provided by IPCC (2001), updated again last year (IPCC, 2007). Another remarkable global assessment was presented by Rahmsdorf (2006). In the Mediterranean, comprehensive or partial sea level change assessments were presented by Ross *et al*. (2000), Tsimplis and Baker (2000), Cazenave *et al*. (2002), Cazenave and Nerem (2003), Tsimplis *et al*. (2005), Vera *et al*. (2005), Vigo *et al*. (2005), Fenoglio-Marc (2004), Fenoglio-Marc and Rosen (2004), Forget and Wunsch (2007), Rosen *et al*. (2007). There is some discrepancy between the results analysed, some due to the period or area covered, other by the data source. One of the common features observed by all of them is the sea level changes in the Eastern Mediterranean basin, in particular in the Levantine basin during the 1992-2000 period. Examples shown in Figures 1 and 2 show the striking rise in the South-Eastern basin and the lowering which occurred in the Ionian, attributed by many to the East Mediterranean Transient. However, none of the studies investigated the contribution of the flow from the Red sea trough the Suez canal in the Mediterranean, which increased in the 1990s following the deepening and widening of the canal, bringing saltier and warmer sea water in the Mediterranean at a discharge presently estimated around 100km^3/year, but possibly changing in the future, due to plans for further widening and deepening as well as due to climate change.

The global rise forecast given by IPCC 2001, Rahmsdorf and IPCC 2007 are presented in Table 1. A higher rise estimate than that of IPCC 2001 was assessed by Rahmstorf (2006) based on a

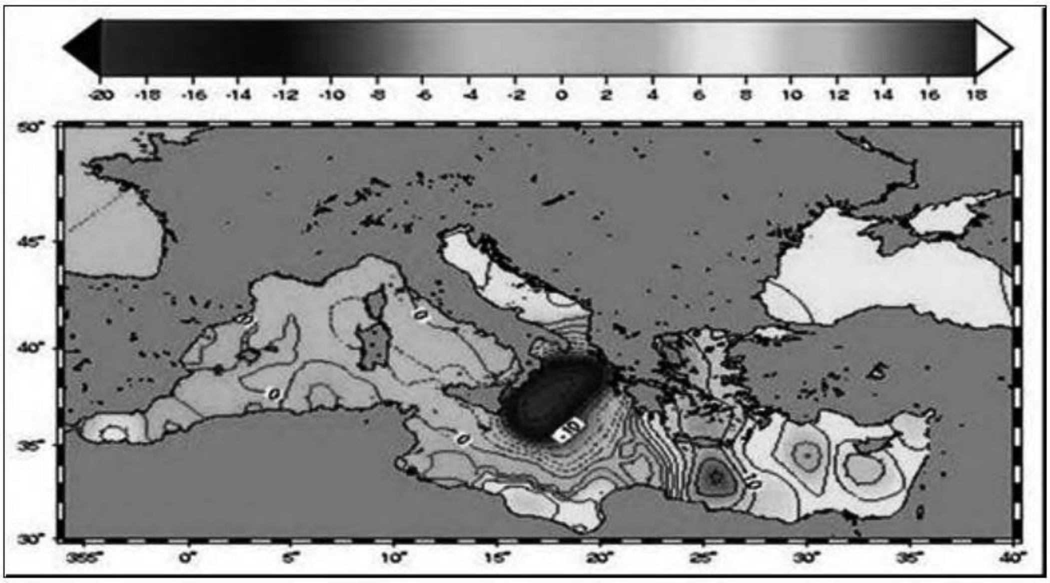

Fig. 1. Sea level changes in the Mediterranean from Topex/Poseidon satellites from 1992 to 2000 (Fenoglio-Marc, 2004).

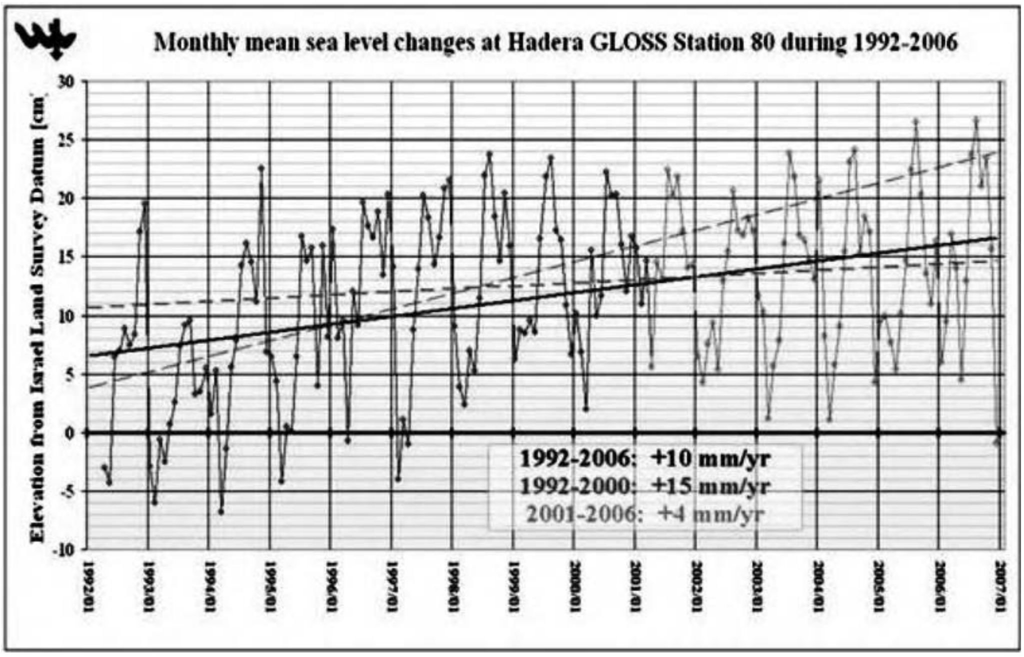

Fig. 2. Sea level rise changing rates at Hadera, Israel (Rosen *et al.*, 2007).

different approach, using the correlation between temperature rise and sea level rise in the previous 150 years. The new IPCC 2007 assessment of sea level rise is lower than the previous one, but states that it does not include contributions due to carbon cycle uncertainties and ice caps melting. Based on Rahmstorf approach, and using the fact that IPCC 2007 assessed higher temperatures increase in the 21th century than those of IPCC 2001, as well as on the forecast of higher temperatures rise in the Mediterranean than worldwide (Somot, 2007), one can assess that sea level rise by 2100 in the Mediterranean would be higher that those assessed by Rahmstorf. This result contradicts the IPCC 2007 forecast as well as that obtained by Tsimplis *et al*. (2007) for A2 scenario for the Mediterranean of only 25cm by 2100 + ice melting contribution (yet unknown). Nevertheless, new information by British scientists however, regarding an accelerated melting of the Arctic ice, further strengthens the warning signal for a faster and more significant sea level rise in the Mediterranean. Rosen *et al*. (2007) assessed a sea level rise for the Mediterranean coast of Israel by 2100 of 100cm. To all these estimates, we did not add the potential influence of the global dimming, which according to some scientists (Cohen *et al*., 2004; Liepert and Romanou, 2005; Minnis *et al*., 2004) counteracts the global warming on one hand, but may be overcome by global warming by 2030s with faster warming and higher sea level rise. All these assessments are only provided to show that there is a need for further detailed monitoring of the sea level in a comprehensive yet systematic and weighted way for the next decades if a more reliable assessment of the expected changes and variability is sought.

Table 1. Global sea level rise assessments.

Source\Year	2025	2050	2100
IPCC, 2001	3cm to 14cm	5cm to 35cm	9cm to 88cm
Rahmstorf, 2006	10cm to 20cm	20cm to 40cm	50cm to 135cm
IPCC, 2007			18cm to 59cm

In addition to the climate change impact, following the Sumatra tsunami in December 2004 and the terrible damage and loss of life it caused, it was "discovered" that in fact the Mediterranean ranks second only in the world for the number of tsunamis which have occurred until now. An intergovernmental coordination group of IOC member states and international organizations was set up in November 2005, which decided to establish a tsunami warning system, based among others by sea level stations. MedGLOSS has been recognized as one of the potential contributors to this warning system, planned to have started its initial stage last December. It was recognized that operation of real time sea level stations just for the sake of waiting to detect a tsunami once in many years would be cumbersome and uneconomical. Hence, it has been agreed that the stations must consist of a multi-purpose multi sensor systems, capable to cope with the needs of operational oceanography, climate change, and tsunami detection. Therefore, one should seek wherever feasible and logical that the monitoring stations become multi-purpose multi parameter stations, particularly at key locations such as Mediterranean all straits, the Suez Canal ends and in the South-eastern Mediterranean, which serves as the "cooking oven" for the water masses flowing through the basin.

Wave climate

I return to climate change impact. According to a number of recent studies (e.g. IPCC, 2001; Woolf *et al*., 2002; Wang *et al*., 2004; Woodworth *et al*., 2006; Caires *et al*., 2006; Wang and Swail, 2006) the wave and wind climate change are estimated to change due to the global warming, expressed by increased frequency of extreme storms, namely by reduction of the return period of extreme events. This assessment, which was studied extensively by Caires *et al*. (2006) is due to lead to increased coastal and beach cliffs erosion and increased events of flooding of coastal areas as well as impact on the coastal and deep sea biogeochemical processes. Monitoring of waves is nowadays done using both satellite altimetry as well as *in situ* directional wave gauges, capable at the same time to monitor the current structure using in particular ADCP wave gauges. The existing numerical models used such as WAM, SWAN and WAVEWATCH are still lacking capabilities to accurately forecast the extreme waves at the front passage, as they are based on hourly averaged wind data, usually derived from pressure data provided by ECMWF and hourly averaged wind data, smoothed of the high turbulence encountered during front passage. Therefore, integration of all operational wave stations together with upgrading (where feasible and logical) of the measurement capabilities is another important element for a comprehensive basin-wide marine observatory.

COASTAL EROSION

As mentioned previously, the expected impact of climate change via sea level rise and increased frequencies of encounter of extreme storms and flooding is an increased rate of erosion of the beaches and coastal cliffs, which in turn would affect the local populations as well as the biogeochemical processes, including potential increased pollution and damage of marine habitat. One of the effective tools to monitor coastal erosion is by carrying out repetitive (yearly) surveys of the beaches and cliffs by aerial photography using "conservative" tools such as video or cameras or more modern and effective tools such as laser based (LIDAR) surveys. By performing differential charts it is possible to determine the rate of coastal erosion not only qualitatively but also quantitatively. This method has the advantage that large coastal sectors can be monitored with relatively moderate costs, enabling to calibrate and validate utilization of numerical sedimentological models for assessment of long-term climate induced changes and selection of proper coastal planning policies, given the fact that many Mediterranean coasts are now facing erosion (Rosen and Calderon, 2006; Androulidakis *et al*., 2006). The application of such monitoring method has been recently applied to the Israeli coasts (Rosen *et al*., 2007) for assessment of the changes expected until 2100.

CLOSURE

The future challenges imposed by climate change and tsunami hazard as well as decadal to secular variability, including solar activity input to the earth climate system (Wei-Hock Soon and Yaskell, 2003), impose a coordinated activity for the setup of a basin-wide marine observatory, which must include *inter alia* the elements mentioned above. Such activity must be coordinated and led by a professional organization with basin-wide strong links at both the decision making and professional community levels. This organization is of course CIESM. It has the needed links to the regions lacking sufficient resources for the establishment and operation of modern properly equipped monitoring stations both in the Mediterranean and in the Black sea and can serve as leader of the set-up and operation of the activities of the proposed multi-disciplinary integrated, basin-wide marine observatory and its future products and services for the benefit not only of the Mediterranean residents but also for the many foreign millions of visitors to the Mediterranean coasts every year.

Shaping the Mediterranean marine observation and data network to target multiple applications and benefits in the region

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1. Preamble

Throughout history the sea has played a crucial role in the socio-economic development of the Mediterranean region. Today the quest for environmental security, based on the concepts of sound ocean governance, sharing of knowledge and the controlled use of resources, is the precursor for prosperity, sustainability and peace. The importance of marine resources to our well being calls for the sustainable use of the sea in both open and coastal domains. There is an ever increasing responsibility on the scientific community to provide accurate and routinely updated information for a more comprehensive knowledge on the state of the sea and the marine ecosystem, to support the chain of policy, planning and decision-making undertakings, to understand and address climatic change impacts, to provide frameworks for more effective surveillance and monitoring, as well as to further applications in marine-related economic activities. There is moreover a recognition of the opportunities and advantages which transpire from regional cooperation on marine research and environmental monitoring especially in a region like the Mediterranean where the multitude of jurisdictions and multiple uses of marine space calls for more stringent regulations, a holistic approach across disciplines, and collaborative management across stakeholders and across countries.

2. The case for a multi-purpose observing system and an integrated data network

The future demands an engagement in a new sustainable relationship with the environment. Marine space and resources will remain key assets for competitiveness and economic strengths especially in the Mediterranean. The quest for sustainable development is thus expected to be more exigent on the intelligent management of the marine environment, to protect the marine ecosystem, minimise the impacts of climate change and anthropogenic influences, and provide wide-ranging benefits. Routine ocean monitoring and forecasting based on sound science, long term and adaptive monitoring, and co-operation between nations, is the main tool for achieving such management goals.

21st century science and technology is called to meet these demands. Further research and developments in methodology, equipment and analysis of observations, as well as additional, improved and cost-effective long-term monitoring systems for reliable systematic observations are required to improve the ability to detect, attribute and understand the various processes - including climatic changes - in order to reduce uncertainties, improve impact assessments, and predict change down to local and coastal scales. Indeed the role of operational oceanography is of essence here, and its evolution towards the provision of integrated service-oriented applications will be an essential step to tackle the needs of a knowledge-based society. The ability to access, share, codify, re-use and transform data into information and knowledge through creation and re-creation, the use of increasingly ramified and complex networks and clusters of distributed activities is already becoming a reality in many realms. Information and innovative knowledge to materials, products and processes is becoming further entrenched into manufacturing and services provision, and integrated into complex chains of creation, production and distribution. This will also be the shape of things in the marine sector. This future is pointing towards multiple-purpose observing systems, linking observations across economical, environmental and social domains, and targeting a wide range of applications that cater not only for monitoring, but also for the provision of services in key marine realms and industries as well as for security, safety and enforcement. The advent of multi-disciplinary, spatially widespread, long-term data sets is expected to trigger an unprecedented leap in the economic value of ocean data. This will bring about a radical transformation in our perception of managing marine resources, and will be critical to competitiveness, product development and enhancement of services.

3. The Contribution of the Mediterranean Operational Oceanography Network (MOON)

In the Mediterranean, routine marine observations using automated systems are already conducted on a national scale in several shelf sea areas along the northern perimeter of the basin. RTD projects, mainly funded by the EC have in recent years contributed to develop pilot basin-scale monitoring activities. These achievements in operational oceanography for the region provide a base for studies of the marine environment, including ocean variability and climatic changes, through the provision of long time series of data, quality controlled and integrated into numerical modelling systems for short term forecasting. Much of the existing structure in operational oceanography has been coordinated by means of the MFS (Mediterranean Forecasting System) which was conducted as a EuroGOOS regional sea program (Pinardi *et al*., 2005). Its continuation, the Mediterranean Operational Oceanography Network – MOON, has established an even larger consortium aiming the development and maintenance of the existing systems. MOON brings together a number of marine research and operational agencies to implement and further develop the ocean observing and forecasting system in the Mediterranean Sea. It promotes the development and optimization of the scientific base, the technology and the information system for operational oceanography, and connects the concerted monitoring and forecasting systems to Sustainable Development, Marine State Assessment and Risks Management. MOON is co-led by the Istituto Nazionale di Geofisica e Vulcanologia (Italy) and MERCATOR-OCEAN (France).

MFS has been implemented with an approximated total investment of more than 15 millions Euro that includes start-up costs for the implementation, and maintenance costs of the first years of operational activities. The existing observing system is shown in Figure 1.

The actual observing system is composed of a specific implementation of SOOP, ARGO, meteo-oceanographic buoys, gliders and analysed satellite data that are both archived and real time. The MOON partners have developed, demonstrated and made operational the Mediterranean Forecasting System that is composed of: a) the Near Real Time Observing system; b) a numerical forecasting system at basin scale with downscaling in sub-regional and shelf areas; c) a product dissemination/exploitation system d) end-users applications. MOON provides a framework for a marine integrated information system, from monitoring to forecasting, that provides a base of valuable scientific information climate change assessment and environmental policy makers.

The MOON Core Service-MCS is organized through a portal with links to all available MCS information that consists of:

1) Satellite and *in situ* observations developed for operational forecasting in the basin;

2) Analyses (fusion of observations and models) at the basin scale;

3) Daily 10 days forecasts for the whole basin and many sub-regions in the Mediterranean Sea;

4) A Monthly Bulletin that synthesises the information of each month with regards to basic ocean state variables and surface meteorological conditions.

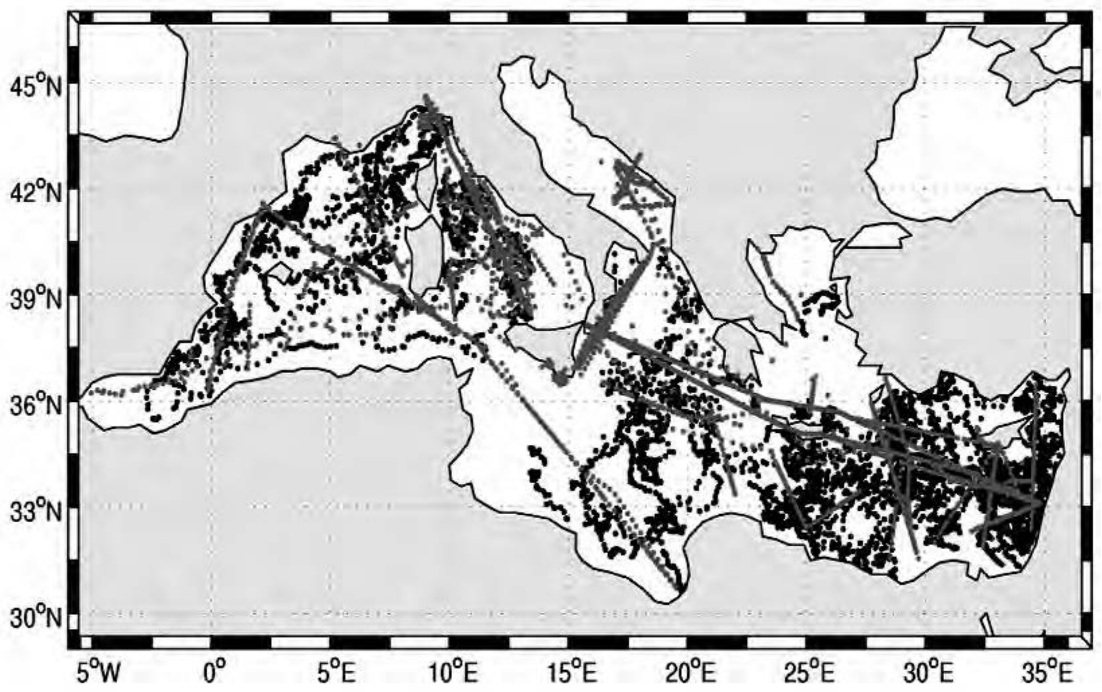

Fig. 1. The MOON observing network for the period June 2004-December 2007. The grey dots indicate the Ship of Opportunity Program-SOOP XBT temperature profiles, the darker dots the MEDARGO floats temperature and salinity profiles locations (700 and 2,000 meters profiles every 5 and 25 days cycles respectively).

MOON aims to promote the following activities:

- the development of the Mediterranean observing system at basin scale in a coordinated way;
- the consolidation of the MFS CORE service in support to the coastal systems and climate;
- the development of end-users applications (downstream services) at each single nation level;
- connection with the research and development local community to upgrade and train on operational forecasting also the non-EU countries bordering the Mediterranean Sea.

4. The role of the Mediterranean Global Ocean Observing System (MedGOOS) and quest for regional cooperation

The recently published Blue Book on the EU Maritime Policy articulates the need for a holistic approach to optimise the economic opportunities offered by the sea in line with the Lisbon Strategy, and in a manner appropriate to the maritime vocation of Europe. It clearly recognises that excellence in marine research, sound governance and international cooperation constitute the key ingredients for achieving the policy targets. Indeed there is an ever increasing responsibility on the scientific community to provide accurate and routinely updated data and information for decision–making and planning. This must be supported by further efforts in marine research and technological development, as well as by the sharing of scientific knowledge among stakeholders.

There is a need for stronger linkages with the SouthEastern Mediterranean countries with the setting up of regional partnerships, arrangements and mechanisms for capacity building, co-management, sharing of efforts and co-exploitation of benefits. The overarching strategy is to increasingly favour the cohesion of the partner and third countries and to develop a greater sense of pan-Mediterranean solidarity.

In the realm of operational oceanography this is the task of MedGOOS, the GOOS Regional Alliance for the Mediterranean. MedGOOS consists of a partnership of 19 members from 16 riparian countries. It is established under the auspices of UNESCO-IOC to provide a regional framework for partnerships, synergies and capacity building for operational oceanography to the benefit of all coastal states in the region. The MedGOOS Secretariat is established in Malta at the IOI-Malta Operational Centre (University of Malta).

One of the key roles of MedGOOS consists in the pooling of information on operational marine monitoring activities in the region. Such inventories of existing operational observation programmes constitute a pre-requisite to the harmonious planning and optimal design of regional ocean observing, modeling and forecasting systems building upon national components, and targeting the exploitation of results by a wide range of end-users. Within this framework MedGOOS targets to increasingly integrate the scientific and social dimension, and address the scope of multipurpose observing and information systems that deal with scientific, technological, social and economic factors in a holistic manner.

5. Future targets and needs

While several drivers, as described in section 2, push towards the establishment of a sustained and integrated marine observing system in the Mediterranean, the climate-related aspects may constitute a starting point and basis for its planning and design. Substantial changes in the hydrological cycle of the Mediterranean area, greenhouse gas warming and other man-induced marine ecosystem changes and pollution, together with natural variability such as the North Atlantic Oscillation, are a major threat and can critically undermine efforts for sustainable development in the region. Global change and variability has far-reaching consequences affecting a whole range of conditions and activities including public health, the integrity of ecosystems and the services they support, industry, raising the risk of social disruption and altering the course of national economies (Drago, 2001). Sustainable development needs thus to be tackled from a wider perspective and include provisions for an improved management in all climate-related domains, especially in relation to climate extremes which bring the greatest risk of environmental degradation. Improving climate understanding and constructing reliable future scenarios is essential to assess impacts and to devise adequate mitigation measures and adaptation strategies.

Such assessments rely on the systematic observations of the climate system, for both the atmospheric and oceanic components.

The main important needs are to:

1) Sustain operational oceanography activities at basin and country level, and enhance the existing systems through the use of state-of-the-art 21st century technology;

2) Extend operations for a wider geographical coverage through the involvement of SouthEastern Mediterranean countries especially for what concerns key meteo-marine parameters like sea level and waves;

3) Enlarge the observing system to monitor the deep water masses of the basin and assess water mass exchanges at straits;

4) Improve the management of the archived and real time mode data for easier access through dedicated intelligent portals, for wider dissemination and the integration of multidisciplinary data for added-value applications;

5) Establish long term capacity building activities, especially through MedGOOS focal points, to promote expertise in operational oceanography where it is lacking, as well as to prompt local applications and benefits through the use of observations to derive relevant information and knowledge for sound assessments, policy formulation and decision-making;

6) Advance the coupled ocean-atmosphere and the marine ecosystem modelling activities.

Figure 2 shows the streamlined observing system design as recommended by the MOON Member assembly for the period 2006-2009. The main elements consist of:

1) MedARGO floats with at least 10 units every year;

2) Monthly Ship Of Opportunity (SOOP) campaigns along key transects with upgrades of a number of tracks to additionally measure meteo-marine parameters in real time;

3) Deep sea buoys in the Ligurian Sea, in the Catalan Sea, in the Southern Adriatic Sea, in the Cretan Sea, in the Southern Levantine basin and in the Aegean Sea;

4) Satellite daily products of Sea Surface Temperature, Sea Level Anomaly and Surface Chlorophyll;

5) Glider long tracks from Genoa to Mallorca (under development in the European Project MERSEA), and in the Alboran and southern Balearic Sea (under the framework of the SESAME European project;

6) A Fishery Observing System (FOS) in the Adriatic Sea collecting data of fishing effort and commercial catches, including the transmission in Near Real Time of Temperature and Pressure data, and conductivity records (CTD).

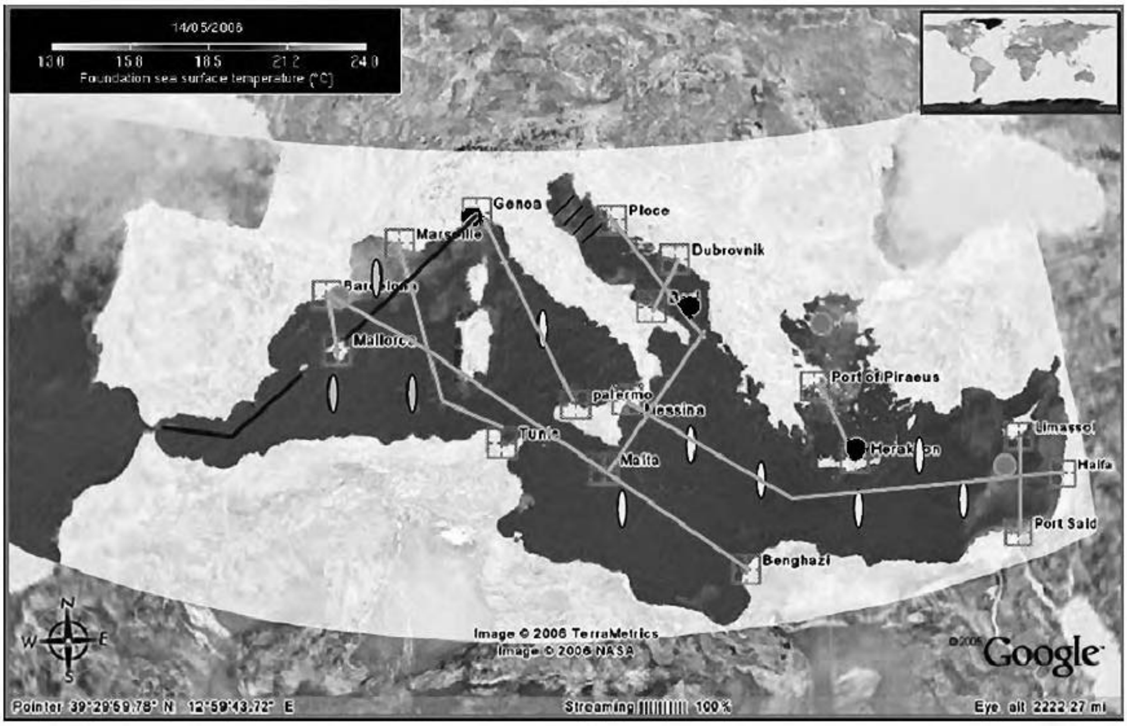

Fig. 2. The optimal observing system designed by MOON for the period 2006-2009. The light grey lines are the recommended SOOP lines; the elliptically shaped forms are the possible locations for MEDARGO floats deployment; the dots are deep sea buoy locations, the grey still under development while the black ones already operational; the dark thick lines are proposed glider tracks, the dark thin lines in the Adriatic Sea represents the area where the Fisheries Observing System (FOS) will be active. The Sea Surface Temperature data are distributed by MERSEA (from GCOS Regional Action Plan for the Mediterranean, 2006).

A main additional effort should be targeted to study some key Mediterranean areas of a) deep water formation; b) deep and intermediate water spreading pathways; c) water properties modification (such as mixing, entrainment, etc.) and exchanges in straits. Such processes are able to amplify and/or filter the global change signals originating from atmospheric forcing and changes in the hydrological cycle. Observations in such focal areas are very effective indicators of the variability of the Mediterranean oceanic system. The key objectives would be to: 1) document the climate variability of the thermohaline structure of the Mediterranean Sea; 2) define the processes transferring the atmospheric signals to the marine system; 3) underpin the mechanisms that convey climatic variability to the biotic part of the ecosystem. Recent technological advances make possible the continuous monitoring through the combined use of bottom-mounted ADCP and gliders. Gliders have been already adapted to the Mediterranean Sea conditions and proven to be efficient and robust. Several marine regions are of particular interest, such as:

- the southern **Adriatic**, where the response to various forcings (atmospheric, river runoff and anthropogenic pressures) can affect the deep water formation events;
- some of the **Straits** (Otranto, Sicily and Cretan Arc) where the signals recorded at such sites are indicators of the transfer of water mass properties between major sub-basins of the Mediterranean Sea.

Such an observing system would extend the range of information products and indicators to serve beyond climate applications.

Acknowledgements

This paper is based on several internal publications and presentations made in international fora made on behalf of MOON and MedGOOS.

The contribution of the SESAME project to the creation of a Mediterranean Marine Observatory

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Introduction

The Mediterranean and Black Sea regions have been the historical birthplace and centre of many civilisations and cultures for thousands of years. Over the past century the population of these regions has expanded substantially. Coastal urbanisation, industrialisation and touristic exploitation (with the associated waste disposal), intensive agriculture, riverine and atmospheric inputs and fisheries are only a few of the many anthropogenic forcings which have exerted a growing pressure on the Mediterranean and Black Sea environment, and which now put its integrity at stake.

The Mediterranean and Black Sea are unique and evolve rapidly with large interannual to decadal variability and abrupt fluctuations due to natural and anthropogenic forcings. In order to tackle these ecosystem changes and understand the possible modifications in their ability to provide goods and services to society, SESAME provides an integrated, ecosystem based approach, considering Mediterranean and Black Sea as a coupled climatic/ecosystem entity, with links and feedbacks to the World Ocean.

The scientific objectives of SESAME are:

1. To assess changes in the SES (South European Seas) ecosystems over the last 50 years.

2. To assess the current status of the SES ecosystems through analysis of existing and newly collected data at basin scale as well as through model simulations.

3. To predict changes in the SES ecosystems, using existing and new observations at a regional and basin scale in order to construct scenarios of the ecosystem responses to likely changes in climate and anthropogenic forcings during the next five decades.

4. To assess and predict changes in the ability of the SES ecosystems to provide goods and services. Ecosystem variability has affected, *inter alia,* specific goods and services with potentially high societal importance (goods: tourism and fisheries - services: ecosystem stability through conservation of biodiversity, and mitigation of climate change through carbon sequestration in deep waters and sediments). SESAME will identify the ecosystem functions (observed and predictable from model simulations) that are pertinent to these goods and services as well as their changes during the last decades.

A number of EU, international and national projects have addressed the issue of ecosystem changes at a regional and basin scale. To list a few:

POEM and POEM-BC projects developed the first synthesis of the eastern Mediterranean circulation and resulted in a major finding by identifying the EMT (Eastern Mediterranean Transient), which modified the thermohaline circulation at basin scale (Theocharis *et al*., 1999; Astraldi *et al*., 2002; Malanotte-Rizzoli *et al*., 1999; Larnicol *et al*., 2002; CIESM, 2000). MTP-MATER addressed, for the first time, the Mediterranean in its entirety and studied the transfer processes of mass and energy between the different compartments as well as the ecosystem's response to these transfers (Monaco and Peruzzi, 2002); it combined physical and ecological modelling with intensive field activity including two trans-Mediterranean cruises MINOS (Moutin and Raimbault, 2002) and MATER. The ADIOS project studied the atmospheric deposition in the Mediterranean Sea and the effect of atmospheric pollutants, particulate elements and nutrients in influencing primary productivity and biogeochemical cycles in the oligotrophic open Mediterranean, while CYCLOPS revealed that the eastern Mediterranean is phosphorus and nitrogen co-limited (Thingstad *et al*., 2005).

SESAME's innovation

SESAME is dedicated to increase scientific capacity to face major societal needs and to foster multidisciplinary collaborations including the broadest range of Mediterranean and Black Sea countries inside and outside the EU. The innovative character of SESAME lies in its design, scope and focus. This is reflected in the close merging of natural and economic sciences over the Mediterranean and Black Sea and the choice of a centennial time scale (from 50 years in the past to 50 years in the future). Innovation will be achieved through activities that focus on Assessment, Prediction, Application and Dissemination, respectively.

Specific examples of the innovative character of SESAME are:

- SESAME considers the Mediterranean and Black Sea and the straits that connect the various basins as one interconnected large system, with contrasts and similarities over a wide environmental spectrum. The compilation of existing data and information with new measurements will be used over the whole system scale to better understand past, present and future environmental changes and their impacts on society.
- SESAME brings together a large team of scientists from across Europe, many of whom work together for the first time. This gives the opportunity to standardise the approach to ecosystem sampling and modelling on a scale hither-to unknown. Such standardization is essential to the success of SESAME.
- WOCE (World Ocean Circulation Experiment) -type stations and monitoring strategy for selected transects in the SES will be established for the first time. SESAME partners have agreed to use selected stations for ocean monitoring, thus potentially establishing a long-term WOCE-type experiment in the SES. The collection of the data and their storage in public domain databases beyond the duration of the project is planned within the project's lifetime.
- SESAME connects ecological models with climatic and socioeconomic scenarios to assess potential changes in the current ability of the marine ecosystems to provide goods and services.

Contribution of SESAME towards the Integrated Mediterranean Observatory

SESAME could contribute to the integrated Observatory by two means:

1. Through the existing multidisciplinary data that are being collected

SESAME collects historical multidisciplinary and time-series quality checked data from: published databases, grey literature, reports and observations, cruise data, unpublished existing datasets as well as from re-treatment of historical samples, where necessary. SESAME will provide comprehensive datasets to be organised and introduced in databases. In addition the data will be analysed and the results will be used to assess the present status of the Mediterranean and Black Sea ecosystems, their resilience against environmental change and changes in their ability to provide goods and services that occurred during the last 50 years (known changes and availability of sufficient data).

2. <u>Through the new data and establishment of WOCE-type stations in the Mediterranean and Black Sea</u>

SESAME will coordinate two multinational and multidisciplinary cruises carried out by ten oceanographic research vessels along selected transects (Figure 1). Satellite images will co-currently be used and sampling of atmospheric aerosols will be carried out. Three moorings of two sediment traps accompanied by current meters were already deployed. The gathering of high quality *in situ* data, the analysis of samples and the preparation of datasets to feed the SESAME

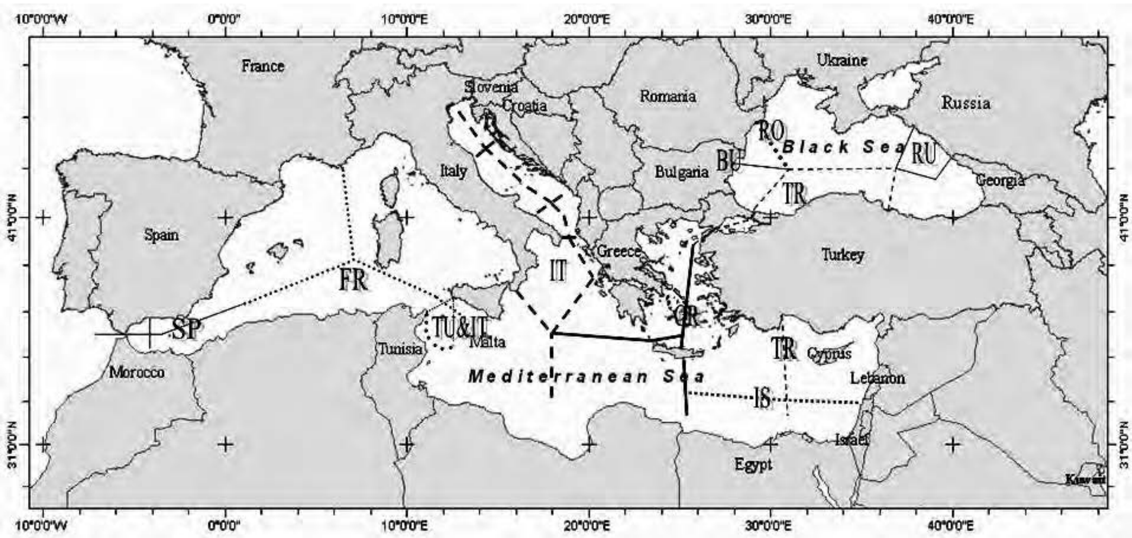

Fig. 1. Map showing the transects of the multidisciplinary cruises.

databases will be used to tune and validate the ecological models. Based on existing and new information, WOCE-type stations in the Mediterranean and Black Sea will be established for the first time, to monitor and assess the future changes. It is imperative to obtain long time-series from selected stations in the Mediterranean and the Black Sea, in order to assess not only the state, but also the variability of the ecosystem both in seasonal and interannual time-scales. The SESAME consortium is determined to maintain the operation of these WOCE-type stations beyond the duration of the project. Acquired data will be incorporated into the SESAME databases.