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Towards an integrated system of Mediterranean marine observatories

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This collection offers a broad range of titles in the marine sciences, with a particular focus on emerging issues. The Monographs do not aim to present state-of-the-art reviews; they reflect the latest thinking of researchers gathered at CIESM invitation to assess existing knowledge, confront their hypotheses and perspectives, and to identify the most interesting paths for future action.

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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.

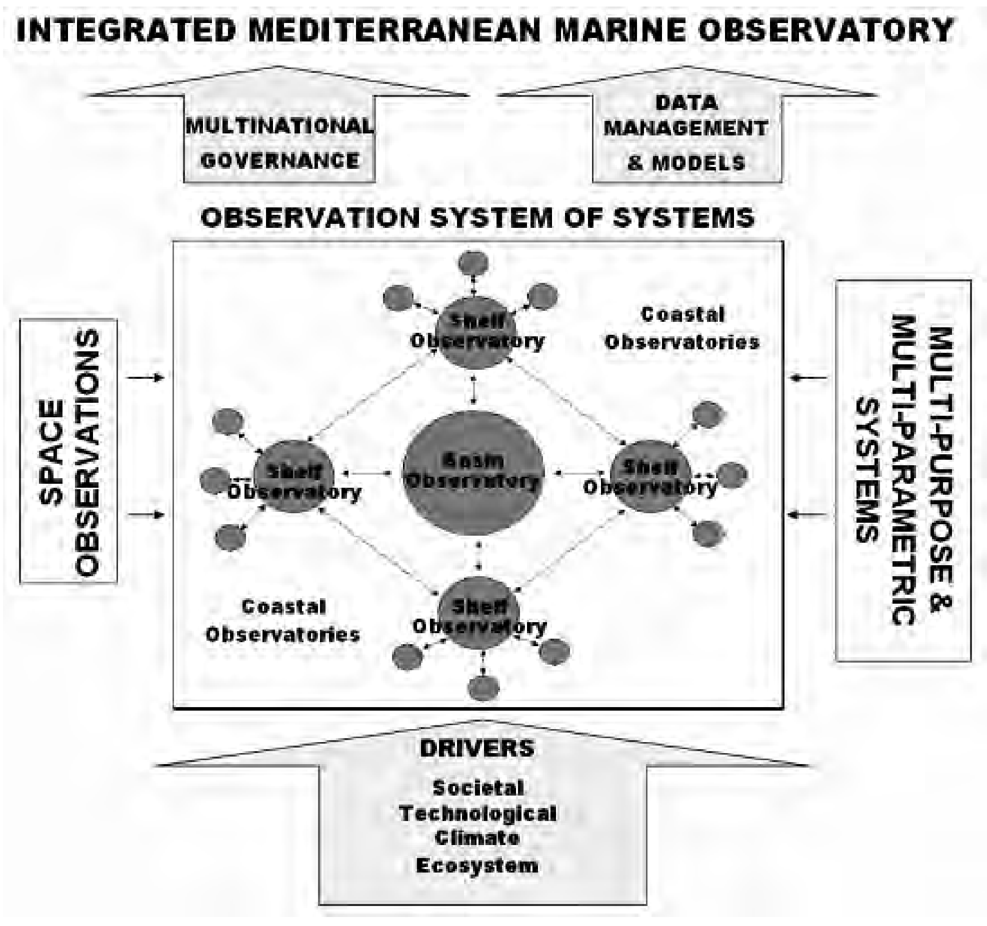

Fig. 1. Schematic design of the Integrated Mediterranean Marine Observatory.

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.

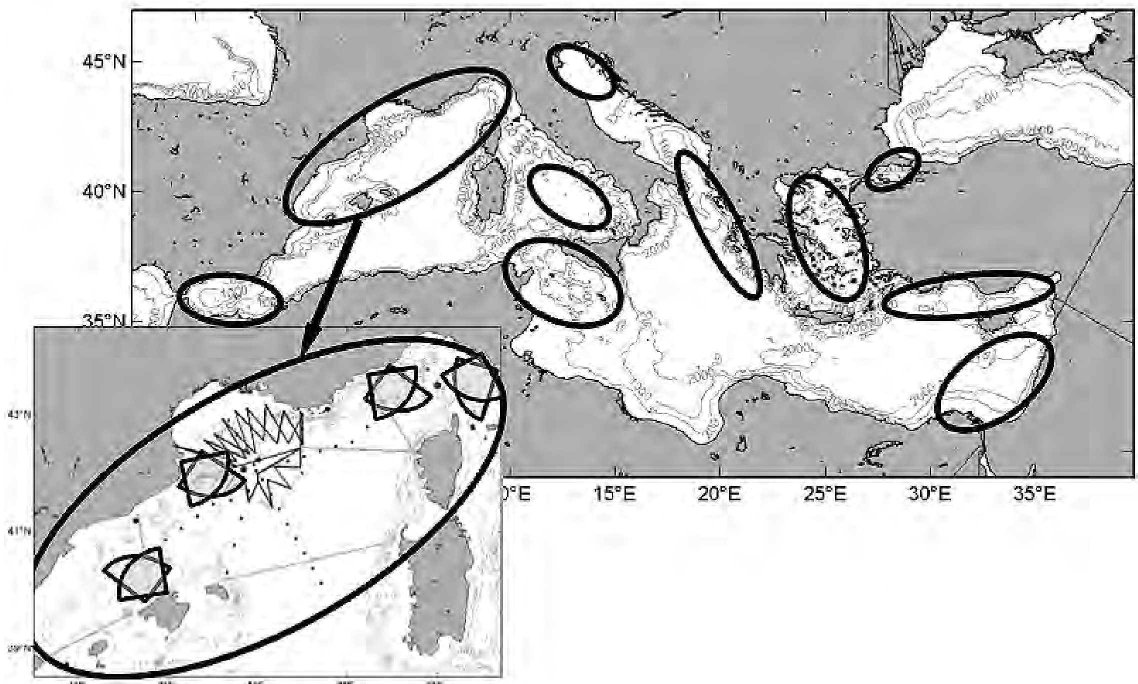

Fig. 2. Key regional components of an Integrated Mediterranean Marine Observatory: areas where integrated regional observatories are in development or that require special attention due to their significant role in the functioning of the basin-wide marine system. The box on bottom shows the sampling 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.