I - Executive Summary

This summary, initiated during the workshop meeting, was synthesized thereafter by Miroslav Gačić and Michèle Barbier upon the basis of further inputs received from all participants, in particular Katrin Schroeder, Mokhtar Guerfi, Toste Tanhua and Nurit Kress.

Frédéric Briand, Monograph Series Editor, reviewed and edited the entire volume. Valérie Gollino was responsible for the final layout and physical production.

1. Introduction

Over the last three decades a number of Basin-wide studies have revealed dramatic and faster than expected changes in the hydrography and biogeochemistry of both Eastern and the Western Mediterranean sub-basins (see syntheses in CIESM, 2009; 2000). As long-term variability in the ocean is, most often, revealed through studying the variability of the basin-wide circulation - and more specifically the changes of the overturning circulation cell - there is a growing need to document changes in the Mediterranean Sea over the entire water column and in different regions, in order to relate them to sea level variations and climatic variations.

In opening the meeting, Frédéric Briand, Director General of the Mediterranean Science Commission, remarked how effective Miroslav Gačić, Chair of the Committee on Climate and the Ocean, had been in persuading him to convene a workshop on such issues. The eighteen scientists (see list at end of volume) gathered here at the invitation of CIESM on the charming, secluded Brac Island would have all the time and latitude necessary to seriously discuss the possible design and implementation of a coordinated program for repeated basin-wide oceanographic surveys in the Mediterranean. Before inviting Dr Gačić to detail the specific objectives of this exploratory seminar, Dr Briand expressed his gratitude to the Director of the Institute of Oceanography and Fisheries (Split), Dr Ivona Marasović, and especially to her assistant Ana Marušič, for allowing this meeting to take place in Supetar in the best possible logistic conditions.

Miroslav Gačić reminded all present that the Global Ocean Ship-based Hydrographic Investigations Programme Initiative (GO-SHIP) had been recently set up as the international response to support and coordinate a system of repeat cruises in the world's oceans (see GO-SHIP White paper[1], OceanObs-09 conference, Venice, 2009[2]). The GO-SHIP plan defines an observational system which, on roughly decadal time-scales, conducts a number of repeat hydrographic lines in all ocean basins (see Tanhua, this volume). The GO-SHIP document specifies a number of core-parameters to be measured and defines protocols and data-policy for the surveys. As part of the GO-SHIP initiative, the WOCE hydrographic manual was revised and a new set of guides of best practices for several common measurements are now accessible on the GO-SHIP website.

[1] The GO-SHIP white paper available at the GO-SHIP website: http://www.go-ship.org/
[2] The Ocean Obs white papers are available at: http://www.oceanobs09.net/proceedings/cwp/index.php

With increasing societal demand for predictions of climate change impacts on the environment and ecosystems, e.g., temperature, sea level rise, occurrence of catastrophic weather events (flash floods, hurricanes, droughts, etc.), the time had come to formulate a possible Mediterranean component - a Med-SHIP Programme - to GO-SHIP. Due to its semi-enclosed nature, the Mediterranean Sea affects the climate of the surrounding land areas, in ways without analogs in other regions of the world. The complex land-sea distribution of the Basin has a strong effect on the atmospheric circulation and its seafloor keeps records of past climate evolution. The analysis of the complex Mediterranean Sea processes and evolution is an essential step to understand the regional environment and climate.

The bathymetry of the Mediterranean Sea is composed of several sub-basins separated by straits and channels with depths ranging from a few hundred meters to more than 4,000 m. This makes this sea very sensitive to atmospheric forcing and resulting changes in seawater characteristics can reach rapidly the deep waters. *In situ* meteorological observations and data time-series are long and spatially dense enough to enable some documentation of longer-term changes, by testing and validating models (see Lionello, this volume). While recent findings indicate that Mediterranean water masses have steadily become saltier and warmer in the last decades at all depths and everywhere in the basin (CIESM HydroChanges papers http://www.ciesm.org/marine/programs/hydrochanges.htm), with rates of change varying from one sub-basin to another, the oceanographic observational system, both here and in the world ocean, is lagging much behind the meteorological system. As a result *in situ* basin-wide data are very scarce; in fact the first basin-wide surveys in the eastern Mediterranean were carried out only in the mid-1980s. Now is the time to fill such gaps.

In the Mediterranean Sea, intense but mostly localized oceanographic campaigns are being carried out within the framework of different national and international projects. The methodology used differs among the projects. Moreover new monitoring technologies such as gliders and mooring are being progressively implemented in coastal ocean observatories (Tintoré *et al.*, this volume). However, there is a lack of a unified international platform that would, similarly to GO-SHIP, coordinate the observational network in order to avoid duplications and assure sufficient coverage in time and space. The GO-SHIP approach and methodology should be applied but adapted to the Mediterranean sea that is characterized by smaller spatial and shorter temporal scales of the circulation features compared to the global ocean (see Taupier-Letage, this volume). Such a programme should also develop data syntheses products and facilitate the interpretation of hydrographic data in partnership with national, regional, and global research programmes. Thus, there is a need to establish a permanent international body, preferably under the umbrella of CIESM, which will facilitate exchange of information on national initiatives in the Mediterranean ship-borne surveys both at basin and sub-basin scales.

Subsequently, a more formal organization is envisaged that would become part of the global GO-SHIP Programme: Med-SHIP which shall promote cooperative repeat hydrographic surveys, optimize national shiptime resources, enable merging and interpretation of collected data and encourage scientists from different countries to join and cooperate during all stages, from sampling to data analysis and interpretation. In this executive summary, we present a series of recommendations for the implementation of Mediterranean basin-wide ship borne repeated surveys: the Med-SHIP Programme.

2. The Mediterranean Sea and its specificity

2.1 The Mediterranean circulation and variability

The Mediterranean Sea is a semi-enclosed marginal sea that communicates with the world ocean through the narrow and shallow Strait of Gibraltar. The Mediterranean circulation is characterized by a variability at different spatial and temporal scales, determined by a complicated bathymetry and variable spatial scales of atmospheric forcing. Basin-wide flow, as a part of the upper circulation cell driven by the negative freshwater and heat balance, is characterized by an eastward surface flow of the relatively fresh Atlantic Water (AW). Generally, this surface current shows energetic meandering, baroclinic instabilities and mesoscale activities. In the Western basin, the main process is the continuous formation of meanders and mesoscale eddies along the North

African Current. According to POEM results and other *in situ* studies (Robinson *et al.*, 2001; Malanotte-Rizzoli *et al.,* 1999), the Eastern Mediterranean, in addition to the strong mesoscale activity, is characterized by a jet of AW entering the basin and crossing the Ionian Sea. On its way toward Israeli's coast it continues meandering between several bottom-trapped or wind-driven quasi-permanent or recurrent gyres. The Levantine Intermediate Water (LIW) is formed in the area of the Rhodes Cyclonic Gyre through the vertical convection reaching intermediate depths (Hayes and Zodiatis, this volume; Özsoy and Aydoğdu, this volume). This water then in a return westward pathway reaches the Gibraltar Strait and represents the main component of the exiting Mediterranean waters. Another proposed scheme of the Eastern Mediterranean surface circulation (Taupier-Letage, 2008; Millot and Gerin, 2010) suggests that the flow pattern is mainly characterized by travelling eddies and vortices that strongly interact with the general circulation along the African coast and divert AW offshore. In the same way, mesoscale eddies entrain intermediate and deep waters deflecting them from their pathway (Millot and Taupier-Letage, 2005a).

The implementation of GO-SHIP like surveys would provide additional *in situ* data and thus a better insight into the circulation pattern in the Eastern Mediterranean, its variability and the biogeochemical properties of the Mediterranean contributing to the understanding of processes and structures.

The deep circulation cell of the Mediterranean is driven by the dense water formation processes that take place in both the Western and in the Eastern Mediterranean. In the Western Mediterranean the dense water is formed in the Gulf of Lion, facilitated by the presence of the salty LIW and generated by the cold air outbreaks associated with the Mistral events in an area of cyclonic circulation. In the Eastern Mediterranean the main dense water formation source is the Southern Adriatic, in an area characterized by the presence of the bottom-trapped basin-wide cyclonic gyre. Again the presence of the saltier waters of the Levantine origin in the intermediate layer facilitates the vertical convection, which takes place during violent air-sea heat loss events associated with the Bora (Northeasterly wind) episodes. Recent results have revealed that during the last decade alternatively the dense water was formed in the Aegean and substituted the Adriatic (Roether *et al*., 2007). This phenomenon, named the Eastern Mediterranean Transient (EMT) (see CIESM, 2000) suggests that the mean circulation in the Mediterranean is subject to sudden changes revealing also that the time scale of the deep circulation cell is much shorter than previously thought. Recent studies showed pronounced decadal inversions in the North Ionian Gyre (NIG) that are important in determining thermohaline properties of the Adriatic as well as the pre-conditioning for the EMT. Inversions of the North Ionian Gyre are responsible for the out-of-phase behaviour of the Adriatic and Aegean as the dense water formation sites (Civitarese and Gačić, this volume) (see Figure 1).

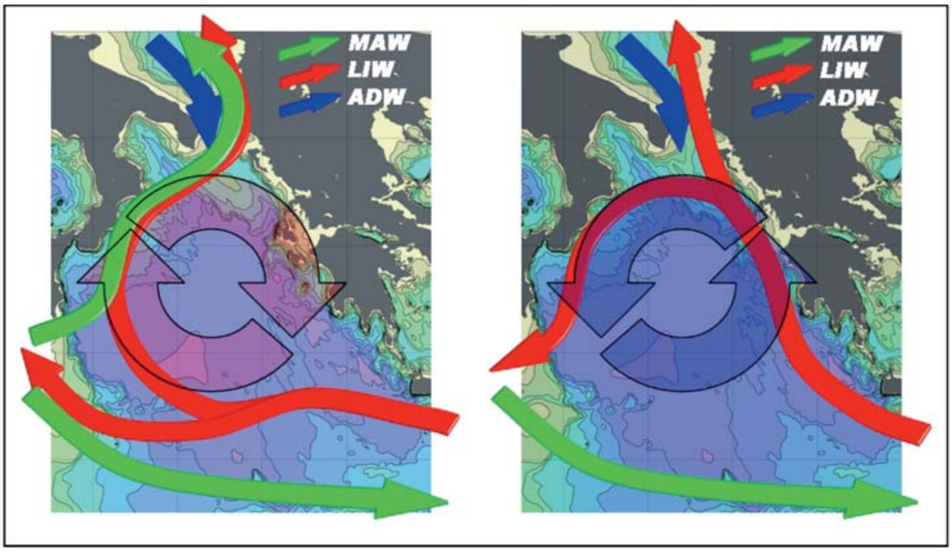

Figure 1. Example of Mediterranean complexity: circulation schemes of the two Ionian horizontal modes (Adriatic-Ionian Bi-Modal Oscillating System - BiOS) and pathways of the principal water masses after Civitarese and Gačić, this volume.

Recently, a significant warming and salinification of the whole water column in the western Mediterranean has been observed and several studies have revealed the abundant formation of a new warmer and saltier WMDW during winters 2004-2005 and 2005-2006 (Schroeder *et al.*, 2006; 2008a; 2010a; Font *et al.*, 2007). The bulk of the new WMDW, in the abyssal plain of the western Mediterranean Sea, showed temperatures of 12.85°–12.88°C and salinities of 38.455–38.473 below 2,000 m depth (Schroeder *et al.*, 2008a). Between 2004 and 2008 the new WMDW occupied a layer which reached hundreds of meters thick, with total increases of salinity and temperature of about $\Delta S = 0.024$ and $\Delta\theta = 0.042$°C, respectively, near the bottom (see profiles in Figure 2). By October 2008 the new deep water had been found everywhere in the western basin below 2,000 m depth, with the exception of the Tyrrhenian subbasin (Schroeder *et al.*, 2009). Furthermore, it has been uplifted toward the Alboran subbasin, where in 2008 it was detected along the Moroccan continental slope at depths <1,000 m. The magnitude of the replacement of the old deep water by the new deep water is clearly evident in the vertical profiles shown in Figure 2. This event has been called the Western Mediterranean Transition (WMT, CIESM, 2009).

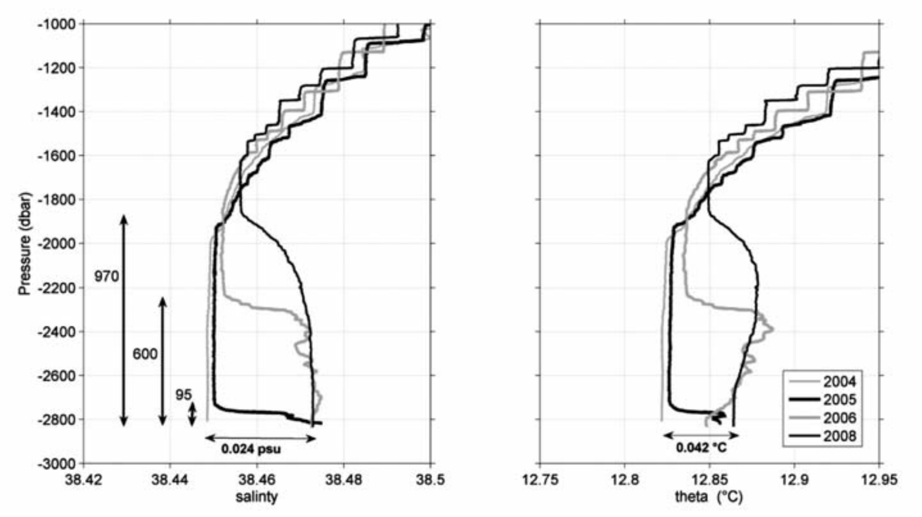

Figure 2. Vertical profiles of (left) salinity and (right) potential temperature measured at an example station in the Algerian basin (5°E, 38°N) in October 2004 (shaded thin), June 2005 (bold line), October 2006 (shaded bold line) and November 2008 (thin line). Vertical arrows indicate the thickness of the new Western Mediterranean Deep Water (WMDW) layer in the different years. Horizontal arrows indicate total salinity and temperature increase at the bottom between 2004 and 2008. From Schroeder *et al.* (2010a).

Long-term changes of the circulation pattern, especially in the Western Mediterranean, show indications of the relationship with the global scale teleconnections pattern.
Property exchange and interaction between shelf and open sea in the Mediterranean are very important and in general have been shown to take place via mesoscale eddies and, very efficiently, via bottom water sinking through canyons (Salat *et al.*, 2010).

2.2 Biogeochemical properties of the Mediterranean

Nitrate and oxygen distribution in the Mediterranean

The Mediterranean is considered an oligotrophic area. Generally, surface waters in the Mediterranean are depleted in nutrients and the thickness of this depleted layer increases eastwards from about 10 m in the Gulf of Lion to more than 100 m in the Levantine basin, more or less as nitracline and thermocline depths (Pujo-Pay *et al.*, 2011). Large phytoplankton blooms are geographically well localized and mainly associated with the physical forcing (dense water formation areas and/or cyclonic circulation pattern). In addition, important phytoplankton biomass densities are located in the Alboran anticyclonic gyres and near the coast adjacent to river mouths (D'Ortenzio and Ribera-d'Alcalà, 2009). The depth distribution of the chemical parameters in the Eastern Mediterranean changed following the EMT and continues to change through its relaxation and the re-establishment of the Adriatic as the deep water source. During the EMT the Cretan Sea

Overflow water (CSOW), that was warmer, saltier, more oxygenated and with lower nutrient concentrations than the Adriatic Deep Water (ADW) uplifted the older ADW and created a mid-depth layer with minimum oxygen (Min_{Ox}) and maximum nutrients (Max_{Nut}) in the Levantine basin and Cretan sea (Kress *et al.,* 2003). The CSOW, first noticed in the vicinity of Crete near its source, propagated initially towards the western Ionian and later towards the Levantine basin, uplifting the Min_{Ox}/Max_{Nut} layer from 1,250 m to 950 m and 750 m in the Levantine and Ionian basin, respectively, between 1995 and 2001. In 2008, this layer was centered at ca. 900 m depth in the Levantine basin, more emphasized in the eastern part and eroded towards the west. In the easternmost part of the Levantine basin, one of the last regions to be influenced by the EMT (Roether *et al.,* 2007), the CSOW was already in place in 2002, as reflected by the Min_{Ox}/Max_{Nut} at mid depth, and higher oxygen and lower nitrate concentration close to the bottom (see Kress *et al.*, this volume). Between 2002 and 2010, the Min_{Ox} vertical span narrowed and the influx of more oxygenated waters (the new, younger ADW) was more evident. The concentration of nitrate at the Max_{Nut} increased with time and shallowed (Figure 3).

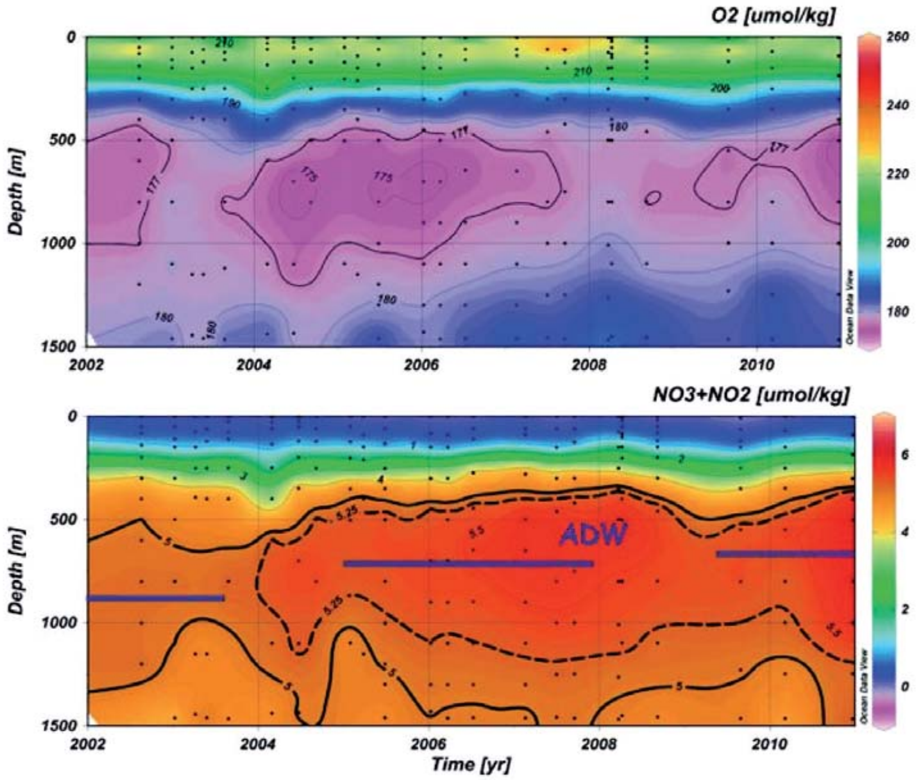

Figure 3. Temporal depth evolution of dissolved oxygen and nitrate at a station located at 33N, 34,5E. The blue line in the lower panel indicates the change in position and concentration of the maximal concentration of nitrate, corresponding to the ADW.

<u>Carbonate system in the Mediterranean</u>

There are only few observations of the carbonate system in the Mediterranean Sea, making it difficult to draw any conclusions on the temporal variability of the inorganic carbon at this stage. However, a recent 2011 survey repeated measurements of Dissolved Inorganic Carbon (DIC) in the Eastern Mediterranean, and a significant increase in normalized DIC (i.e. corrected to a common salinity) could be detected in the period between 2001 and 2011. However, when corrections are made for the remineralization of organic matter using changes in oxygen, only a small and mostly insignificant increase in DIC is observed. For the deepest layer in the southwest Ionian Sea a significant increase in respiration corrected DIC is noted: this is a consequence of recently formed ADW.

The Mediterranean does hold large amounts of anthropogenic carbon as a consequence of the high buffer factor and the active ventilation (Schneider *et al*., 2010). With the assumption that the anthropogenic carbon (C_{ant}) behaves like an inert gas, its distribution can be calculated with the "transit time distribution" (TTD) method from observations of transient tracers. Figure 5 shows the C_{ant} concentrations calculated from the TTD method for 2001 and 2011 for a zonal section in the Eastern Mediterranean Sea. An increase of C_{ant} calculated with the TTD method is equivalent to active ventilation. Figure 5 shows the signal of active ventilation in the western Ionian Sea, whereas the Cant concentration in the deeper layer of the Levantine Basin is very similar in 2001 and 2011, indicating a slowdown of deep ventilation in this area. This is consistent with the direct observations of changes in respiration corrected DIC (Figure 4). Figures 4 and 5 demonstrate the value of repeat observations of transient tracers and DIC in the Mediterranean Sea.

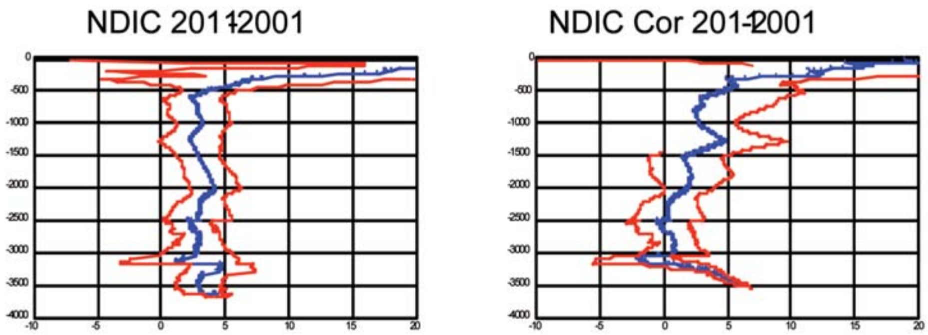

Figure 4. Changes in Dissolved Inorganic Carbon (DIC) between 2001 and 2011 in the Eastern Mediterranean Sea. Left panel shows changes in salinity corrected DIC, and the right panel a correction for respiration (from Alvarez, pers. comm.).

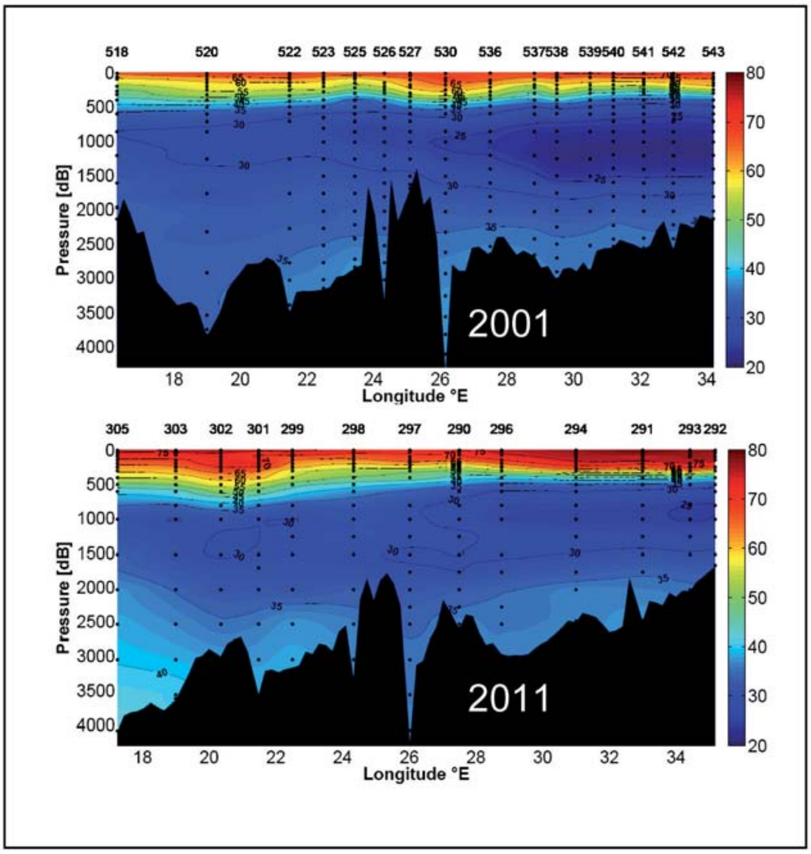

Figure 5. Anthropogenic carbon in the Eastern Mediterranean Sea in 2001 (top panel) and 2011 (bottom panel) calculated with the TTD method from observations of CFC-12 and SF6 (Stöven, 2011).

3. Objectives and significance of the Med-SHIP Programme

The Med-SHIP Programme aims at documenting and understanding the physical and biogeochemical water property distributions, their long term variations, and drivers at decadal and sub-decadal scales within the Mediterranean Sea, including physical and biogeochemical properties.

The specific objectives of this programme are to:

- Determine the long term variability and controls of water mass properties;
- Determine changes in circulation patterns and ventilation rates;
- Determine the variability of natural and anthropogenic carbon, and other biogeochemical properties;
- Reduce uncertainty in the heat, freshwater and property budgets, and sea-level;
- Augment the historical database of full water column observations necessary for understanding the Mediterranean Sea variability on multiple timescales and for numerical model evaluation.

The strength of the Med-SHIP Programme is in the long term, repeated, sustainable basin-wide surveys, that will complement the more frequent but localized studies. It shall include systematic long-term measurements, further optimize ship-time resources, integrate data collection, analysis, interpretation and management including dissemination through central coordination and governance. The implementation of such coordinated surveys would provide further insight into the circulation pattern, its variability and the associated changes in the biogeochemical properties of the Mediterranean.

4. Recommendations for the implementation of the Med-SHIP Programme

In order to address the complexity and the main scales/processes occurring in the Mediterranean Sea, recommendations are presented here for an efficient Med-SHIP Programme. The survey should consist of three components:

- Basin-wide half decadal (sub-decadal) zonal surveys;
- Cross-basin (north-south) transect at two-three years intervals;
- Higher frequency surveys using different platforms (e.g. ships gliders and floats mainly) at sub-basin and the mesoscale in order to follow the variability of structures/processes that influence the basin scale circulation and THC.

As reported by Tanhua (this volume) and Taupier-Letage (this volume), it is reasonable to suggest that a somewhat more intense observational programme is needed in the Mediterranean compared to the world ocean programme (GO-SHIP). The zonal transect, repeated on a low-frequency basis and including the full suite of the GO-SHIP core parameters, would allow to assess long-term variations of heat and freshwater budgets (and their steric influence on sea-level) and to compute basin-wide inventories of natural and anthropogenic carbon in the Mediterranean, with a focus on its deeper layers, being less subject to small (time/space) scale variability. But, the Mediterranean is a coastal ocean with open ocean characteristics (Tintoré *et al.,* this volume; Robinson *et al.*, 2001), where the circulation is not driven by basin scale forcings, but by intense, variable and diverse subbasin forcings. With this in mind the high-frequency repetition of subbasin, meridional transect, including a subset of the GO-SHIP core parameters, is essential to capture the observed degrees of variability.
In addition, an integration of all other important on-going programmes will provide higher spatial and temporal resolution than the one set up by ordinary Med-SHIP cruises. More specifically, remotely sensed data will be essential for resolving smaller scale features. In addition, the HydroChanges network of moored CTDs sponsored by CIESM as well as the installation of low-cost autonomous thermosalinometers on ships of opportunity will allow the monitoring at high temporal resolution (~weekly) of the temperature and salinity of the sea surface, and provide a synoptic picture at basin scale (see Taupier-Letage, this volume).

4.1 Basin wide (sub-decadal) surveys – Recommendations for full water column ship-based long term observations in the Mediterranean Sea

Two types of repeated hydrographic surveys shall be envisaged, further combined with other platforms, specifically with gliders, for studies of mesoscale variability:

- High-frequency lines (3 years), generally North-South;

- Low-frequency line (6 years), East-West hydrographic transect.

• Recommendations on transects –

Backbone activities will mainly be carried out at these two types of transects which shall be integrated with existing sampling at higher spatial and temporal resolution.
The optimal surveys are drafted on the map below.

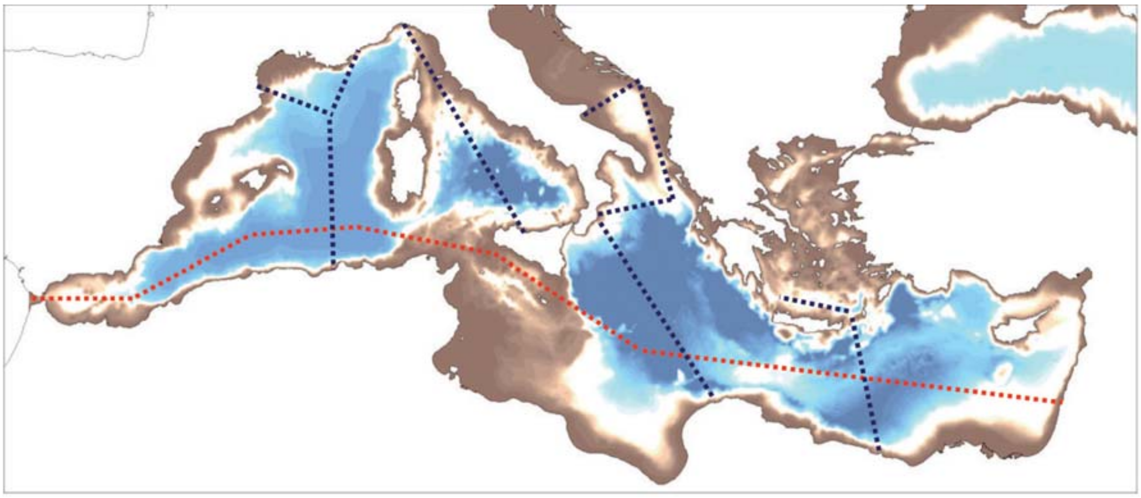

Figure 6. Proposed Med-SHIP survey transects with north-south high-frequency lines (every 3 years) in blue, and east-west low-frequency line (every 6 years) in red.

It is recommended that spacing between stations should be 30 nm but reduced to 10 nm in the vicinity of sharp bathymetry. Full chemistry stations should be designed at least every 60 nm but adapted in sharp bathymetry areas. The preferred period for sampling would be in August-October. The surveys shall include the entire water column since the deep Mediterranean circulation is strongly impacted by processes that take part in the upper part of the water column and thus cannot be excluded in this study. Note that all of the lines are designed to reoccupy long-term monitored stations and cruises, both deep stations (GEOSECS, SESAME (Adios, Haifa), DYFAMED, etc.), coastal monitoring stations or ship of opportunity tracks.

• Recommendations on key parameters measurements – *In situ* continuous profiles core measurements should include temperature, salinity, pressure, dissolved oxygen and fluorescence. Refraction and Photosynthetically Active Radiation (PAR) are recommended.

Water column sampling at designated stations should include the full chemistry of:

- Dissolved oxygen;

- Inorganic nutrients (phosphate, nitrate, nitrite (separately if possible and if not nitrate+nitrite and silicate). Measurements to nanomolar levels are recommended for the upper water column;

- CO_2 variables (preferred are measurements of alkalinity and total inorganic carbon, measurements of pH is an alternative);

- Transient tracers such as CFCs, SF_6.

Additional recommended variables are organic carbon, nitrogen and phosphorous, chlorophyll *a*, HLPC pigments, flow cytometry.

Stations should be complemented by underway sampling measurements:

- Meteorological variables;
- Thermosalinograph;
- Aerosols;
- *In situ* underway CO_2 measurements;
- Fluorometer;
- Hull-mounted ADCP for current profiles.

4.2 Sub basin/mesoscale survey – Recommendation for high frequency sub-basin surveys

Zonal backbone basin-wide transects will add on existing activities as well as on small scale national surveys. Specific attention will be paid to the integration of glider data and data collected during both high-frequency lines and the low-frequency east-west hydrographic transect. Especially, the incorporation of gliders should be an important contribution to the Med-SHIP initiative. Data collected during the two types of cruises will also be integrated with measurements from all available platforms.

• Recommendations for key process study areas for understanding the variability of water masses, ventilation and impact on basin-wide circulation –

To document the effects of deep and intermediate waters (DW and IW) on circulation and biogeochemical variability at basin and sub-basin scale, the study of the following key sub-basins/processes is recommended:

- BIOS/EMT as an example of Mediterranean complexity in the Ionian Sea/Otranto Strait and Cretan passage (anticyclonic mode: AW enters Adriatic increasing buoyancy cyclonic mode: the AW feeds directly the Levantine and the Aegean). Study of the impact on the ecosystem and biochemical features.
- Cretan Sea.
- Levantine eddies/gyres: Rhodes, Mersa Matruh, Cyprus, Shikmona.
- Sicily Strait and Sardinia section.
- Southern Gulf of Lion / Eastern Menorca (towards Sardinia).
- Balearic Sea and channels (related to identification of presence of 'deep' 600 m WIW eddies and their relation to blocking of surface and intermediate waters flow). This area allows the assessment of impact on the ecosystem: for example the Bluefin tuna (*Thunnus thynnus*) spawns, each summer, south of the Balearic Islands, in proximity to the AAW/MW convergences.

• Recommendations for key areas for understanding mesoscale variability and impact on the general circulation –

For intense meandering current and baroclinic instabilities that modify the general circulation, the study of the following key areas is recommended:

- Alborán Sea / Algerian current;
- Asia Minor current.

For weak sub-basin circulation and strong mesoscale impact on general circulation, the study of the following key areas is recommended:

- Balearic Sea;
- Levantine eddies.

5. Data management, sharing and products development

Data management is likely to be the most challenging issue for the Med-SHIP Programme, in view of the richness of the data already harvested in different areas of the Basin (see Table 1) and with due consideration to the important data divide between the North and South of the Mediterranean. The deployment of new monitoring technologies [gliders, AUV's, etc.] is allowing a high resolution sampling in the north, while the south part of the basin is under sampled (see Tintoré *et al.*, this volume).

Table 1. List of Mediterranean areas, observing tools and variables under current monitoring.

Location	Monitored Area/ Process	Tools	Parameters / variables
Western Mediterranean	Gibraltar strait	Deep CTD mooring CIESM Hydrochanges Program	Temperature, salinity, current
	Balearic sea	Gliders,	Temperature salinity
		Mooring buoys	
		Radar	Surface currents
		ARGO profilers /surface drifters	Current, temperature
		RADMED time series CTD	pH, TA (*pCO2 to come*)
	Gulf of Lion	Deep CTD mooring CIESM Hydrochanges Program	Temperature, salinity, current
		buoys DYFAMED	
		Buoys (W1-M3A)	TA, pH (*pCO2 to come*)
	Corsica channel	Mooring buoys	Temperature, salinity
	Tyrrhenian sea	CTD casts	Temperature, salinity
	Sardinian channel	Deep CTD mooring CIESM Hydrochanges	Temperature, salinity, current
	Transect Marseille-Malta	Autonomous CTD on ship of opportunity (CIESM PartnerSHIPS)	Sea surface Temperature salinity
Eastern Mediterranean (Adriatic sea)	Gulf of Trieste	Surveys at Paloma site	pH, TA, biogeochemical variables
	Northern and central Adriatic	CTD + sampling survey	Temperature, salinity nutrients, disolved Oxygen
		Deep CTD mooring CIESM Hydrochanges	Temperature, salinity
	Southern Adriatic sea	Buoys (E2-M3A)	Temperature, salinity pCO2
Sicily strait		Mooring buoys	Temperature, salinity
		Deep CTD mooring CIESM Hydrochanges	
Eastern Mediterranean	Cretan sea/	Deep CTD mooring CIESM Hydrochanges	Temperature, salinity,
		M3A Buoy	pH , pCO2 (in the near future)
	(Bosphorus strait/ Marmara sea)	Ship survey - CTD cast	Temperature, salinity
	Mersa Matruh gyre	CTD +sampling survey	Temperature, salinity nutrients, dissolved Oxygen
	Cyprus eddy and Shikmona gyre	Gliders	Conductivity, Temperature, disolved oxygen, chla fluorescence, optical backscatter
	Eastern Levantine	CTD + sampling survey (CYCOFOS Buoy)	Temperature, salinity, dissolved Oxygen
	Haifa section	About 3 times a year 6 stations from Haifa westwards to 1700 m depth station Oceanographic campaigns	Temperature, salinity, pressure, dissolved oxygen, fluorescence, refraction, dissolved oxygen, inorganic nutrients (phosphate, nitrate, nitrite and silicate, total N and total P, TOC, chl a.
Western, Central and Eastern Mediterranean		MedArgo floats[1]	Current, vertical profile for temperature and some biochemical properties

[1] MedArgo float (updated position of argofloats available at http://nettuno.ogs.trieste.it/sire/medargo/active/index.php)

The general strategy proposed here is built upon the IODE/IOC/UNESCO model, with a central data assembly center, playing also the role of a communication and coordination center, as the backbone of the new regional Ocean Data infrastructure, linked to a well established ODN (Ocean Data Network), by a strong cooperation and coordination with National Oceanographic Data Committees (NODCSs). This strategy moves toward a basin-wide data capability, sharing capacity, and data management standards.

A task team shall be created to propose ways and solutions to improve technology and data policies, to release data in a more timely manner; to coordinate with other international programmes, and to propose a mechanism for products development and data synthesis (see Guerfi, this volume).

5.1 The data management and sharing policy

The data management is designed on a distributed model, where National Oceanographic Data Committees maintain control of their data resources, and are responsible for data collection, analysis, documentation, quality control (QC) archiving, and ii) the data assembly center is responsible for data merging, online dissemination and documentation, etc. The strategy of the ODN model is built to develop and improve national, sub-regional and regional capacities, with the involvement, cooperation and coordination with all hydrographic stakeholders.

The Med-SHIP panel recommends that the data-release guideline of the GO-SHIP Programme should be adopted to be in harmony with the global programme as following:

- Preliminary dataset released within 6 weeks;

- 6 months for final physical data;

- One year for final data of all other variables.

While for some countries, where frameworks for data sharing are well established, the strategy and the guidelines proposed for the global GO-SHIP Programme could be adopted without constraint, meaning quick data release, real-time or near-real time and a broader coverage - more variables exchanged (CTD, SST, salinity, etc.). Principles, to produce scientific products on a shorter time scale, should be respected-. In other Mediterranean countries, governments are still considering publicly-funded research data either as secret or as commercial commodities, so the absence of a clear policy and legislative framework at the national level can seriously disturb the effective implementation of the basin-wide data sharing objectives.

5.2 Existing data management centre/infrastructure

During the last decade, many projects/programmes related to oceanographic data and information management in the Mediterranean were conducted. These projects were both for research and/or specifically devoted to oceanographic data and information management. They allowed the establishment of a pan-Mediterranean network of data centers and specialized marine institutions. They cover in particular the European countries, with a basin-wide aspiration. They permitted the development of several oceanographic and marine metadata directories for the Mediterranean, established data format, data management quality control and standards for interconnecting the data centers, enabling the provision of integrated online access to comprehensive sets of multi-disciplinary, *in situ* and remote sensing marine data, metadata and products.

The most recent and important initiatives are:

MyOcean, the Ocean Monitoring and Forecasting component of the GMES (Global Monitoring for Environment and Security) Marine Core Service. It provides the users with the main variables needed to depict the ocean state: temperature, salinity, currents, sea level, ice coverage and thickness, or primary ecosystem characteristics.

EMODNet (European Marine Observation and Data Network) which is actually in a pilot phase and has a portal that provide users with hydrographic data collated for a number of Mediterranean regions.

SeaDataNet which is a Pan-European infrastructure for managing, indexing and providing access to ocean and marine data sets and data products, from more than 35 National Oceanographic Data

Centers (NODCs) and international organizations (IOC/UNESCO, ICES, EU-JRC) from European and Mediterranean countries.

5.3 Recommendations

Series of recommendations have been made on all aspects of data management/data sharing policy, based on the Mediterranean context summarized below:

- The creation of a data management/data policy working group to assess the development and operation of an integrated Mediterranean hydrographic network by;
  - Identifying gaps in data sharing policies, data managements practices, legal frameworks for a sustained basin-wide hydrographic programme;
  - Assessing the data management infrastructure in terms of data gathering, data management, etc.
- Establishing the link with other international programmes that already implemented infrastructure for marine and ocean data management that provide users with harmonized services, products, standards and tools - SeaDataNet, MyOcean, and EMODNet-.

6. Coordination and governance

The efficient execution of the repeat multidisciplinary international hydrographic surveys as a part of the future Med-SHIP Programme needs an overall coordination, especially to ensure that links are strong between ongoing cruises, ship surveys under national and international programmes, high frequency measurements profiles, upcoming projects, financial aspects, data analysis and integration.

Some desirable components of an efficient Med-SHIP Programme are mapped in the Figure 7 below.

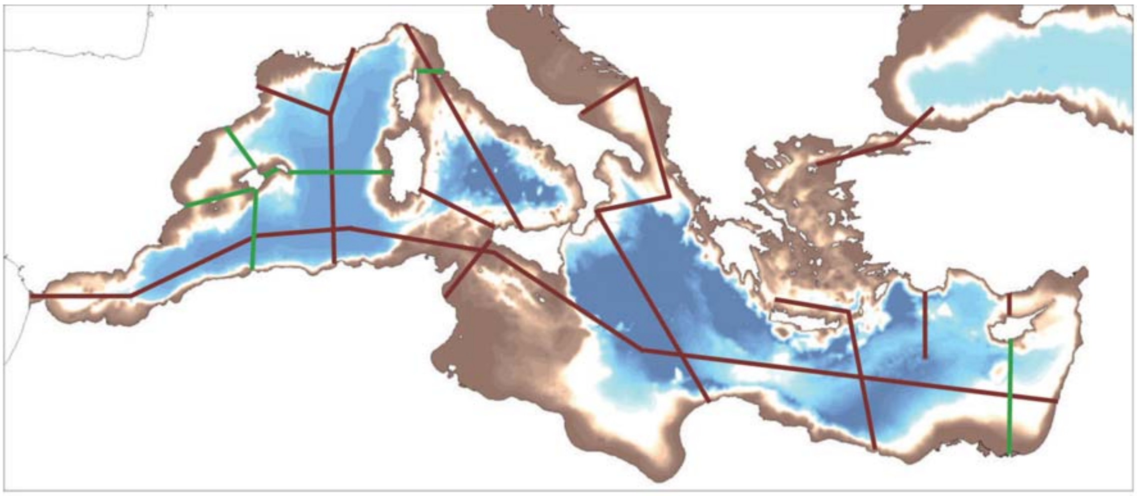

Figure 7. Desirable grid of repeated oceanographic surveys, including ship cruises (in brown) and gliders (in green).

Considering the large number of ongoing and up-coming activities including oceanographic campaigns, monitoring programmes at the national, regional or international level, the Med-SHIP Programme requires already in this phase some coordination.

More specifically the following organizational aspects should be addressed: preparation of a Memorandum of Understanding between the countries and CIESM regarding data sharing policies; data management development; coordination with existing data centers coordination with GO SHIP initiative; inventory of available resources and capabilities as well as national/international programmes (current and upcoming); design and implementation of a training programme for capacity building including trials; administrative management and dissemination of the programme; development and update of web pages dedicated to the Med-SHIP Programme on CIESM web site; coordination with large international ongoing operational oceanography activities

(MOON, MYOCEAN, etc.); preparation of the Med-SHIP Special session during the next CIESM Congress (2013) dedicated to the 2011 ship campaigns results.

In addition, scientific aspects for such a programme should be considered: synthesis of relevant scientific questions and the scientific rationale of the programme; standardization of protocols (Methodology of measurements) following GO-SHIP standards, adapted to the Mediterranean; appropriate data analysis and integration; proper presentation of scientific results and application of the publication policy; data use policy, etc.; integration of complementary/multidisciplinary data related to biogeochemistry and climate science (e.g. satellite data; precipitation records); integration to modelling and observational studies (see Rixen, this volume); synergies with modelling efforts to focus observations when and where they have the largest impact on reducing uncertainties.

I - Executive Summary

This summary, initiated during the workshop meeting, was synthesized thereafter by Miroslav Gačić and Michèle Barbier upon the basis of further inputs received from all participants, in particular Katrin Schroeder, Mokhtar Guerfi, Toste Tanhua and Nurit Kress.

Frédéric Briand, Monograph Series Editor, reviewed and edited the entire volume. Valérie Gollino was responsible for the final layout and physical production.

1. Introduction

Over the last three decades a number of Basin-wide studies have revealed dramatic and faster than expected changes in the hydrography and biogeochemistry of both Eastern and the Western Mediterranean sub-basins (see syntheses in CIESM, 2009; 2000). As long-term variability in the ocean is, most often, revealed through studying the variability of the basin-wide circulation - and more specifically the changes of the overturning circulation cell - there is a growing need to document changes in the Mediterranean Sea over the entire water column and in different regions, in order to relate them to sea level variations and climatic variations.

In opening the meeting, Frédéric Briand, Director General of the Mediterranean Science Commission, remarked how effective Miroslav Gačić, Chair of the Committee on Climate and the Ocean, had been in persuading him to convene a workshop on such issues. The eighteen scientists (see list at end of volume) gathered here at the invitation of CIESM on the charming, secluded Brac Island would have all the time and latitude necessary to seriously discuss the possible design and implementation of a coordinated program for repeated basin-wide oceanographic surveys in the Mediterranean. Before inviting Dr Gačić to detail the specific objectives of this exploratory seminar, Dr Briand expressed his gratitude to the Director of the Institute of Oceanography and Fisheries (Split), Dr Ivona Marasović, and especially to her assistant Ana Marušič, for allowing this meeting to take place in Supetar in the best possible logistic conditions.

Miroslav Gačić reminded all present that the Global Ocean Ship-based Hydrographic Investigations Programme Initiative (GO-SHIP) had been recently set up as the international response to support and coordinate a system of repeat cruises in the world's oceans (see GO-SHIP White paper[1], OceanObs-09 conference, Venice, 2009[2]). The GO-SHIP plan defines an observational system which, on roughly decadal time-scales, conducts a number of repeat hydrographic lines in all ocean basins (see Tanhua, this volume). The GO-SHIP document specifies a number of core-parameters to be measured and defines protocols and data-policy for the surveys. As part of the GO-SHIP initiative, the WOCE hydrographic manual was revised and a new set of guides of best practices for several common measurements are now accessible on the GO-SHIP website.

[1] The GO-SHIP white paper available at the GO-SHIP website: http://www.go-ship.org/
[2] The Ocean Obs white papers are available at: http://www.oceanobs09.net/proceedings/cwp/index.php

With increasing societal demand for predictions of climate change impacts on the environment and ecosystems, e.g., temperature, sea level rise, occurrence of catastrophic weather events (flash floods, hurricanes, droughts, etc.), the time had come to formulate a possible Mediterranean component - a Med-SHIP Programme - to GO-SHIP. Due to its semi-enclosed nature, the Mediterranean Sea affects the climate of the surrounding land areas, in ways without analogs in other regions of the world. The complex land-sea distribution of the Basin has a strong effect on the atmospheric circulation and its seafloor keeps records of past climate evolution. The analysis of the complex Mediterranean Sea processes and evolution is an essential step to understand the regional environment and climate.

The bathymetry of the Mediterranean Sea is composed of several sub-basins separated by straits and channels with depths ranging from a few hundred meters to more than 4,000 m. This makes this sea very sensitive to atmospheric forcing and resulting changes in seawater characteristics can reach rapidly the deep waters. *In situ* meteorological observations and data time-series are long and spatially dense enough to enable some documentation of longer-term changes, by testing and validating models (see Lionello, this volume). While recent findings indicate that Mediterranean water masses have steadily become saltier and warmer in the last decades at all depths and everywhere in the basin (CIESM HydroChanges papers http://www.ciesm.org/marine/programs/hydrochanges.htm), with rates of change varying from one sub-basin to another, the oceanographic observational system, both here and in the world ocean, is lagging much behind the meteorological system. As a result *in situ* basin-wide data are very scarce; in fact the first basin-wide surveys in the eastern Mediterranean were carried out only in the mid-1980s. Now is the time to fill such gaps.

In the Mediterranean Sea, intense but mostly localized oceanographic campaigns are being carried out within the framework of different national and international projects. The methodology used differs among the projects. Moreover new monitoring technologies such as gliders and mooring are being progressively implemented in coastal ocean observatories (Tintoré *et al.*, this volume). However, there is a lack of a unified international platform that would, similarly to GO-SHIP, coordinate the observational network in order to avoid duplications and assure sufficient coverage in time and space. The GO-SHIP approach and methodology should be applied but adapted to the Mediterranean sea that is characterized by smaller spatial and shorter temporal scales of the circulation features compared to the global ocean (see Taupier-Letage, this volume). Such a programme should also develop data syntheses products and facilitate the interpretation of hydrographic data in partnership with national, regional, and global research programmes. Thus, there is a need to establish a permanent international body, preferably under the umbrella of CIESM, which will facilitate exchange of information on national initiatives in the Mediterranean ship-borne surveys both at basin and sub-basin scales.

Subsequently, a more formal organization is envisaged that would become part of the global GO-SHIP Programme: Med-SHIP which shall promote cooperative repeat hydrographic surveys, optimize national shiptime resources, enable merging and interpretation of collected data and encourage scientists from different countries to join and cooperate during all stages, from sampling to data analysis and interpretation. In this executive summary, we present a series of recommendations for the implementation of Mediterranean basin-wide ship borne repeated surveys: the Med-SHIP Programme.

2. The Mediterranean Sea and its specificity

2.1 The Mediterranean circulation and variability

The Mediterranean Sea is a semi-enclosed marginal sea that communicates with the world ocean through the narrow and shallow Strait of Gibraltar. The Mediterranean circulation is characterized by a variability at different spatial and temporal scales, determined by a complicated bathymetry and variable spatial scales of atmospheric forcing. Basin-wide flow, as a part of the upper circulation cell driven by the negative freshwater and heat balance, is characterized by an eastward surface flow of the relatively fresh Atlantic Water (AW). Generally, this surface current shows energetic meandering, baroclinic instabilities and mesoscale activities. In the Western basin, the main process is the continuous formation of meanders and mesoscale eddies along the North

African Current. According to POEM results and other *in situ* studies (Robinson *et al.*, 2001; Malanotte-Rizzoli *et al.,* 1999), the Eastern Mediterranean, in addition to the strong mesoscale activity, is characterized by a jet of AW entering the basin and crossing the Ionian Sea. On its way toward Israeli's coast it continues meandering between several bottom-trapped or wind-driven quasi-permanent or recurrent gyres. The Levantine Intermediate Water (LIW) is formed in the area of the Rhodes Cyclonic Gyre through the vertical convection reaching intermediate depths (Hayes and Zodiatis, this volume; Özsoy and Aydoğdu, this volume). This water then in a return westward pathway reaches the Gibraltar Strait and represents the main component of the exiting Mediterranean waters. Another proposed scheme of the Eastern Mediterranean surface circulation (Taupier-Letage, 2008; Millot and Gerin, 2010) suggests that the flow pattern is mainly characterized by travelling eddies and vortices that strongly interact with the general circulation along the African coast and divert AW offshore. In the same way, mesoscale eddies entrain intermediate and deep waters deflecting them from their pathway (Millot and Taupier-Letage, 2005a).
The implementation of GO-SHIP like surveys would provide additional *in situ* data and thus a better insight into the circulation pattern in the Eastern Mediterranean, its variability and the biogeochemical properties of the Mediterranean contributing to the understanding of processes and structures.

The deep circulation cell of the Mediterranean is driven by the dense water formation processes that take place in both the Western and in the Eastern Mediterranean. In the Western Mediterranean the dense water is formed in the Gulf of Lion, facilitated by the presence of the salty LIW and generated by the cold air outbreaks associated with the Mistral events in an area of cyclonic circulation. In the Eastern Mediterranean the main dense water formation source is the Southern Adriatic, in an area characterized by the presence of the bottom-trapped basin-wide cyclonic gyre. Again the presence of the saltier waters of the Levantine origin in the intermediate layer facilitates the vertical convection, which takes place during violent air-sea heat loss events associated with the Bora (Northeasterly wind) episodes. Recent results have revealed that during the last decade alternatively the dense water was formed in the Aegean and substituted the Adriatic (Roether *et al.*, 2007). This phenomenon, named the Eastern Mediterranean Transient (EMT) (see CIESM, 2000) suggests that the mean circulation in the Mediterranean is subject to sudden changes revealing also that the time scale of the deep circulation cell is much shorter than previously thought. Recent studies showed pronounced decadal inversions in the North Ionian Gyre (NIG) that are important in determining thermohaline properties of the Adriatic as well as the pre-conditioning for the EMT. Inversions of the North Ionian Gyre are responsible for the out-of-phase behaviour of the Adriatic and Aegean as the dense water formation sites (Civitarese and Gačić, this volume) (see Figure 1).

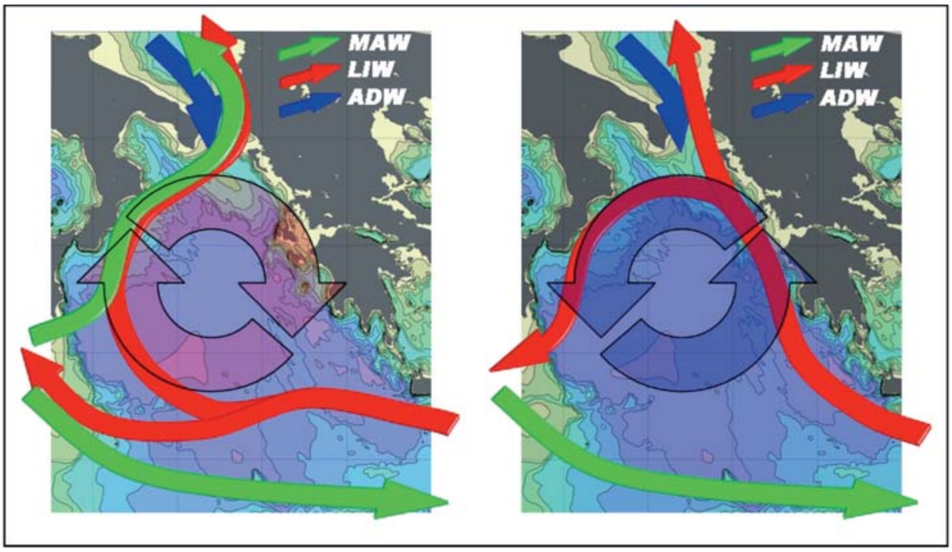

Figure 1. Example of Mediterranean complexity: circulation schemes of the two Ionian horizontal modes (Adriatic-Ionian Bi-Modal Oscillating System - BiOS) and pathways of the principal water masses after Civitarese and Gačić, this volume.

Recently, a significant warming and salinification of the whole water column in the western Mediterranean has been observed and several studies have revealed the abundant formation of a new warmer and saltier WMDW during winters 2004-2005 and 2005-2006 (Schroeder *et al.*, 2006; 2008a; 2010a; Font *et al.*, 2007). The bulk of the new WMDW, in the abyssal plain of the western Mediterranean Sea, showed temperatures of 12.85°–12.88°C and salinities of 38.455–38.473 below 2,000 m depth (Schroeder *et al.*, 2008a). Between 2004 and 2008 the new WMDW occupied a layer which reached hundreds of meters thick, with total increases of salinity and temperature of about $\Delta S = 0.024$ and $\Delta\theta = 0.042$°C, respectively, near the bottom (see profiles in Figure 2). By October 2008 the new deep water had been found everywhere in the western basin below 2,000 m depth, with the exception of the Tyrrhenian subbasin (Schroeder *et al.*, 2009). Furthermore, it has been uplifted toward the Alboran subbasin, where in 2008 it was detected along the Moroccan continental slope at depths <1,000 m. The magnitude of the replacement of the old deep water by the new deep water is clearly evident in the vertical profiles shown in Figure 2. This event has been called the Western Mediterranean Transition (WMT, CIESM, 2009).

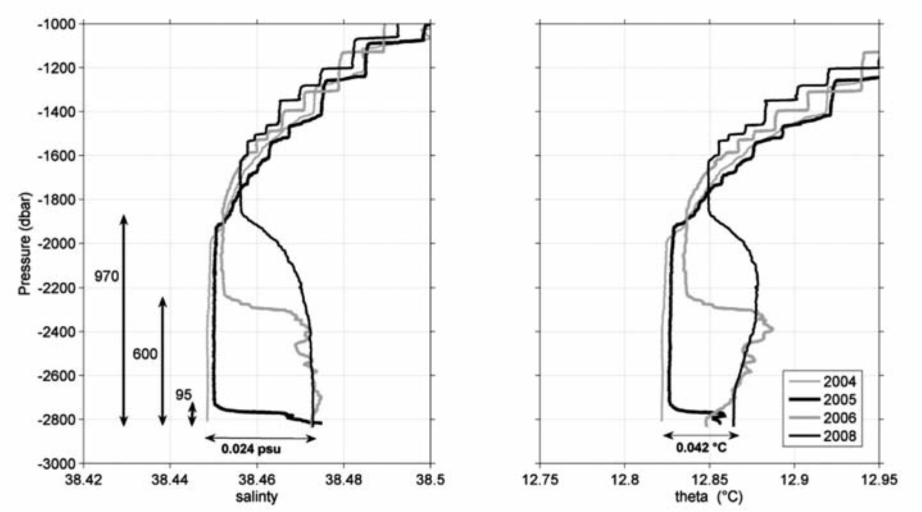

Figure 2. Vertical profiles of (left) salinity and (right) potential temperature measured at an example station in the Algerian basin (5°E, 38°N) in October 2004 (shaded thin), June 2005 (bold line), October 2006 (shaded bold line) and November 2008 (thin line). Vertical arrows indicate the thickness of the new Western Mediterranean Deep Water (WMDW) layer in the different years. Horizontal arrows indicate total salinity and temperature increase at the bottom between 2004 and 2008. From Schroeder *et al.* (2010a).

Long-term changes of the circulation pattern, especially in the Western Mediterranean, show indications of the relationship with the global scale teleconnections pattern.
Property exchange and interaction between shelf and open sea in the Mediterranean are very important and in general have been shown to take place via mesoscale eddies and, very efficiently, via bottom water sinking through canyons (Salat *et al.*, 2010).

2.2 Biogeochemical properties of the Mediterranean

Nitrate and oxygen distribution in the Mediterranean

The Mediterranean is considered an oligotrophic area. Generally, surface waters in the Mediterranean are depleted in nutrients and the thickness of this depleted layer increases eastwards from about 10 m in the Gulf of Lion to more than 100 m in the Levantine basin, more or less as nitracline and thermocline depths (Pujo-Pay *et al.*, 2011). Large phytoplankton blooms are geographically well localized and mainly associated with the physical forcing (dense water formation areas and/or cyclonic circulation pattern). In addition, important phytoplankton biomass densities are located in the Alboran anticyclonic gyres and near the coast adjacent to river mouths (D'Ortenzio and Ribera-d'Alcalà, 2009). The depth distribution of the chemical parameters in the Eastern Mediterranean changed following the EMT and continues to change through its relaxation and the re-establishment of the Adriatic as the deep water source. During the EMT the Cretan Sea

Overflow water (CSOW), that was warmer, saltier, more oxygenated and with lower nutrient concentrations than the Adriatic Deep Water (ADW) uplifted the older ADW and created a mid-depth layer with minimum oxygen (Min_{Ox}) and maximum nutrients (Max_{Nut}) in the Levantine basin and Cretan sea (Kress *et al.,* 2003). The CSOW, first noticed in the vicinity of Crete near its source, propagated initially towards the western Ionian and later towards the Levantine basin, uplifting the Min_{Ox}/Max_{Nut} layer from 1,250 m to 950 m and 750 m in the Levantine and Ionian basin, respectively, between 1995 and 2001. In 2008, this layer was centered at ca. 900 m depth in the Levantine basin, more emphasized in the eastern part and eroded towards the west. In the easternmost part of the Levantine basin, one of the last regions to be influenced by the EMT (Roether *et al.,* 2007), the CSOW was already in place in 2002, as reflected by the Min_{Ox}/Max_{Nut} at mid depth, and higher oxygen and lower nitrate concentration close to the bottom (see Kress *et al.*, this volume). Between 2002 and 2010, the Min_{Ox} vertical span narrowed and the influx of more oxygenated waters (the new, younger ADW) was more evident. The concentration of nitrate at the Max_{Nut} increased with time and shallowed (Figure 3).

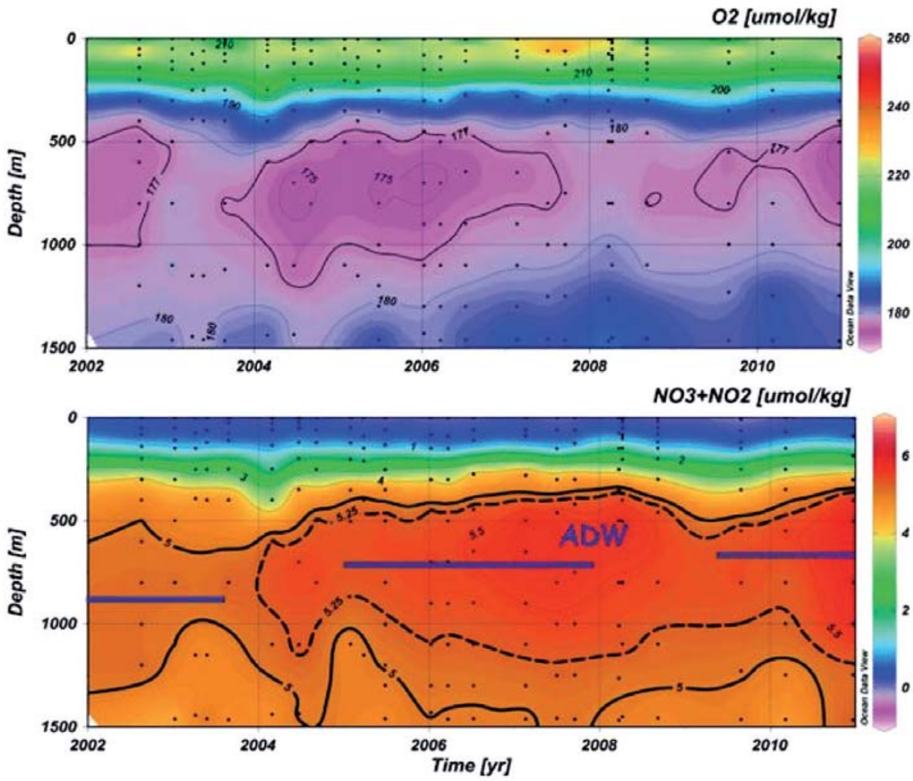

Figure 3. Temporal depth evolution of dissolved oxygen and nitrate at a station located at 33N, 34,5E. The blue line in the lower panel indicates the change in position and concentration of the maximal concentration of nitrate, corresponding to the ADW.

Carbonate system in the Mediterranean

There are only few observations of the carbonate system in the Mediterranean Sea, making it difficult to draw any conclusions on the temporal variability of the inorganic carbon at this stage. However, a recent 2011 survey repeated measurements of Dissolved Inorganic Carbon (DIC) in the Eastern Mediterranean, and a significant increase in normalized DIC (i.e. corrected to a common salinity) could be detected in the period between 2001 and 2011. However, when corrections are made for the remineralization of organic matter using changes in oxygen, only a small and mostly insignificant increase in DIC is observed. For the deepest layer in the southwest Ionian Sea a significant increase in respiration corrected DIC is noted: this is a consequence of recently formed ADW.

The Mediterranean does hold large amounts of anthropogenic carbon as a consequence of the high buffer factor and the active ventilation (Schneider *et al*., 2010). With the assumption that the anthropogenic carbon (C_{ant}) behaves like an inert gas, its distribution can be calculated with the "transit time distribution" (TTD) method from observations of transient tracers. Figure 5 shows the C_{ant} concentrations calculated from the TTD method for 2001 and 2011 for a zonal section in the Eastern Mediterranean Sea. An increase of C_{ant} calculated with the TTD method is equivalent to active ventilation. Figure 5 shows the signal of active ventilation in the western Ionian Sea, whereas the Cant concentration in the deeper layer of the Levantine Basin is very similar in 2001 and 2011, indicating a slowdown of deep ventilation in this area. This is consistent with the direct observations of changes in respiration corrected DIC (Figure 4). Figures 4 and 5 demonstrate the value of repeat observations of transient tracers and DIC in the Mediterranean Sea.

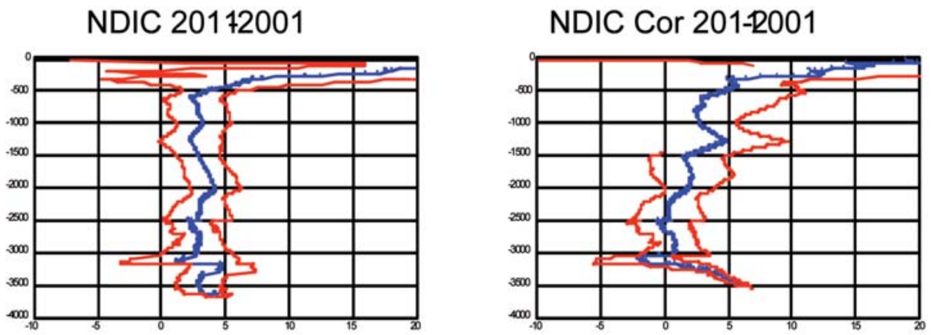

Figure 4. Changes in Dissolved Inorganic Carbon (DIC) between 2001 and 2011 in the Eastern Mediterranean Sea. Left panel shows changes in salinity corrected DIC, and the right panel a correction for respiration (from Alvarez, pers. comm.).

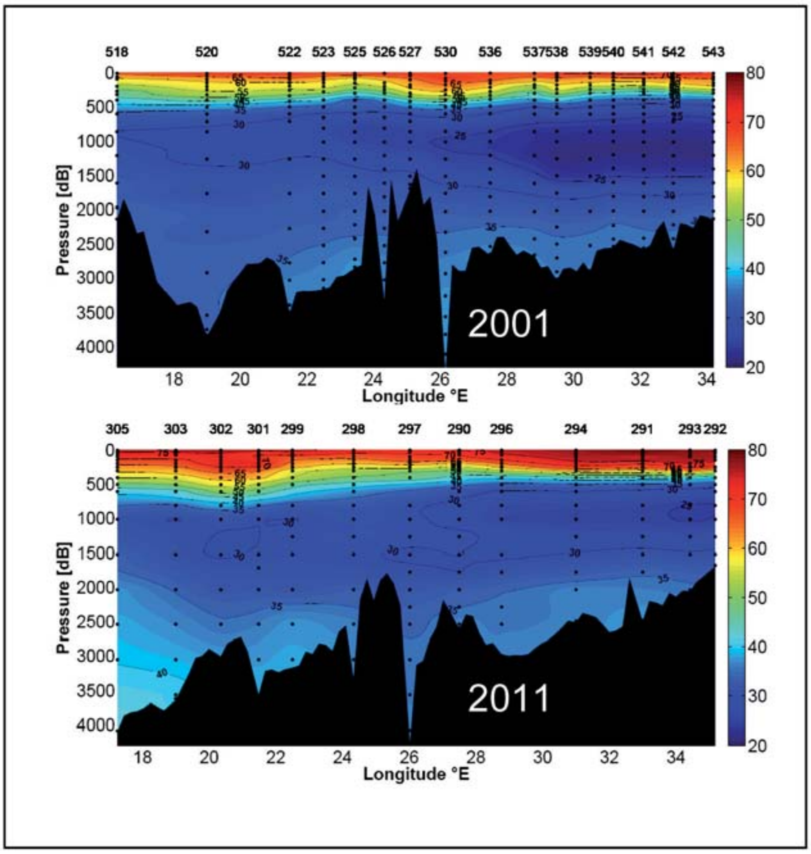

Figure 5. Anthropogenic carbon in the Eastern Mediterranean Sea in 2001 (top panel) and 2011 (bottom panel) calculated with the TTD method from observations of CFC-12 and SF6 (Stöven, 2011).

3. Objectives and significance of the Med-SHIP Programme

The Med-SHIP Programme aims at documenting and understanding the physical and biogeochemical water property distributions, their long term variations, and drivers at decadal and sub-decadal scales within the Mediterranean Sea, including physical and biogeochemical properties.

The specific objectives of this programme are to:

- Determine the long term variability and controls of water mass properties;
- Determine changes in circulation patterns and ventilation rates;
- Determine the variability of natural and anthropogenic carbon, and other biogeochemical properties;
- Reduce uncertainty in the heat, freshwater and property budgets, and sea-level;
- Augment the historical database of full water column observations necessary for understanding the Mediterranean Sea variability on multiple timescales and for numerical model evaluation.

The strength of the Med-SHIP Programme is in the long term, repeated, sustainable basin-wide surveys, that will complement the more frequent but localized studies. It shall include systematic long-term measurements, further optimize ship-time resources, integrate data collection, analysis, interpretation and management including dissemination through central coordination and governance. The implementation of such coordinated surveys would provide further insight into the circulation pattern, its variability and the associated changes in the biogeochemical properties of the Mediterranean.

4. Recommendations for the implementation of the Med-SHIP Programme

In order to address the complexity and the main scales/processes occurring in the Mediterranean Sea, recommendations are presented here for an efficient Med-SHIP Programme. The survey should consist of three components:

- Basin-wide half decadal (sub-decadal) zonal surveys;
- Cross-basin (north-south) transect at two-three years intervals;
- Higher frequency surveys using different platforms (e.g. ships gliders and floats mainly) at sub-basin and the mesoscale in order to follow the variability of structures/processes that influence the basin scale circulation and THC.

As reported by Tanhua (this volume) and Taupier-Letage (this volume), it is reasonable to suggest that a somewhat more intense observational programme is needed in the Mediterranean compared to the world ocean programme (GO-SHIP). The zonal transect, repeated on a low-frequency basis and including the full suite of the GO-SHIP core parameters, would allow to assess long-term variations of heat and freshwater budgets (and their steric influence on sea-level) and to compute basin-wide inventories of natural and anthropogenic carbon in the Mediterranean, with a focus on its deeper layers, being less subject to small (time/space) scale variability. But, the Mediterranean is a coastal ocean with open ocean characteristics (Tintoré *et al.,* this volume; Robinson *et al*., 2001), where the circulation is not driven by basin scale forcings, but by intense, variable and diverse subbasin forcings. With this in mind the high-frequency repetition of subbasin, meridional transect, including a subset of the GO-SHIP core parameters, is essential to capture the observed degrees of variability.
In addition, an integration of all other important on-going programmes will provide higher spatial and temporal resolution than the one set up by ordinary Med-SHIP cruises. More specifically, remotely sensed data will be essential for resolving smaller scale features. In addition, the HydroChanges network of moored CTDs sponsored by CIESM as well as the installation of low-cost autonomous thermosalinometers on ships of opportunity will allow the monitoring at high temporal resolution (~weekly) of the temperature and salinity of the sea surface, and provide a synoptic picture at basin scale (see Taupier-Letage, this volume).

4.1 Basin wide (sub-decadal) surveys – Recommendations for full water column ship-based long term observations in the Mediterranean Sea

Two types of repeated hydrographic surveys shall be envisaged, further combined with other platforms, specifically with gliders, for studies of mesoscale variability:

- High-frequency lines (3 years), generally North-South;

- Low-frequency line (6 years), East-West hydrographic transect.

• Recommendations on transects –

Backbone activities will mainly be carried out at these two types of transects which shall be integrated with existing sampling at higher spatial and temporal resolution.
The optimal surveys are drafted on the map below.

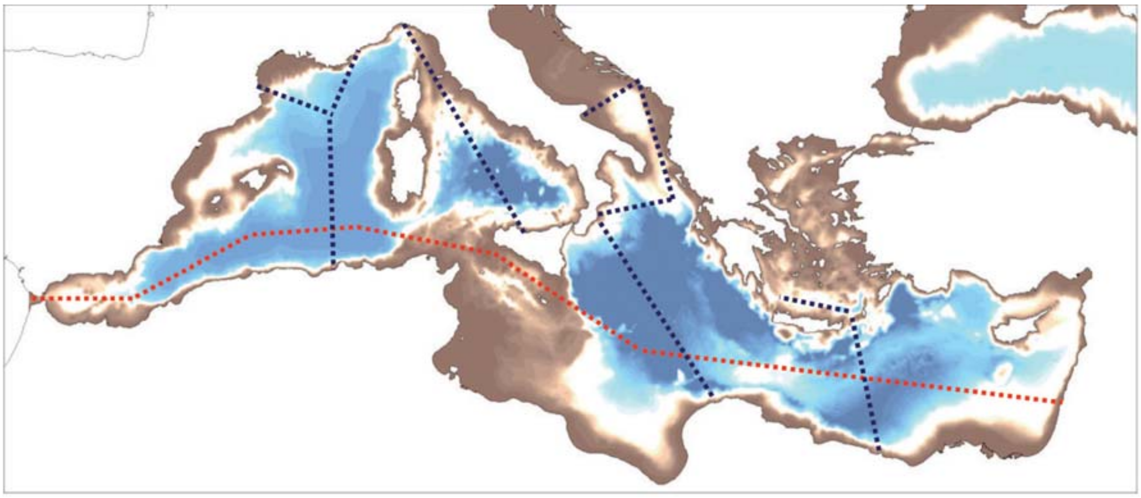

Figure 6. Proposed Med-SHIP survey transects with north-south high-frequency lines (every 3 years) in blue, and east-west low-frequency line (every 6 years) in red.

It is recommended that spacing between stations should be 30 nm but reduced to 10 nm in the vicinity of sharp bathymetry. Full chemistry stations should be designed at least every 60 nm but adapted in sharp bathymetry areas. The preferred period for sampling would be in August-October. The surveys shall include the entire water column since the deep Mediterranean circulation is strongly impacted by processes that take part in the upper part of the water column and thus cannot be excluded in this study. Note that all of the lines are designed to reoccupy long-term monitored stations and cruises, both deep stations (GEOSECS, SESAME (Adios, Haifa), DYFAMED, etc.), coastal monitoring stations or ship of opportunity tracks.

• Recommendations on key parameters measurements – *In situ* continuous profiles core measurements should include temperature, salinity, pressure, dissolved oxygen and fluorescence. Refraction and Photosynthetically Active Radiation (PAR) are recommended.

Water column sampling at designated stations should include the full chemistry of:

- Dissolved oxygen;

- Inorganic nutrients (phosphate, nitrate, nitrite (separately if possible and if not nitrate+nitrite and silicate). Measurements to nanomolar levels are recommended for the upper water column;

- CO_2 variables (preferred are measurements of alkalinity and total inorganic carbon, measurements of pH is an alternative);

- Transient tracers such as CFCs, SF_6.

Additional recommended variables are organic carbon, nitrogen and phosphorous, chlorophyll *a*, HLPC pigments, flow cytometry.

Stations should be complemented by underway sampling measurements:

- Meteorological variables;
- Thermosalinograph;
- Aerosols;
- *In situ* underway CO_2 measurements;
- Fluorometer;
- Hull-mounted ADCP for current profiles.

4.2 Sub basin/mesoscale survey – Recommendation for high frequency sub-basin surveys

Zonal backbone basin-wide transects will add on existing activities as well as on small scale national surveys. Specific attention will be paid to the integration of glider data and data collected during both high-frequency lines and the low-frequency east-west hydrographic transect. Especially, the incorporation of gliders should be an important contribution to the Med-SHIP initiative. Data collected during the two types of cruises will also be integrated with measurements from all available platforms.

• Recommendations for key process study areas for understanding the variability of water masses, ventilation and impact on basin-wide circulation –

To document the effects of deep and intermediate waters (DW and IW) on circulation and biogeochemical variability at basin and sub-basin scale, the study of the following key sub-basins/processes is recommended:

- BIOS/EMT as an example of Mediterranean complexity in the Ionian Sea/Otranto Strait and Cretan passage (anticyclonic mode: AW enters Adriatic increasing buoyancy cyclonic mode: the AW feeds directly the Levantine and the Aegean). Study of the impact on the ecosystem and biochemical features.
- Cretan Sea.
- Levantine eddies/gyres: Rhodes, Mersa Matruh, Cyprus, Shikmona.
- Sicily Strait and Sardinia section.
- Southern Gulf of Lion / Eastern Menorca (towards Sardinia).
- Balearic Sea and channels (related to identification of presence of 'deep' 600 m WIW eddies and their relation to blocking of surface and intermediate waters flow). This area allows the assessment of impact on the ecosystem: for example the Bluefin tuna (*Thunnus thynnus*) spawns, each summer, south of the Balearic Islands, in proximity to the AAW/MW convergences.

• Recommendations for key areas for understanding mesoscale variability and impact on the general circulation –

For intense meandering current and baroclinic instabilities that modify the general circulation, the study of the following key areas is recommended:

- Alborán Sea / Algerian current;
- Asia Minor current.

For weak sub-basin circulation and strong mesoscale impact on general circulation, the study of the following key areas is recommended:

- Balearic Sea;
- Levantine eddies.

5. Data management, sharing and products development

Data management is likely to be the most challenging issue for the Med-SHIP Programme, in view of the richness of the data already harvested in different areas of the Basin (see Table 1) and with due consideration to the important data divide between the North and South of the Mediterranean. The deployment of new monitoring technologies [gliders, AUV's, etc.] is allowing a high resolution sampling in the north, while the south part of the basin is under sampled (see Tintoré *et al.*, this volume).

Table 1. List of Mediterranean areas, observing tools and variables under current monitoring.

Location	Monitored Area/ Process	Tools	Parameters / variables
Western Mediterranean	Gibraltar strait	Deep CTD mooring CIESM Hydrochanges Program	Temperature, salinity, current
	Balearic sea	Gliders,	Temperature salinity
		Mooring buoys	
		Radar	Surface currents
		ARGO profilers /surface drifters	Current, temperature
		RADMED time series CTD	pH, TA (*pCO2 to come*)
	Gulf of Lion	Deep CTD mooring CIESM Hydrochanges Program	Temperature, salinity, current
		buoys DYFAMED	
		Buoys (W1-M3A)	TA, pH (*pCO2 to come*)
	Corsica channel	Mooring buoys	Temperature, salinity
	Tyrrhenian sea	CTD casts	Temperature, salinity
	Sardinian channel	Deep CTD mooring CIESM Hydrochanges	Temperature, salinity, current
	Transect Marseille-Malta	Autonomous CTD on ship of opportunity (CIESM PartnerSHIPS)	Sea surface Temperature salinity
Eastern Mediterranean (Adriatic sea)	Gulf of Trieste	Surveys at Paloma site	pH, TA, biogeochemical variables
	Northern and central Adriatic	CTD + sampling survey	Temperature, salinity nutrients, disolved Oxygen
		Deep CTD mooring CIESM Hydrochanges	Temperature, salinity
	Southern Adriatic sea	Buoys (E2-M3A)	Temperature, salinity pCO2
Sicily strait		Mooring buoys	Temperature, salinity
		Deep CTD mooring CIESM Hydrochanges	
Eastern Mediterranean	Cretan sea/	Deep CTD mooring CIESM Hydrochanges	Temperature, salinity,
		M3A Buoy	pH , pCO2 (in the near future)
	(Bosphorus strait/ Marmara sea)	Ship survey - CTD cast	Temperature, salinity
	Mersa Matruh gyre	CTD +sampling survey	Temperature, salinity nutrients, dissolved Oxygen
	Cyprus eddy and Shikmona gyre	Gliders	Conductivity, Temperature, disolved oxygen, chla fluorescence, optical backscatter
	Eastern Levantine	CTD + sampling survey (CYCOFOS Buoy)	Temperature, salinity, dissolved Oxygen
	Haifa section	About 3 times a year 6 stations from Haifa westwards to 1700 m depth station Oceanographic campaigns	Temperature, salinity, pressure, dissolved oxygen, fluorescence, refraction, dissolved oxygen, inorganic nutrients (phosphate, nitrate, nitrite and silicate, total N and total P, TOC, chl a.
Western, Central and Eastern Mediterranean		MedArgo floats[1]	Current, vertical profile for temperature and some biochemical properties

[1] MedArgo float (updated position of argofloats available at http://nettuno.ogs.trieste.it/sire/medargo/active/index.php)

The general strategy proposed here is built upon the IODE/IOC/UNESCO model, with a central data assembly center, playing also the role of a communication and coordination center, as the backbone of the new regional Ocean Data infrastructure, linked to a well established ODN (Ocean Data Network), by a strong cooperation and coordination with National Oceanographic Data Committees (NODCSs). This strategy moves toward a basin-wide data capability, sharing capacity, and data management standards.

A task team shall be created to propose ways and solutions to improve technology and data policies, to release data in a more timely manner; to coordinate with other international programmes, and to propose a mechanism for products development and data synthesis (see Guerfi, this volume).

5.1 The data management and sharing policy

The data management is designed on a distributed model, where National Oceanographic Data Committees maintain control of their data resources, and are responsible for data collection, analysis, documentation, quality control (QC) archiving, and ii) the data assembly center is responsible for data merging, online dissemination and documentation, etc. The strategy of the ODN model is built to develop and improve national, sub-regional and regional capacities, with the involvement, cooperation and coordination with all hydrographic stakeholders.

The Med-SHIP panel recommends that the data-release guideline of the GO-SHIP Programme should be adopted to be in harmony with the global programme as following:

- Preliminary dataset released within 6 weeks;

- 6 months for final physical data;

- One year for final data of all other variables.

While for some countries, where frameworks for data sharing are well established, the strategy and the guidelines proposed for the global GO-SHIP Programme could be adopted without constraint, meaning quick data release, real-time or near-real time and a broader coverage - more variables exchanged (CTD, SST, salinity, etc.). Principles, to produce scientific products on a shorter time scale, should be respected-. In other Mediterranean countries, governments are still considering publicly-funded research data either as secret or as commercial commodities, so the absence of a clear policy and legislative framework at the national level can seriously disturb the effective implementation of the basin-wide data sharing objectives.

5.2 Existing data management centre/infrastructure

During the last decade, many projects/programmes related to oceanographic data and information management in the Mediterranean were conducted. These projects were both for research and/or specifically devoted to oceanographic data and information management. They allowed the establishment of a pan-Mediterranean network of data centers and specialized marine institutions. They cover in particular the European countries, with a basin-wide aspiration. They permitted the development of several oceanographic and marine metadata directories for the Mediterranean, established data format, data management quality control and standards for interconnecting the data centers, enabling the provision of integrated online access to comprehensive sets of multi-disciplinary, *in situ* and remote sensing marine data, metadata and products.

The most recent and important initiatives are:

MyOcean, the Ocean Monitoring and Forecasting component of the GMES (Global Monitoring for Environment and Security) Marine Core Service. It provides the users with the main variables needed to depict the ocean state: temperature, salinity, currents, sea level, ice coverage and thickness, or primary ecosystem characteristics.

EMODNet (European Marine Observation and Data Network) which is actually in a pilot phase and has a portal that provide users with hydrographic data collated for a number of Mediterranean regions.

SeaDataNet which is a Pan-European infrastructure for managing, indexing and providing access to ocean and marine data sets and data products, from more than 35 National Oceanographic Data

Centers (NODCs) and international organizations (IOC/UNESCO, ICES, EU-JRC) from European and Mediterranean countries.

5.3 Recommendations

Series of recommendations have been made on all aspects of data management/data sharing policy, based on the Mediterranean context summarized below:

- The creation of a data management/data policy working group to assess the development and operation of an integrated Mediterranean hydrographic network by;
  - Identifying gaps in data sharing policies, data managements practices, legal frameworks for a sustained basin-wide hydrographic programme;
  - Assessing the data management infrastructure in terms of data gathering, data management, etc.
- Establishing the link with other international programmes that already implemented infrastructure for marine and ocean data management that provide users with harmonized services, products, standards and tools - SeaDataNet, MyOcean, and EMODNet-.

6. Coordination and governance

The efficient execution of the repeat multidisciplinary international hydrographic surveys as a part of the future Med-SHIP Programme needs an overall coordination, especially to ensure that links are strong between ongoing cruises, ship surveys under national and international programmes, high frequency measurements profiles, upcoming projects, financial aspects, data analysis and integration.

Some desirable components of an efficient Med-SHIP Programme are mapped in the Figure 7 below.

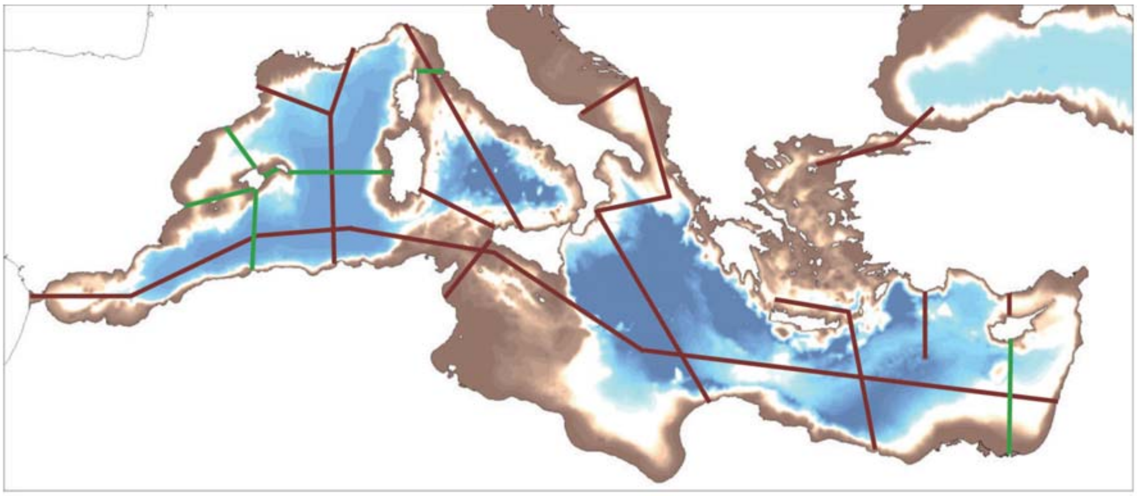

Figure 7. Desirable grid of repeated oceanographic surveys, including ship cruises (in brown) and gliders (in green).

Considering the large number of ongoing and up-coming activities including oceanographic campaigns, monitoring programmes at the national, regional or international level, the Med-SHIP Programme requires already in this phase some coordination.

More specifically the following organizational aspects should be addressed: preparation of a Memorandum of Understanding between the countries and CIESM regarding data sharing policies; data management development; coordination with existing data centers coordination with GO SHIP initiative; inventory of available resources and capabilities as well as national/international programmes (current and upcoming); design and implementation of a training programme for capacity building including trials; administrative management and dissemination of the programme; development and update of web pages dedicated to the Med-SHIP Programme on CIESM web site; coordination with large international ongoing operational oceanography activities

(MOON, MYOCEAN, etc.); preparation of the Med-SHIP Special session during the next CIESM Congress (2013) dedicated to the 2011 ship campaigns results.

In addition, scientific aspects for such a programme should be considered: synthesis of relevant scientific questions and the scientific rationale of the programme; standardization of protocols (Methodology of measurements) following GO-SHIP standards, adapted to the Mediterranean; appropriate data analysis and integration; proper presentation of scientific results and application of the publication policy; data use policy, etc.; integration of complementary/multidisciplinary data related to biogeochemistry and climate science (e.g. satellite data; precipitation records); integration to modelling and observational studies (see Rixen, this volume); synergies with modelling efforts to focus observations when and where they have the largest impact on reducing uncertainties.

Ideas for a repeat hydrography program in the Mediterranean Sea based on the GO-SHIP framework

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Circulation of the Mediterranean Sea

The overturning circulation of the Mediterranean Sea can be described schematically as an open thermohaline cell with two closed secondary cells, one for the western and one for the eastern Mediterranean Sea. The main cell transforms the inflowing Atlantic water at the surface to the outflowing Levantine Intermediate Water (LIW), which flows westwards at depths between 200 and 500 m and leaves the Mediterranean Sea through the Strait of Gibraltar. The secondary cells describe the transformation of surface and intermediate waters to the Western and Eastern Mediterranean Deep Water, which takes place in the Gulf of Lion and the Adriatic Sea, respectively, when chilly winds cool the high salinity surface waters. The Western and Eastern Mediterranean Deep Waters (WMDW and EMDW) flow near the bottom into the two main basins where they slowly upwell and mix with overlying water. The deep water renewal time has been estimated to be 20 - 40 years in the western basin (Stratford *et al.*, 1998) and about 100 years in the eastern basin (Roether *et al.*, 1996; Stratford and Williams, 1997; Stratford *et al.*, 1998). The mean age (calculated with the TTD method from CFC-12 data) of the deep waters in the Eastern Basin is in the order of 60 years in the deep water, with the oldest waters at about 1000 meters depth in the eastern extreme of the basin (Schneider *et al.*, 2010).

The outflow of Mediterranean waters into the Atlantic Ocean supports a water layer or high salinity and temperature present over much of the North Atlantic at intermediate depths, the Mediterranean Overflow Water (MOW). The characteristics of the MOW has direct implications for the stability of the North Atlantic Meridional Overturning Circulation, and rises the possibility of feedback mechanisms that, on different time-scales, may have direct climatic implications for the region and, potentially, over larger areas (e.g. Ulbrich *et al.*, 2006). During recent decades significant changes in the circulation and ventilation of the Mediterranean Sea have been observed (e.g. Tsimplis *et al.*, 2006). However, little is known of the effects on the biogeochemistry of the Mediterranean system, and the possible implications for climate relevant feedback mechanisms. The Mediterranean Sea is evidently not in steady-state, and is potentially sensitive to climatic changes. Monitoring the evolution of the circulation, ventilation and the impact on biogeochemistry is an essential part of climate observations.

The last few decades have seen dramatic changes in the circulation of the Mediterranean Sea. This is manifested amongst others as a shift of deep water formation from the Adriatic to the Aegean Sea, and back again to the Adriatic. The deep water formed from these two sources has different properties of salinity and temperature and a different biogeochemical signature.

The characteristics of the Mediterranean Sea are such that it has the potential to sequester large amounts of anthropogenic CO_2, C_{ant}, (i.e. high alkalinity and temperature and an active overturning circulation). In fact, the column inventories of C_{ant} are higher in the Mediterranean than anywhere else in the world ocean (Schneider *et al.*, 2010), and the C_{ant} storage in the Mediterranean is a significant portion of the anthropogenic emissions of CO_2. However, few carbon data exist in the Mediterranean Sea, and very little is known about how the recent changes in circulation has affected the storage rate of C_{ant}.

Repeat hydrography

The following section is extracted and only slightly modified from the GO-SHIP white paper that was presented at the OceanObs'09 meeting in Venice in 2009 (Hood *et al.*, 2010, available at http://www.go-ship.org/Documents.html#CWPs), and serves as a back ground document for the discussion on the development of a GO-SHIP style program in the Mediterranean Sea.

Despite numerous technological advances over the last several decades, ship-based hydrography remains the only method for obtaining high-quality, high spatial and vertical resolution measurements of a suite of physical, chemical, and biological parameters over the full water column. Ship-based hydrography is essential for documenting ocean changes throughout the water column, especially for the deep ocean below 2 km (52% of global ocean volume). Hydrographic measurements are needed to:

- reduce uncertainties in global freshwater, heat, property and sea-level budgets,
- determine the distributions and controls of natural and anthropogenic carbon (both organic and inorganic),
- determine ocean ventilation and circulation pathways and rates using chemical tracers,
- determine the variability and controls in water mass properties and ventilation,
- determine the significance of a wide range of biogeochemically and ecologically important properties in the ocean interior, and
- maintain the historical database of full water column observations necessary for the study of long-timescale changes.

These results will be critical for evaluating ocean models and providing data constraints for state estimation, assimilation and inverse models. In addition, ship-based hydrographic measurements provide a guaranteed standard for validating new autonomous sensors and a reference/calibration data set for other observing system elements (in particular Argo profiling floats, expendable bathythermographs and gliders). Hydrography cruises also provide cost-effective access to remote ocean areas for the deployment of these instruments.

The first attempt at a global hydrographic survey took place during the International Geophysical Year (1957-1958), but only in the Atlantic was a systematic high-quality survey conducted (King *et al.*, 2001). Geochemical Ocean Sections Study (GEOSECS) did provide hydrographic surveys in all three major ocean basins (Atlantic 1972-73, Pacific 1973-74, and Indian (plus two stations in the Mediterranean Sea 1977-78), but focused on the chemistry without providing high-resolution coast to coast transects. It was not until the decade of the 1990s that the World Ocean Circulation Experiment (WOCE) conducted an extensive survey of hydrographic properties and circulation in the global ocean in an effort to develop a global picture of ocean properties that was as synoptic as possible. In collaboration with the WOCE global survey, the Joint Global Ocean Flux Study (JGOFS) ensured that carbon measurements were made on a majority of the cruises. The WOCE/JGOFS effort led to numerous scientific advances in understanding the physical and biogeochemical state of the global ocean.

While WOCE and JGOFS were successful in answering many first-order questions about large-scale ocean circulation and carbon inventories, results also raised many new questions concerning ocean variability and controls on carbon and tracer inventories and distributions. These programs confirmed that the ocean is not evolving with smooth decadal trends that can be detected in a straightforward manner as part of patterns of global change. WOCE and JGOFS, along with many other studies conducted over the last two decades, demonstrated that the effect of climate variability on the ocean is substantial, but poorly understood, and that the next generation of hydrographic surveys would need to be designed to examine the drivers and impacts of this variability.

The GO-SHIP program

Two types of surveys are presently required to meet scientific objectives: (1) decadal surveys and (2) a sub-set of the decadal survey lines sampled at high-frequency (repeats every 2-3 years); ideally, repeats of lines sampled in the past decade. To capture the change within a quarter or shorter period of the decadal timescale, the-decadal repeat survey requires full basin synopticity over a < 3 year period.

Ideally, core program lines for the decadal repeats should measure temperature, salinity, pressure, nitrate + nitrite (with clear reporting of what was measured), phosphate, silicate, oxygen, chlorofluorocarbon tracers (CFC-11, -12), shipboard and lowered ADCP, and at least two carbon parameters (e.g., DIC, Alk, pCO_2, pH). DIC and ALK are the preferred pair of carbon parameters, but spectrophotometric pH is a useful third parameter because of high measurement precision and growing interest in ocean acidification.

There were no WOCE/JGOFS hydrographic line in the Mediterranean Sea during the global survey in the 1990s, and only two Mediterranean stations (from the GEOSECS survey) are included in the GLODAP data collection (Key *et al.*, 2004). In an effort to increase the availability of high quality carbon relevant data in the Atlantic Ocean, the CARINA data collection was released in 2009 (Key *et al.*, 2010), but only one cruise was available for the Mediterranean Sea. The data base Medar/Medatlas II contains a wealth of data for the Mediterranean Sea, including nutrient, oxygen, alkalinity and pH, although it contains neither dissolved inorganic carbon (DIC) data nor transient tracer data, and the pH data lacks information on scale and reference temperature.

Rapid release of data is a key component of the GO-SHIP idea: “While it is important to protect the individual scientific interests and investment of effort by investigators, evolving towards a more operational system will be essential for justifying a sustained program with national funding support, and closer coordination with the operational programs may require some changes to data release practices”.

At present, the GO-SHIP panel recommends the following data release guidelines:

- preliminary dataset released within six weeks (e.g. all data measured on the ship),
- six months for final physical data,
- one year for final data of everything else (except for isotopes or tracers with shoreside analysis where one year is difficult).

Similar guidelines for a repeat hydrography program in the Mediterranean Sea are essential for justifying the costs, and to optimize the benefits of the program. The establishment of a recognized data acquisition centre is important for the success of a Med-GOSHIP program.

The GO-SHIP panel sees the need of data synthesis activities on a regular basis (e.g. MEDATLAS) but stresses that the “traditional 10 year approach” in producing these products is not enough: “A repeat hydrography program will need to continually justify its value through publications and data products, and while analyses of individual and small groups of investigators will play a valuable role in this regard, development of a mechanism for data syntheses should also help to address these needs.”

One essential task for GO-SHIP panel was the revision of the WOCE hydrographic manual to reflect the improvements in technology since the WOCE era. This task is now completed and the manual can be found on the GO-SHIP website. It is strongly recommended that any future Med-GOSHIP program adheres to those guidelines.

Ideas for a sampling strategy in the Mediterranean Sea

Since the Mediterranean is well ventilated and is documented to undergo significant changes on decadal or sub-decadal time scales, it is reasonable to suggest that a somewhat more intense observation program in the Mediterranean compared to the world ocean in general (the GO-SHIP plan suggests also more frequent sampling at key high latitude areas and in the western boundaries). Sub-decadal synoptic surveys are clearly needed to monitor the Mediterranean Sea in a systematic way. However, for several of the biogeochemical parameters, signals of changes are sometimes below detection limit on sub-decadal scales. The full biogeochemical sampling program with all the core-parameters should be conducted at least on a decadal scale.

One suggestion for a Med GO-SHIP sampling strategy could rest on two bases: 1) bi-annual synoptic observations, potentially with a somewhat reduced set of parameters, and 2) decadal repeats with full biogeochemistry program.

1) High frequency (bi-annual?) repeats: These surveys should, in addition to physical parameters, at a minimum include measurements of oxygen and nutrients; transient tracers would be beneficial as would measurements of the carbonate system. These survey could be with high horizontal resolution so that two (or more) synoptic cruises will be needed, one for the eastern basin and one for the western basin.

2) Decadal repeats: On these repeats the full suite of the GO-SHIP core parameters should be measured. This could be done with a slightly less horizontal resolution and cover all the main areas of the Mediterranean Sea, and ideally a few stations west of the Gibraltar Strait. Ideally, the high frequency repeats should be conducted together with the Decadal repeat to provide a more complete synoptic picture.

3) Choke points: Detailed studies with seasonal resolution on key choke points, such as the Gibraltar Strait, Strait of Sicily, Otranto Strait etc. (frequent lines, fixed observatories, etc.). This point could potentially fit better under another umbrella than Med GO-SHIP, but would provide essential information to the Mediterranean observing system.

4) The use of gliders equipped with oxygen sensors (and additional biogeochemical sensors as they become available) to frequently occupy the bi-annual repeats would be a great contribution to an observation program in the Mediterranean Sea, providing information on timing of events and a better understanding of small scale events.

Where to sample

Figure 1 shows a map with suggestions for a decadal repeat line (red dots) and for high frequency repeat lines (green dots). These positions, distance between stations, etc., should be taken only as a starting point for further discussions. There is a sometimes conflicting rationale between keeping a fixed distance between stations (GO-SHIP recommends 30 nm, with full chemistry every 60 nm) and the wish to repeat previously occupied stations.

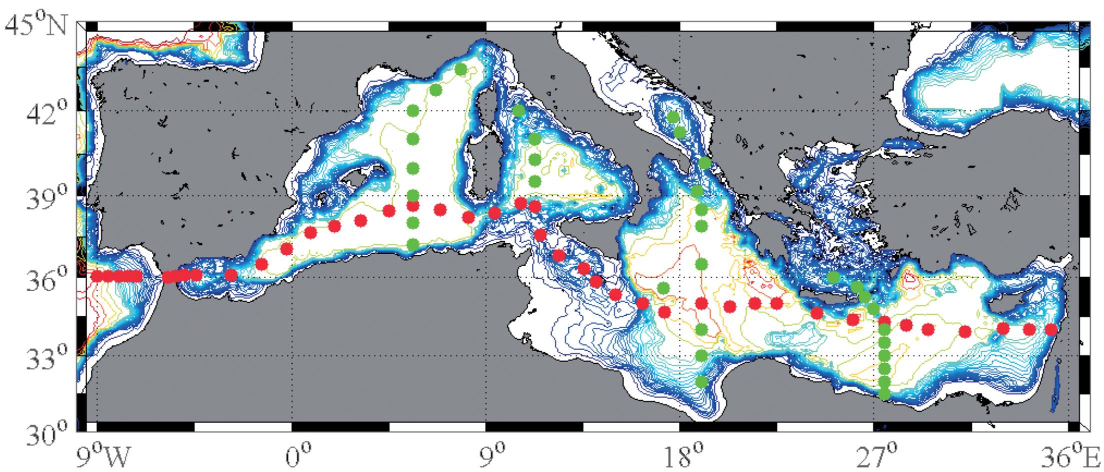

Figure 1. Proposed track for the Decadal Survey.

Considerations should be given to:

- already existing sections where data exist on which repeat observations can be built on,
- topography so that important deep channels, sills, etc., are considered,
- the main deep basins needs to be sampled,
- political context as some areas will be potentially more difficult to obtain permission for.

A Med SHIP effort: spatio-temporal considerations, parameter recommendations and complementarities with other observing systems

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Abstract

Ensuring repeated basin-wide surveys for climate studies is a challenge in the Mediterranean, owing to the diversity of stakeholders, uncertain resources, changing geopolitical landscape and time-evolving scientific priorities. The opportunity of a Med SHIP initiative is considered under the angle of relevant spatio-temporal sampling scales, critical parameters and complementarities with other observing systems. Recommendations for cost-effective monitoring strategies to maximize possible leveraging are made to ensure long-term quality records which meet climate studies requirements. Synergies with the modeling community are also suggested to fine-tune some of these efforts.

1. Introduction

The Mediterranean Sea is a semi-enclosed basin which represents an ideal laboratory for the study of oceanic processes of global importance, endowed moreover with a geographic configuration that makes possible intensive field work and advanced numerical modeling. Moreover, the coastal areas are characterized by wide and narrow shelves with important interactions with the open ocean.

Despite the semi-enclosed nature of this basin, the Mediterranean Sea is highly reactive to external forcings at the air-sea interface and at the open-sea boundaries (e.g. Rixen *et al.*, 2005) and exhibits hence a relative small inertia due to the short residence time of water masses. This region, which has been identified as a “hotspot” for climate change, is therefore expected to experience environmental impacts that are considerably greater than those in many other places around the world. These natural pressures interact with demographic and economic developments occurring heterogeneously in the coastal zone, making the Mediterranean even more sensitive. Global change, natural variability and anthropogenic pressure are expected to significantly affect the Mediterranean Sea’s physical and biogeochemical cycles, ecosystems, biodiversity and socio-economics.

The oceanic processes to be observed include among others the physics and dynamics underlying air-sea exchanges of momentum, heat, moisture and greenhouse gases; basin-scale thermohaline circulations with possible multiple equilibria; sub-basin scale wind-driven circulations and their seasonal, interannual and decadal variability; jet current instabilities and the generation and energetics of the mesoscale eddy field; the physics of convection and intermediate and deep water mass formation, spreading and transformation; strait dynamics. The coastal processes involve important exchanges with the open ocean, the effects of land runoff and underground fresh water sources.

Furthermore, the Mediterranean Sea comprises widely different ecosystems, ranging from the oligotrophic Eastern Mediterranean to eutrophic areas under the influence of the river discharges. Physical processes greatly influence the seasonal dynamics and species composition of marine populations. Climate changes are in progress (Tsimplis and Rixen, 2002; Beuvier *et al.*, 2009) and the related modifications of the hydrological cycles and mechanisms of water exchanges among different sub-basins can favor undesirable phenomena, like intrusion of alien species, harmful algal blooms including toxic species, anoxia events in eutrophic regions. Furthermore, climate changes have left important signatures in the water column and sediments, such as sapropels.

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. The fleet of operational oceanographic ships is getting old and suffering increased maintenance cost, being only slowly replaced by new and more efficient ships. Nevertheless, oceanographic ships will still be required to conduct calibration and validation surveys (McQuatters *et al.*, 2011; David, 2011), to deploy refurbish and recover moorings and other platforms (Perkins *et al.*, 2000), etc. The growing field of operational oceanography may contribute to the overall picture by enhancing climate records.

Field experiments conducted in the Mediterranean are very often driven by specific science questions but lack the general systematic approach to meet the quality required for climate studies. In essence, the Mediterranean Sea is still lacking a coordinated effort to ensure repeated basin-wide surveys for climate studies. The diversity of stakeholders, and inevitable competition for ship-time under strong financial pressure and growing fuel prices in an unstable Mediterranean geopolitical environment is a further motivation to improve the coordination of efforts so as to maximize exploitation of existing resources for the benefit of all interested communities at science and policy making levels (Rixen, 2008; Rixen *et al.*, 2009).

2. Climate studies relevant spatio-temporal scales

Climate relevant scales may encompass paleoceanography sediment cores of great importance to understand some of the fundamental mechanisms of climate change and tele-connections. However, policy making has been mostly concerned by the recent history of climate record and the water column itself for what regards the ocean component.

Processes which have a notable impact on climate variability in the Mediterranean cover a wide range of temporal scales. Whilst it would be unrealistically ambitious to consider all scales ranging from turbulence to geological time scales, the following phenomena are believed to play a major role on the medium term expected climate changes.

Of prime importance to conduct heat content and fresh water budget analyses, is the monitoring of air-sea and open-ocean boundaries. Atmospheric forecasts and re-analyses use advanced techniques to best fuse *in situ* (ship, coastal, etc.) and satellite observations with dynamical information. The continuous monitoring of water column properties at major straits such as the Gibraltar, Bosphorus and Dardanelles, Sicily, Bonifacio, Messina would allow closing the budget in simple box model approaches but is unlikely to provide any comprehensive explanation on the mechanisms which have triggered any observed change. Moreover, ship-based sampling in this case seems less adequate.

In the interior of the Mediterranean, the path of incoming Atlantic Water and its gradual transformation play a major role in preconditioning subsequent processes such as Deep water formation in the Gulf of Lions, the Northern and Southern Adriatic and Levantine intermediate water formation and should be monitored all year long. These water masses show some significant interannual variability and have experienced severe transformations, such as the LIW cooling in the 80s and the Eastern Mediterranean Transient (EMT, Beuvier *et al.*, 2009) characterized by a sudden warming and salting of Eastern Mediterranean Deep Waters around the 90s. These dramatic events may also generate cascading effects on other water masses (e.g. uplifted outflows, etc.) which are not well understood. Full water column continuous profiling in each of the main basins is a necessity, with a minimum 3-months revisit time.

At smaller scale, permanent, seasonal or intermittent features such as gyres (e.g. Alboran, Adriatic, Sikmona, Ionian, Ierapetra, Mersa-Matruh), eddies (e.g. Algerian, Antalia) and fronts (e.g. Almeria-Oran) and river outflow (e.g. Nil, Rhone, Po, etc.) all play a significant role in the Mediterranean circulation, water mass exchanges, nutrients, bio-geochemistry and ecosystems biodiversity, and deserve the same monitoring effort for these very same reasons but can be usually limited to the upper 200-300 m of the water column.

3. Climate studies relevant parameters

Physics mainly forces biogeochemistry with usually only limited but not negligible feedback on the physics. The selected set of variables is sometime partially redundant (e.g. steric level and tide gauges), sometime of little value if not available as a whole (e.g. CO2 speciation). There are thus many reasons to consider a multi-disciplinary approach to monitoring so as to ensure that a full picture of climate change may be reconstructed.

At the global scale, international programs such as the Global Climate Observing System (GCOS) sponsored by the World Meteorological Organization (WMO), IOC, UNEP and ICSU have identified a number of Essential Climate Variables (ECV). Data typically fall into two categories: 1) *In situ* and Non-Satellite and 2) Satellite. The selection of the data sets is based on information from Scientific Steering committees and scientific expert advisory groups.

The Essential Climate Variables (ECV) are required to support the work of the United Nations Framework Convention on Climate Change (UNFCCC) and the Intergovernmental Panel on Climate Change (IPCC). All ECV are technically and economically feasible for systematic observation. It is these variables for which international exchange is mostly required for both current and historical observations. It is emphasized that the ordering within the table is simply for convenience and is not an indicator of relative priority. Currently, there are 50 ECVs (see list in Table 1).

Table. 1. List of GCOS Essential climate variables.

ATMOSPHERIC (over Land, Sea & Ice)	OCEANIC	TERRESTRIAL *[2]*
Surface *[4]*	**Surface** *[6]*	River Discharge *(ECV T1)*
Pressure	Carbon Dioxide Partial Pressure	Water Use *(ECV T2)*
Air Temperature***	Current	Ground Water *(ECV T3)*
Precipitation	Ocean Acidity *	Lakes *(ECV T4)* *
Surface Radiation Budget	Ocean Color *(for Biological Activity)*	Snow Cover *(ECV T5)* ***
Water Vapor	Phytoplankton *	Glacier and Ice Caps *(ECV T6)* */***
Wind Speed and Direction	Sea Ice	Permafrost *(ECV T7)*
Upper-Air *[5]*	Sea Level***	Albedo *(ECV T8)* *
Cloud Properties	Sea State	Land Cover *(including Vegetation Type) (ECV T9)*
Earth Radiation Budget *(including Solar Irradiance)* */***	Sea Surface Salinity *(SSS)*	Fraction of Absorbed Photosynthetically Active Radiation (FAPAR) *(ECV T10)*
Temperature	Sea Surface Temperature *(SST)*	Leaf Area Index (LAI) *(ECV T11)*
Water Vapor	**Sub-Surface**	Above Ground Biomass *(ECV T12)* *
Wind Speed and Direction	Carbon	Fire Disturbance *(ECV T13)*
Composition	Current	Soil Moisture *
Aerosols Properties	Nutrients	Soil Carbon *
Carbon Dioxide***	Ocean Acidity *	Ice Sheets *
Methane and other Long-Lived Green House Gases *[1]* ***	Oxygen *	
Ozone	Salinity	
Precursors (supporting the Aerosols and Ozone ECVs) *[3]* *	Temperature	
	Tracers	
	Global Ocean Heat Content **/***	

The Global Ocean Observing System (GOOS) initiative and the growing field of operational oceanography are undoubtedly contributing to this overall picture by enhancing climate records.

At the European scale, a similar analogy exists for example between Coriolis, a French infrastructure strongly involved at European level, dedicated to the acquisition, processing and quality check and distribution of real-time ocean observations and SeaDataNet, a Pan-European infrastructure for Ocean and Marine Data Management, which aims at developing an efficient distributed Marine Data Management Infrastructure for the management of large and diverse sets of data deriving from *in situ* and remote observation of the European seas and oceans.

The SeaDataNet precursor projects MODB and MEDAR/MEDATLAS have focused on similar data, namely temperature, salinity dissolved oxygen, nitrate, nitrite, ammonium, silicate, phosphate, alkalinity, pH, chlorophyll-A, hydrogen sulphide, total nitrogen and total phosphorus at full profile resolution and on standard WOCE-kind vertical levels. This list is by no means complete. Iron for example may contribute to nutrient supply through Sahara dust storms.

At the European level these efforts have offered direct contributions to initiatives such as the MedCLIVAR program.

4. Synergies with other observing systems and measurement platforms

The Mediterranean has been the focus of regular climate and operational oceanography international monitoring efforts and hosts a wide series of observing and modeling systems, yet to be integrated. Rather than providing a comprehensive view of all existing systems, we illustrate hereafter a subset of emerging solutions which ideally complement ship-based observations.

Fixed mooring strategies at the key exchange locations described above are a first and mandatory complement to repeated surveys for climate studies. Ship of opportunity approaches, such as the Med-VOS program, have been successfully implemented with onboard unattended self-recording system but are still dependent upon good will and seasonal schedule.

Cross-calibration issues of measurement systems have to be considered carefully. Moreover, one has to be extremely careful in the way data sets of different spatio-temporal scales are fused together. This has led recently to a wrong belief that phytoplankton was declining in the World Oceans.

Euro-Argo

The main objective of Euro-Argo, of which MED-Argo is a component (see Figure 1), is to ensure that Europe will be able to deploy and operate an array of 800 floats and to provide a world-class

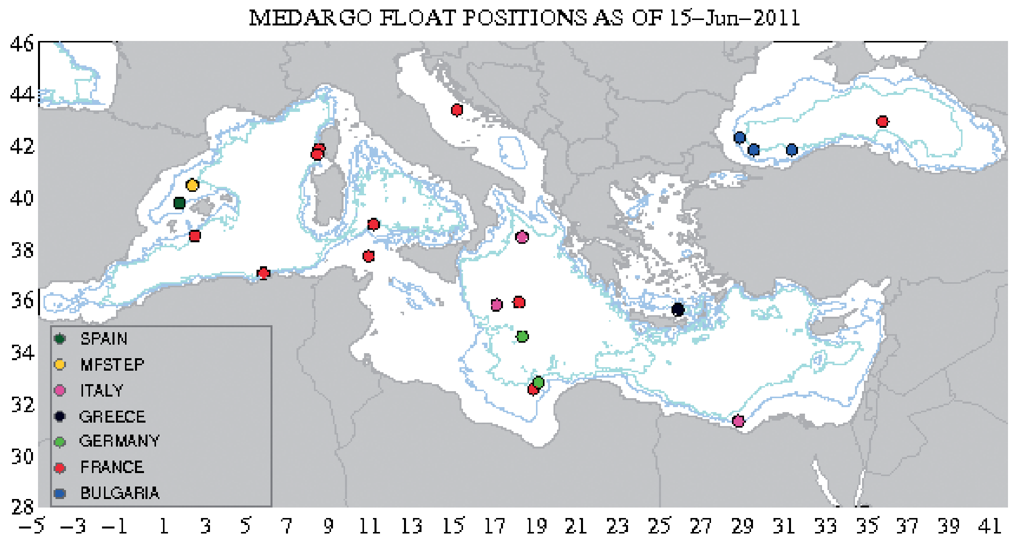

Fig. 1. MEDARGO float positions as of 25 April 2011.

service to the research (climate) and environment monitoring (e.g. GMES) communities, so as to consolidate and broaden the European participation in Argo and to further develop a leading role of Europe in global ocean observations and in ocean and climate research. Such profilers ideally target continuous water column sampling at sub-basin scale.

EGO and GROOM

The main objective of the EGO COST-Action is the coordination of ongoing research using gliders (Garau *et al.*, 2009; Grasso *et al.*, 2010; Alvarez, 2011), and the conception of future research, to operate fleets of autonomous underwater gliders in order to provide cost-effective methods for the discovery and monitoring of the ocean at global, regional and coastal scales with benefit to basic oceanographic research, operational applications and climate studies. (see Figure 2)

Fig. 2. Left: illustration of a glider deployment phase. Right: 3 glider simultaneous tracks showing regular transects and adaptive sampling phases.

The main objectives of the EGO ESF COST-ACTION and the EC GROOM project are to design, develop and coordinate a sustainable European glider infrastructure for safe and cost-effective operations of underwater gliders to fill the gaps in present marine observing systems on global, regional and coastal scale, with benefits for both fundamental marine research and operational oceanography. A series of glider capable centers already exists in Europe. Glider measurements are particularly suited for regional and coastal scales dominated by mesoscale dynamics. Glider fleets can be scaled to meet target requirements as necessary.

JERICO

The EC JERICO project aims at creating a solid and transparent organization towards an operational service for the timely, continuous and sustainable delivery of high quality environmental data and information products related to the marine environment in European coastal seas. With a clear coastal ocean focus, JERICO suitably complements the Euro-Argo basin-scale and GROOM regional scale focus. (see Figure 3)

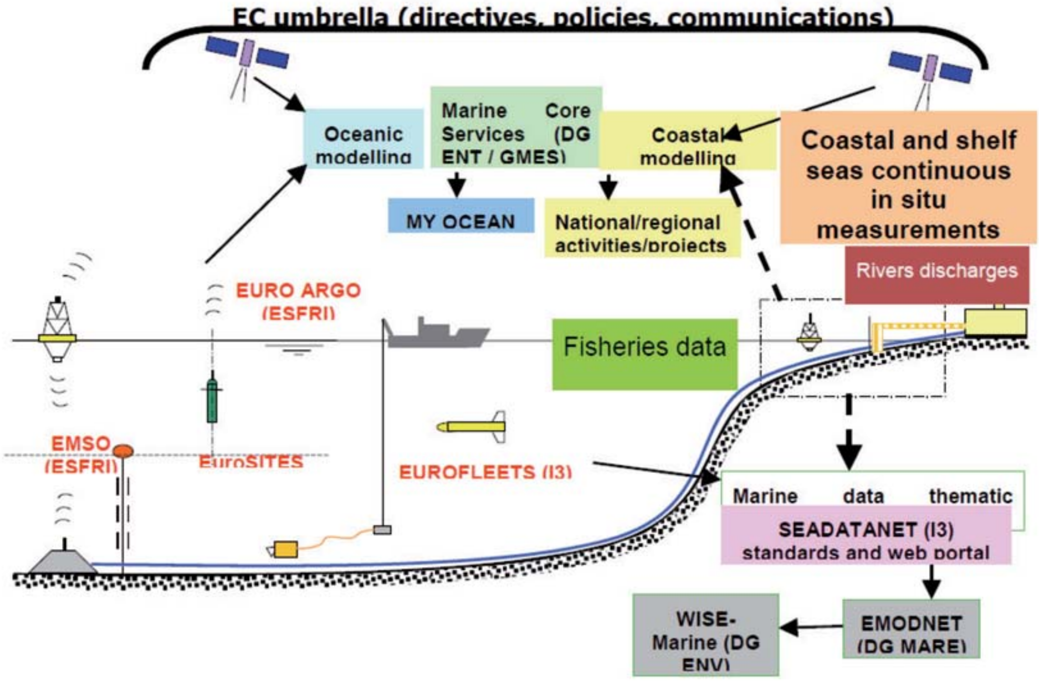

Fig. 3. JERICO concept infrastructure.

5. Synergies with modeling and data assimilation efforts

As pointed out in Rixen (2008), certain variables or parameters 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 to Sea Surface Temperature (SST) which is also strongly correlated on the horizontal through advection processes. This dynamical knowledge is ideally provided by numerical modeling (see Figure 4) and may be exploited to optimize sampling efforts in time, space and parameters range, as different variables may also be strongly correlated.

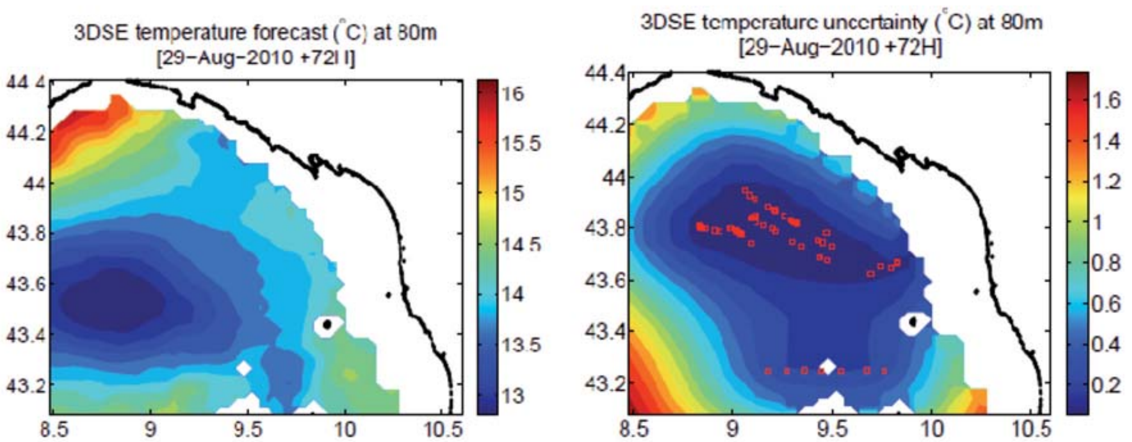

Fig. 4. Left: Ensemble temperature forecast valid for 1 September 00:00 (T0+72h). Right: associated uncertainty (red squares display the position of assimilated adaptive observations at this depth).

The information provided by satellite remote sensing (Pujol *et al.*, 2010) also offers suitable correlation scale information which needs to be propagated vertically through data assimilation methods. Observing System Simulation Experiment (OSSE) and adaptive sampling are typical approaches to maximize the impact of measurements on minimizing the overall uncertainty (Lermusiaux *et al.*, 2006) within numerical (Evensen, 2006; Barth *et al.*, 2007) and super-ensemble multi-model predictions (Rixen *et al.*, 2009; Lenartz *et al.*, 2010).

6. Conclusions

The challenge of planning repeated basin-wide surveys for climatic studies in the Mediterranean Sea has been considered under the angle of typical processes and features and a multi-disciplinary set of essential parameters. It is suggested to complement the available ship-based observations, or even substantially replace them by emerging autonomous monitoring infrastructures, such as drifting floats, gliders, which may be more cost-effective on the long-term and may free-up funding to focus ship time on specific observations difficult to achieve by these new systems. The complementarities of systems being currently developed in the Mediterranean may probably fulfill climate studies requirements if properly coordinated. Because of the inter-relationship and correlation between variables, it is also recommended to exploit lessons learned from modeling efforts (Adani *et al.*, 2011) to focus observations when and where they have the largest impact on reducing uncertainties in climate studies.

Technical coordination of the global hydrographic programme - The GO-SHIP and its Mediterranean component from the IOCCP perspective

Maciej Telszewski

IOC / UNESCO

The International Ocean Carbon Coordination Project (IOCCP) promotes the development of a global network of ocean carbon observations for research through technical coordination and communications services, international agreements on standards and methods, and advocacy and links to the global observing systems. The IOCCP is co-sponsored by the Intergovernmental Oceanographic Commission of UNESCO and the Scientific Committee on Oceanic Research.

I. Background

Ship-based hydrography is essential for documenting ocean changes throughout the water column, especially for the deep ocean below 2 km (52% of global ocean volume not sampled by profiling floats). Ship-based hydrography is also one of the most valuable tools oceanographers have at the present time to understand carbon fluxes and processes, to observe trends and to demonstrate the crucial role the carbon cycle plays in climate regulation and feedbacks. Ship-based hydrographic measurements provide a standard for validating new autonomous sensors and a reference/calibration dataset for other observing system elements (in particular, Argo profiling floats, expendable bathythermographs and gliders). Hydrography cruises in remote ocean areas also provide a unique opportunity and cost-effective access for the deployment of these instruments.

The ocean absorbs more than 25% of the CO_2 emitted to the atmosphere every year, greatly reducing the impact of CO_2 on climate. But how will this carbon sink behave in the future in a warmer climate, and what impacts will this excess CO_2 have on marine ecosystems? Ship-based hydrography is one of the oldest methods for observing the ocean interior, and despite numerous technological advances over the last several decades, it remains the only method for obtaining high-quality, high spatial and vertical resolution measurements of a suite of physical, chemical, and biological parameters over the full water column. In addition, data from hydrography are critical for evaluating ocean models and providing data constraints for state estimation, assimilation and inverse models. Any attempts to reduce and stabilize atmospheric CO_2 concentrations will depend on the strength and functioning of the ocean carbon sink. Predictive models about what will happen to the ocean carbon sink at the end of this century differ significantly, ranging from no significant change in sink functioning to a complete shut-down. With current carbon emissions selling at $20-200 US dollars / ton, the uncertainty in our projections of the ocean carbon sink at the end of this century represents several trillion US dollars. Reducing this uncertainty is critical for planning and implementation of carbon stabilization projects.

Both the CLIVAR community and the ocean carbon community (IOCCP) have recognized the urgent need for better coordination of planning, implementation, standardization, data synthesis and interpretation efforts for hydrography. Issues addressed by today's hydrography programs are different than those addressed during the WOCE era; and therefore require a more integrated approach both in terms of variables measured, sampling strategy, and integration of ship-based sampling with other platforms such as Argo and time-series stations.

II. Implementation

Following an action set at the International Repeat Hydrography and Carbon Workshop (Shonan Village, Japan, November 2005), the IOCCP, CLIVAR, and the SOLAS-IMBER Carbon Coordination Group are sponsoring the Global Ocean Ship-based Hydrographic Investigations Panel (GO-SHIP) to bring together interests from physical hydrography, carbon, biogeochemistry, Argo, OceanSITES, and other users and collectors of hydrographic data, to develop guidelines and advice for the development of a globally coordinated network of sustained ship-based hydrographic sections that will become an integral component of the ocean observing system.

The ship-based hydrographic cruises in the Mediterranean Sea should become an integral part of this global network. The principal scientific objectives for a sustained ship-based hydrography programme in the Mediterranean should include two closely linked components: (1) understanding and documenting the large-scale, basin-wide water property distributions, their changes, and drivers of those changes, and (2) addressing questions of how a future Mediterranean that will increase in dissolved inorganic carbon, become more acidic and more stratified, and experience changes due to global warming and perturbed water cycle, will alter its natural variability. To develop the scientific justification and general strategy for a ship-based repeat hydrography network (see Figure 1) in the Mediterranean, building on the GO-SHIP experience, considerations should include:

1. Joint Planning:

Nations come together for joint basin-wide planning exercises to agree on implementation to avoid gaps and duplications. Nations agree to adhere to a set of basic (GO-SHIP) requirements to define sampling resolution, measurement of core variables, and data release policy. Individual sections have much scientific merit on their own, but to make the most use of both financial and human resources, these lines should also be contributing to a basin-scale and global view that is only possible with international planning and cooperation. The lack of international coordination can lead to disparate data sharing policies, some sections being occupied without the full suite of core variables and, probably less so in the Mediterranean, duplication of some sections.

2. Implementation:

Nations commit to implement sections according to agreements and timeframes. International collaborations are established where necessary to ensure that the full suite of measurements is made on at least all lower frequency cruises.

3. Data Assembly and Quality Control:

National programs and/or individual scientists submit their data following data release timeframes to the appropriate data assembly centers. The Data Assembly Centers assemble, check, and disseminate data to the scientific community. Accuracy requirements are verified and problems signalled. While there are good examples of national DACs operating for hydrographic variables worldwide, most are not able to manage international data and no international agreements are currently in place to encourage this. The Global DAC serves as a clearinghouse for all hydrographic data variables, and provides global coordination for monitoring data flow.

4. Data Product Development and Joint Scientific Syntheses:

As the basin surveys are completed, scientific synthesis group is brought together to develop data products and establish collaborations for global, interdisciplinary science projects, including collaborations with other parts of the observing System that can either contribute to or use hydrography data, such as the Argo profiling float program, Ship of Opportunity Program, Volunteer Observing Ship Program, GEOTRACES programme, OceanSITES (and other) time-series stations and satellite remote sensing.

5. Network Evaluation and System Design Feedback:

Based on the science, implementation and data flow evaluations, the observing network is reviewed and redesigned as necessary in collaboration with other components of the observing system.

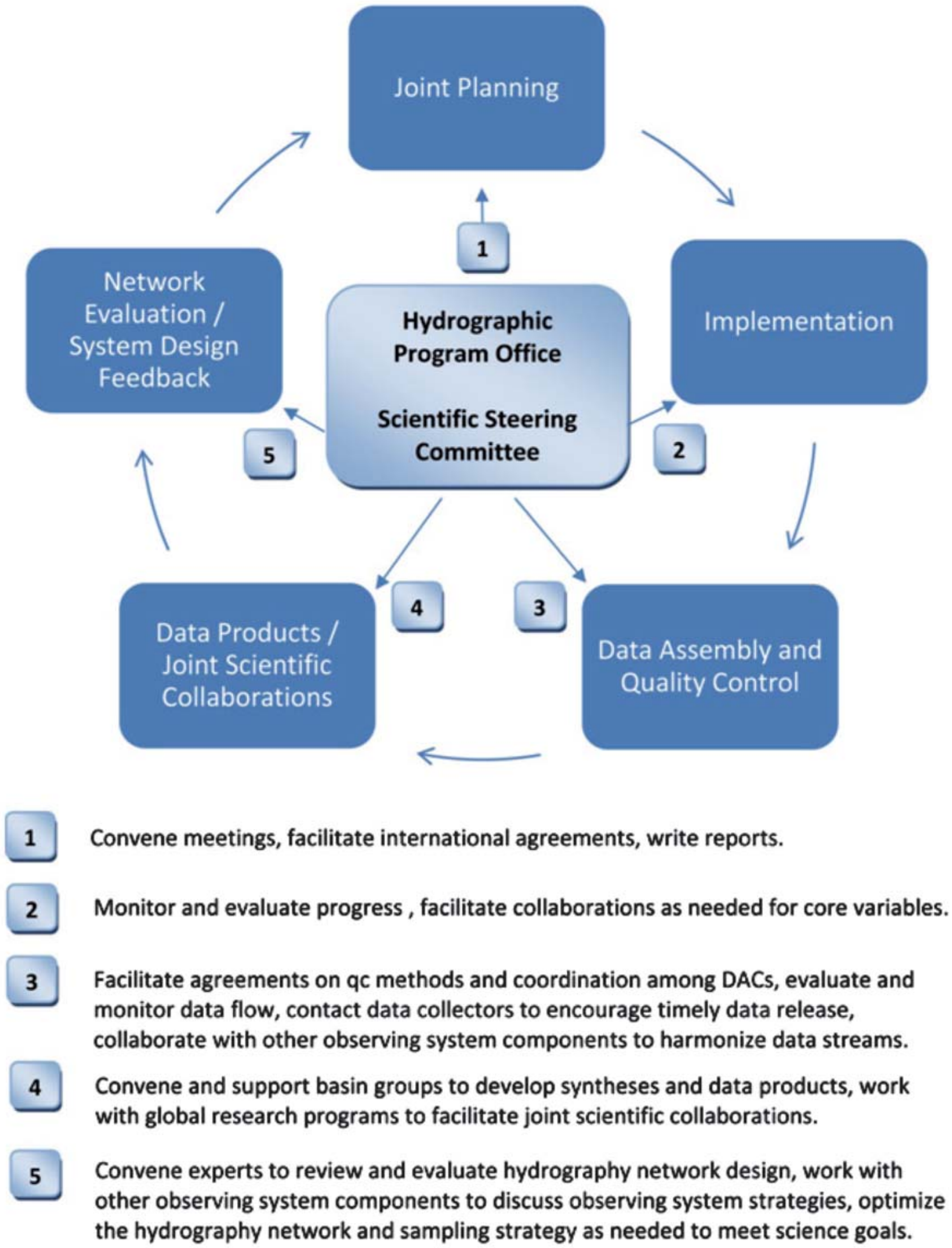

Figure 1. The components of a repeat hydrography programme.

III. Capacity building and adding the Mediterranean component to the GO-SHIP SSC

Capacity building is needed to ensure that Med GO-SHIP investigators participating in the coordinated survey understand and correctly use standard methods and protocols, including data and metadata reporting. One priority for the GO-SHIP program was to revise the 1994 WOCE Hydrographic Programme manual. In the 15 years since the original publication of the manual, many methods and techniques have changed and new sensors have been developed. The GO-SHIP Repeat Hydrography Manual – A Collection of Expert Reports and Guidelines (http://www.go-ship.org/HydroMan.html) – provides detailed instructions for the high quality collection and analysis techniques of numerous ocean parameters. The manual addresses both physical and biogeochemical parameters. Sixteen chapters covering CTD methods, discrete samples, and underway measurements have been reviewed and revised by more than 50 experts in field oceanography. Chapters have been through a period of open community review and comment and have also been reviewed through an informal peer review process. While most chapters were written specifically for this new version of the manual, several chapters are recently published guides that have been adopted as the GO-SHIP reference for specific variables. These chapters include the Calculation of the Thermophysical Properties of Seawater (McDougall *et al.*, 2009), The Guide to Best Practices for Ocean CO_2 Measurement (Dickson *et al.*, 2007), A Guide to Making Climate Quality Meteorological and Flux Measurements at Sea (Bradley and Fairall, 2006), and the IHO Standards for Hydrographic Surveys (2008).

A new guide for thermosalinograph installation and operation is being developed and will be added to this collection when it is published. The goal of this effort is to promote standardized methods for a core set of parameters measured on the GO-SHIP hydrographic reference sections, although the hope is that the techniques described in this manual will be adopted by others wishing to make high quality measurements.

Longer-term issues involve gaining access to waters under national jurisdiction in areas where capacity building partnerships may be required.

Over the last two years, GO-SHIP has demonstrated that, without dedicated global coordination for planning and implementation of sections, significant gaps and duplications arise, and most sections do not measure the full suite of core variables. An international hydrographic program office is needed to provide global oversight for program development and implementation. The interdisciplinary scope of hydrography and the scale of the coordination required exceed the ability of the IOCCP and CLIVAR to continue to provide the necessary support. Within the framework of the global ocean / climate observing system, hydrography is currently the only platform for Essential Climate Variables without an international program for coordination. The sponsors and committee members of GO-SHIP are seeking support for the development of an international program officer that can meet the coordination and communication needs of the research community and the system development needs of the international community. GO-SHIP is currently determining the best options for funding. Working with an international scientific steering committee, the program office would be responsible for facilitating international agreements on implementation, data release and sharing, and data management; monitoring cruise implementation and data flow; facilitating collaborations to ensure that the full suite of core variables are measured on each cruise; providing technical support for meetings of the scientific steering committee, the data management committee, the synthesis groups, and the network evaluation group; working with the other observing system components to harmonize and integrate observations and data streams; and serving as a central communications and information forum for the hydrography community.

The GO-SHIP SSC could be enlarged by one or more scientist(s) representing the Mediterranean community once the regional strategy becomes compatible with for the global ocean. This would that give the Mediterranean community an opportunity to voice its concerns and strengthen its visibility, while the global community would widen the support network trying to address the issues raised above.

The CO_2 system observations in the Mediterranean Sea: past, present and future

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Abstract

Compared with other areas, our knowledge about the CO_2 system dynamics in the Mediterranean Sea (Med Sea, hereafter) is fairly poor despite being a sort of laboratory for studying global change in the oceans and particularly the carbon cycle and feedbacks. This paper present a short introduction to the complexity of the CO_2 system in seawater and comments on current methods to measure these variables along with the precision and accuracy attained is also commented. An overview of the past and recent measurements of CO_2 in the Med Sea is given. Finally a series of CO_2 observations, both surface and interior, ship and buoy based are proposed.

1. Introduction

The oceans play a major role in the global carbon cycle: compared to the atmosphere and the terrestrial biosphere they contain about 90% of the global carbon (Sarmiento and Gruber, 2004). Additionally they act as a sink for the anthropogenic carbon released to the atmosphere by human activities (Sabine *et al.*, 2004). Most of the carbon accumulated in the oceans is inorganic carbon, which, in its gas phase is rapidly exchanged with the atmosphere. Once in the ocean CO_2 dissolves giving rise to the CO_2 thermodynamic equilibrium system, crucial to maintain the seawater pH within a very narrow band, so the oceans act as a buffer system.

Marginal seas as the Med Sea do play an important role in the anthropogenic carbon uptake and storage (see review by Lee *et al.*, 2011). They also suffer more acutely the consequences of global change and are therefore particularly interesting to study the connections and feedbacks between climate change, direct human perturbations and biogeochemical cycles in the ocean.

Basin wide CO_2 measurements, pH, TA, TIC and pCO_2 are generally scarce in the Med Sea. Contrasted data against Certified Reference Material, released in the '90s, are even scarcer.

1.1 Concepts about the CO_2 system

The thermodynamics of the carbonate or CO_2 system in natural waters is governed by the following equilibria:

CO_2 (g) ⇔ CO_2 (aq), governed by K_0 (CO_2 solubility)

CO_2 (aq) + H_2O ⇔ $H^+ + HCO_3^-$, governed by K_1

HCO_3^- ⇔ $H^+ + CO_3^{2-}$, governed by K_2

$Ca^{2+} + CO_3^{2-}$ ⇔ $CaCO_3$ (s), governed by K_{SP} (solubility of $CaCO_3$)

Each equilibrium equation is governed by an equilibrium or stoichiometric constant dependent on temperature, salinity and pressure. The constants are determined in real and artificial seawater by experimental analysis and there is a wide literature about the appropriate constants to define the CO_2 system in seawater (see the review in Millero (2007)).

1.2 CO_2 variables and methods to measure them

The CO_2 system in seawater is defined by four variables: pH, partial pressure of CO_2 (pCO_2), total alkalinity (TA) and Total Inorganic Carbon (TIC) also referred as Dissolved Inorganic Carbon (DIC or TCO_2 or ΣCO_2). The current estimates of the precision and accuracy for these measurements are given in Table 1. The cookbook for the CO_2 system determination in seawater is Dickson *et al.* (2007). Here a detailed description of the methodology basics, equipment, procedure and quality control for each CO_2 variable is given.

Table 1. Estimates of the analytical precision and accuracy of the CO_2 measurements in seawater.

Analysis	Precision	Accuracy	Reference
pH (spectrophotometric)	±0.0004	±0.002	Clayton and Byrne (1993)
TA (potentiometric)	±1 µmol/kg	±3 µmol/kg	Millero *et al.* (1993)
TIC (coulometric)	±1 µmol/kg	±2 µmol/kg	Johnson *et al.* (1993)
pCO_2 (infrared)	±0.5 µatm	±2 µatm	Wanninkhof & Thoning (1993)

Adapted from Millero (2007).

Measuring two of the CO_2 variables is possible to calculate the other two, using a given set of constants. The estimated probable errors in the calculated variables are shown in Table 2, using the uncertainties in Table 1.

Table 2. Probable error in the calculated variables of the CO_2 system using different input variables.

Input	pH	TA (µmol/kg)	TIC (µmol/kg)	pCO_2 (µatm)
pH-TA			±3.8	±2.1
pH-TIC		±2.7		±1.8
pH-pCO_2		±21	±18	
pCO_2-TIC	±0.0025	±3.4		
pCO_2-TA	±0.0026		±3.2	
TA-TIC	±0.0062			±5.7

Adapted from Millero (2007).

The pH has been historically measured using potentiometry and nowadays by spectrophotometry. Although is it easy to understand that pH= -log $[H^+]$, its difficulty derives from being dependent on temperature and the different existing scales to define it which are related with the fact that protons in seawater behave different than in dilute solutions.

Briefly, there are four scales for pH: 1) a practical scale defined by the National Bureau of Standards (now National Institute of Standards and Technology, NIST), which uses the activity of protons not the concentration; 2) the free scale accounts for the concentration of free protons; but usually there are protons associated with fluoride and sulphate, therefore two more scales are defined, 3) total scale and 4) seawater scale. They are related with:

$$[H^+]_{SWS} = [H^+]_F + [HSO_4^-] + [HF]$$

$$[H^+]_T = [H^+]_F + [HF]$$

$$pH_F > pH_T > pH_{SWS}$$

It is crucial to report the scale and temperature at which pH is measured as the difference between scales is one order higher than the accuracy.

Total alkalinity of seawater is defined as the concentration of all bases that can accept H+ when a titration is made with HCl to the carbonic acid end point, so a pH of 4.5. The definition of TA given by Dickson (1981) is:

$TA= [HCO_3^-] + 2[CO_3^{2-}] + [B(OH)_4^-] + [OH^-] – [H^+] + [SiO(OH)_3^-] + [MgOH^+] + [HPO_4^{2-}] + 2[PO_4^{3-}]$.

The carbonate and borate systems are the main contributors in seawater. For anoxic waters, HS^- and NH_3 also contribute to TA, which is independent of pressure and temperature.

TA is usually determined by titrating a given amount of water with HCl till a final end point. A full potentiometric titration takes about 20 minutes (see Dickson *et al.* (2007)). A faster (4 minutes) method was proposed by Pérez and Fraga (1987) with a double end point titration also commented and accepted in Millero (2007) and Mintrop *et al.* (2000).

TIC is also independent of pressure and temperature and defined as the sum of all the CO_2 species in seawater:

$TIC = [CO_2^*] + [HCO_3^-] + [CO_3^{2-}]$

Where $[CO_2^*] = [CO_2] + [H_2CO_3]$

It can be measured by potentiometry, coulometry and spectrometry. The two first methods are described in Dickson *et al.* (2007). The most widely used is coulometry where, after acidification with H_3PO_4, the stripped CO_2 with N_2 is determined within a coulometric cell.

The pCO_2 is usually measured at the surface of the ocean and compared with the atmospheric pCO_2 in order to check whether the ocean is a source ($pCO_2sw > pCO_2atm$) or a sink for CO_2 ($pCO_2sw < pCO_2atm$). Surface seawater pCO_2 is measured using an equilibration system where a continuous stream of air is equilibrated with seawater. The content of CO_2 in the air is measured with an infrared detector system (Dickson *et al.*, 2007).

1.3 Quality control

Dr. Dickson's laboratory at the Scripps Institution of Oceanography provides Certified Reference Material (CRM) for the quality control of TIC and TA measurements. They are of compulsory use for these measurements. pCO_2 quality is controlled using standard mixtures of CO_2 externally determined using manometry or infrared analysis. There is still a lack for pH standards: pH accuracy mainly stems from internal consistency analysis.

1.4 The Mediterranean Sea specificity

The Mediterranean Sea is a particular sea with high salinity and warm temperatures from surface to bottom with a general anti-estuarine circulation (surface atlantic water flows eastwards and Levantine Intermediate Water flows westwards and finally spills into the North Atlantic). Deep water formation processes both in the eastern and western basins of the Mediterranean Sea take place. The turnover time is around 100 years.

These features make the Med Sea special in terms of CO_2 dynamics, global carbon cycle and the possible feedbacks between global change (pollution, warming, acidification, eutrophication, etc.) and the carbon cycle in the Med Sea. The Med Sea can be considered as a small case study for global change.

The Med Sea is very high in TA and pH compared to other oceans. Being relatively warm and alkaline, it has a low Revelle factor, therefore, for a given increase in atmospheric CO_2 surface Med Sea water TIC increases more than in other oceans, uptaking more CO_2. This excess of CO_2 is rapidly transported to deep and intermediate layers where is stored as part of the overturning circulation. More details can be found in very recent publications (Schneider *et al.*, 2010; Lee *et al.*, 2011).

2. Past observations, until 1995

The most widely known collection of Med Sea physical and biogeochemical variables is the MEDAR/MEDATLAS/2002 data set which contains some data for TA and pH, but practically no TIC and none pCO_2 (Fig.1).

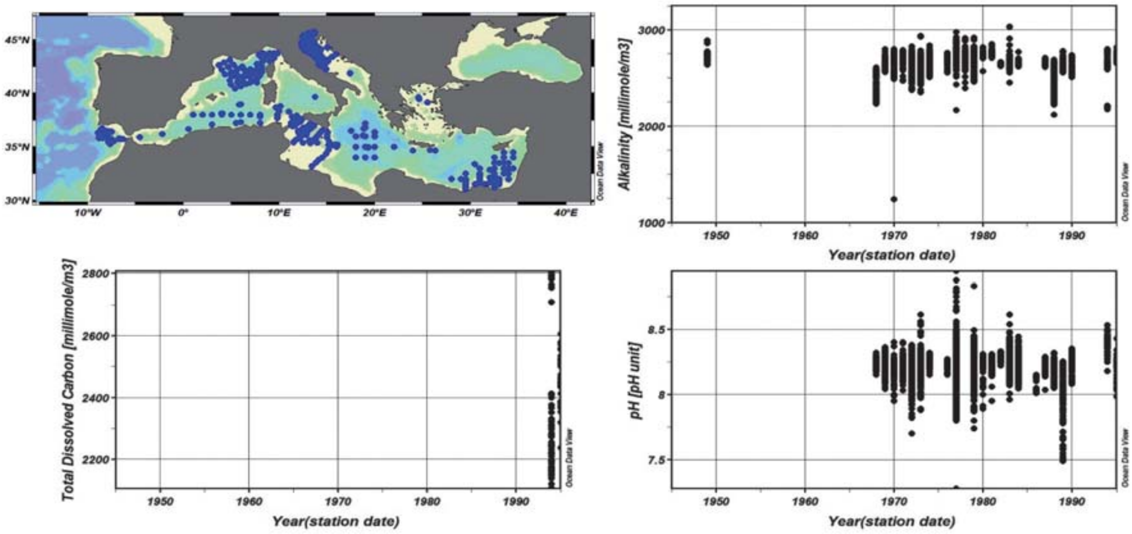

Figure 1. CO_2 data available from the MEDATLAS/2002 climatology.

Other publicly available data bases as CDIAC contain surface pCO_2 data from the INDOMED 3-4 cruise (December 1977 by R.F. Weiss). Along with station 404 from the GEOSECS expedition (1977-1978), sampled in the eastern Med Sea (Weiss *et al.*, 1983).

Other publications refer to CO_2 data not included in any data base:

- Copin-Montegut (1993): Almofront cruise (April-May 1991), pH and TA in the Alboran Sea. Hydrographic data in MedAtlas but no pH and TA.

- Millero *et al.* (1979). Cruise in September 1976 Alboran Sea and south of Balearic Islands, pH and TA (both potentiometric) were measured. No data found.

- Brunet *et al.* (1984). Mediprod IV, 15 October –17 November 1981 (Figure 2). pH and TA not available in SISMER (Ifremer), other data in MedAtlas and SISMER.

- Pérez *et al.* (1986). Catalan-Balearic Sea, cruise in July 1983. pH and TA (potentiometric). No data found.

- Frankignoulle *et al.* (1990). From information in Copin-Montegut (1993), TA data would be in the Alboran Sea area. But no other information found.

- Delgado and Estrada (1994): cruises in the Catalan-Balearic Sea, 1986, 1987, 1989. pH and TA (potentiometric). No data found.

- A recent publication (Krasakopoulou *et al.*, 2011) deals with TA and TIC collected in the Otranto strait in February 1995 within the frame of the EU Otranto project (Hydrodynamics and geochemical fluxes in the Strait of Otranto). This work studies the transport of inorganic carbon, natural and anthropogenic across the strait.

- Another recent publication (Luchetta *et al.*, 2010a) presents pH_{NBS} and TA from the northern Adriatic Sea measured in 1983.

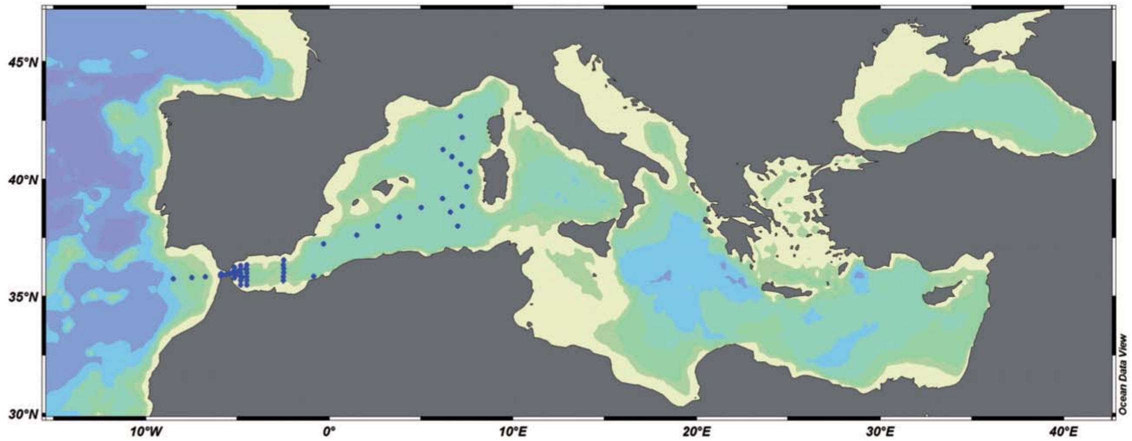

Figure 2. Mediprod IV cruise track in 1981 where pH and TA data were measured.

3. Recent results (1996-2010): time series, cruises, buoys and models

Times series and buoys:

- Ligurian Sea: The most widely known time series station within the Med Sea is the DYFAMED station located in the Ligurian Sea, active since 1993 but TIC and TA data were analysed only for some periods (Feb 1998-Feb 2000; July 2003-Dec 2004; June-Dec 2005). These results were presented in several papers (Bégovic and Copin-Montegut, 2002; Copin-Montegut and Bégovic, 2002; Copin-Montegut *et al.*, 2004; Hood and Merlivat, 2001). C. Goyet (University of Perpignan) is responsible since 2005 for the monthly measurements of pH, TA and TIC on bottle samples.

Regarding surface pCO2, at the DYFAMED station several CARIOCA buoys were deployed in 1995-1997 (Hood and Merlivat, 2001) and 1999 (Copin-Montegut *et al.*, 2004). They studied seasonal variations of pCO_2 at the surface. To our knowledge no continuous pCO2 measurements are currently done.

- Spanish Mediterranean coast: IEO times series, RADMED (Figure 3), three times a year the Spanish Mediterranean coast is surveyed, TA and pH (both potentiometric, against CRMs) are measured in the water column. Soon surface pCO2 will be measured. I.P: M. Vargas (IEO, Malaga).

- Medes Islands: shallow monitoring (80 m deep) where discrete TA (potentiometric) and pH (spectrophotometric) samples are measured at four levels. From 2008-ongoing. Additionally, from 2009-ongoing a buoy with a SAMI-pH sensor has been deployed. IP: E. Calvo and C. Pelejero (ICM, Barcelona).

- Within the Gulf of Trieste the Vida buoy reported pCO_2 data from a SAMI-CO_2 during several periods in 2007 and 2008 (Turk *et al.*, 2010).

- Still within the Gulf of Trieste seasonal surveys starting in 2011 are carried out for pH, TA and other biogeochemical variables at several stations (A. Luchetta, ISMAR) (Luchetta *et al.*, 2010a). Additionally since January 2008 pH, TA and other biogeochemical variables are analyzed on the whole water column of the coastal site PALOMA (centre of Gulf, 25 m deep) (Luchetta *et al.*, 2010b).

- In the southern Adriatic Pit, five seasonal datasets (from September 2007 to October 2008) for TA and pH have been collected at the station AM1 (1250m, 41º50'N and 17º45'E within the VECTOR and SESAME projects (Luchetta *et al.*, 2010b). This monitoring program will be continued under the umbrella of PERSEUS.

- within the EuroSites project (www.eurosites.info) several observational sites with buoys monitor surface CO_2-related parameters within the Med Sea: 1) the E1-M3A (Aegean/Cretan Sea) will soon deploy a pCO2 system for continuous measurements; 2) the E2-M3A (southern Adriatic Sea) measures pH and pCO2 since 2009; 3) the W1-M3A (Ligurian Sea) measures pCO2 since October 2010.

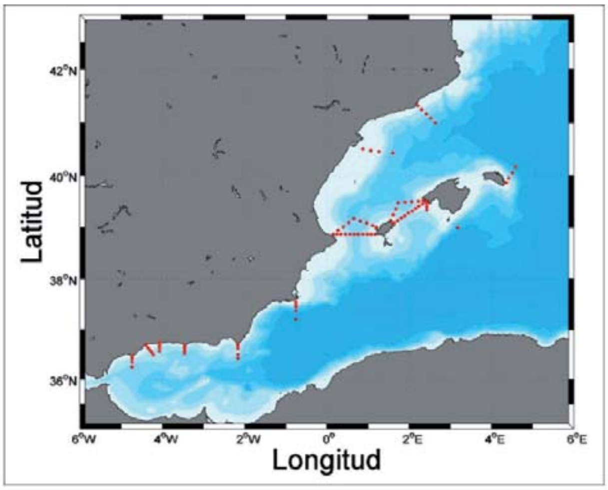

Figure 3. RADMED time series by IEO-Malaga. Sampled 4 times a year. pH and TA data are collected. Surface pCO2 in the near future.

<u>Cruises</u>

Up to my knowledge during 1996-2005 only the PROSOPE (Sept-Oct 1999) cruise measured along-track surface pCO_2 from the western to the Ionian Basin (Claustre *et al.*, 2002). Water column discrete pH and TA are potentiometric, measured against CRMs. Physical data in Medatlas. CO_2 data can be found in http://www.obs-vlfr.fr/cd_rom_dmtt/pr_main.htm

Within the Bay of Palma during the EUBAL cruises in March and June 2002, surface pCO_2, pH (potentiometric) and TA (potentiometric) were measured. No CRMs were reported (Gazeau *et al.*, 2005).

Borges *et al.* (2006) reported values for surface pCO2, TIC and TA in the Bay of Angels, near Villefranche.

Publicly available (CDIAC): I am aware only of the R/V Meteor 51/2 (October-November 2001) cruise crossing the Med Sea from east to west (Figure 4). Measurements of TA (potentiometric) and TIC (coulometric) were done against CRMs and published in Schneider *et al.* (2007; 2010) but only in 14 stations from a total of 42.

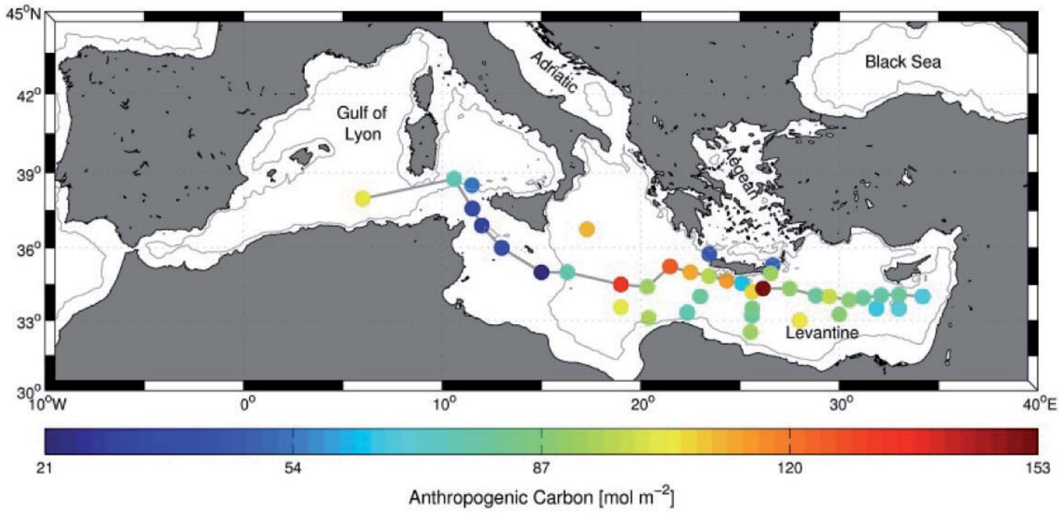

Figure 4. Meteor 51/2 cruise track in 2001 where TIC and TA data were measured. Figure from Schneider *et al.* (2010).

Another relevant data base for MedSea data contains CO_2 related variables, within the SESAME-Cast data management portal several cruises with CO2 related variables were found (http://isramar.ocean.org.il/SESAMEMETA/db_login.aspx). See following Table 3.

Table 3. Available cruises in the SESAME data portal containing CO_2 related variables.

Cruise Name	Start Date	End Date	Variables	Area	Contact information	Country
SESAME-IT7_BOT	10/8/2008	10/14/2008	pH/TA	Adriatic (Figure 5, left)	* V. Kovacevic	Italy
S-IT4_BOT	3/18/2008	4/5/2008	pH/TA/TIC	Western MedSea (Figure 5, right)	C. Santinelli	Italy
SESAME-IT1_BOT	2/15/2008	2/26/2008	pH/TA	Adriatic	* V. Kovacevic	Italy
MATER_MAI8_FEB99_BOT^3	2/23/1999	3/8/1999	pH/TA/TIC?	Southern Adriatic /Ionian	No contact	Italy
MATER_MAI6_AUG98_BOT^3	8/18/1998	8/31/1998	pH/TA/TIC?	Southern Adriatic /Ionian	No contact	Italy
MATER_MAI5_MAR98_BOT^4	3/10/1998	3/26/1998	pH/TA/TIC?	Southern Adriatic /Ionian	No contact	Italy
MATER_MAI2_AUG97_BOT^4	8/27/1997	9/11/1997	pH/TA/TIC?	Southern Adriatic /Ionian	No contact	Italy
MATER_MAI1_MAR97_BOT^4	3/4/1997	3/17/1997	pH/TA/TIC?	Southern Adriatic /Ionian	No contact	Italy

TIC? Stands for the variable described in the searching engine as *Concentration of carbon (total inorganic) {tco2} per unit mass of the water column [dissolved plus reactive particulate phase]*

* The SESAME-IT7_BOT and SESAME-IT1_BOT cruises are reported in Luchetta *et al.* (2010b).

Figure 5. Distribution of the cast stations sampled in the SESAME-IT7_BOT (left) and S-IT4_BOT (right) cruises.

Other CO_2 data sets reported but no yet publicly available, as far as I know, are:

- TRANSMED cruise (Figure 6), May-June 2007, Italian project VECTOR, west to east Med Sea, 10 stations were sampled for pH (potentiometric) and TA (potentiometric), measured against CRMs (Rivaro *et al.*, 2010).

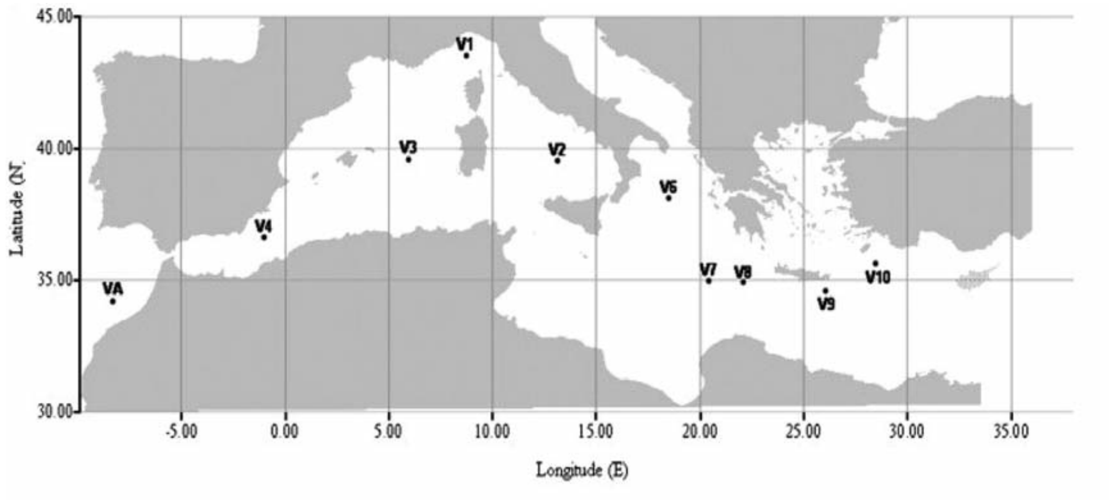

Figure 6. TRANSMED track in 2007 where pH and TA data were measured.

- Southern Tyrrhenian Sea, Italian project VECTOR, five cruises from the coast to VTM station, November 2006, February, April and July 2007, February 2008. Same methodology as previous point. Published in Rivaro *et al.* (2010). Figure 7.

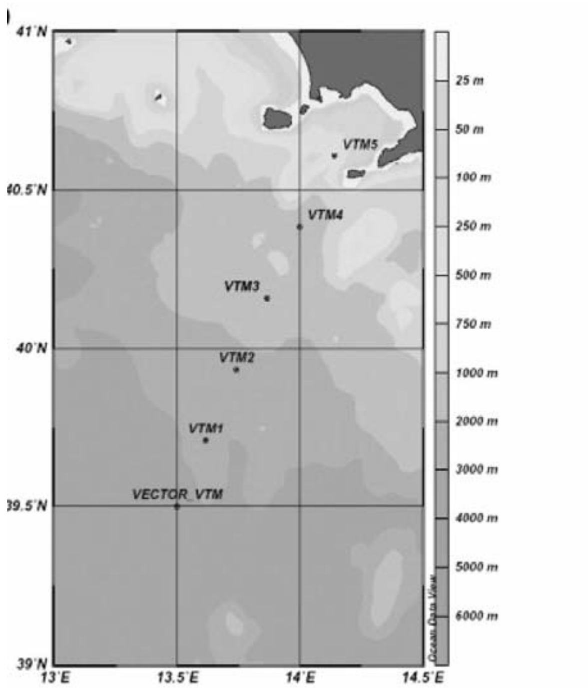

Figure 7. Southern Tyrrhenian cruises from Vector project where pH and TA data were measured.

- BOUM transect (IP: T. Moutin, LOPB, Marseille): 16-6 to 20-7-2008. TA and TIC data were measured potentiometrically against CRMs. IP: F: Touratier (IMAGES, Univ. Perpignan). Not publicly available. Figure 8.

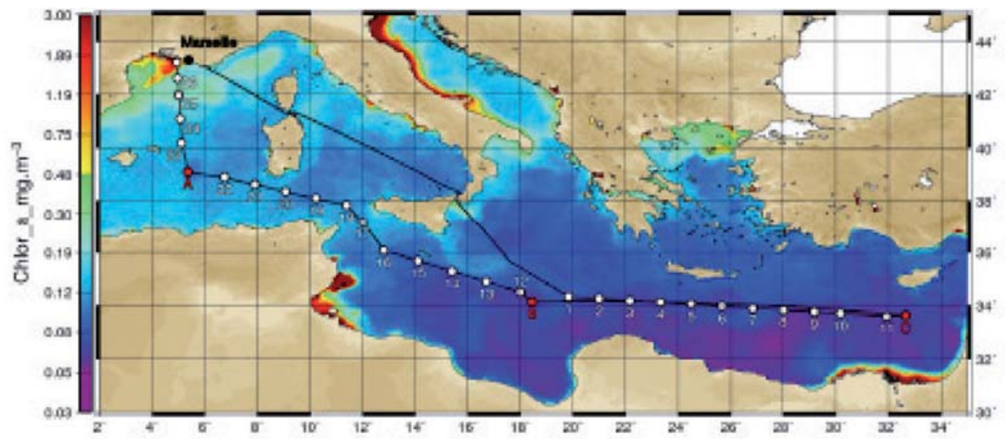

Figure 8. BOUM cruise track in 2008 where TIC and TA data were measured.

Underway:

Surface pCO_2 data in the Aegean Sea in February 2006 were reported by Krasakopoulou *et al.* (2009).

The SESAME data base contains some surface pCO_2 data from Greek cruises in 2007 and 2008 that could really contribute to the recent SOCAT data base. No contact name is given in the web page.

ICCABA project (IP: M. Gonzalez-Davila, ULPG, Spain): surface CO_2 in VOS line between Canary Islands and Italy. From 2007-2009?. No more information given. No data available.

Within the recently released SOCAT (www.socat.info, Surface Ocean CO_2) data base several cruises across the Med Sea are reported in 1998, 1999 and 2002.

Models:

Mémery *et al.* (2002): 1D biogeochemical model simulating N and C cycles using Dyfamed and Carioca CO_2 data. Concludes that sampling period must be not greater than few days to estimate CO_2 fluxes with an error smaller than 20%.

D'Ortenzio *et al.* (2008): using an array of unconnected 1D physical-biological-chemical coupled models, estimated the variability of surface pCO2 and mixed layer TIC between 1994-99 and 2003-2004. They concluded that the Med Sea is a slight sink for atmospheric CO_2 and that the carbon budget is mainly controlled by biology in both basins.

Louanchi *et al.* (2009) used the MEDAR/MEDATLAS climatology to constrain a diagnostic model and obtain the temporal evolution of surface pCO2 from 1960s to 1990s, transforming from a source to a sink. They also concluded that pCO2 is mainly temperature controlled.

4. The Meteor 83/4 (April 2011) raw CO_2 results

This is the first cruise up to our knowledge where three variables of the CO_2 system, pH, TA and TIC, were measured full-depth in a west-east transect covering the whole Med Sea. All variables were measured against CRMs.

pH was measured spectrophotometrically following Clayton and Byrne (1993). Roughly, this method consists on adding a dye solution to the seawater sample, so that the ratio between two absorbances at two different wavelengths is proportional to the sample pH.

TA was measured using an automatic potentiometric titrator "Titrando Metrohm", with an Aquatrode PT1000 combination glass electrode which also checks the temperature. Potentiometric titrations were carried out with hydrochloric acid ([HCl = 0.1 M) to a final pH of 4.40 (Pérez and

Fraga, 1987). The electrodes were standardized using a buffer of pH 4.4 made in CO_2 free seawater (Pérez *et al.*, 2000). Concentrations are given in µmol/kg-sw.

TIC was measured with a UIC coulometer (model 5012), after extraction of CO_2 from the sample by a SOMMA system (Johnson *et al.*, 1993). The system was operated at 20°C by thermostating the sample and sample pipette with a circulation bath. Titration took between 8 and 10 minutes (4 endpoints), which, including sample handling, allowed to measure about three samples/hour. Concentrations are given in µmol/kg-sw.

5. Future observations: suggestions

Clearly, there is a lack of basin-wide coordinated CO_2 observations, both surface and at depths in the Med Sea. Up to my knowledge there is no current specific program (like WOCE, IOCCP, etc.) coordinating the study of the carbon system in this marginal but relevant sea. Practically no Med Sea data is found within any of the available and most known data bases for CO_2 data in the ocean (CDIAC, SOCAT, etc.). Most of the data were found after a literature review.

There is a clear need for:

- A general coordination program to observe surface and interior CO_2 variables indicating the relevant temporal and spatial scales to be studied.

- A data rescue effort to compile and hopefully, if possible, calibrate all the available CO_2 data in the Med Sea.

- Collaboration with countries in the southern margin of the Med Sea in studying the present and future role of the Med Sea in the carbon cycle.

Oceanographic observations and the climate of the Mediterranean region

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Introduction

The Mediterranean Sea has non analogues in other regions of the world. This large and almost completely closed body of water (with a mean depth of 1500 m.), which deeply penetrates the large land mass constituted by Africa, Asia and Europe, is a large source of moisture and a significant heat reservoir for the surrounding land areas (considering the annual average it acts as a moderate source of heat). The complex land-sea distribution has a strong effect on the atmospheric circulation determining many mesoscale processes, and intense air sea interactions, such as those responsible for dense water formation processes, drive the Mediterranean thermohaline cells.

This promotes the use of coupled regional climate models including high resolution ocean circulation models of the Mediterranean Sea (e.g. Artale *et al.*, 2009).

The inclusion of the Mediterranean Sea in climate studies is necessary for answering important questions. A main issue is understanding the global role of the Mediterranean climate system, i.e., whether it is a passive component or can feedback at global scale. The Mediterranean region is relatively small and regional processes mainly produce large spatial gradients in externally forced patterns, which would otherwise be more homogeneous. The Mediterranean storm track is a consequence of morphology and local interaction, but its variability is, to a large extent, caused by the storm track over north Europe (Lionello *et al.*, 2006a,b). However, there are critical feedbacks: the outflow of salty Mediterranean water in the Atlantic stabilizes the Atlantic thermohaline circulation (Artale *et al.*, 2006); the Mediterranean Sea is an important source of moisture for the surrounding areas, particularly for the eastern Mediterranean countries; finally, because of its location, climate signal from the Mediterranean propagates downstream and eastwards and influence remote regions of the globe (Li, 2006).

A potentially interesting contribution for identifying an active role of the Mediterranean climate system is the existence of internal climate oscillations, as suggested by the Eastern Mediterranean Transient (EMT). While EMT shows that multiple equilibria of thermohaline cells are possible, the role of internal dynamics and the occurrence of different states of the thermohaline circulation in the past are not yet documented. It is further important to investigate the importance of on the overall EMT Mediterranean climate and environment.

Within this set of general research issues, the effort for repeated oceanographic surveys is fundamental and needs to be strongly supported by the scientific community. It should, however, be complemented by a systematic analysis and monitoring of air-sea interactions, as basic information on heat and mass fluxes are insufficiently known. Precipitation over the Mediterranean Sea, briefly discussed in the next section, is an example of poorly known variable.

Precipitation over the Mediterranean Sea

Precipitation over sea is important because it affects salinity and it is a major contribution in the overall water mass balance. Precipitation is the second contribution to the water budget in order of importance, after evaporation and before river runoff balance (this issue is extensively discussed in Schroeder *et al.*, 2011). The best estimate of the net surface freshwater budget (Dubois *et al.*, 2011) is -1.8 mm/d, which is equivalent to about +0.05Sv for the Gibraltar net water transport and agrees with its recent estimates. Note that decreasing precipitation trends during the second half of the last century have been detected over large areas of land surrounding the Mediterranean Sea (e.g. Xoplaki *et al.*, 2004), but uncertainties on data over sea are too large for identifying trends, key to understanding present evolution of climate.

The following datasets are presently available for analysing precipitation over sea, from which values over the Mediterranean can be extracted. The list includes three datasets largely (if not entirely) based on satellite data (GPCP, CMAP, HOAPS), one based on meteorological reports (NOC1.1), four on model simulations (NCEP, NCEP2, ERA-40, ERA-INTERIM).

- GPCP: Global Precipitation Climatology Project (Adler *et al.*, 2003) is a multi-satellite dataset covering the period 1979 - 2008. Data from over 6,000 rain gauge stations, and satellite geostationary and low-orbit infrared, passive microwave, and sounding observations have been merged to estimate monthly rainfall on a 2.5-degree global grid.

- CMAP: the Climate Prediction Center (CPC) Merged Analysis of Precipitation (Xie and Arkin, 1997) dataset includes time series of monthly and 5-day mean precipitation on a 2.5 degree grid for the whole globe and for the period from January 1979 to 2009. Since observations are not available for some areas, particularly the polar caps, a supplementary version incorporating model forecasts of precipitation from the NCEP/NCAR reanalysis is also available.

- HOAPS: the Hamburg Ocean Atmosphere Parameters and Fluxes from Satellite Data set contains updated global fields of precipitation over the global ocean. HOAPS-3 covers the time span from 07/1987 to 12/2005, resulting in a climatology containing 18 complete years of data at 1deg resolution.

- NOC1.1: This flux climatology is the renamed version of the Original SOC flux climatology (Josey *et al.*, 1998). The flux fields have been determined from *in situ* meteorological reports in the COADS 1a (Comprehensive Ocean Atmosphere Dataset) covering the period 1980-93 at 1deg resolution. A major innovation in the production of the climatology was the correction of the meteorological reports for various observational biases, using additional information from the WMO47 list of ships.

- NCEP1: The NCEP/NCAR Reanalysis Project (Kalnay *et al.*, 1996) is a joint project between the National Centers for Environmental Prediction (NCEP) and the National Center for Atmospheric Research (NCAR). It consists of atmospheric analyses using historical data (1948 onwards) and the Climate Data Assimilation System, CDAS. It covers the period 1948-1998 at T62 model (about 210 Km).

- NCEP2: It is a rerun of the NCEP1 reanalysis introducing more up-to-date physics and correcting known errors in NCEP1, It covers the period 1979-2010 (Kanamitsu *et al.*, 2002).

- ERA-40: The re-analysis project of ECMWF (Uppala *et al.*, 2005), covers the period from mid-1957 to mid-2002, overlapping the earlier ECMWF re-analysis, ERA-15 (covering the period from 1979 to 1993) at resolution N80 (about 1.1 degs, T159 for the atmospheric model).

- ERA-INTERIM: it covers the period 1989-present. With respect to ERA-40 it has a higher resolution (T255), improved physics and data assimilation, and it includes more observations.

The comparison among datasets shows that there are large uncertainties on the precipitation over Sea. The Figures 1 and 2 show the seasonal precipitation fields derived from two alternative datasets: NOC1.1 (Fig. 1) and CMAP (Fig. 2). The data refer to different periods: 1979-1993 for COADS and 1979-2002 for CMAP. It would be, however, surprising that the large differences could be explained by the different time coverage. Note the large differences in the Ionian Sea and in the Levantine basin close to the coast of Anatolia.

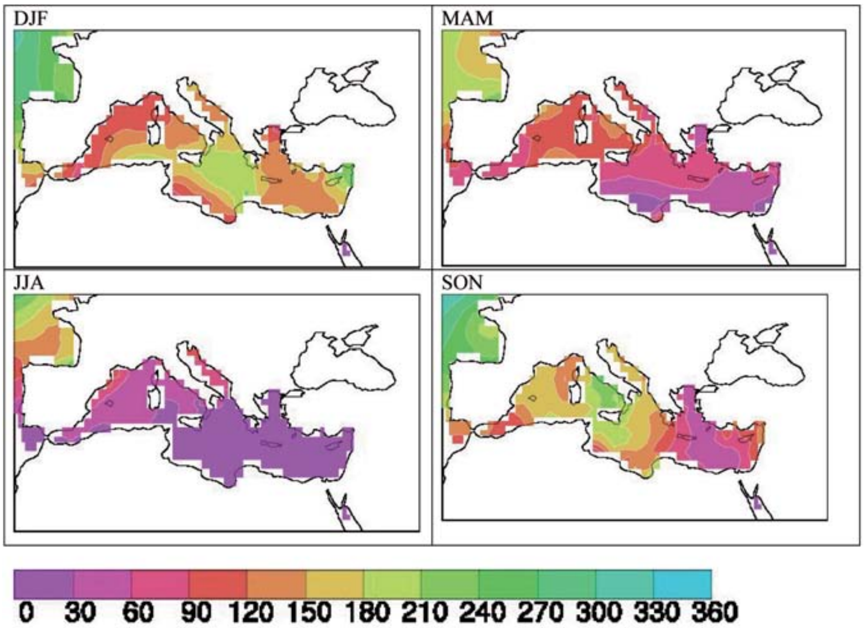

Figure 1. Maps based on NOCS precipitation fields 1980-1993 The fields have been derived from the COADS1a (1980-93) dataset enhanced with additional metadata from the WMO47 list of ships.

The SOC climatology was generated from an enhanced version of the Comprehensive Ocean Atmosphere Dataset 1a (COADS1a, Woodruff *et al.*, 1993), which consists of marine meteorological reports spanning the period 1980 - 1993. The individual ship meteorological reports were first corrected for observational biases using additional metadata describing observing procedure from the International List of Selected, Supplementary and Auxiliary Ships (WMO Report 47, e.g. WMO, 1993).

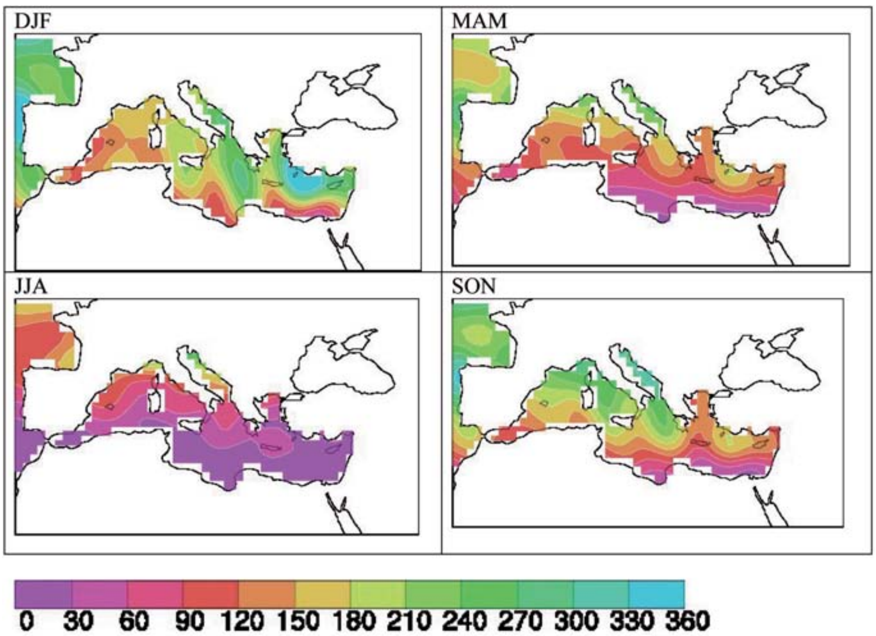

Figure 2. CMAP Precipitation for the Period 1979-2002, res 1 x 1 degree grid: CPC Merged Analysis of Precipitation based on a technique which produces 5-day and monthly analyses of global precipitation in which observations from rain gauges are merged with precipitation estimates from several satellite-based algorithms (infrared and microwave) (from Lionello *et al.*, 2011b).

The large differences between Figures 1 and 2 are not only due to the completely different origin of the data and the quite different space and time coverage. One cannot assume that satellite data are virtually error free (Sanchez-Gomez *et al.*, 2011). In the Mediterranean for example, there is a more than 100% discrepancy between the satellite-based GPCP estimates (Adler *et al.*, 2003) with a mean value of 1.6 ± 0.1 mm day^{-1} (1979-2008) and the satellite-based HOAPS estimates with a mean value of 0.7 ± 0.1 mm day^{-1} (1988-2005) following Dubois *et al.* (2010). The differences between CMAP, HOAPS and GPCP products, except where clearly associated with algorithm or data differences, are likely an estimate of uncertainty in the satellite data.

Same is true for the comparison among the various reanalysis products. Figure 3 shows the different estimate produced by four different models. Resolution is certainly an issue and precipitation estimates tend to increase with the grid resolution. In case of models, spatial distribution is similar among models, but the intensity of the features is quite different. Even when precipitation data are integrated over the whole basin, the resulting annual cycles are significantly different.

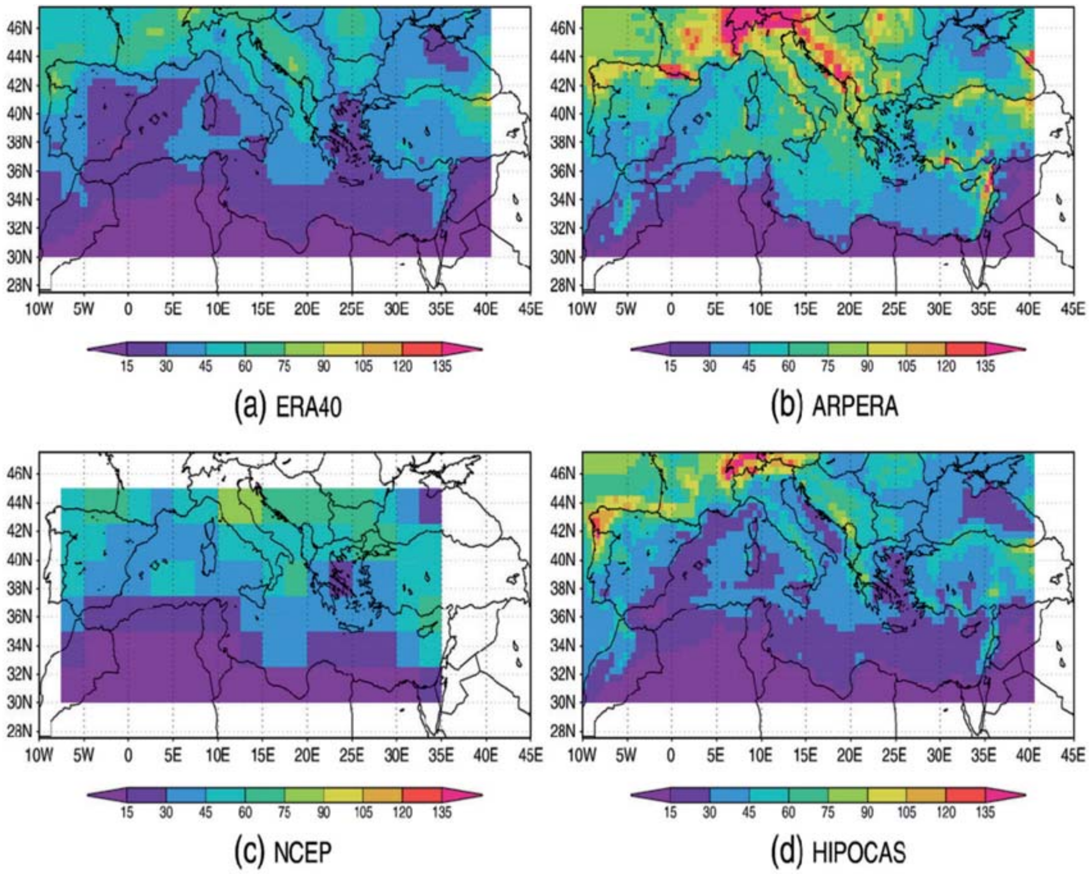

Figure 3. Spatial distribution of the mean precipitation obtained from a) ERA40, b) ARPERA, c) NCEP and d) HIPOCAS. Units are mm/month (from Aznar *et al.*, 2010).

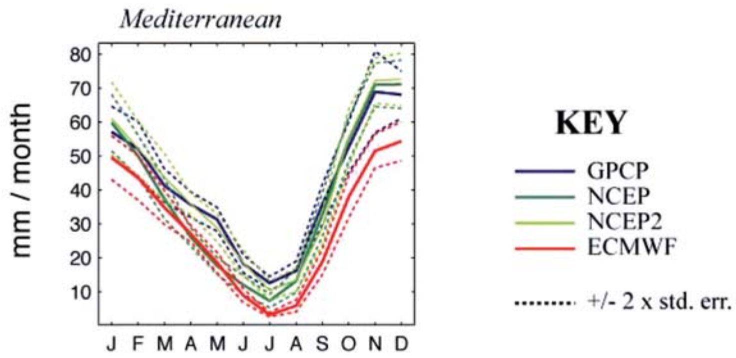

Figure 4. Annual cycle of precipitation over the Mediterranean Sea, based on models (NCEP and ECMWF) and satellite data (GPCP) (Figure courtesy of M. Tsimplis).

Therefore, though a number of data sets exist from which the spatial and temporal distribution of precipitation can be inferred, differences among them suggest that a sensible method for combining the various inputs and addressing errors is required. Results would be very important for the study of seasonal to decadal variability in precipitation. In this framework ship reports are needed because the satellite estimates used are significantly flawed (Arkin, 2010). The infrared-based estimates depend upon an empirical relationship between cloudiness and precipitation that is poorly known, and which surely varies in space and time. The absolute values given are generally less worthy of confidence than the variability. Global averages appear to be accurate to within 5-10%, but in limited areas, such as the Mediterranean Sea, values have probably much greater uncertainties.

The following steps are recommended:

- Use ship observations together with other datasets to monitor variability in space and time; a continuous program covering at least the next 10 years (see also LOP of the HyMeX project) would be an important asset.

- Develop optimal datasets combining the various satellite rain products with *in situ* observations and model reanalysis.

- Merge ship observations and satellite data for improving estimates of precipitation over the Mediterranean Sea, and construct datasets suitable for the analysis of seasonal, inter-annual and, inter-decadal variations, if recovery of past data is feasible.

- Identify footprints of climate change in spatial distributions of rain.

Resolution at which the problem needs to be addressed is one deg. or lower. There are features in the Ionian Sea and Levantine basin that need to be accurately monitored. Synergies with weather centers (NCEP and ECMWF) and satellite observations are essential.

Outlook and other issues

These short notes are focused on the problem of the reconstruction of the precipitation over the Mediterranean Sea, aiming to stress the importance of an issue integrating the more traditional targets of the observation of the ocean interior. In a more general perspective, issues that need to be addressed by an integrated program with continuous regular monitoring and repeated surveys reaching the deep part of the Mediterranean Sea are:

- Observation of the temperature and salinity distribution for determining the steric (thermosteric and halosteric) contribution to Med sea level variability. A recent review (Gomis *et al.*, 2011) shows that presently model and observation do not agree on trends (positive for models negative for observations).

- Closure of the Mediterranean Sea heat budget. This has not been achieved, yet. The measurement of the water exchange across the strait of Gibraltar poses a strong constraint on a negative heat budget corresponding to a loss of -5W/m^2. The most recent estimates based on flux computations result in a heat gain of about 5W/m^2. Ship based observations of areas where intense sensible and heat losses take place could help to improve the accuracy of the balance.

- Hydrological cycle and mass balance. The individual terms of the mass budget are difficult to determine accurately and a closure of the budget has not yet been obtained by summing the present estimate (Schroeder *et al.*, 2011).

- Climate change detection. Many studies have reported warming and salting trends in the deep layers of both western and eastern Mediterranean. A similar consensus is still lacking for the intermediate and upper layers, where trends are more "patchy" and different results have been obtained in different areas. Monitoring at low and intermediate depth seems very important, especially to identify the penetration of a climate signal towards the Mediterranean Sea interior.

These issues clearly call for a stronger involvement of the oceanographic community in studying the climate of the Mediterranean region and its interaction with the thermo-haline circulation, its decadal variability, mixed layer dynamics and the sea-level rise.

The monitoring of thermohaline variability in the Mediterranean combining continuous strait measurements and periodic basin scale surveys

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Abstract

Despite real advances in recent years, there are still huge gaps in current knowledge of the Mediterranean Sea functioning and evolution on long time scales, as well as the need of a monitoring effort of anomalies and abrupt events. Here we describe the current efforts undertaken in this direction by CNR-ISMAR and a proposal for a WOCE-like transect to be carried out on a 5-10 years basis with internationally coordinated efforts.

1. Introduction

Ship-based hydrography is the only method for obtaining high-quality, high horizontal and vertical resolution measurements of a suite of physical, chemical, and biological parameters over the whole ocean water column, and in areas of the ocean that are inaccessible to other platforms. Large-scale or global hydrographic surveys have been carried out every decade since the 1970s through research programs such as GEOSECS, TTO/SAVE, WOCE / JGOFS, and CLIVAR.

As shown in the map below (Fig. 1), an important area has been completely neglected: the Mediterranean Sea. Besides having a global role, such as its influence on the increasing salt content of the intermediate layer in the North Atlantic, this marginal sea is of primary importance for the regional climate, and its morphological characteristics make the Mediterranean Sea a moderate source of heat for the surrounding land areas and a large source of moisture (Lionello *et al.*, 2011a).

The Mediterranean Sea is in many ways a miniature ocean. It has deep water formation varying on interannual time scales and a well-defined overturning circulation, and there are distinct surface, intermediate and deep water masses circulating between the western and the eastern basin. What makes the Mediterranean particularly useful for climate change studies is that its time scale with a turnover of 60 years is much shorter than for the global ocean (500 years). Changes can happen faster, on the time scale of a human lifetime. Thus the Mediterranean is useful as a laboratory for documenting changes within it (and hence anticipating similar changes in the global ocean) and for understanding the role of key processes involved in climate change (thus to make inferences

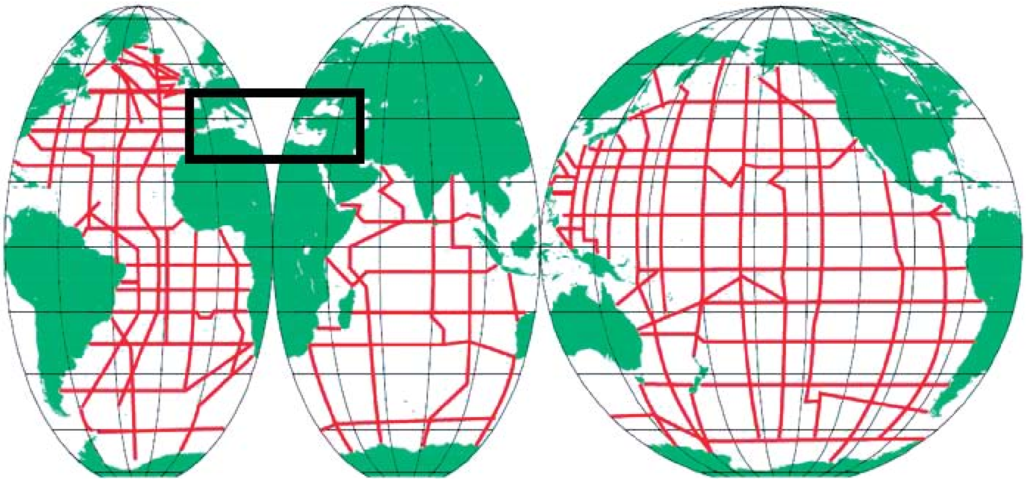

Figure 1. The global WOCE survey grid, the black frame highlights the gap in the Mediterranean Sea.

on those processes on the global scale). Important tasks are: to define a realistic survey strategy, focalized on a continuous monitoring of key regions, to capitalize the existing time series for the understanding of the time scales of variability, and to provide elements of comparison and verification to models.

2. Approaches

A continuous monitoring of the Mediterranean circulation is necessary to detect possible changes when they happen and to understand their time scales. Straits and channels form an important network inside the basin: their monitoring permits to determine, at a basin scale, the evolution of the water mass characteristics and the transport variability. Therefore an adequate survey strategy would consist in (Fig. 2):

1. Long-term monitoring of Mediterranean straits, to define the main interbasin exchanges.
2. Repeated observations in sites of special interest, to maintain a deep-basin monitoring with repeated CTD casts at fixed stations.
3. Large-scale monitoring, through basin-wide hydrographic surveys with closed transect, a necessary tool for budget calculation, e.g. by means of box models (Fig. 3, upper panel), to initialize and validate general circulation models, and to be assimilated in models to improve their forecast capability.

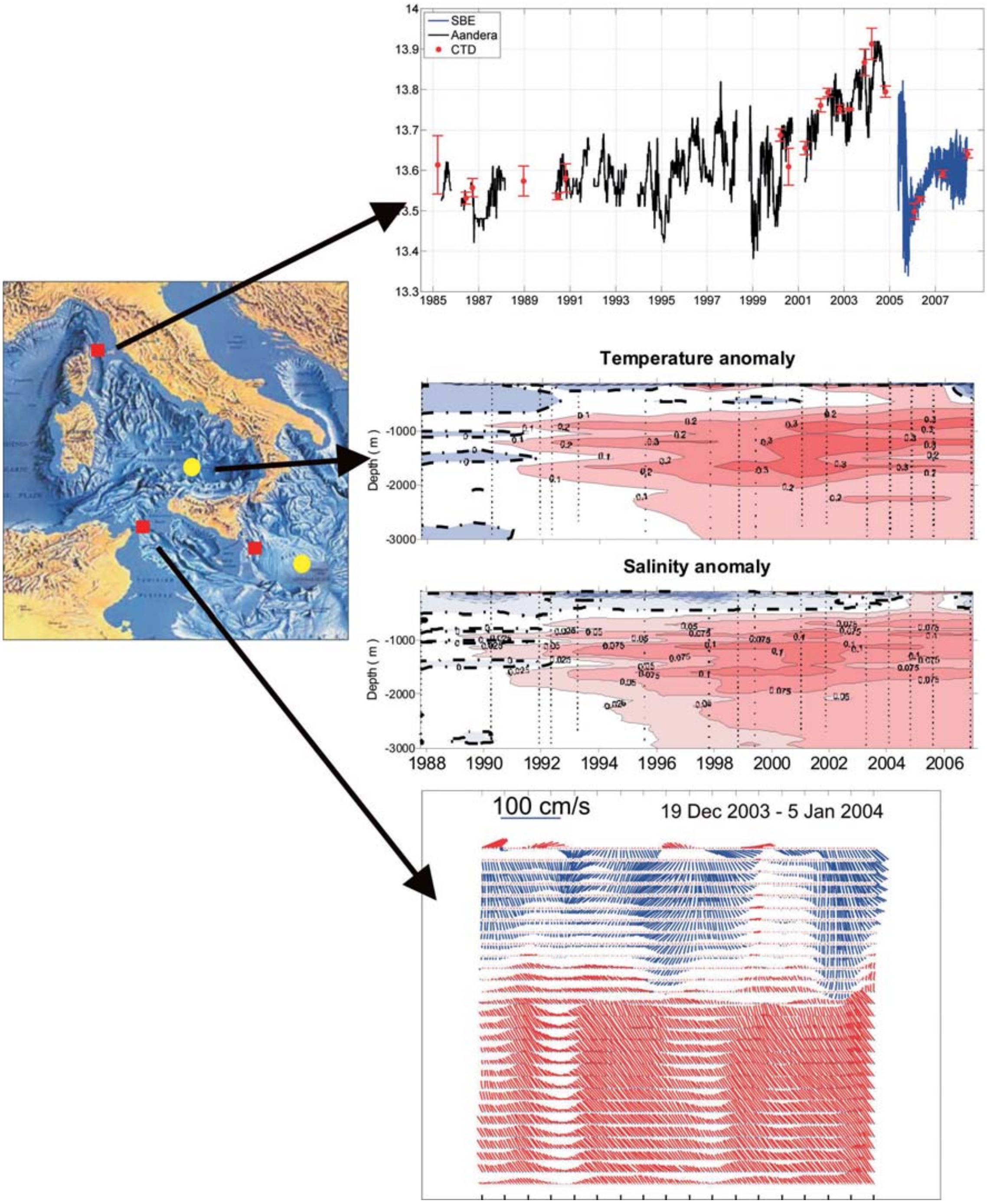

Figure 2. Location of moored chains (red squares on the map) and sites of special interest (yellow circles on the map). Examples of data collected: (up) time series of potential temperature in the Corsica Channel (moored instruments since 1985); (centre) temperature and salinity anomalies in the central Tyrrhenian basin (repeated CTD casts since 1988); (bottom) current profiles in the Sicily Channel (moored instruments since 1994).

3. Implementation

To implement this strategy in the Mediterranean, the observational activity of CNR-ISMAR (Marine Sciences Institute of the National Research Council of Italy), involving its research vessels fleet, includes long-term mooring deployments in straits and channels, periodically visited hydrological stations, as well as periodically visited transects, to collect hydrological and chemical data.

In particular (with reference to Fig. 2), the Institute is operating two moorings in the Sicily Channel (western sill, Fig. 2 lower plot) since more than 20 years, to monitor the exchanges between eastern (EMED) and western Mediterranean (WMED). Another moored chain is operating in the Corsica Channel since more than 25 years, which monitors continuously the exchange between the Tyrrhenian and the Ligurian subbasins. This site is particularly useful since it is located on the Topex Jason and ERS ground tracks that cross the study area. These three mooring sites are part of the CIESM HYDROCHANGES Programme. The long-term monitoring of the hydrographic and dynamic properties of water masses in those key positions during the last 20 years permitted to follow the interannual variability of the east-west exchanges, considering the propagation of the Eastern Mediterranean Transient (EMT) signature toward the WMED (Gasparini *et al.*, 2005; Schroeder *et al.*, 2006). It is also relevant to remark that the EMED outflow is still experiencing an increase in temperature and salinity, as shown by the long term continuous recording of properties in the Sicily Channel, suggesting that the eastern basin is far to have recovered the pre-transient condition. During 2008 the highest temperature and salinity values since 1985 have been recorded. In the Corsican time series there is a long-term oscillation, with increasing temperature until 2004, followed by a sharp decrease until spring 2006. Finally, the return of a warming period in the intermediate layer started in May 2006 (see upper plot in Fig. 2). Interestingly, the record at 400 m depth reached its absolute maximum and absolute minimum in a time period of only two years (from 2004 to 2006), suggesting dramatic changes occurring in recent years (Schroeder *et al.*, 2006; 2008a).

The Institute is also conducting periodic visits to fixed hydrological stations in other key regions, in particular in deep basins, such as the Ionian and the Tyrrhenian (1-2 casts per year, since more than 20 years, see Fig. 2, central plot), to document long-term changes in the deep water properties (Gasparini *et al.*, 2005; Schroeder *et al.*, 2010a), as well as at the three moored chains locations (1-2 times per year).

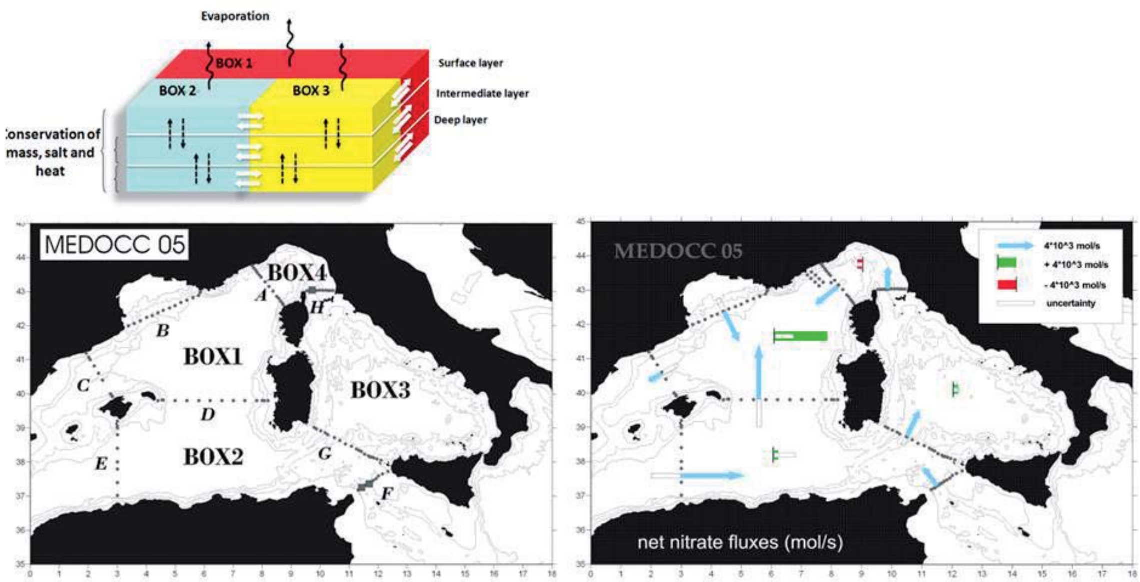

Figure 3. (upper) Box model scheme (left) definition of real boxes using data of a cruise in the western Mediterranean, (right) nitrate fluxes estimate over the basin (from Schroeder *et al.*, 2008a; 2010b).

The periodically visited transect are planned in order to be useful for: (i) budget computations (of mass, heat, salt, biogeochemical components), i.e. with transects defining closed volumes of water, (ii) long-term evaluation of anomalies of physical and biogeochemical properties, i.e. intercepting the main flow of water masses. This experimental design allows the application of inverse techniques (see box model scheme in Fig. 3, upper panel) to estimate the interbasin exchanges of matter and properties. Wide-ranging dedicated field experiments have been carried out almost every year since 2005, to get a quasi-synoptic view of the circulation in the WMED (Fig. 3, left panel). A first comprehensive estimate of water fluxes in the WMED was obtained by means of a physically robust approach, aimed to an inter-comparison of differently achieved results. Three approaches have been adopted to describe the WMED circulation and velocity field, resolving different spatial-temporal scales and components of the motion, in order to evaluate their degree of accordance: a geostrophic approach, a direct approach and a modeling approach. The results confirm the qualitative overall circulation pattern, providing a solid quantitative basis to be used for budget estimates of different chemical/biological properties (Schroeder *et al.*, 2008b). This quantitative basis has indeed been used to quantify biogeochemical fluxes (of dissolved inorganic nutrients) between the different basins of the WMED (Figure 3, right panel), allowing to distinguish between nutrient sink and source regions (Schroeder *et al.*, 2010b).

In the northern Adriatic, a section from Senigallia to Susak Island (Fig. 4) is periodically surveyed, since 1988, collecting CTD data and samples for dissolved oxygen and nutrients, being an excellent observation site for the water masses transiting in and out of the northern Adriatic. The same parameters are collected seasonally along a transect in the central Adriatic, across the Pomo Pit (Fig. 4), since 1980. The analysis of time series of physical (shown in Fig. 5) and chemical parameters in the northern (Senigallia – Susak Island transect) and middle (Jabuka depression area, or Pomo) Adriatic allows to highlight and to increase the understanding of the anomalies in physical processes, such as seasonal and interannual changes in temperature, salinity, density, dissolved oxygen and nutrients.

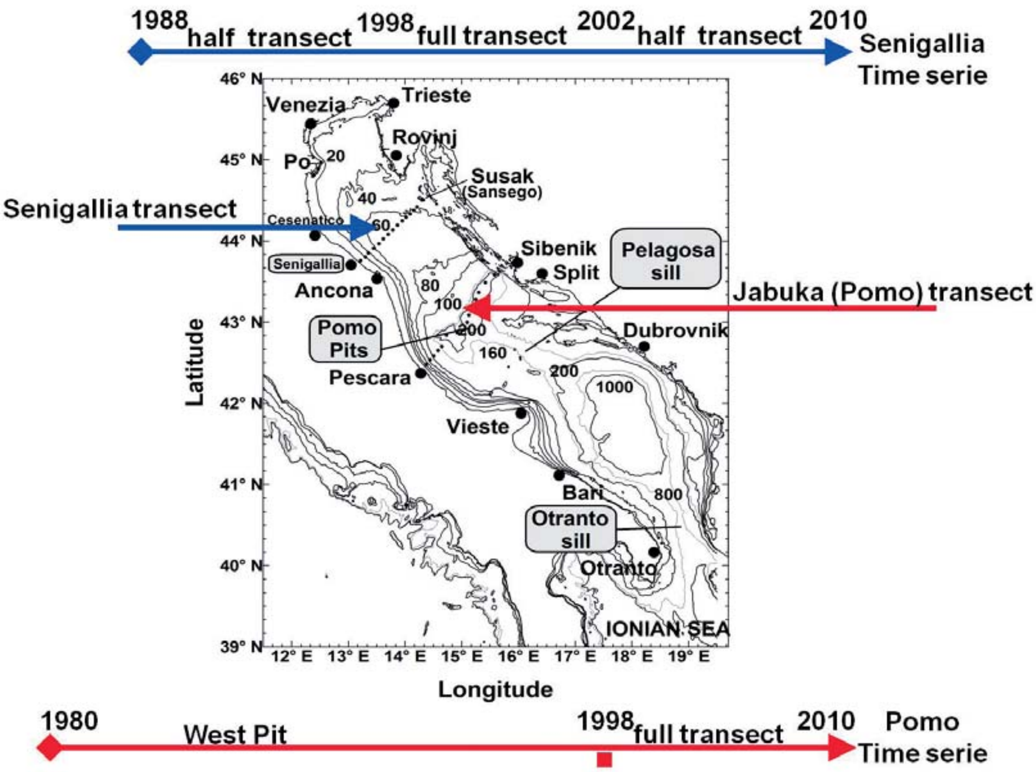

Figure 4. Repeated transects in the Adriatic Sea.

Senigallia has been chosen as monitoring site because it is far enough from the Po Delta and is in an area where the dense water formed during winter in the Northern Adriatic (North Adriatic Dense Water or NAdDW), crosses the Senigallia transect (along its western side) as a bottom boundary current. This water mass flows along the Italian western coast and reaches the second site, the mesoadriatic depression (Pomo Pits). The resident bottom water masses in this area are periodically renewed by NAdDW, at one to three years intervals (Marini *et al.*, 2006), leading to a density and oxygen increase and to a temperature and nutrient decrease. The periodic survey of these transects gave one of the first signals that after the EMT the Adriatic has reassumed a major role as a source of Eastern Mediterranean Deep Water (Marini *et al.*, 2006). Analogously to what has been done in the WMED, these two transects have been used also to estimate mass transports across the Adriatic and the associated nutrient fluxes by Grilli *et al.* (2005a;b).

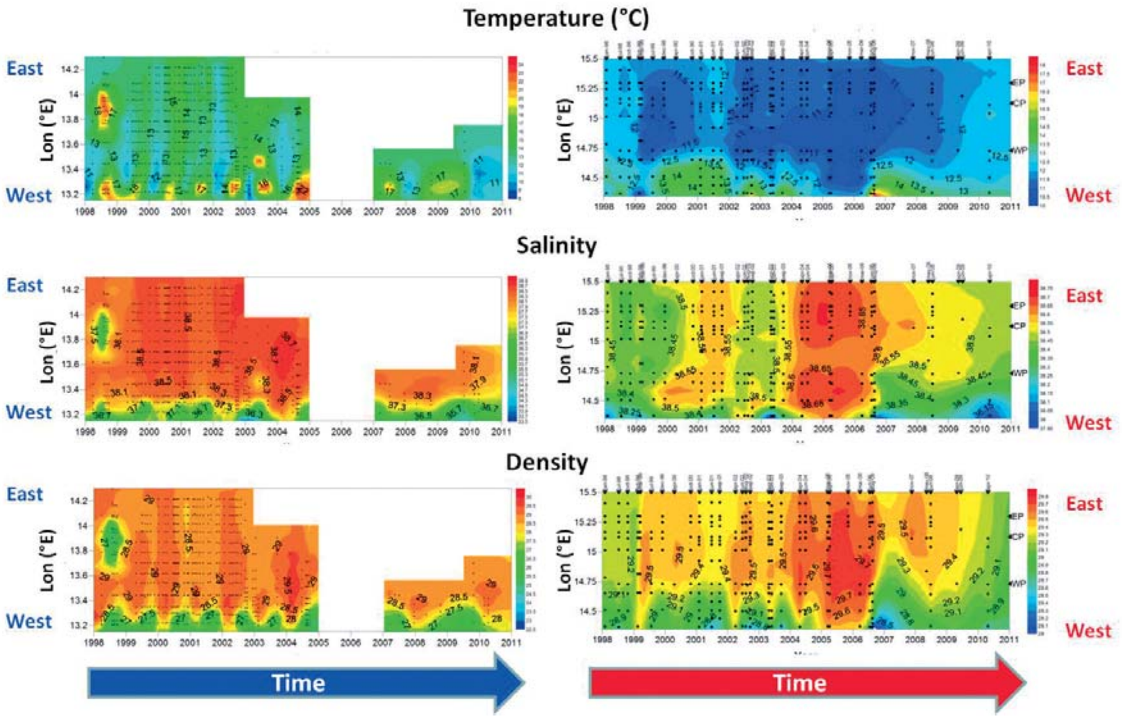

Figure 5. Space-time evolution of bottom water properties along the two transects (on the left the Senigallia transect, on the right the Pomo Pits transect).

4. Proposal

In addition to what is currently done by CNR-ISMAR, as well as by other institutions around the basin, we envisage to build up an international effort (under the CIESM umbrella, and in particular of a forthcoming Med-GO-Ship Programme) to conduct an almost synoptic survey (Fig. 6 left) of the hydrological and bio-chemical characteristics of the water across the whole Mediterranean, occupying (every 5 years for instance) a single zonal transect from the eastern Levantine subbasin, crossing the Sicily Channel, to the Strait of Gibraltar. The distances between stations shall not be lower than 30 nautical miles. Parameters to be measured (depending on partnerships that could be established) should include all those that are considered in the global Go-Ship program, i.e. temperature, salinity, dissolved oxygen, CFC, dissolved inorganic nutrients, dissolved/particulate organic nutrients, dissolved/particulate organic carbon, Caesium, Tritium, Helium, ph, alkalinity, currents (on station and underway).

One of the motivation is to provide an update of the east-west detailed description of water masses, as the one published by Wüst (1961, Fig. 6 right), which is missing at the time (at least with a relative high resolution). In the sense of WOCE, the Mediterranean cruise should contribute to improve also the ocean models necessary for predicting decadal climate variability and change, as well as providing benefits to a wide range of research and operational marine activities, not necessarily related to climate research.

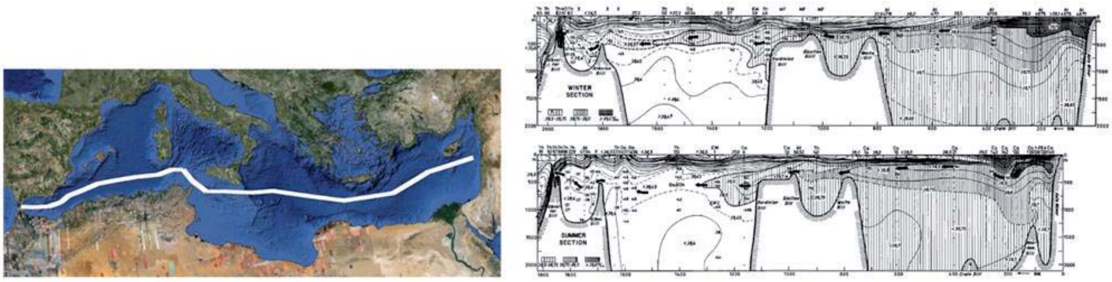

Figure 6. Basin scale transect proposal for a Med-GO-Ship Programme (left panel); winter and summer salinity distribution across a similar transect from Wüst, 1961 (right panels).

5. Conclusion

The main general need, and thus a priority for future research, is a better understanding of the thermohaline stability and/or variability in the Mediterranean Sea, as well as the identification of factors that can modulate this variability. An internationally coordinated action should be aimed at gathering information and understanding the interactions between physics, biogeochemistry and biology, as well as the interactions between the WMED and EMED, thus improving the interpretation and synthesis capability of new available observations to assess feedbacks of the Mediterranean dynamics on the global climatic system. New available technologies are able to significantly improve the present monitoring in terms of space/time resolution and to extend the coverage of biogeochemical parameters. A closer interaction with model simulation is a further important task able to improve both the model results and interpretation of observational data, providing more reliable scenarios of the Mediterranean conditions for the next decades.

The need for coordinated, repeated surveys in the Eastern Mediterranean Basin: a review of the Levantine Basin circulation and the Asia Minor Current

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Introduction

The complex, multi-scale dynamics of the Mediterranean Sea still holds many surprises for oceanographers trying to understand and predict its short or long-term behavior. Despite the growing public awareness of the oceans' role in our future, the requirement for multi-disciplinary, multi-scale sampling of a complex basin such as the Mediterranean often puts serious constraints on coordinated efforts. The gathering of useful new information can only be anticipated when the experimental design is guided by a synthesis of the existing knowledge consistent with theoretical considerations.

National / international efforts to date have traditionally focused on the western / northern domains of the Mediterranean, while the southern and eastern parts remain less explored. The eastern Mediterranean has become the subject of advanced studies towards the end of the last century, starting with the POEM program (1985-1991), later followed up by many other activities. Among these, the most recent investigations under the SESAME European project deserve special attention for addressing the entire basin, sub-basins, shelves and straits of the Mediterranean and Black Seas in an integrated way. There seems to be an urgent need for better cross-basin coordination of systematic observations, making full use of the present technological potential to close gaps in knowledge at a time of increased environmental changes. After so many studies performed to date, there still exists a strong need for coordination, multi-disciplinary integration and synchronization, to avoid duplication or incomplete sampling. Some of the features noted in this brief introduction deserve further study and integration within a larger effort to understand the role of the Mediterranean in the regional climate system (The POEM Group, 1992; Özsoy *et al.*, 1993; Sur *et al.*, 1993; Özsoy, 1999; Gündüz and Özsoy, 2004; Özsoy, 2005; Lionello *et al.*, 2006c; Hoepfner, 2006; Özsoy, 2008; Uysal *et al.*, 2008; CIESM, 2008).

The Eastern Mediterranean – Levantine Basin

The regional climate of the Levantine Basin is typical of the eastern Mediterranean, with hot, humid summers and rainy, mild winters, southwesterly winds followed by northerlies during passing storms in winter and a coastal sea-breeze system superimposed on westerlies in summer. Weather steered by steep mountain ranges but intercepted by valleys along the northern shore often leads to the development of local gale force winds in winter (Reiter, 1979; Özsoy, 1981).

The basic circulation of the Eastern Mediterranean and especially the Levantine Basin has long been a subject of debate, not as a result of insufficient information, but perhaps because of the large variability it displayed throughout the years. The pioneering works of Nielsen (1912) Ovchinnikov (1966) and Lacombe and Tchernia (1972) described a simple cyclonic circulation following the coast in the Levantine Basin, although the latter two papers acknowledged the presence of the separated flow issuing from the Sicily Strait area in the Ionian Sea (later referred to as the 'mid-Mediterranean jet') and the possibility of large anticyclonic gyres in the southern part of the basin. These simple schemes underwent significant change with the POEM experiments (The POEM Group, 1992), resulting in a new synthesis based on several basin-wide synoptic data sets collected on joint cruises by ships from several countries during the program. In the Levantine Sea (Figs. 1 and 2), analyses of the combined data sets (Özsoy *et al.*, 1989; 1991; 1993) showed quasi-permanent features such as the Rhodes and Mersa Matruh gyres, the Shikmona eddy complex, the mid-Mediterranean jet sweeping between them with a large transport of water with Atlantic origin, bifurcating east and west of Cyprus finally to contribute to compensating current systems such as the meandering Asia Minor current along the Anatolian coast and the southern eddies. The flow appeared to have a large barotropic component as many features survived with depth.

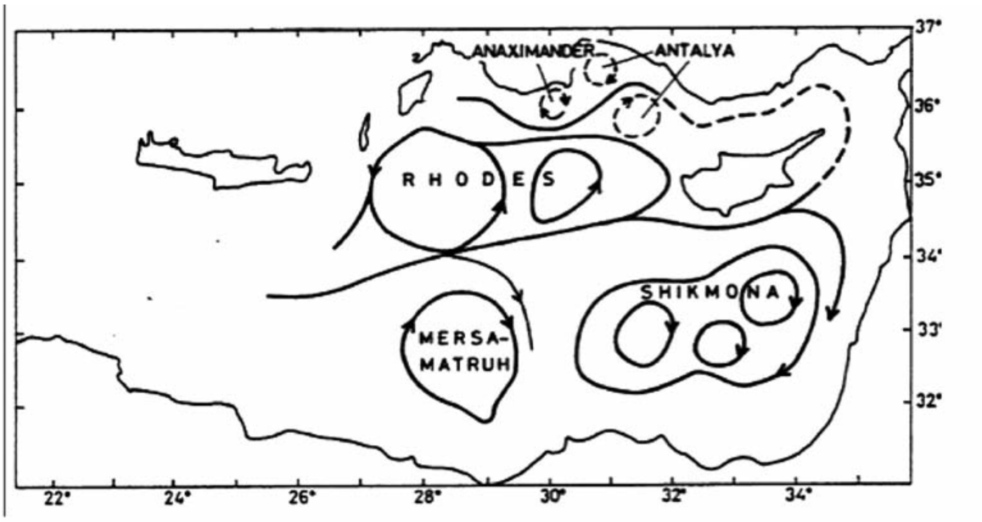

Figure 1. Levantine Basin surface circulation as revealed by the first POEM cruises (after Özsoy *et al.*, 1989).

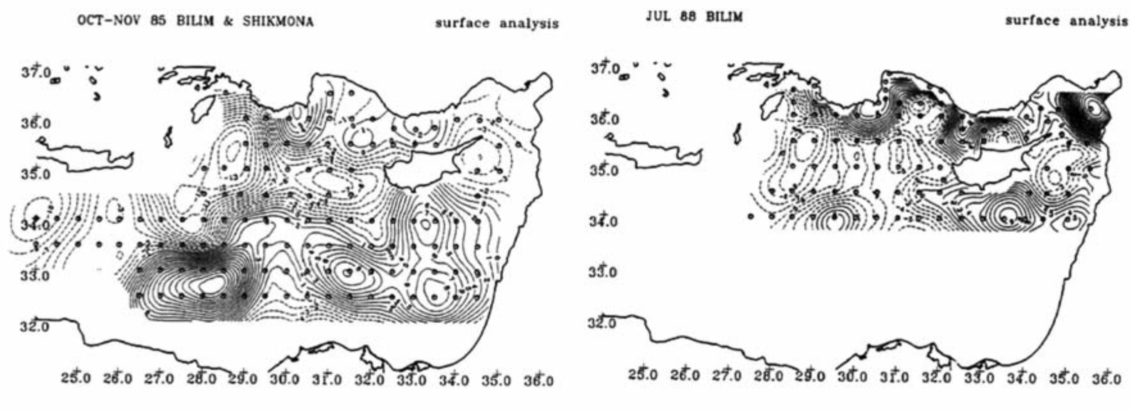

Figure 2. Levantine Basin circulation features in (a) October-November 1985 (first POEM coordinated cruises of research vessels BILIM and SHIKMONA), (b) July 1988 (BILIM).

The mid-Mediterranean jet was a real feature detected by in-situ measurements during POEM experiments. Besides being revealed in the circulation features, the jet appeared to be the main easterly transport path of Atlantic water into the Levantine Sea, as it was associated with a clearly distinguishable subsurface signal of this water mass, which was later traced along the return path of the Asia Minor Current. Yet there appeared considerable variations from one year to another, in the relative strength of the various circulation features, their water mass signatures and the stability of the various coherent features embedded in the circulation (e.g. Figs. 2a,b and 4b). The effects of seasonal to inter-annual scale variations in the local circulation and mixing characteristics resulted in changes in the production and transport of the water masses (e.g. Sur *et al.*, 1992; Özsoy *et al.*, 1993; Malanotte-Rizzoli *et al.*, 1999).

An alternative interpretation was offered later by Hamad *et al.* (2005; 2006), who claimed that the Nielsen-Ovchinnikov scheme could be reinstated based on the analyses of satellite sst data, which only provided a surface image of the non-conservative temperature field. In contrast to this interpretation of biased data, the earlier POEM synthesis was based on the systematic analyses of three-dimensional, quasi-synoptic sets of in-situ data, as well as model simulations, and therefore remains intact, although variations can be expected.

On the other hand, POEM experiments did not cover the close proximity of the north African coast, so as to leave unspecified the nature of currents in the shallow area adjoining the wide shelf. The possibility of easterly or westerly currents or eddies there (e.g. Fusco *et al.*, 2003) were not excluded, but what was inferred from the deeper data as well as numerical experiments later seemed to indicate that this flow was relatively more confined. While the return current for the mid-Mediterranean jet seemed to be mainly occurring through the Asia Minor current, the mainly anticyclonic circulation in the south did not leave much room for cyclonic currents except possibly for some local stretches. Data-driven numerical simulations confirmed the main features of the circulation; e.g. Robinson and Golnaraghi (1993), who in fact had to consider coastal leakage of streamlines in their 2D analyses at depth levels, in order to account for the truly three-dimensional basin circulation. The roles played by islands (such as Cyprus) in the three dimensional circulation were emphasized by the study of Özsoy *et al.* (1992).

A very convincing confirmation of the POEM synthesis of the Levantine Basin circulation has been obtained from multi-year operational simulations of the Mediterranean Forecasting System. The recent reanalysis of 20 years of forecast model results assimilating all the experimental data in the forecasting system verifies the scheme of Fig. 1, reached by the POEM program. Nested model simulations (presented below) produce similar features in the northern Levantine region.

Eddies and meanders, wind driven currents, topographic / continental shelf waves, inertial / internal oscillations add significant time and space dependence to the basic circulation scheme described above and exemplified by the satellite SST and chlorophyll fields in Fig. 3.

The catchments of many small rivers along the northern coast Mediterranean are confined by mountain ranges, while rivers on the southern coast are either non-existent or water input from large rivers such as the Nile are curtailed by the need for water. Focusing on the Levantine basin of the Eastern Mediterranean (Fig. 1), we observe that the shallow continental shelves in the region are confined to the Nile Cone and the Cilician Basin - Gulf of İskenderun. These localities are also the confluence regions of large rivers, i.e., regions of freshwater influence (ROFI) supporting and driving active shelf ecosystems, contrasting with the otherwise oligotrophic deep sea. Perennial rivers Göksu, Lamas, Tarsus, Seyhan, Ceyhan, Asi plus some smaller rivers account for a total fresh water flux of 27km^3/yr (870 m^3/s), much greater than the present discharge of the Nile in the Eastern Mediterranean (estimated to be 540 m^3/s, Pinardi *et al.*, 2006).

It is well known that the Levantine Intermediate Water (LIW) originating from the east and influencing the entire Mediterranean thermohaline circulation is formed in the northern Levantine region, especially around the Rhodes gyre and along the entire Anatolian coast (POEM Group, 1992; Özsoy *et al.*, 1993). Early spring dense water formation and cascading events contributing to LIW formation along the shelf near the Gulf of İskenderun have been repeatedly observed and also predicted by operational forecasts (Figs. 4a,b).

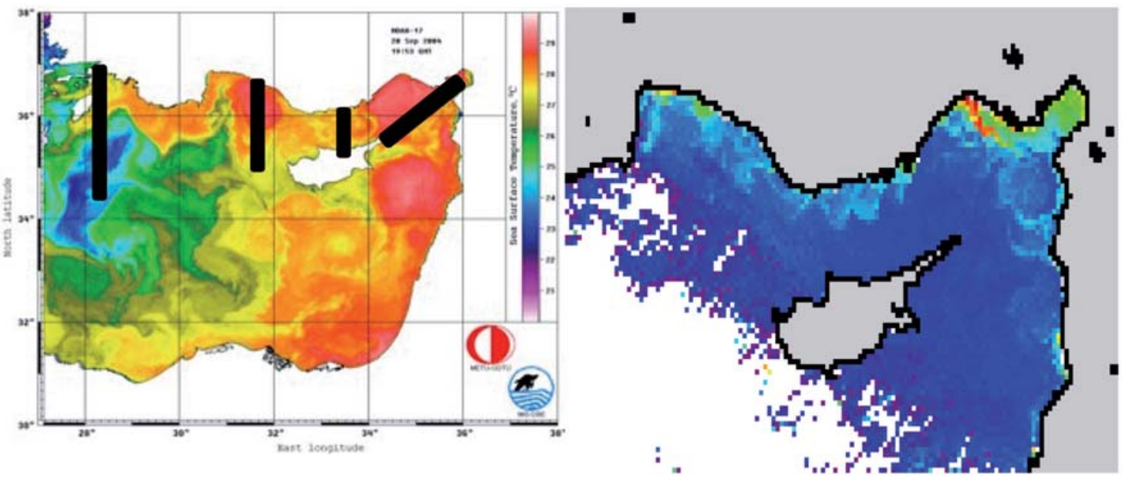

Figure 3. (a) Eddies, jets and gyres in the Levantine Basin revealed in satellite SST, with proposed northern Levantine sections for collaborative studies, (b) summer chlorophyll distribution showing river influence dispersed by meso-scale eddies and transported by the Asia-Minor current.

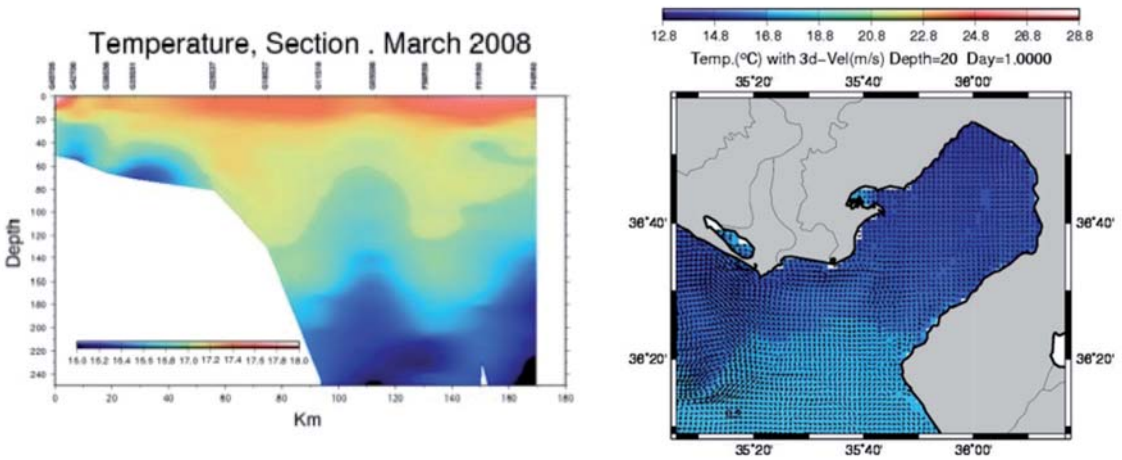

Figure 4. (a) Observed dense water formation in the Gulf of İskenderun in March 2008, (b) temperature and currents forecast on 20 Feb. 2009 showing cold water flowing out at a depth of 20 m.

Models and operational forecasts

Operational oceanography, including observing systems and forecasts, has progressed in parallel with a number of European and local projects in the north Levantine basin. A coastal observation network concurrent with marine and atmospheric modeling has been built under the MOMA project through the support of Turkish Scientific and Technical Research Council (TÜBİTAK). The NLEV operational forecast model has been developed in MFSTEP and later extended in operational use by the MOMA, ECOOP and MyOcean projects. The IMS-METU is a member of the Mediterranean Operational Oceanography Network (MOON).

The Northern Levantine (NLEV) forecast model domain covers the Turkish Mediterranean coast (35.12-36.93ºN, 28.15-36.25ºE) with fine scale horizontal grid resolution of 1.35 km in both directions, and making use of the Mediterranean Forecasting System (MFS) to provide initial and boundary conditions and atmospheric fields to drive the system. The initial Princeton Ocean Model (POM) has been recently upgraded to Regional Ocean Modeling System (ROMS), including the effects of river sources in the northern Levantine Sea. Coupled simulations with an ecosystem model (Fig. 5) have been added in the SESAME project, and used to test climate scenarios.

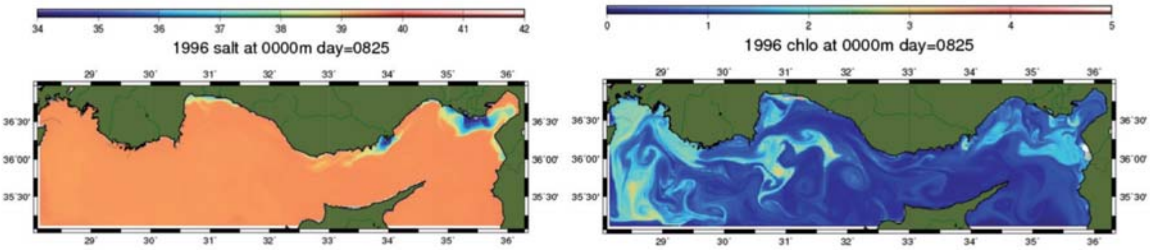

Figure 5. (a) Surface salinity and (b) surface phytoplankton concentration (bloom conditions) simulated in April 1998, based on the NLEV model.

The salinity distribution in Fig. 5a shows the offshore and coastal influences of rivers in the Cilician Basin, feeding a plankton bloom there, while a concurrent bloom takes place at the Rhodes Gyre region, under the influence of convective effects. The sea level in Fig. 6 shows the influence of the Rhodes cyclonic gyre in the western part, and the evolution of well developed anti-cyclonic eddies and jets along the Asia Minor current, through coastal interactions.

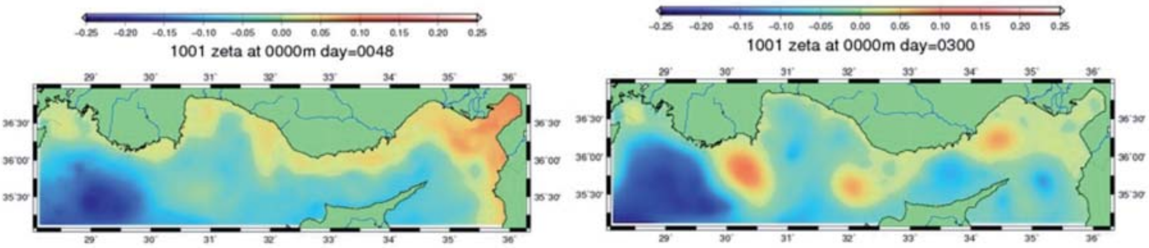

Figure 6. Sea surface height in (a) March 2009 and (b) November 2009 based on the NLEV model forecast.

Proposed repeated sections program in the Northern Levantine

The proposed measurement program to be complemented by the collaborating parties in the proposed Mediterranean GO-SHIP initiative aims to monitor and sample dynamic circulation features along the Mediterranean coast of Turkey, i.e. the Asia Minor Current supporting preconditioning, eddy and frontal mixing, instabilities, shelf mixing, transport by jets and motions of cyclonic / anti-cyclonic eddies and meanders. The transition from a deep oligotrophic ecosystem to shallow, nutrient rich regions of fresh water influence (ROFI) along the shelf can also be explored.

It is the objective of this research activity to design compact experiments to test the following hypotheses:

- the eddies and meanders of the Asia Minor current along the Anatolian coast of Turkey transports and disperses materials;

- the deep overflow through the narrow sill between the Lattakia and Cilician Basins and its attachment to the Anatolian continental slope, as well as eddy transports are main features of the Asia Minor current, finally merging into the Rhodes Gyre system;

- the wide shelf adjoining the Gulf of İskenderun, fed by several rivers, represents a differentiated ecosystem where active interaction takes place between the coastal and the open sea;

- similarly, the upwelling circulation and deep convection effects in the Rhodes Gyre results in water mass transformations and a differentiated ecosystem with higher production;

- winter convection over the wide eastern shelf leads to dense water formation and its cascading contributes to the Levantine Intermediate Water;

- the relative partition of transport in the Asia Minor current in relation to the part that bypasses Cyprus in the multiply connected domain of the Levantine basin can be determined by monitoring the transport in the Cilician channel;

- the dominant features of the cyclonic Rhodes Gyre, and anticyclonic coherent eddies contribute to water transformations and deep sea ecosystem interactions through mixing and dispersion effects.

The marine observational program developed will complement existing programs involving field experiments and marine forecast activities, contributing to the development of new initiatives for better dynamical understanding of the circulation and mixing at sub-basin to meso-scales in the region, with important impacts on the ecosystem.

Two decades of studies document oceanographic changes in the easternmost part of the Mediterranean Sea. Insights towards the design of repeated basin-wide surveys

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In a recent book review (Kress *et al.*, 2011) we described how the Eastern Mediterranean Transient (EMT) event in the 1990s (Roether *et al.*, 2007) changed the physical and chemical oceanography of the Eastern Mediterranean, in particular the Levantine Basin. The area of study covered the southern Ionian basin between 34-36 ºN, the Cretan Passage and the Levantine basin. Data between 1987 and 2008 were assembled from different sources: R/V "Meteor" cross-basin cruises (M5/6, M31/1, M44/4 and M51/2 in 1987, 1995, 1999 and 2001) (Klein *et al.*, 2003; Kress *et al.*, 2003; Roether *et al.*, 2007; Schlitzer *et al.*, 1991), POEM Cruise (1991) (Kress and Herut, 2001; Malanotte-Rizzoli *et al.*, 1999), Haifa Section cruises (2002-2010) and Israel's SESAME cruises (2008) (http://www.sesame-ip.eu, unpubl. results). Here, we summarize and add to the review and stress the changes occurring in the last years in the easternmost part of the Levantine basin and provide some insights towards the design of future basinwide hydrographical surveys.

Mid and Deep Layers physical oceanography – 1990s to 2008

The EMT event produced a new deep water mass, the Cretan Sea Outflow Water (CSOW) that was warmer and saltier than the Adriatic Deep Water (ADW). The CSOW uplifted the older ADW and changed the distribution of the physical parameters in the Eastern Mediterranean, creating a mid-depth layer with minimum temperature and salinity across the basin. A comprehensive analysis of Levantine Basin deep water evolution during the EMT (Roether *et al.*, 2007) brought a vivid picture of CSOW cascading through the Cretan Arc straits and spreading in the Eastern Mediterranean intermediate and bottom layers. Advection of abnormally saline Levantine Surface Water in the Aegean Sea during 1989-1990 (Gertman *et al.*, 2006) followed by extremely cold winters 1992-1993 (Lascaratos *et al.*, 1999) forced the formation of deep water with potential (relative 2000 db) density anomaly (σ) of about 37.83 kg m^{-1}. The excess over the pre- EMT bottom water density was just 0.03 kg m^{-1}. However it was enough to generate a wide spreading of newly formed water. In 1995, three years after the apogee of dense water outflow from the Cretan Basin, the Levantine Deep Water below 2000 m had a stable inversion layer both in salinity and potential temperature (Fig. 1). No inversion was present in 1987. A coarse estimation of propagation rate of dense water from Cretan Passage to the south-eastern continental slope was about 280 km per year.

Observations in October 2001 at R/V "Meteor" M51/2 cruise (Roether *et al.*, 2007) revealed quite homogeneous water for regions east of 25°E and deeper than 2000 m (38.82±0.02, 13.71±0.02°C). However, at the western stations, an intrusion of new water was already observed, as shown in later publications (Manca *et al.*, 2002; Rubino and Hainbucher, 2007). This water was slightly less

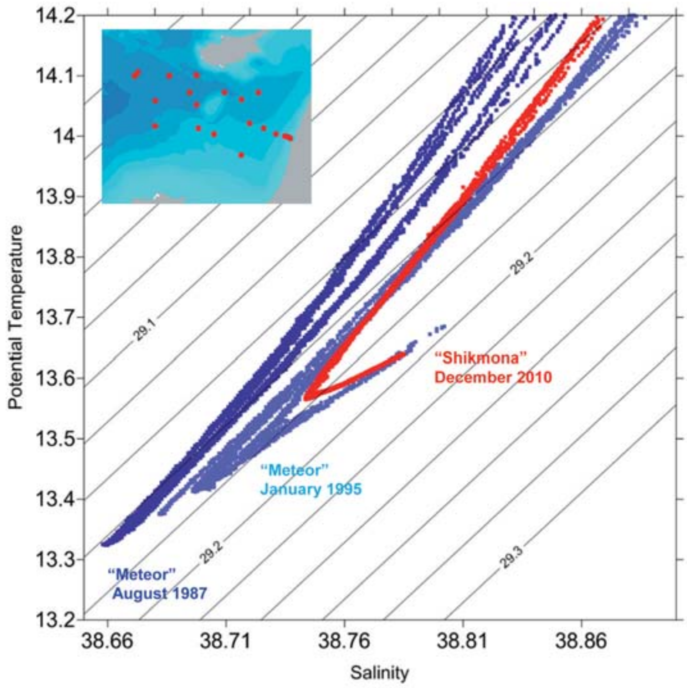

Figure 1. T-S diagrams in the Levantine basin in 1987, 1995 and 2010.

saline (38.78) and colder (13.56°C) than the CSOW. Further eastward propagation of the new water of Adriatic origin was observed in September 2008 during the R/V "Shikmona" cruise carried out in the framework of SESAME. The western boundary of the CSOW moved to ca. 27.5°E; this is clearly shown in the salinity field (Fig. 2) as well as in potential temperature and dissolved oxygen. The CSOW became less salty and colder (38.79, 13.63°C) in 2008 than in 2001 due to mixing while no changes were recorded in the properties of the new Adriatic deep water.

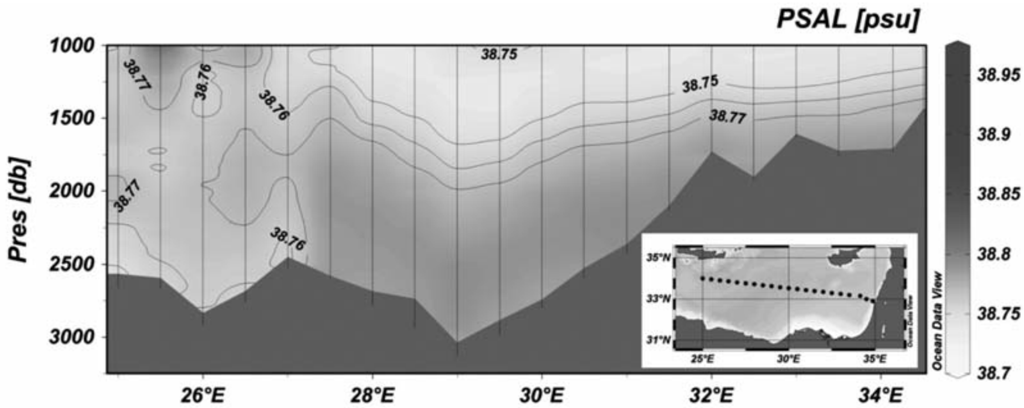

Figure 2. Vertical distribution of salinity at the deep layers of the Levantine Basin in September 2008.

Mid and Deep Layers chemical oceanography – 1990s to 2008

The warmer and saltier CSOW was also more oxygenated and with lower nutrient concentrations than the ADW. The uplift of the older ADW by the CSOW changed the depth distribution of dissolved oxygen and nutrients in the Eastern Mediterranean, creating a mid-depth layer with minimum oxygen (Min_{Ox}) and maximum nutrients (Max_{Nut}) layer in the Levantine basin and Cretan sea (Kress *et al.*, 2003), corresponding to the minimum temperature and salinity layer. In 1999, ca.

nine years past the EMT, the CSOW was established in the whole basin, discernible in the dissolved oxygen and nutrient vertical distributions (Klein *et al.*, 2003; Kress *et al.*, 2003) (Fig. 3). The Min$_{Ox}$/Max$_{Nut}$ layer was found at the 300-1500 m depth interval, the layer thickening and deepening eastwards. The Min$_{ox}$ concentrations were similar in the Levantine and western Ionian (175 µmol kg^{-1}) but located at different depth layers, 600-1500 m and 300-800 m, respectively. The Min$_{Ox}$ at the Cretan Passage was slightly higher (175 -180 µmol kg^{-1}), indicating the presence of younger water. The maximal concentrations of phosphate and nitrate (> 0.175 and > 5.5 µmol kg^{-1}, respectively) (Fig. 3) were similar in the Levantine and the western Ionian with lower concentrations at the Cretan Passage and eastern Ionian. The maximal concentration of silicic acid increased eastwards, from ca. 8.5 to >9.5 µmol kg^{-1} due to increasing age of the water mass. Maximal values were centered at 1200-1400 m, deeper than the maxima for nitrate and phosphate, due to the different remineralisation pathways (slower chemical dissolution for silicic acid as opposed to biological remineralisation). The CSOW was very noticeable in the Levantine, the concentrations of nutrients decreasing from the maxima in the ADW to minima of 4.7, 0.17 and 8.2 µmol kg^{-1} for nitrate, phosphate and silicic acid, respectively in the CSOW. Before the EMT event, nitrate and phosphate concentrations were constant below 1200 m while silicic acid concentrations continued to increase with depth (Kress and Herut, 2001). In the eastern Ionian and western Crete (19-25.5 °E), below 2000 m, the concentrations of nutrients were lower (<4.4, <0.15 and < 7.8 µmol kg^{-1} for nitrate, phosphate and silicic acid, respectively) and dissolved oxygen higher than those found in the Levantine and in the westernmost Ionian, indicating a source of younger water. The continuing influence of the EMT was also detected in September 2008. The Min$_{Ox}$ layer, corresponding to the ADW, was centered at ca. 900 m depth (Fig. 3), shallower than in 1995 and 1999 (1250 and 1100 m, respectively). The layer was more emphasized in the eastern part of the transect (<175µmol kg^{-1} up to 27 °E) and eroded towards the west (minimal concentrations of 180-175 µmol kg^{-1}). The concentrations increased towards the bottom, in particular westwards of 27 °E, indicating mixing and erosion of the CSOW in the east and penetration of younger waters in the west, as shown by the physical parameters. The ADW was detected also by the Max$_{nut}$ of nitrate (Fig. 3) and phosphate located at 400-1500 m depth interval with maximal concentrations of > 5 and > 0.2 µmol kg^{-1}, respectively, the upper isoline shoaling eastwards up to 400 m depth. The concentrations decreased towards the bottom, except for phosphate at 25.5-26.5 °E. The maximum in silicic acid was positioned at the 700-1750 m depth

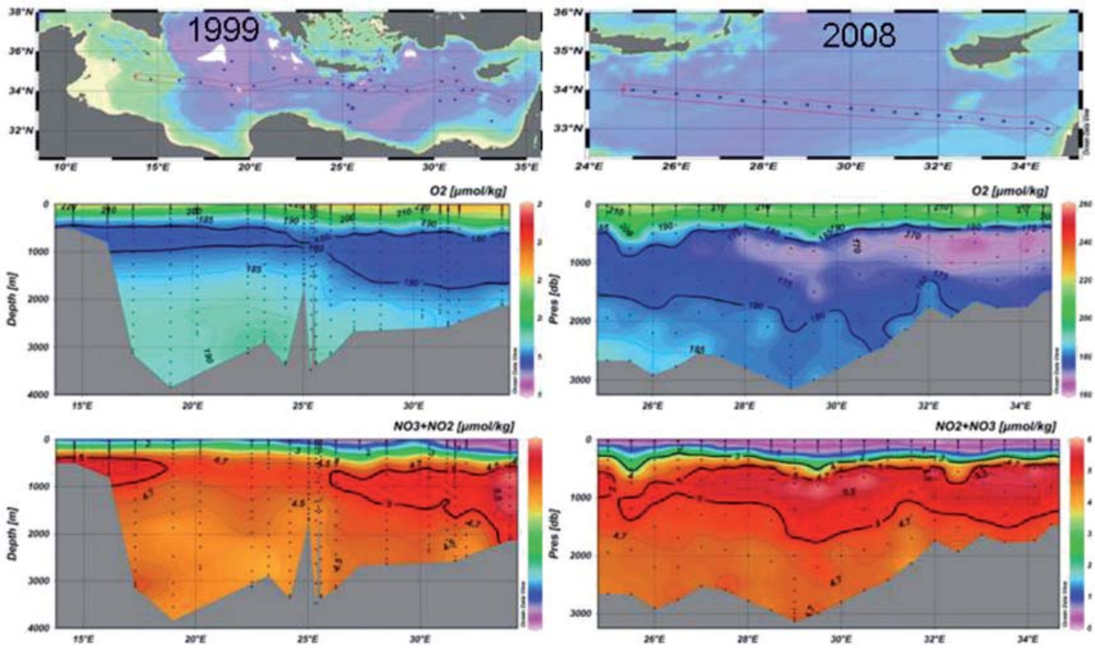

Figure 3. Station location and vertical sections of dissolved oxygen and nitrate in 1999 (left panel) and 2008 (right panel).

interval, centered at 1200 m, and shallower than in 1995 (1750 m) and 1999 (1300 m). This layer shoaled eastwards with the upper 9 µmol kg^{-1} isoline reaching 700 m depth. There were indications of deep intrusion of seawater with lower silicic acid concentration in the vicinity of Crete.

Easternmost Levantine Basin 2002-2010, Haifa Section Cruises

The poor temporal and spatial coverage of the easternmost part of the Levantine basin prompted the Israel Oceanographic & Limnological Res. (IOLR) to initiate in August 2002 the Haifa Section (HaiSec) program, dedicated to perform short seasonal hydrographic cruises. Six stations are occupied along a transect off Haifa, from 50 m to 1700 m depth (Fig. 4). Twenty six cruises were performed until August 2011. In this paper we show the temporal evolution of the physical and chemical parameters at station H05 that was occupied also prior to the HaiSec program. This station was proposed to serve as a WOCE type permanent hydrographic station (Papathanassiou *et al.*, this volume).

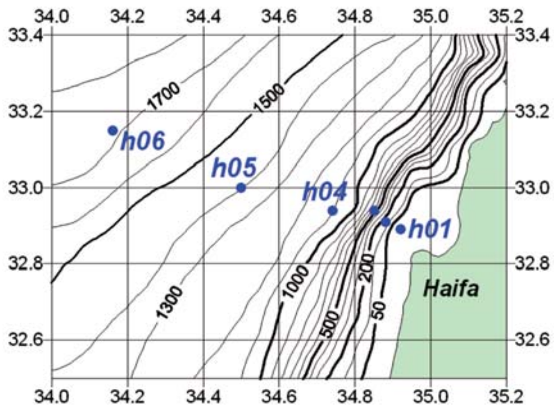

Figure 4. Map of stations of the Haifa Section program.

As shown in Fig. 5, before the EMT influence, the salinity at 1400 m at station H05 was 38.68±0.02 (Fig. 5) with a negative vertical gradient of about 0.005 per 100 m while potential temperature was 13.37 ±0.02°C (Fig. 5) with a decrease rate of 0.015°C per 100 m. Between 1996 - 2002 there was only one survey in the area so we cannot attest to the shape of the change but since 2002, salinity and potential temperature reached 38.77 and 13.59 °C, respectively, and changed the vertical gradients signs. Salinity and potential temperature from 2002 to 2009 fluctuated by 0.02 and 0.02°C, respectively.

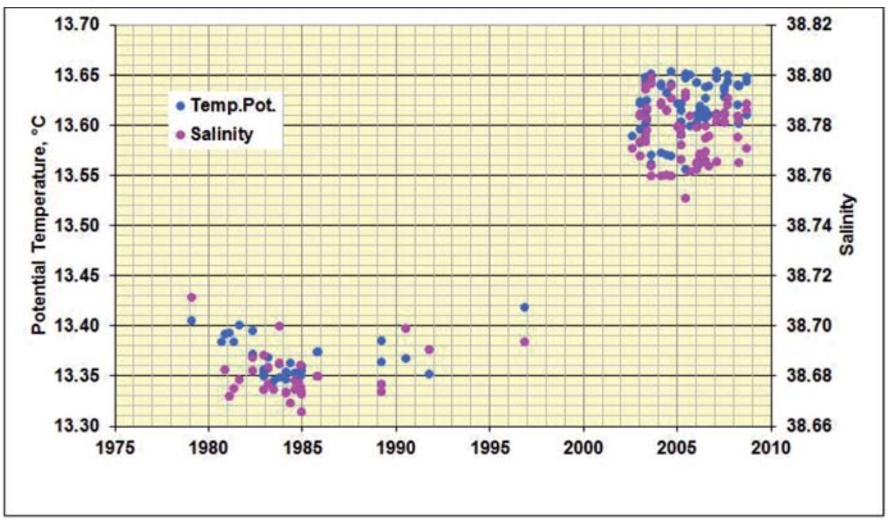

Figure 5. Temporal changes of salinity and potential temperature at the bottom layer at station H05.

The salinity at the upper mixed layer changed as well, showing lower salinity at the beginning of the 1980s and 2000s and higher salinities at the beginning of the ’90s (onset of the EMT) and since 2006 (Fig. 6). This is in good agreement with the BIOS mechanism in the Ionian Basin (Civitarese *et al.*, 2010) (Civitarese and Gačić, this volume).

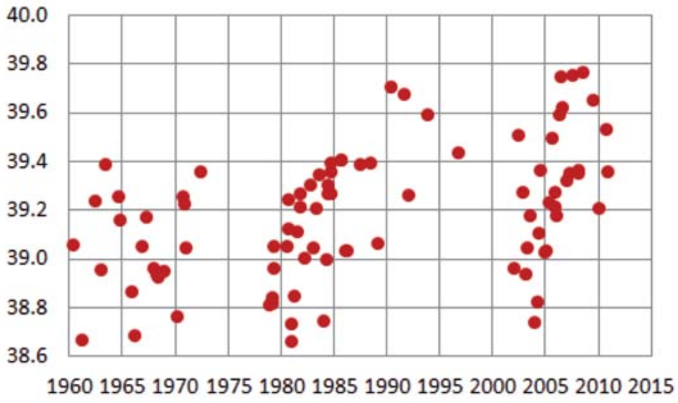

Figure 6. Temporal changes of salinity at the upper mixed layer of station H05.

There are no data on the chemistry at station H05 prior to the HaiSec program. However, between 2002 and 2010 the vertical distribution of dissolved oxygen and nutrients (exemplified by nitrate) changed (Fig. 7). The CSOW was already in place in 2002 as seen by the Min_{Ox}/Max_{Nut} at the mid depth, and higher oxygen and lower nitrate concentration close to the bottom. As time evolved, the Min_{Ox} vertical span narrowed and the influx of more oxygenated waters (the new, younger ADW) was more evident. The concentration of nitrate at the Max_{Nut} increased with time and shallowed.

The shallowing of the isolines brought more nutrients closer to the photic zone and within reach of the microbial communities. Until 2008, satellite images and basinwide surveys did not show an increase in Chlorophyll *a* (D’Ortenzio *et al.*, 2003; Kress *et al.*, 2011). However, the temporal evolution of Chlorophyll *a* at station H05 indicates that the depth of the deep Chlorophyll maximum shallowed from ca. 120 m in 2002 to above 100 m in 2010 and the concentration increased. This finding is still being analyzed within the HaiSec program.

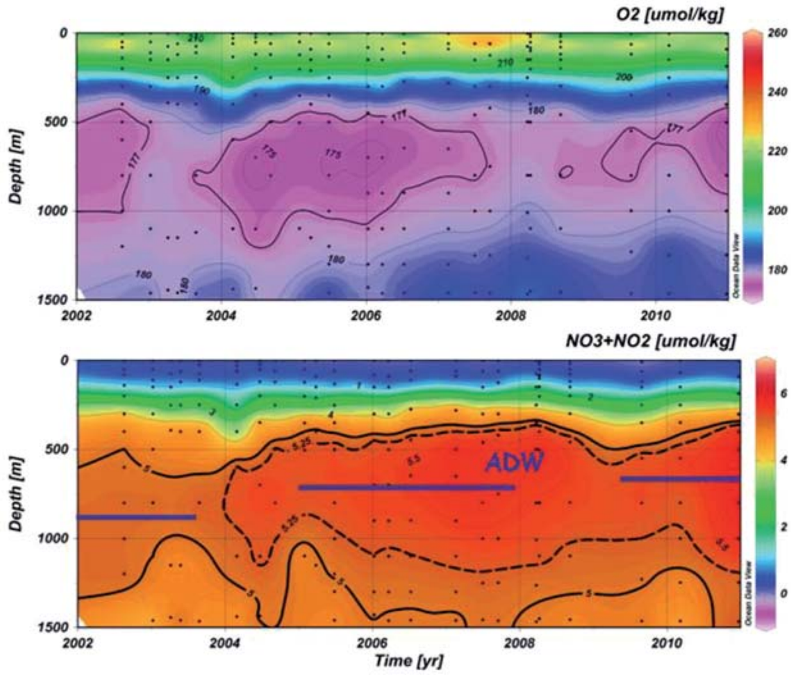

Figure 7. Temporal depth evolution of dissolved oxygen and nitrate at station H05. The blue line in the lower panel indicates that change in position and concentration of the maximal concentration of nitrate, corresponding to the ADW.

Insights towards the design of repeated basin-wide surveys

The synthesis of the available data allowed us to pinpoint important considerations, missing data and improvements to be incorporated in the planning of repeated basin-wide surveys.

1. Time scale. The changes in the Eastern Mediterranean are fast. The lack of basinwide hydrographic surveys between 1991 and 1995 caused the community to observe the first stages of the Eastern Mediterranean Transient effects in a holistic way. The fast changes in the Eastern Mediterranean can be shown by comparing the results of the three basinwide surveys conducted in 1995, 1999 and 2001 and to a lesser degree in 1991. This should be taken into account when deciding on the temporal frequency of the surveys.
2. Spatial resolution. It seems that stations at every half degree is satisfactory. There should be one west-east transect from the Sicily straits to the easternmost part of the Levantine, with north-south transects in special places (we do not address the Ionian and the Aegean).
3. The transect should reach the continental slope, in order to connect the open sea with the shelf areas, more likely to be affected by climatic changes.
4. The upper layer, where most of the biological processes occur and are of particular importance concerning climate change, is under-sampled, preventing a robust analysis. The concentration of nutrients at the upper layers in the Eastern Mediterranean are very low, therefore nanomolar techniques should be implemented. More biological measurements, that are not difficult to perform and can help to connect physical, chemical and biological processes, should be incorporated as routine measurements during each hydrographic cast. For example, picophytoplankton enumeration by FACS, pigment distribution by HPLC. There are also new methodologies being developed for the speciation of phytoplankton that could be adopted in the future.
5. The whole water column should be sampled. During the 1991 POEM cruise, most of the stations were sampled only to 1000 m in order to save ship time. In retrospect, it was unfortunate.
6. New optic, chemical and biological sensors should be incorporated into a cast. Fluorescence and transmissometers are now routinely used. It is possible to use a nitrate sensor (for example – ISUS) to obtain continuous profiles that can be used to support the physical data and be connected to the biology, even though the detection limit is 1 μM, and it will not be of use at the upper (ca.) 100 m in the Eastern Mediterranean.
7. More intensive measurements should be performed at selected stations as a function of key biological processes.
8. Data mining and quality control of historical chemical and biological data should be performed.
9. Hydrographic measurements are still needed even at the age of satellite observation and autonomous data collectors. Deep water physical characterization is not within the reaches of autonomous profilers, entire water column measurements of properties are not covered by automatic sensors, and satellite, sensors and autonomous data collectors require ground truth data for calibration and validation.

Circulation pattern of the southeastern Mediterranean waters off Egypt: a review

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Abstract

Circulation pattern in the southeastern Mediterranean is reviewed. The water circulation is dominated by the Atlantic water inflow along the North African Coast and by the Mersa Matruh gyre in the west and El-Arish gyre in the east. Better understanding is needed about the current system and changes in the hydrographic structure in this part of the Mediterranean as a result of climate change.

Introduction

The southeastern part of the Mediterranean Sea was one of the least investigated areas until the last two decades. Most of the known patterns of water circulation of the Egyptian Mediterranean waters have been obtained through indirect methods; by constructing T-S diagrams, and sections of horizontal and vertical distributions of some physical and chemical properties of seawater such as salinity, temperature and oxygen (Morcos and Hassan, 1976; Abdel-Moati and Said, 1987; Said and Karam, 1990; Said *et al.*, 2007) by dynamic method (Sharaf El-Din and Karam, 1976; Said and Eid, 1994a) by Steric height (Eid and Said, 1995) and by using numerical modeling (Said and Rajkovic, 1996; Hazem, 2007).

Direct current measurements were very scarce. Gerges (1981) studied the monthly patterns of surface currents obtained by averaging all current measurements carried out in each one-degree square along the Egyptian coast over a period of 50 years, up to the early Seventies. Currents were measured on the continental shelf off Egypt using ADCP during the joint Soviet-Egyptian expedition carried out along the Egyptian Mediterranean Sector during December 20-27, 1988 aboard RV "Akademik Levrentyev" (Said, 1994).

The aim of the present work is to describe the water circulation in the southeastern Mediterranean using different techniques and more recent observations, and define the more accurate details of the current system in this part of the Mediterranean Sea.

Area of investigation

The investigated area, which is the Egyptian Mediterranean coast, lies between longitudes 25°30'E and 34°E and extends northward to the 33°N latitude (Fig.1). Its surface area is about 154,840 km^2, with an estimated water volume of about 225 km^3.

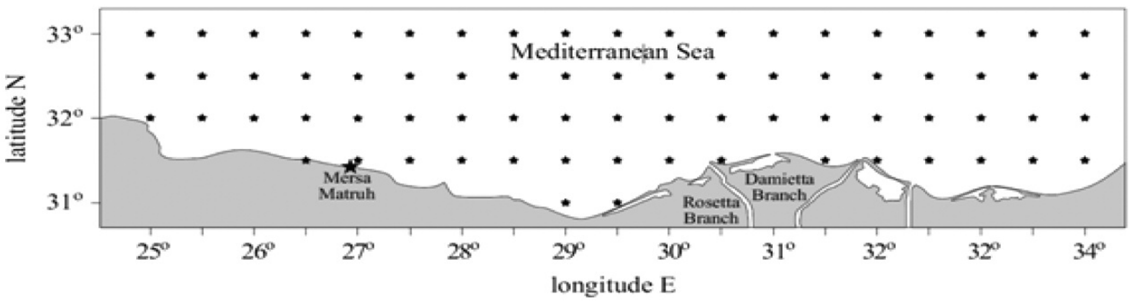

Fig 1. The Egyptian Mediterranean coast.

A-CIRCULATION PATTERN USING GEOSTROPHIC METHOD

Said and Eid (1994a), computed the circulation pattern of the Egyptian Mediterranean waters using the dynamic method. The reference level was taken at the 1000 db surface. In shallow parts of the study area where the depths were less than the depth of the reference level, Groen's method(1948) was applied. The surface circulation during winter and summer seasons is dominated by the Atlantic water inflow along the North African coast and by the Mersa Matruh anticyclonic gyre in the western part of the Egyptian coast (Figure 2). This gyre has been called the Egyptian anticyclonic gyre by Said (1984), the Egypt high by Brenner (1989) and Mersa Matruh by Ozsoy *et al.* (1989). In summer, the Mersa Matruh gyre splits into two centers at the 50 and 100 m levels. Below these levels, the gyre is intensified and split into multiple centers. At the 500 m level, the gyre could be observed during both seasons.

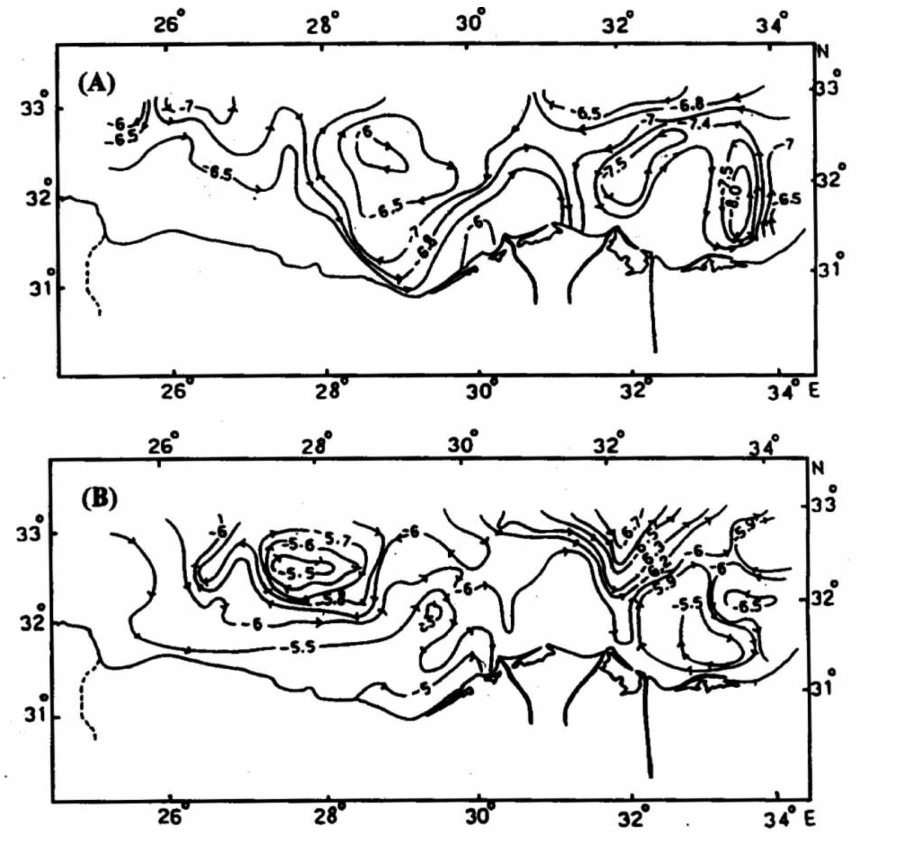

Fig 2. Dynamic relief (dyn. m) for the sea surface during (A) winter and (B) summer.

In the eastern side of the Egyptian coast off El-Arish city, the circulation is cyclonic in winter. This circulation exhibits a strong winter to summer variability, reversing from cyclonic to anticyclonic. In the scientific literature there was no evidence of the existence of such a gyre. Consequently, they called it El-Arish gyre. This gyre is more intense in winter and weaker in summer. To the east of El-Arish gyre, the southern extent of the Shikmona gyre is observed in both seasons.

The geostrophic current velocity at the edges of Mersa Matruh gyre varies between 12.5 and 29.1 cm/sec in winter and between 6.5 and 13.1 cm/sec in summer. The current velocity reaches its maximum values (>40 cm/sec) at El-Arish gyre in winter. The current velocity at the two gyres decreases with increasing depth.

On the basis of the hydrostatic equation, the total steric height was calculated during winter and summer seasons off the Egyptian coast by Eid and Said (1995) in order to show the role of water density on the variability of water motion due to the direct effect of water density. The charts of water circulation based on their calculation were typically the same as the charts of geostrophic circulation constructed for winter and summer.

B-Circulation pattern using a three dimensional numerical model

The Princeton Ocean Model (POM) which makes use of a curvilinear orthogonal grid and of a sigma-coordinate system was used by Said and Rajkovic (1996) to study the general circulation of the Egyptian Mediterranean waters. The model was described in details by Blumberg and Mellor (1987). The grid resolution ranges from 22 to 27 km. The model has three open boundaries to the west, east and north.

The surface circulation of the Egyptian Mediterranean waters, as obtained from the model results (Figures 3 and 4), is dominated by the easterly flow parallel to the coast and by anticyclonic circulation in the western part of the area. In winter, the water incoming from the west flows eastward parallel to the coast. It circulates at longitude 27°E into anticyclonic gyre. This is the Mersa Matruh gyre. It occupies the area between 27° and 29°E and latitudes 31°30' and 32°45'N.

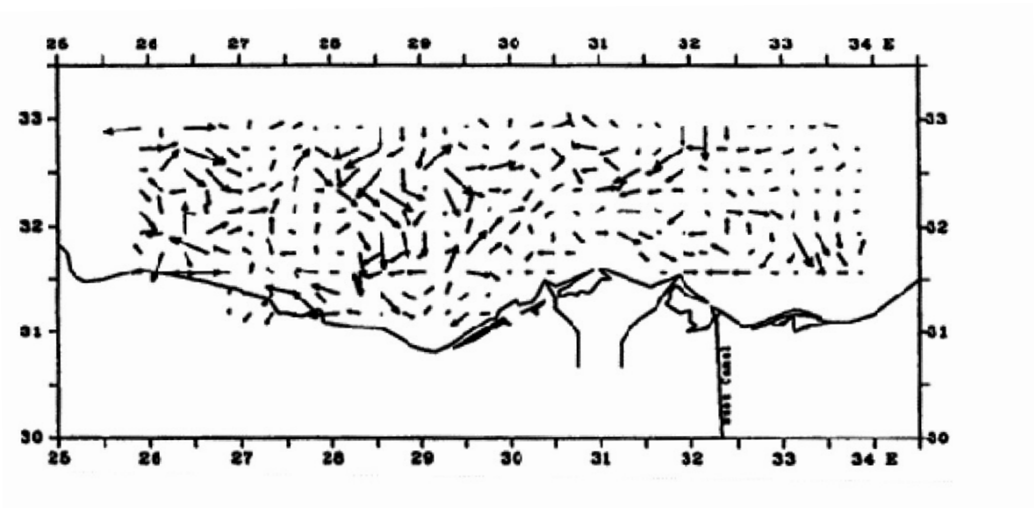

Fig 3. Current velocity at the surface during winter.

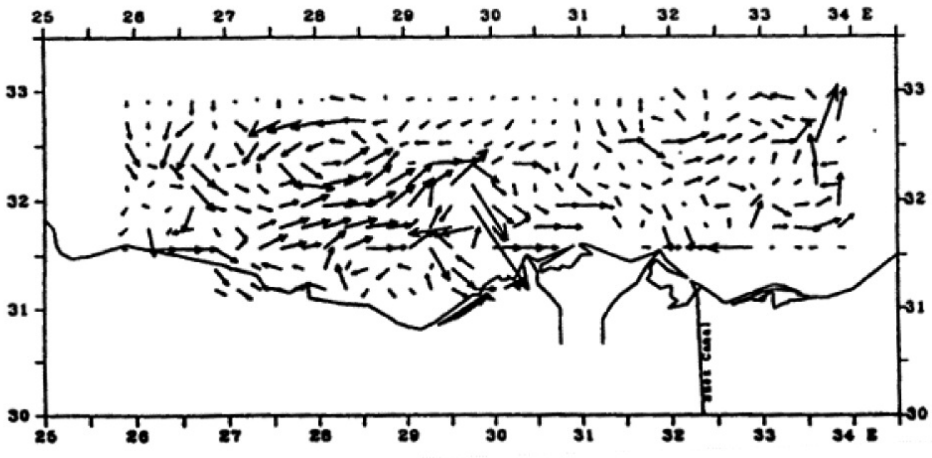

Fig 4. Current velocity at the surface during summer.

The North African flow in its way from west to east bends over the Nile Delta from southeast near the coast to northeast at longitude 32°E. It bifurcates into two branches; one is reversed and closely follows the Egyptian coast towards the west. This reversing circulation is strongly observed in winter from surface to bottom near the coast. In summer, the reversing circulation is very weak and could be found only near the Arab Gulf coast, west of Alexandria. The other branch circulates into the anticyclonic gyre, off El-Arish city, between longitudes 32° and 33°30'E and latitude 32°N. El-Arish gyre was observed and described in details by Said and Eid (1994a). In the present work, the gyre was clearly observed in winter and completely disappeared in summer.

In winter, the northeastern part of the experimental area is fed by water coming from the Levantine basin; part of it moves toward the south and part recirculates into the anticyclonic and returns back to the Levantine basin. In summer, the Levantine basin is fed by water coming from the experimental area through the northeastern boundary.

C-Surface current using Lagrangian Drifters

The data used in the present study were collected by the EGITTO/EGYPT-1 program led by OGS (Gerin *et al.*, 2007). The program started in September 2005 to quantify the circulation and eddy variability in the Eastern Mediterranean with major attention to the eastern and southern regions of the Levantine sub-basin. A total of 81 SVP drifters were deployed from September 2005 to October 2006. In particular, 31 drifters were released in the Sicily Channel on a seasonal basis and 50 drifters were deployed in the southern Ionian, the Cretan Passage and the Levantine sub-basin during four oceanographic cruises. All the drifters were equipped with a holey sock drogue centered at a nominal depth of 15m to minimize the influence of the local winds and with a radio transmitter emitting every 90 seconds to send data (e.g. sea surface temperature) and tracked by the Argos system aboard the NOAA near polar orbiting satellites (Gerin *et al.*, 2007).

The raw Argos positions were edited for outliers and spikes using statistical and manual techniques (Poulain *et al.*, 2004) and interpolated at regular 2-hours interval (Hansen and Poulain, 1996), filtered with a low pass Humming filter of 36 hours to eliminate tidal and intertidal currents and finally sub-sampled every 6 hours. Surface velocity was calculated by central finite differencing the interpolated positions (Gerin, 2007).

The mean flow and the variance were calculated for the whole period from the filtered data using a spatial averaging scale of 1°×1° overlapping bins. The released SVP drifters in the Cretan Passage which the entered the Egyptian waters indicated the existence of strong current (about 20-25 cm/sec) and flow eastward along the continental slope off Egypt. Anticyclonic circulation features off the Libyan coast and in Ierapetra and Mersa Martuh areas are striking (Figure 5).

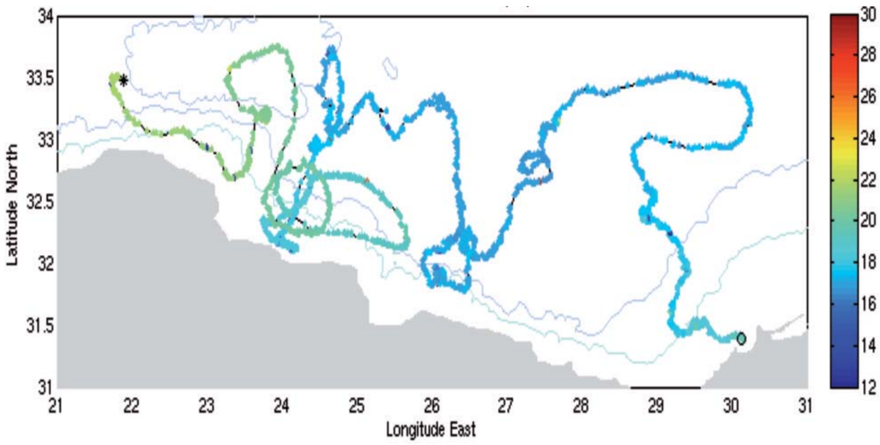

Fig 5. Drifter trajectories during April 2006.

D-Changes in the characteristics of the Atlantic waters off Egypt

Four water masses in winter and five in summer are identified from the south-eastern Mediterranean. These are: the surface water mass of high salinity; the subsurface water mass of minimum salinity and maximum oxygen, which is of Atlantic origin and extends between 50-150 m; the intermediate water mass of maximum of salinity that extends below 150 m to about 300-400 m depth and the deep Eastern Mediterranean waters (Said and Eid, 1994b).

Long-term variations of water temperature and salinity for the Atlantic waters along the Egyptian Coast were studied by Said *et al.* (2011). The data used were taken from several expeditions carried out by Egypt and different countries from within and outside the Mediterranean region, for the last 50 years (1959-2008). The annual average temperature of the Atlantic waters, was between 16.72 and 20°C, giving a temperature trend of 0.28°C/dec for the last 25 years (1983-2008). In the meantime, the annual average salinity of AW varied between 38.64 and 38.788 psu, indicating a salinity trend of 0.014 psu/dec for the last 25 years (Figure 6). This increase in temperature and salinity of AW with time is therefore confirmed as being attributable to anthropogenic modifications, especially the damming of the River Nile, in addition to local climatic changes.

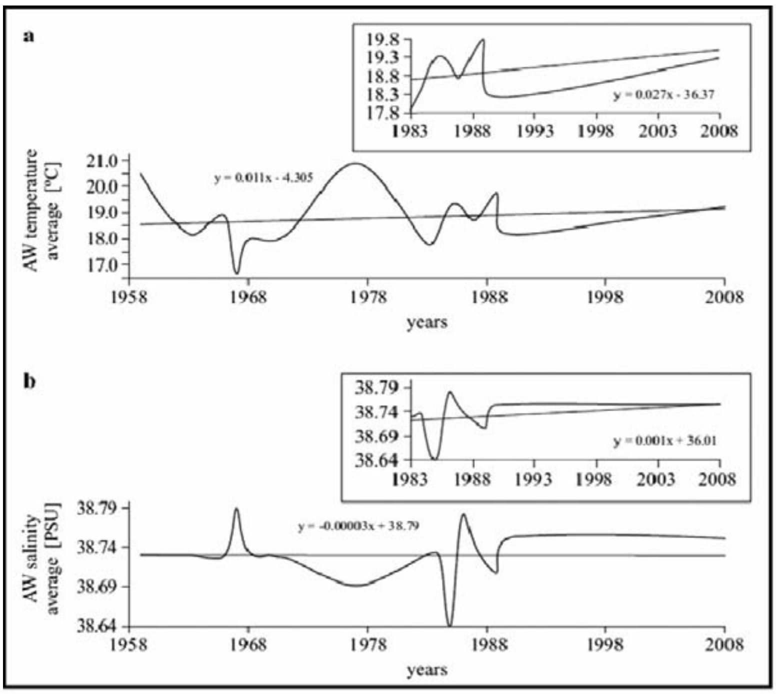

Fig 6. Annual average of (a) temperature and (b) salinity for the Atlantic water during 1958- 2008.

Millot (2007), using an autonomous CTD set at 80 m depth on the Moroccan shelf to monitor the inflowing AW during the period 2003-2007, found that the AW registered considerable salinification at the rate of about 0.05/yr, i.e. ~0.2 in the 4-year period of observation, together with consequent densification (~0.03 kg/m3/yr in the same period, i.e. 0.12 kg/m^3).

Conclusion

The circulation of the southeastern Mediterranean off Egypt obtained from the POM model, from the charts of winter geostrophic circulation and from the steric height distributions are in a good agreement with the current measurements taken over the Nile Delta using ADCP during winter of 1988 by the Russian Academician RV "Levrentyev" and the results obtained from the movement of the SVP drifters. Although the EGITTO drifter database represents an unprecedented effort for that region, there are still areas and periods where data are scarce. More efforts must be done in order to have better understanding about the current system and changes in the hydrographic structure in this part of the Mediterranean.

Surface and intermediate circulation in the Eastern Levantine Basin from *in situ* observations

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Abstract

The surface and intermediate depth circulation in the eastern Levantine basin as determined from *in situ* data is described here. A number of methods have been used. Since 1995, annual or semi-annual hydrographic cruises have been repeated on a grid in the Eastern Mediterranean Levantine Sea, south of Cyprus. From 1999, regular expendable bathythermograph profiles were collected between Cyprus and Egypt, particularly from 2004-2005. Beginning in March 2009, two gliders of the Oceanography Center of the University of Cyprus began occupying a hydrographic endurance line for measurements of temperature, salinity, dissolved oxygen, optical backscatter, and fluorescence in the region. The transects follow a butterfly pattern near the Eratosthenes Seamount, extending to a maximum depth of 1000 m. These operational transects represent the first in a time series of transects. These data support the hypothesis of a permanent anticyclonic eddy, the Cyprus eddy, located near the Eratosthenes Seamount south of Cyprus with a radius of about 45 km and tangential barotropic current speeds of approximately 0.30 m s^{-1}. It consists of a core of Levantine Intermediate Water to a depth of about 400 m. The surface signature is very weak, particularly in summer. However, it is visible in maps of absolute dynamic topography. Other anticyclonic eddies have been observed, such as the Shikmona eddy between Cyprus and Israel. Around the periphery of these eddies is seen a clear signal of Atlantic Water, a branch of the mid-Mediterranean Jet. To the northwest of the observed region is found the eastern edge of the cyclonic Rhodes Gyre. Because of the strong mesoscale variability, a sampling program with resolution of at least 10 km is recommended. This sampling program should be designed with the thought of data assimilation into numerical models in mind, because no observing system alone can capture the variability suggested by existing *in situ* measuring programs over long periods.

Introduction and methods

Schematics of the Mediterranean circulation have been proposed by several authors since Nielsen (1912), who depicted the Levantine basin as one simple cyclonic gyre with the current near the coast. The Levantine basin, located at the easternmost part of the Mediterranean, is separated from the rest of the Mediterranean by the Cretan Passage to the Ionian Sea and the straits of the Cretan Arc to the Aegean Sea. The circulation of the Levantine Basin was first described in detail by Ovchinnikov and Fedoseyev, 1965; Ovchinnikov *et al.*, 1976, who also postulated the general cyclonic circulation around the circumference of the basin, but with sub-basin scale features in the interior. With the Physical Oceanography of the Eastern Mediterranean (POEM) cruises of the

1980s, an even more detailed description of the vertical and horizontal distributions and movements of the water masses of the Levantine Sea was achieved: the Levantine Surface and Intermediate Water (LSW and LIW) masses sandwiching the Atlantic Water (AW), with the Eastern Mediterranean Deep Water (EMDW) at the deepest observed levels (Robinson *et al.*, 1991; POEM Group, 1992). Variability at basin scales, sub-basin scales, and the mesoscale has been recognized and described by many authors (Hecht *et al.*, 1988). A picture has been established of intense mesoscale anticyclonic activity within a backdrop of the generally cyclonic circulation of the Levantine basin (Robinson and Golnaraghi, 1993; Zodiatis *et al.*, 2005a). These anticyclones typically encase warmer, saltier LIW, with subsurface currents meandering amongst eddies with an AW signature. The POEM group identified this meandering current as the mid-Mediterranean Jet (MMJ) which separates the region of anticyclonic eddies in the south from the cyclonic Rhodes Gyre to the north (Robinson *et al.*, 1991). The permanence and possibly the generation of the Cyprus eddy south of Cyprus is strongly tied to the bottom topography, being located in a deep basin formed by the Middle East coast to the east, Cyprus to the north, the Eratosthenes Seamount to the west, and the Nile Fan to the south (Robinson and Golnaraghi, 1993). The generation of the Cyprus eddy could be a result of interaction of eastward current with the seamount, advection from the region of LIW formation in the Rhodes Gyre followed by attachment to the favorable topographic conditions, or local intermediate water formation, although it is more likely that the winter mixing simply reinforces an existing eddy (Brenner *et al.*, 1991). A second non permanent eddy, named as the Shikmona eddy has been observed to pinch off and move westward from the coastal current of Israel and Lebanon. It appears as an eddy with strong surface signatures consistent with waters of coastal origin before dissipating (Gertman *et al.*, 2010). However, the Cyprus eddy has little or no surface signature in the summer season because of the strong surface heating and evaporation, while in winter the surface signature is also very small because of the strong mixing with LSW (Brenner *et al.*, 1991). The generation mechanism and evolution of the eddy field and MMJ are not yet clear because of the difficulty in obtaining *in situ* data sets with adequate resolution *and* coverage in time and space. Because of the strong eddy and MMJ variability, it has been difficult to describe the region with a single current schematic for surface or intermediate depths.

Illuminating data sets have been collected by ship-based hydrographic sampling and have shed light on the variability of the Cyprus eddy, typically surrounded by a subsurface core of AW (a branch of the MMJ). Building on knowledge gained from the POEM cruises, a new observational program was initiated in 1995 by the Oceanographic Center of the Cyprus Department of Fisheries and Marine Research to investigate the characteristics of the sea south of Cyprus. Since 2003, the responsible Oceanography Center has been based at the University of Cyprus (OC-UCY) and maintains the observation program. With 23 extensive hydrographic cruises since 1995, the Cyprus Basin Oceanography program (CYBO) provides an impressive background regarding the expected location and properties of the Cyprus eddy and the MMJ (Zodiatis *et al.*, 2005a; Zodiatis *et al.*, 2005b). The sampling pattern is repeated so that cruises can be more easily compared from year to year. The grid is a telescopic one, with high resolution near the coast (5-10 km), and lower in the open sea (25-50 km). Each cruise lasts 10 days and covers approximately 90 stations; typically measuring to 1200 m (Fig. 1). Cruises are consistently done in late August or early September, and often in April or May. A few cruises have taken place in other months (January, February, and October). A rosette is used carrying a Seabird Electronics 911+ system, with sensors for conductivity, temperature, pressure, and dissolved oxygen. The data are transmitted in real time to the operator. Filtering, thermal mass corrections to conductivity and bin averaging are done, as well as visual checks on data quality. Sensors are calibrated at the manufacturer every year.

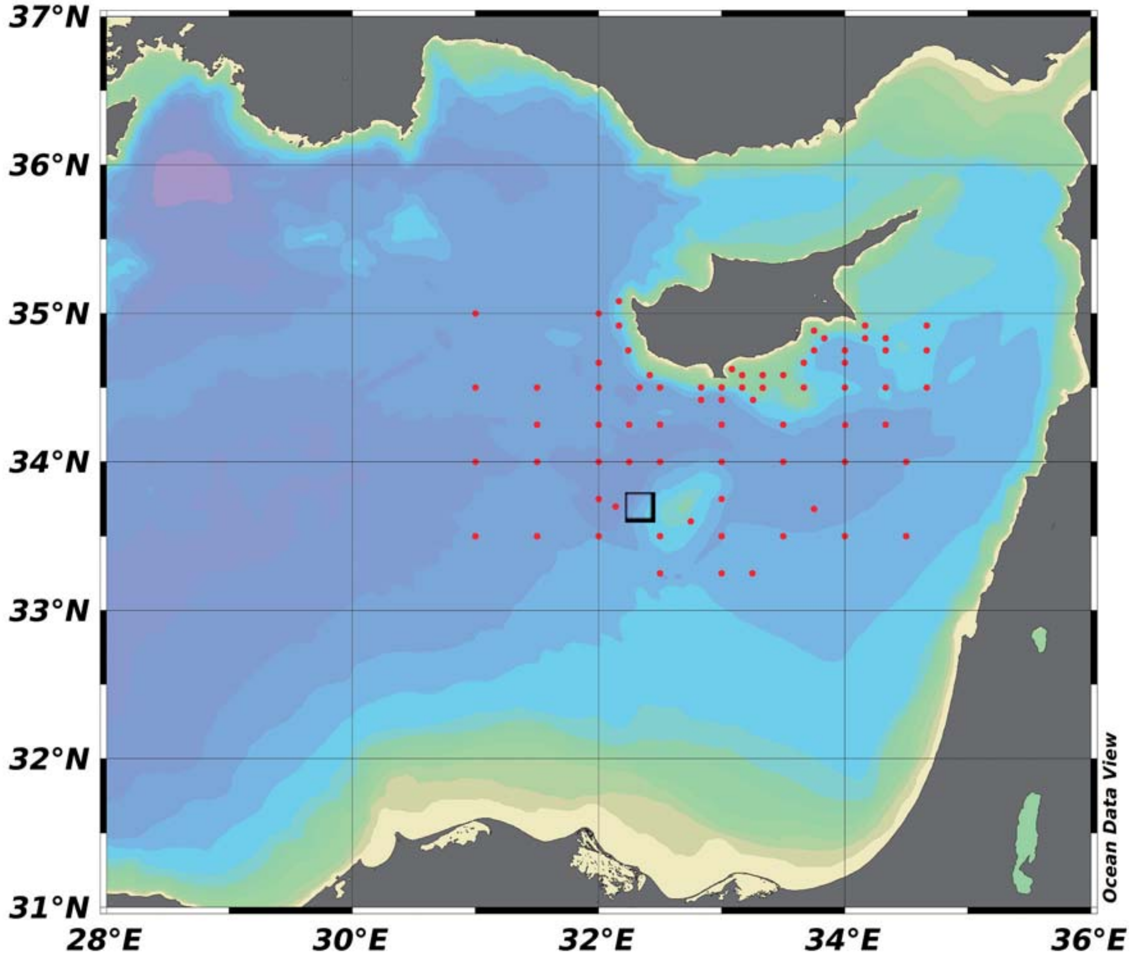

Fig. 1. Map of Cyprus Basin Oceanography (CYBO) sampling stations overlaid on bathymetry. A total of about 80 stations are typically visited. The cruise has occurred 23 times since 1995, most stations extend to 1200 m or the full water column in shallower areas. Small square indicates the position of the CYCOFOS-MedGOOS-3 buoy.

Because of the difficulty in interpreting annual, coarse resolution hydrographic data sets with the aim of describing the mesoscale eddy field and its evolution, and the inability of remote sensing to provide a detailed view of eddy structure and dynamics, a new platform has been utilized in the Levantine basin: the ocean glider. This autonomous underwater vehicle travels long distances over a programmed course while making measurements in the water column (Davis *et al.*, 2002; Rudnick *et al.*, 2004). Because it propels itself by modifying its buoyancy and its altitude, creating forward lift on the wings and body, it moves slowly and with high efficiency (about 20 km per day for up to 6 months for the configuration used here). It also moves in a sawtooth pattern at angles of 15-40 degrees from horizontal. When at the surface it exchanges data and commands with a land station using the Iridium satellite communication constellation. In the current study, two Seagliders, manufactured by the Seaglider Fabrication Center of the University of Washington were used (Eriksen *et al.*, 2001). These gliders carry a suite of sensors consisting of Seabird Electronics unpumped conductivity and temperature (SBE-03, 04) and dissolved oxygen (SBE43) sensors, and a WetLabs BB2FVMG ECO puck for chlorophyll-a fluorescence and optical backscatter (470 nm and 700 nm). Dive-average currents (DAC) are computed based on GPS locations and an on-board model of the vehicle trajectory. The gliders are programmed to dive to 1000 m (when the bathymetry allows) over butterfly patterns south of Cyprus. The size of the pattern has been chosen to allow the glider to traverse any given leg of the pattern in a matter of 7-10 days (Fig. 2). The variability of the AW pathway, the eddy structures, generation, and evolution, and effect on heat and salt transport are all to be addressed by the operational "section series" carried out by the ocean gliders.

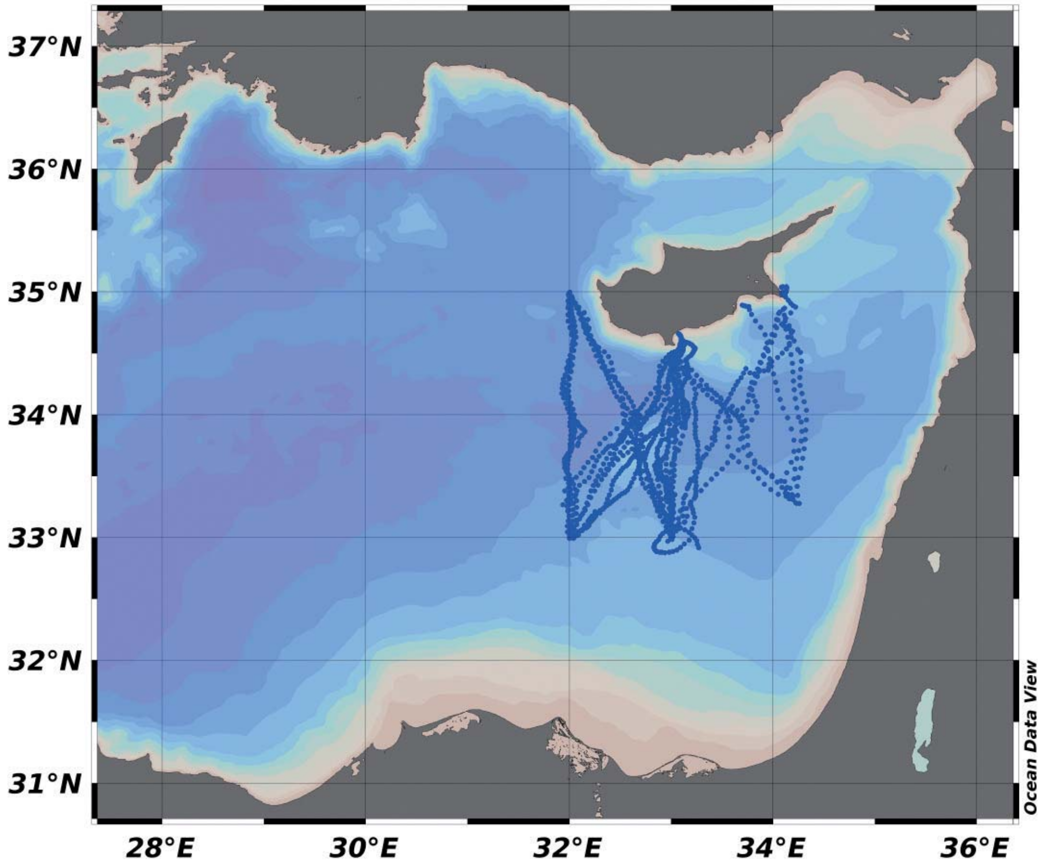

Fig. 2. Map of all OC-UCY glider surface positions since March 2009 overlaid on bathymetry. A total of 1471 dives have been completed, most to 1000 m.

Other sources of *in situ* observations exist in this area as well. Since 1999, there have been periods of intense, bi-weekly expendable bathythermograph (XBT) observations during the MFSPP project (Manzella *et al.*, 2007). Monthly XBT transects were taken from Limassol to Port Said from May 2004 to October 2005 as part of the MFSTEP projects (Fig. 3). (Two of the transects were from Limassol to Alexandria.) Spacing was set at 10 nautical miles in order to resolve mesoscale features, and measurements were taken from the surface to 800 m at 1 m depth intervals. From September 2004 to February 2005, monthly transects also were carried out between Alexandria and Rhodes, Haifa and Messina (Italy). Also in the Levantine, a fixed buoy, CYCOFOS–MedGOOS-3, has been collecting temperature and salinity in the upper 50 m since 2004. Five Seabird Electronics Seacat temperature and conductivity sensors are set to record data every 30 minutes (Fig. 1). Finally, surface drifters have been deployed and have revealed some of the complex characteristics of the surface circulation (Gerin *et al.*, 2009), although observations are too scarce in space and time to draw conclusions apart from the clear signal of the Cyprus eddy.

Fig. 3. Map of Expendable Bathythermograph (XBT) repeat lines carried out by the Oceanography Center, University of Cyprus. During the most intensive sampling period, temperature profiles were collected down to 800 m every 10 nautical miles along one of these lines monthly from May 2004 to October 2005.

In this paper, the circulation features of the surface and intermediate layers of the Levantine basin will be described, as observed from ship and autonomous platforms. First, a summary of the observations will be made: what exists and what can be learned regarding the currents and eddies in the region. Then, a summary of recommendations will be proposed that will identify the relevant time and space scales, and how they can be observed more effectively.

Results and discussion

Because of the large volumes of data and their complexity, only a brief overview will be given here. It is also noted that the data discussed here were collected in the Cyprus Exclusive Economic Zone, so they do not cover the entire Levantine basin, but the central portion of it. Generally speaking, in this region of observation, four primary structures (or portions of them) are observed: the Cyprus eddy, the eastern extension of the Rhodes gyre, the mid-Mediterranean Jet (MMJ) and the periodically present Shikmona gyre. The simplest way to view the region is with maps of dynamic height, because they represent the vertically averaged circulation. Since hydrographic profiles extend to at least 700 m in all but the near coastal zones, a suitable level of no motion is available. As will be discussed below, this assumption is reasonable: the absolute currents at depths up to 700 m have been directly observed in a recent experiment carried out on the *Maria S. Merian* with acoustic Doppler current (ADCP) measurements. Anticyclonic features are clearly present in the annual hydrographic data from the Cyprus Basin Oceanography (CYBO) program since 1995, with variable position, and sometimes with two or three such features (Zodiatis *et al.*, 2005a; 2010). Maps of dynamic height derived from CYBO data since 1996 show the predominance of the Cyprus eddy (high sea surface elevation in red), and in some cases a second eddy, the Shikmona eddy to the east, also anticyclonic. It is also clear that the eddy, however permanent it is, is not fixed to one location. It should be noted that the pattern and spacing of stations sometimes result in only three or four stations in the Cyprus eddy. In the upper left of the dynamic height maps is always seen a region of low height, corresponding to the southeast edge of the cyclonic Rhodes Gyre. Separating these two regions, and sometimes separating the two anticyclonic eddies, is a branch of the MMJ.

A section along 33˚E has been visited for every cruise and is illustrative of the water masses and their movement. Figure 4 shows the salinity and temperature from the surface down to 700 dbar along this line during the CYBO-22 cruise of 18-25 August, 2009. The very warm and salty surface water is hardly apparent, but a core of warm and salty LIW (salinity above 39.0 psu) is present, centered at 33.75˚ N: the Cyprus eddy. Above the LIW, especially at the edges of the core, there is a salinity minimum which characterizes the AW. If one calculates the geostrophic velocity relative to 700 dbar, the anticyclonic nature of the eddy is obvious (Fig. 5). The radius is approximately 50 km, and the vertical extent ranges from under the thermocline down to 400 m at the center. This particular situation is evident many times over the CYBO cruises: the anticyclonic Cyprus eddy with a core of LIW and a subsurface current around its perimeter (MMJ). The deepest observed levels show the upper part of the gradual transition to EMDW.

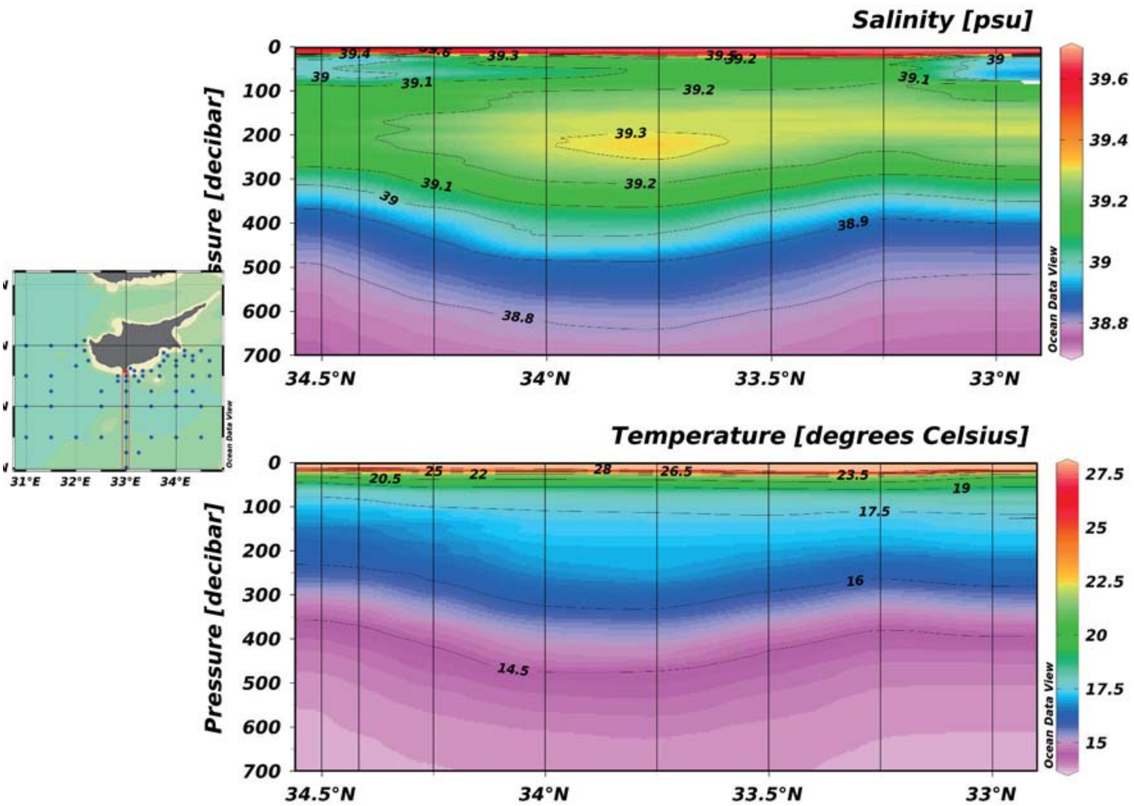

Fig. 4. Vertical section of a) Salinity and b) Potential temperature from CYBO-22 from 18-25 August 2009. The section begins at the north terminus of the transect. Station positions are shown with vertical black lines. The core of the Cyprus Eddy is visible as the region of high salinity (>39).

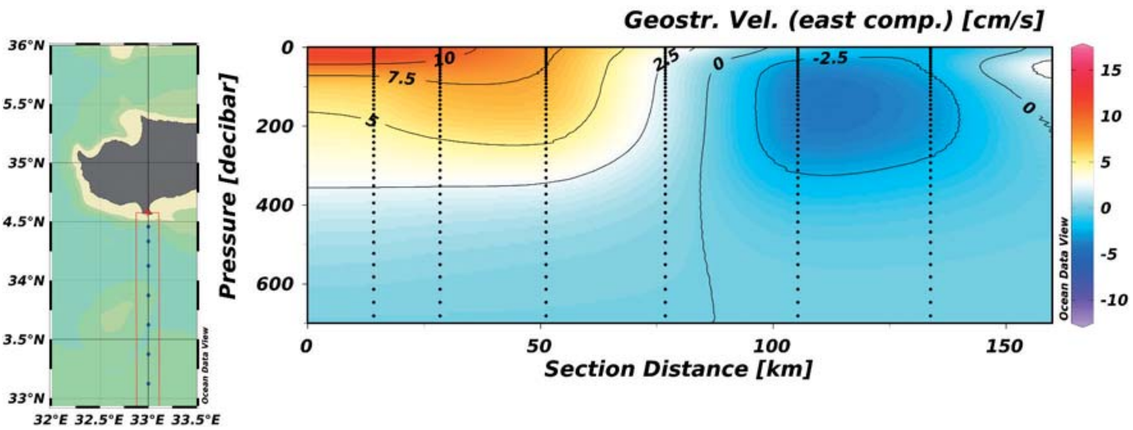

Fig. 5. Eastward component of geostrophic velocity relative to 700 dbar calculated from density profiles during CYBO-22 section from Fig. 4. Positive speeds at the northern terminus of the section (left side) correspond to eastward flow, and the return westward flow is visible in the southern half of the section.

Glider experiments have been designed in the same region in order to further investigate the position, characteristics, and evolution of the Cyprus eddy and the MMJ. All multi-month missions indicate the presence of the Cyprus eddy with peripheral AW. The first long mission was carried out by an OC-UCY glider in March 2009 for approximately one month. The V-shaped transect from the southeast tip of Cyprus to (33°N, 33°E) then north towards Cyprus did not reveal anticyclonic circulation. It did, however, indicate the presence of near-surface LIW, although it does not appear to have been locally formed. Water of nearly the same character was found in the eddy core in the second glider mission from May to August 2009 which was completed just before CYBO-22 (not shown). The warmer and saltier LIW core of the eddy is visible at 300 dbar (~300 m), which is approximately the depth of widest eddy extent (80 km).

With this information in hand, the "Eye of the Levantine" experiment was planned. A fleet of six gliders was deployed in November and December 2010, along with surface drifters and profiling floats. Also, the *TARA/Oceans* research and sailing vessel was able to sample the eddy based on prior information from the glider fleet. The Cyprus eddy was again found near the Eratosthenes Seamount. As in the 2009 CYBO and glider data sets, the eddy had a radius of about 50 km and consisted of a core of LIW extending down to 400 m. The slightly fresher AW was found just below the thermocline, most noticeable around the periphery of the Cyprus eddy. Dissolved oxygen, optical scattering, and chlorophyll fluorescence typically show maximum values also in the layer just below the thermocline.

Comparisons with ship-based measurements before, during, and after the EYE project indicate good agreement with the glider data. In particular, Acoustic Doppler Current Profiler (ADCP) data from the *Maria S. Merian* cruise MSM 14/1 collected in the seamount area from mid-December 2009 to early January 2010 agree well with currents estimated from gliders. During MSM 14/1, a hull-mounted 76.8 kHz ADCP was used to measure the current profiles during each CTD station. Vertical bin thickness was set to 16 m, the center of the first bin is at 24 m. Fifty bins were collected, and the maximum range was 800 m (high quality data up to 700 m depth). The Teledyne-RDI software WinADCP was used for the final pre-processing of the ADCP data, including referencing to true currents in geographical coordinates using the shipboard GPS. They contain 1 sec ensembles nearly continuously for the duration of the cruise. A Matlab script was used to read and average the files produced by WinADCP. Currents were averaged for periods when the ship was carrying out CTD casts. The depth-averaged currents from the ADCP (approximately 16-800 m) compare well to the dive-averaged currents from Seaglider 150 navigation model (Fig. 6). The vertically-averaged currents are between 0.10 and 0.20 m s^{-1} and show the anticyclonic rotation of the eddy. According to the glider-derived currents, the center of the eddy appears to have moved to the west a few km from January 5 to 17. It is also shown that the currents on the south side of the eddy are slightly more intense than the northern side, at least in the glider transect. Since gliders measure density profiles, it is possible to calculate the geostrophic velocity with an arbitrary reference level. The rotation of the eddy core is visible as well as the more intense and tightly focused southern edge of the eddy. It is also possible to use the depth average currents to correct the geostrophic velocity from a relative one to an absolute one. Even without this correction, the geostrophic velocities closely resemble the absolute. It is clear that the assumption of no motion at deep levels is reasonable, as shown by the velocity section through the eddy during MSM 14/1 (Fig. 7). The major difference is the inability of the ADCP stations, which are tied to the CTD stations, to adequately sample the eddy with only 10 km spacing, in particular the westward current on the southern edge of the eddy. (The region of strong current at 33.75° N was not sampled.)

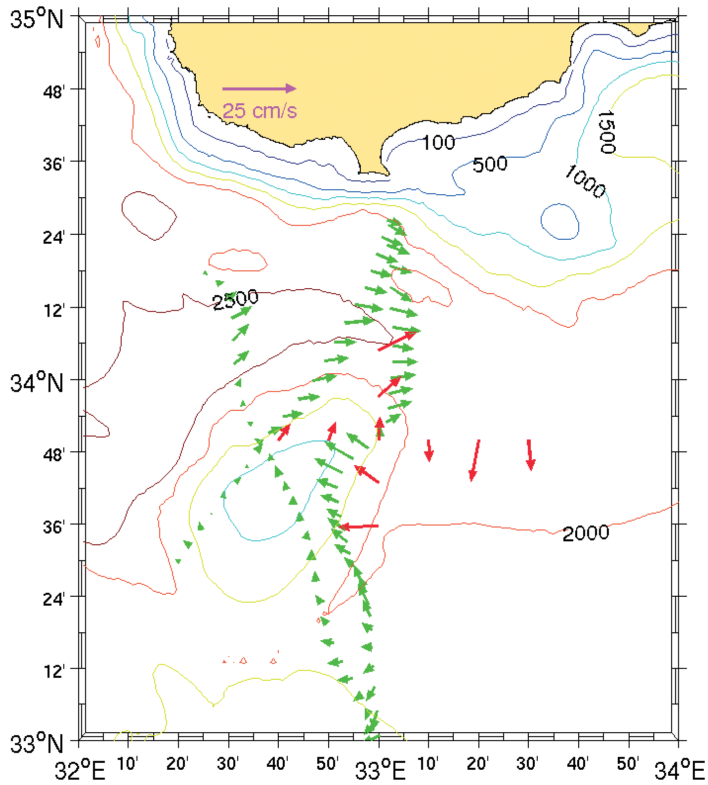

Fig. 6. Surface map of Glider-derived dive average currents (top 1000 m, grey) and ship ADCP-derived currents vertically-averaged (top 800 m, black) overlaid on contours of bathymetry during a glider mission (January 7-31, 2010) and MSM 14/1 (January 4-5, 2010).

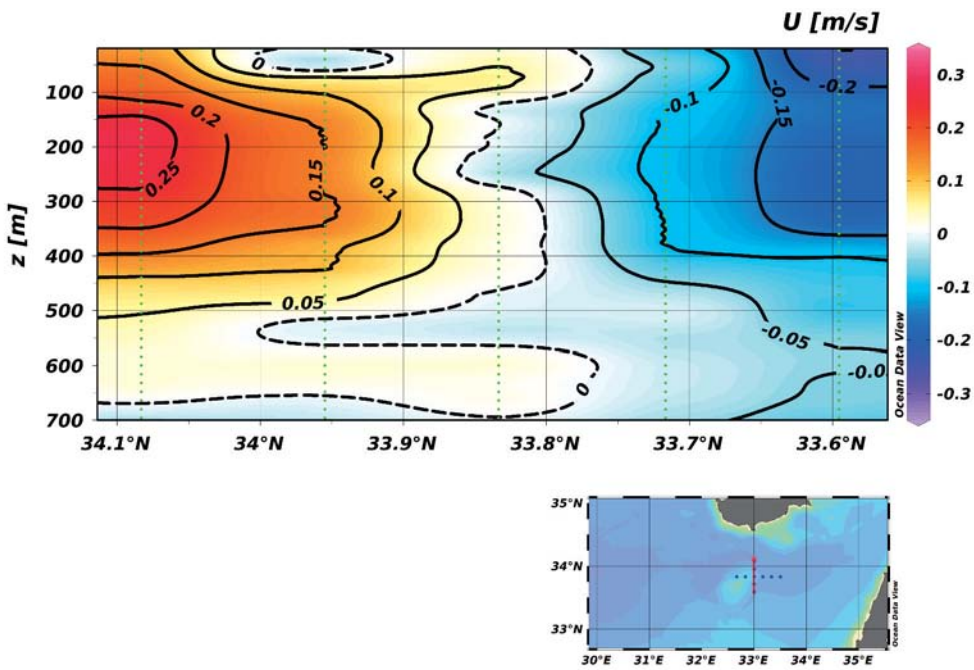

Fig. 7. Eastern component of absolute velocity along 33°E from the Maria S. Merian cruise 14/1, January 4-5, 2010. Data were collected with a hull-mounted ADCP during CTD stations carried out across the Cyprus Eddy. Location map is shown.

The most recent transects from October to December 2010 once again reveal the presence of the Cyprus eddy, although this time located about 80 km to the east (Fig. 8). The data illustrate a complicated “stacked” core of the Cyprus eddy as lower salinity water is injected into the core of the eddy at mid-depths (about 200 m) and separates the eddy vertically with regard to salinity. Neither temperature nor density indicates vertical splitting. While slight, the slope of the eddy’s base is steeper on the south edge and more gradual on the north edge. This is observed in all transects, and may provide clues as to the mechanism for the eddy’s longevity. In Fig. 8, it is also possible to see the dive average currents from each glider. Nearly all dives are to 1000 m, except for those directly over the seamount (which peaks at about 700 m). Currents averaged over the 1000 m dives peak at the edge with magnitudes of 0.25 m s^{-1}.

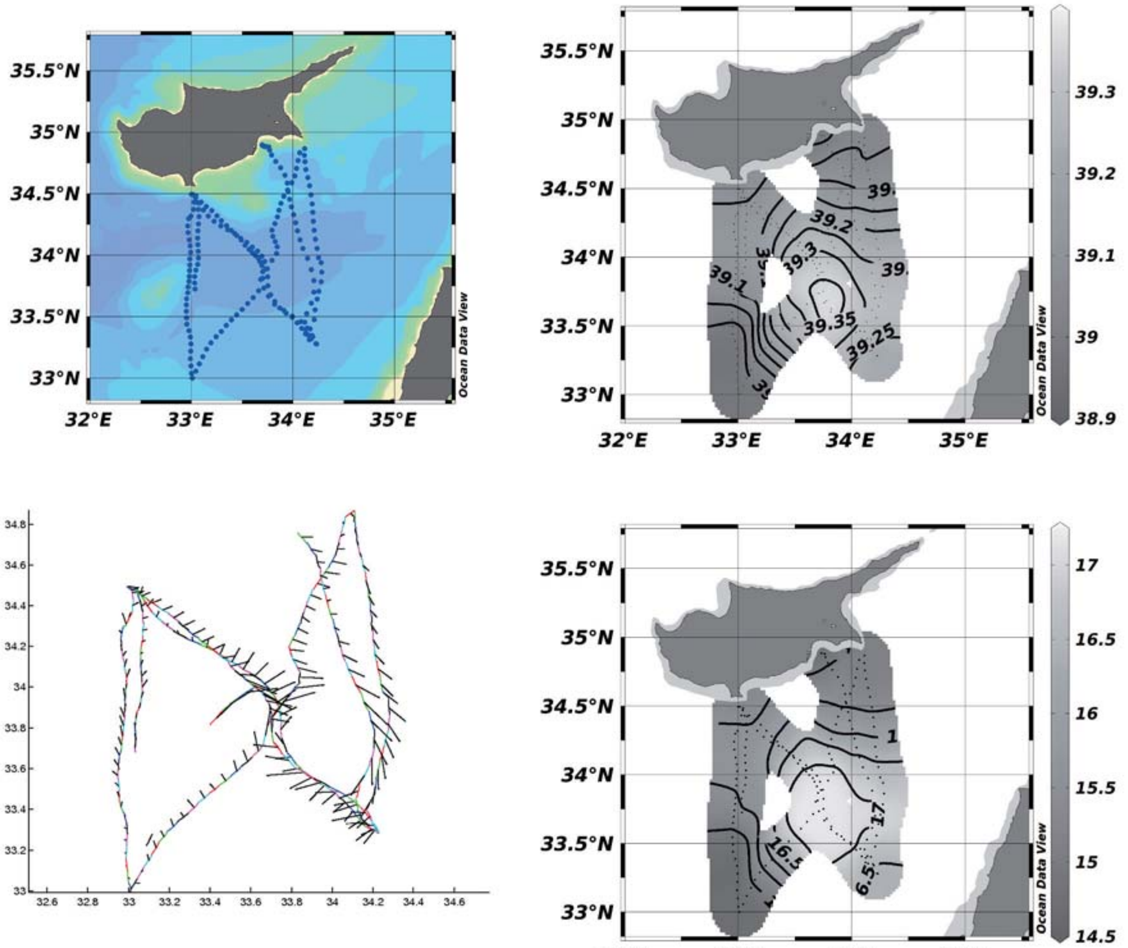

Fig. 8. Surface map of a) glider surface positions and shaded bathymetry, b) dive averaged current, c) salinity and d) potential temperature at 300 dbar during a glider mission (October-December 2010). Note the eddy center is located at about (33.8°E, 33.8°N).

Operational forecasts were successful in late 2010 and early 2011 in predicting the position and characteristics of the Cyprus eddy, while 2009-2010 results were not in agreement. The eddy seems to have appeared in the model after changes in data assimilation by the Mediterranean Forecasting System hydrodynamic model (from which the ALERMO operational hydrodynamic model of the University of Athens and in turn CYCOFOS of OC-UCY are downscaled). With the eddy present in the model, one can follow its evolution and compare to existing and future glider missions. It is clear that the eddy field and meandering current separating them evolves, yet it is not yet clear what factors are most important in driving this evolution and if it can be predicted. The assimilation of the glider profiles directly into the operational CYCOFOS forecasting system at OC-UCY is currently being tested for this reason.

Conclusion

Particular attention has been given in this paper to *in situ* data collected by ships and underwater gliders, long-range autonomous underwater vehicles with the ability to collect seawater characteristics in the upper 1000 m of the ocean every few kilometers for thousands of kilometers over several months. The Cyprus eddy has been observed as a permanent feature as far back as the 1980s from ships and more recently from gliders. It is an anticyclonic eddy with a core of relatively warm and salty Levantine Intermediate Water extending from just below the Levantine Surface and Atlantic Water to a maximum of 400 m. It is embedded in a generally cyclonic basin circulation, with other eddies often present, such as the Shikmona eddy to the east. A meandering sub-surface current of Atlantic Water is found around the upper periphery of the eddy: a branch of the Mid-Mediterranean Jet. The eddy generation mechanism is not yet certain, but most likely the LIW originates from the intermediate water formation site of the cyclonic Rhodes Gyre according to modeling studies (Lascaratos and Nittis, 1998). Neither are the details certain of how or why the eddy is located where it is, or why it seems to move only slightly around an approximately steady position. It is likely that the bottom topography plays an important role, in particular the Eratosthenes Seamount (Brenner, 1989). Further studies examining the described data in terms of quasi-geostrophic theory as well as ocean state determination from the combination of the OC-UCY circulation model and glider data using assimilation techniques are required to address these questions.

Of course, new data should be collected to monitor and further understand the circulation of the Eastern Levantine basin. The relevant features must be considered: the Cyprus eddy, the Shikmona eddy, the MMJ pathways, and LIW formation and spreading from the Rhodes Gyre. These processes occur on spatial scales of order 50 km, and in some cases down to 10 km. Unless sampling is informed from other observations, it is likely that the features or processes are missed or are only partially observed. For the Cyprus EEZ, more glider missions are planned, as are more CYBO cruises. However, this is not enough as the Cyprus EEZ is only a part of the basin. Cooperation is desired with neighboring countries and pan-European or pan-Mediterranean projects in order to generate synoptic data sets over wide regions. These data sets should have approximately 10-15 km horizontal resolution. The data should be made available to operational forecasting centers in order to improve the model results using data assimilation. Only in this way can an accurate, fully three-dimensional and evolving ocean state be determined. This ocean state can then be used for a variety of applied purposes such as ecological modeling, pollution or drift models and high resolution coastal forecasts.

Acknowledgments: the scientists who collaborated on the "Eye of the Levantine" experiment are recognized for their willingness to provide instruments and expertise: L. Mortier, L. Beguery, K. Bernadet, F. D'Ortenzio, E. Mauri, F. Lekien, R. Gerin, P. Poulain and A. Lazar. The crew and scientists of the *Marian S. Merian* assisted greatly by allowing the successful sampling program with limited time available. The employees and vessels of the Department of Fisheries and Marine Research of Cyprus have been instrumental in glider deployment and recovery. Sarantis Sofianos of the University of Athens is also acknowledged for providing ALERMO model output.

The Adriatic-Ionian Bimodal Oscillating System (BiOS) and the decadal variability of the thermohaline cells in the Eastern Mediterranean

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In the last two decades of the 20th century, after no more than 15 years of intense oceanographic research, the view of the stationary Mediterranean circulation profoundly changed. Since the discovery of the well known (but not yet completely explained) Eastern Mediterranean Transient (EMT) (Roether *et al.*, 1996), the scientific community is now dedicating efforts to understanding the sensitiveness of the Mediterranean basin to the global changes, and forecasting its evolution during the next decades.

The Adriatic-Ionian Bimodal Oscillating System

Recently, Gačić *et al.* (2010), as quoted by Civitarese *et al.* (2010), have shown that the variability in the upper-layer Ionian circulation is linked with the thermohaline processes associated with modifications in the properties of Adriatic Dense Water (AdDW) outflowing through the Strait of Otranto. This mechanism, called Adriatic-Ionian Bimodal Oscillating System (BiOS), operates locally, in the Southern Adriatic (SA)-northern Ionian region, and extends its effects to the entire EMed.

Basically, the BiOS mechanism can be explained as follows (Fig. 1 – see original colour illustration p. 9): when the North Ionian Gyre (NIG) is anticyclonic (Fig. 1 left), the Atlantic Water (AW) coming from the Sicily Channel is in part deviated toward the northern Ionian and eventually enters the SA, decreasing the salinity and the density of the AdDW. The change in the properties of the outflowing AdDW causes a progressive weakening of the anticyclonic upper-layer circulation in the Ionian Sea (IS); the circulation finally reverses (Fig. 2 right), modifying the pathways of the water masses. In fact, the cyclonic NIG suppresses the northern branch of the AW flow and favours the rapid advection of salty Levantine and/or Cretan Intermediate Water (LIW; CIW) along the eastern flank of the IS into the SA. This results in an increase in the salinity (and density) of AdDW outflowing into the IS that gradually impairs the cyclonic NIG, eventually reversing it to an anticyclone (Fig. 1 left). Therefore, the BiOS is a negative feedback mechanism that modulated the pathways of the main water masses in the EMed on a decadal scale.

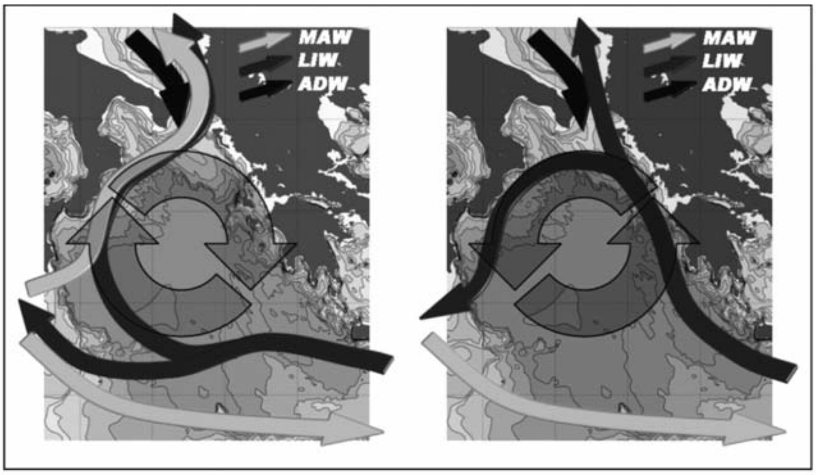

Fig. 1. Schematic representation of the Adriatic-Ionian BiOS. Left: anticyclonic circulation mode; right: cyclonic circulation mode. [see original colour illustration p. 9]

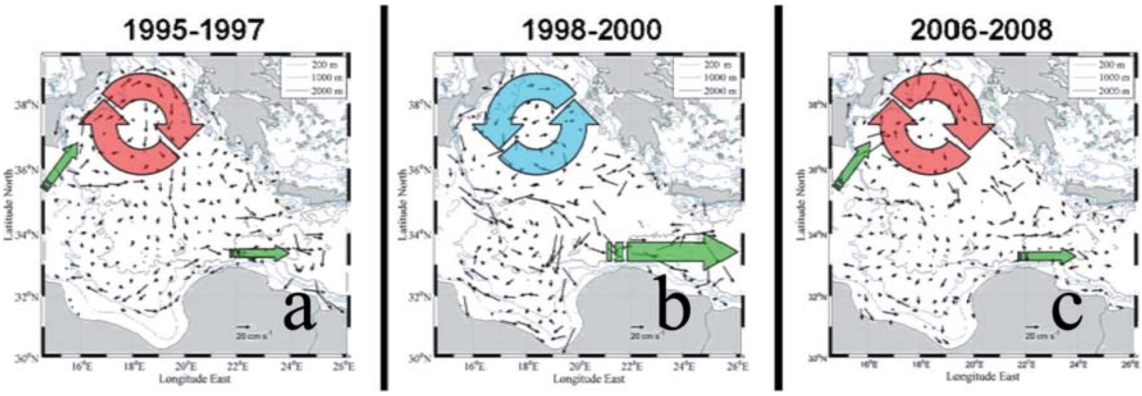

Fig. 2. Quasi-Eulerian mean surface circulation during the anticyclonic phases (a, c) and the cyclonic phase (b). The green arrows qualitatively indicate the directions and the flow of AW (modified from Gačić *et al.,* 2011).

The BiOS mechanism has a number of impacts on various aspects of the EMed[1]:

- it modulates the decadal variability of the average thermohaline properties of the Adriatic through the alternate advection of AW and LIW/CIW across the Strait of Otranto. This results in a concomitant variability of the preconditioning effectiveness (buoyancy gain or loss) in the SA, that in turn affects the winter convection and, consequently, the dense water formation and the annual biomass produced;

- it modulates the decadal variability of the nutrients pool in the SA, out of phase with the thermohaline curve, as follows from the vertical displacement of related interfaces (nutricline, maximum nutrient layer) at the border of the NIG, according with the decadal alternation of its sense of rotation;

- it impacts the biodiversity of the Adriatic, brings species of different origins (Atlantic or Levantine/Lessepsian) to enter the Adriatic, according to the advective pattern;

[1] For an extended treatment of this subject, refer to Civitarese *et al.* (2010), Gačić *et al.* (2010), and Gačić *et al.* (2011).

- it has some influence on the food web structure in the Ionian Sea, mitigating the oligotrophy at its interior during the cyclonic phase of the NIG;

- it varies the salinity distribution of the entire EMed, conveying the main water masses along different pathways, according to the NIG circulation, and representing the preconditioning factor (haline) for the dense water formation in the Cretan Sea.

The last point deserves particular attention because it has profound implications on the functioning of the thermohaline cells in the EMed.

The switches between the two dense water producers: a simple coincidence?

The first time that the Mediterranean revealed not to be so stationary as previously thought was during the 1990s, the years of the EMT. The EMT was basically considered the switch of the deep water formation area from the SA to the Cretan Sea (CS), with the consequent change of the two thermohaline cells of the Eastern Mediterranean (EMed). A number of theories, mechanisms and processes were formulated in order to explain why the Cretan Sea started to produce dense water in such a quantity to feed for about 7 years the deepest layer of the EMed, forming the new EMDW (see among others, Malanotte-Rizzoli *et al.*, 1999). On the other hand, one of the most curious aspects of the EMT, i.e. the switch between the two dense water formation areas (the SA and the CS), was not explained and is still an open question.

Tsimplis *et al.* (2006) already remarked that *"Curiously, the recently observed initiation of dense water formation in the Aegean Sea was accompanied by diminution of deep water formation in the Adriatic"*, and Pisacane *et al.* (2006) and Artale *et al.* (2006) hypothesized that *"The whole EMed undergoes a cyclic variation in the intensity of its circulation, which can be related to the alternative predominance of the Adriatic or the Aegean Sea in the production of dense water"*.

It is hard to think about the switch, or better, the switches (since at the beginning of 2000s the Adriatic returned again to produce water sufficiently dense to feed the EMDW instead of the Cretan Sea), as coincidental events. Thus, the questions now arising are: what is the link between the SA and the CS, and which is the mechanism that makes the dense water production such a mutually exclusive process between the two basins? Could the answer be found looking at the salt redistribution operated by the BiOS mechanism in the EMed?

The dense water formation is always associated with a loss of buoyancy, that can be attained both via salinity increase and temperature decrease. The salinity increase represents the preconditioning of the convection, whilst the temperature decrease (associated with cold and dry winds) determines the isopycnals outcropping, with the consequent opening of the convective chimney. The salinity increase is due either to the advection of intermediate salty water or to the evaporation. The temperature decrease is prevalently associated with the local meteorological conditions.

During the period 1987-1995, the NIG was anticyclonic (Gačić *et al.*, 2010; Civitarese *et al.*, 2010), the AW invaded the interior of the IS, eventually entering the SA. At the same time, the AW flow through the Cretan Passage into the Levantine basin was reduced (Fig. 2a). The final result was the reduction of salinity in the IS (and in the SA), and, on the other hand, the increase of salinity in the Cretan Passage and in the Levantine basin, as documented by Manca *et al.* (2000). The anti-correlation between the salt content variations of the upper layer in the IS and Levantine basin can be easily extended to the SA (see Gačić *et al.*, 2010) and CS. In the CS, Theocharis *et al.* (1999) found in fact that the process of salification and rapid salt transfer to depth started in 1987 and concluded in the first half of 1990s, during which the deep water became saltier first (from 1987 to 1991) and then saltier and cooler (from 1991 to 1995).

In the following period 1996-2005, the NIG was cyclonic. Since the NIG reversal (1996), according to the BiOS mechanism, the salinity in the IS and in the SA increased, due to the penetration of salty intermediate waters of Levatine/Cretan origin and to the absence of AW because of the upper-layer cyclonic circulation. At the same time, the flow of AW through the Cretan Passage into the Levantine basin increased (Fig. 2b), leading a general decrease of salinity in the upper-layer of those areas. Again, the anti-correlation between IS and Levantine basin can be extended to the SA and CS. In fact, the SA started again to produce deep water after 2000 (Klein *et al.*, 2000), whilst the CS ceased its deep water production.

It is interesting to note that, for the periods previously considered, also the sea level in the IS was anti-correlated with both the Levantine and CS levels (Fig. 3). This suggests that the halosteric effect (the change of specific volume due to the change of salinity) is produced by the circulation reversals of the NIG.

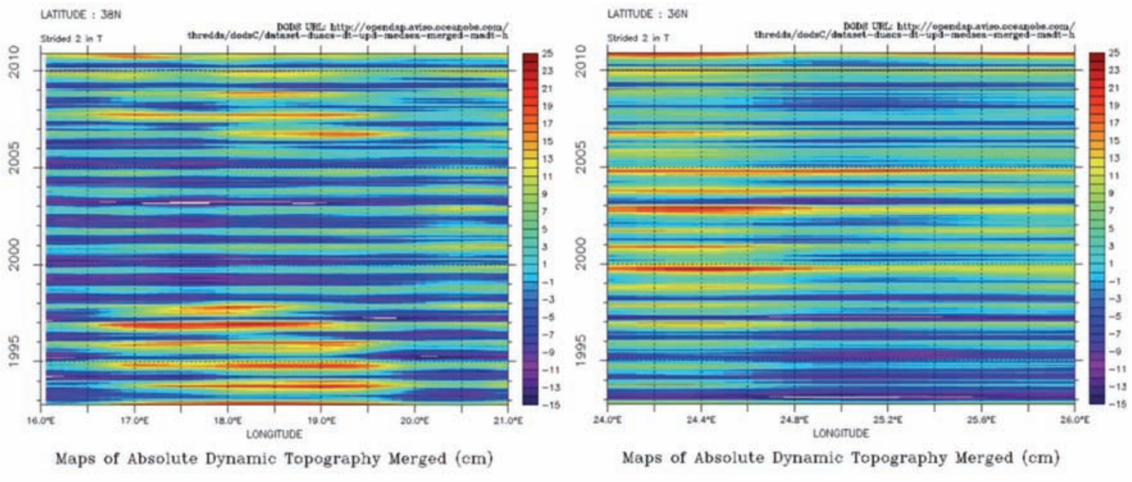

Fig. 3. Hofmoeller plots of Absolute Dynamic Topography along a section in the northern Ionian (left) and in the Cretan Sea (right). The sea levels of the two areas are anticorrelated.

Decadal variability was observed as well in the upper mixer layer salinity off the Israeli coast (Kress *et al.*, this volume). The integrated salinity of the upper 250 m layer (Fig. 4, calculated from the same dataset) shows higher salinity in the first half of the 1990s and in the second half of the 2000s. On the other hand, lower salinity values occurred at the beginning of the 1980s and the 2000s. Although in need of more detailed analyses, these results seem to be in agreement with the timing of the NIG reversals and with Gačić *et al.* (2011).

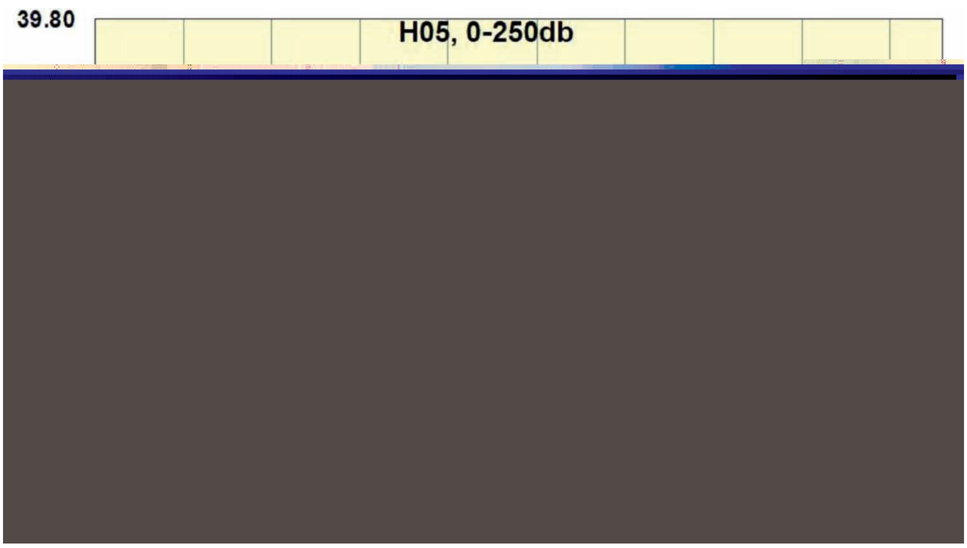

Fig. 4. Time series of integrated salinity on the 0-250 m layer at statio H05 in the eastern Levantine basin (see Kress *et al.*, this volume for the station map).

To summarize, experimental evidences supports the interconnection between the salt content in the Levantine basin and the BiOS mechanism. The alternating predominance of the CS or the SA as a dense water source for the EMed is related to the fact that, while low salinity/high buoyancy waters enter the SA from the IS, the CS is impacted by low buoyancy/salty waters, and viceversa (Gačić *et al.*, 2011). Numerical simulations carried out within long-term climatic studies (Artale *et al.*, 2006) already documented the collapse of the Adriatic deep water formation concurrent with the enhanced Cretan deep water production. All these considerations let us to conclude that the preconditioning of the EMT-like events is a recurrent process, internally driven by the Adriatic-Ionian BiOS. Though the switch of the dense water formation areas from the SA to the CS occurs only under favorable winter climatic conditions over the Aegean region, the thermohaline cell characteristics in the EMed are determined by BiOS.

In 2006, the NIG reversed again to anticyclone. Data collected in the SA from 2006 to 2010 showed the average salinity decrease and a general decrease of the dense water produced (Cardin *et al.*, 2011). According to the BiOS mechanism, we are now in the decade favourable to the preconditioning of a new EMT-like event (Fig. 2c). Will the thermohaline cell switch again to the CS configuration?

Field observations in the EMed: how to capture its decadal variability?

Though a small basin, the EMed can be considered a laboratory basin for studying processes typical of the ocean. We have just seen that the time scale variability can be very short (years/decades), also for the deep thermohaline cell, in comparison with the oceanic ones (centuries/millenium). One interesting aspect due to the BiOS is that the upper layer dynamics and the deep thermohaline cell are mutually linked together. We have also shown that the BiOS mechanism dictates the decadal variability in the EMed. Thus, a field observation plan should be properly tuned in order to capture the decadal variability of the NIG circulation, the evolution of deep waters property, the pathways of the main water masses in the basin. In Fig. 5a we propose some hydrographic sections

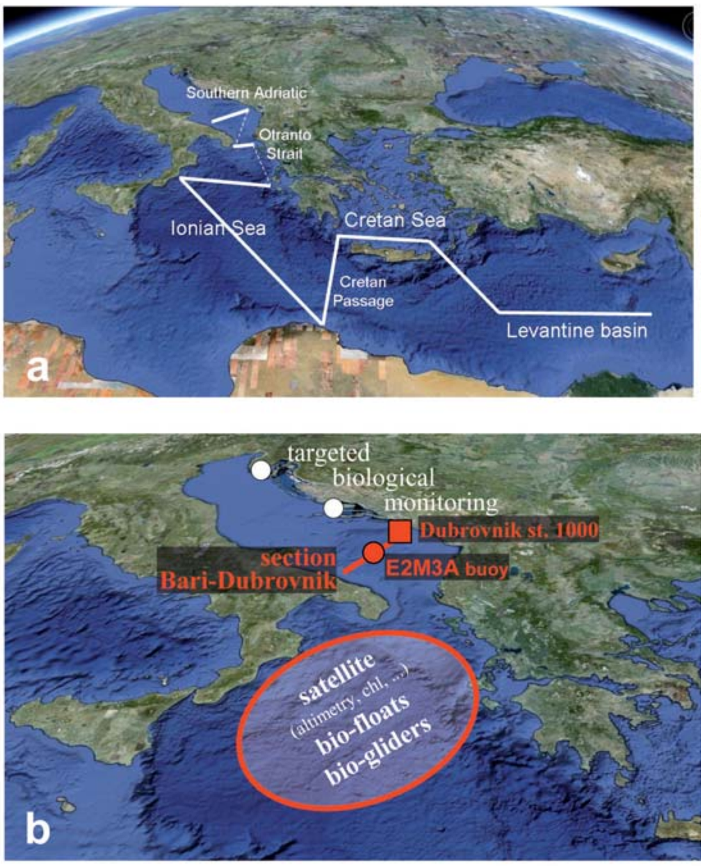

Fig. 5. (a) Suggested repeated hydrographic sections for the EMed. (b) Multiplatform approach for the BiOS investigation.

with multidisciplinary sampling in key areas of the EMed. These strategic sections should be repeated at least every three years, but this does not exclude that they could be modified and/or carried out more frequently, according to the national/international research plans and to the final strategy plan of the desirable next Med-Ship programme (outlined in this volume).

In addition, the complete assessment of the BiOS impacts will need a multiplatform approach in order to establish in more details the correlation between the circulation/dynamics and the ecosystem characteristics and functioning. Fig. 5b schematizes the suite of platforms, including satellite observations, autonomous devices, moorings, and fixed sections/stations, part of them already being operative for a long time.

SOCIB: the impact of new marine infrastructures in understanding and forecasting the Mediterranean Sea

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Abstract

New monitoring technologies are being progressively implemented in coastal ocean observatories. As an example, gliders allow high resolution sampling, showing the existence of new features, such as sub-mesoscale eddies that are characterised by strong horizontal gradients and intense vertical motions. These structures interact with the underlying mean flow and topography and can block the general circulation or give rise to intensified upper ocean biogeochemical exchanges. These are just two examples of scientific topics of worldwide relevance in a climate change context. New observing and modelling systems are needed to describe the three-dimensional structures and understand the underlying processes of multiple interacting spatial and temporal scales that characterise the variability of our oceans. The Mediterranean Sea is a well-known reduced scale ocean, an ideal natural laboratory to study this type of processes, their non-linear interactions as well as the medium and long-term response of ocean ecosystems. SOCIB, the Balearic Islands Coastal Observing and Forecasting System, is one of such ocean observatories, a new multiplatform observing system, a facility of facilities extending from the nearshore to the open sea. SOCIB takes advantage of the strategic position of the Balearic Islands at the Atlantic/Mediterranean transition area, one of the 'hot spots' of biodiversity in the world's oceans. SOCIB is unique among the new observing and forecasting systems in that its mission and objectives are science, technology and society driven. Such new marine infrastructures are presently establishing new ways of international cooperation that will lead to major science breakthroughs, innovations in oceanographic instrumentation and new ways of science based coastal and ocean management. In this paper we describe the major elements and structure of

SOCIB and present some examples of recent scientific results of relevance in the Mediterranean Sea and at global scale show the importance of this type of new marine infrastructures to understand the oceans variability for a more science based, sustainable management of marine resources.

1. Introduction; the international context of new ocean and coastal observatories

Oceanographic information, combined with integrated predictive models, are increasingly needed to manage national coastal and ocean areas, to depict the state of the ocean today, next week or the next decade, for example to increase the efficiency of shipping, to mitigate storm damage and flooding of coastal areas, to sustain fisheries, to protect important ecosystems from degradation, to develop science based sustainable management of marine and coastal areas, and to improve climate forecasting in response to global change. However, as the ocean changes continuously, it must be observed continuously in order to deliver accurate and effective ocean services. This, combined with the understanding that we have a responsibility to maintain healthy, resilient and sustainable coasts and oceans, together with the curiosity driven advancement of knowledge and technology is the foundation for new ocean observing networks.

The establishment of such ocean observing systems is being adopted as an important component of marine strategy by the European Union and by most countries that are advanced in marine science research and with economically significant coastal areas. These new observatories (such as among others, IMOS, OOI, IOOS, Neptune/Venus, Cosyna, Poseidon, etc.) are today discovering new insights of the oceans' variability. These discoveries will in turn trigger new theoretical developments, increasing our understanding of coastal and nearshore processes and contributing towards a more science based and sustainable management of the coastal area. SOCIB, the new Balearic Islands Coastal Observing and Forecasting System is one of such systems, a new facility of facilities, a scientific and technological infrastructure which is just starting at the end of 2011 to provide free, open, quality controlled and timely streams of oceanographic data and modelling services to support operational oceanography in a Mediterranean and international framework, therefore contributing to the needs of marine and coastal research in the context of global change.

In line with EuroGOOS, operational oceanography is here understood in a wide sense, including both systematic long-term measurements of the seas and their interpretation and dissemination, and also the sustained supply of multidisciplinary data to cover the needs of a wide range of scientific research and societal priorities. This will allow a quantitative increase in our understanding of key questions on oceans and climate change, coastal ocean processes, ecosystem variability, etc.

SOCIB activities, included in the Spanish Large Scale Scientific Infrastructures Programme (from the Ministry of Science and Innovation) and in the Balearic Islands Regional Research and Innovation Plan, are funded until 2021 and are described in detail in SOCIB Implementation Plan approved by SOCIB Board of Trustees on July 2010 (full document available at www.socib.eu). SOCIB construction phase started just after this approval and continued during 2011 when some facilities already started initial operations. SOCIB will gradually become a key element of operational oceanography in the western Mediterranean. SOCIB will also contribute with significant scientific and/or technological results but also with specific products and services of direct interest to society in areas such as science based sustainable coastal and ocean management.

In this paper we present SOCIB, the drivers, objectives and major components and also briefly describe some of the major achievements reached during 2011 focusing on the observing, modelling and data centre facilities. The reader more interested on technology developments and/or applications and tools for coastal and ocean management is referred to SOCIB web page.

2. Mission, drivers, objectives and vision

SOCIB mission is to develop an observing and forecasting system, a scientific and technological infrastructure which will provide free, open, quality controlled and timely streams of data to: (1) Support research and technology development on key internationally established topics such as:

the role of the oceans in the climate system at inter-annual scale, the interaction between currents and eddies, addressing vertical exchanges and physical and ecosystems variability, the variability in nearshore morpho-dynamics and the sea level variability in response to climate change. (2) Support (on a longer term) strategic needs from society in the context of global change: sustainable management, science-based mitigation and adaptation strategies and also policy development and operational tools for decision support. (3) Consolidate operational oceanography in the Balearic Islands and in Spain, contributing to the establishment of a well-structured center of excellence in an international frame.

More specifically, SOCIB objectives are driven by state of the art international scientific and technological priorities and also, by the specific interests of the Spanish and Balearic Islands society. The general objective is twofold: (1) to contribute to address and respond to international scientific, technological and strategic challenges for operational oceanography in the coastal ocean and (2) to enhance operational oceanography research and technology activities being carried out in the Balearic Islands, contributing to the consolidation of a well structured centre of excellence.

On a long term, our vision is to advance on the understanding of physical and multidisciplinary processes and their non-linear interactions, to detect and quantify changes in coastal systems, to understand the mechanisms that regulate them and to forecast their evolution and or adaptation under, for example, different IPCC scenarios.

SOCIB will specifically address the preservation and restoration of the coastal zone and its biodiversity, the analysis of its vulnerability under global change and consider new approaches, such as science based sustainable fisheries and/or connectivity studies and Marine Protected Areas (MPA's) optimal design.

3. Strategic location in the Western Mediterranean

SOCIB activities are mostly (but not only) centered in the western Mediterranean, with focus in the Balearic Islands and adjacent sub-basins (specifically Algerian and Alborán/Gibraltar) and covering the nearshore, the coastal ocean and the blue open ocean waters and their associated processes. SOCIB takes profit of the strategic position of the Balearic Island at the Atlantic / Mediterranean transition area, one of the 'hot spots' in world's oceans research, and also a region where mesoscale and submesoscale dynamics are of particular relevance (Internal Rossby Radius - Ri=10km). Thus physical mechanisms can be more easily monitored in this 'ocean basin', contributing to the advancement of knowledge of physical interactions and biogeochemical coupling at nearshore, local, sub-basin and global scales. In this context, coastal ocean research and technology development in the Balearic Islands have significantly contributed to our understanding of different oceanographic problems of worldwide interest over the last 20 years (see for example the TMOOS 2010-2013 Strategic Plan at http://www.imedea.uib.es/tmoos/).

The oceans and coastal areas of the Balearics provide jobs, food, resources, recreation and tourism opportunities, and play a critical role in transportation, economy, trade and security and so management of this resource is of strategic societal interest in this region[1]. The Balearics dependence on marine activities (maritime traffic, fishing, tourism) places Balearic society at the forefront of confronting issues related to sustainability management of the coastal zone and this a strategic location for the development and implementation of new ICOM based tools and applications. In addition the existence of the Cabrera National Park, areas of barely disturbed marine ecosystems such as Menorca and the small islands of the Pitiuses, and areas with sensitive habitats and special interest ecosystems, such the NE of Mallorca, N and S of Menorca, Menorca channel and S. Cabrera, or Natural Parks of Ibiza and Formentera, are of great interest for the analysis of natural variability in, and human interaction with, pristine and threatened systems.

[1] For example need balance coastal resources with tourism, shipping and coastal development, surge prediction and variability and sustainability of important marine ecosystems.

4. Guiding principles and operational scope

The SOCIB Implementation Plan describes the design and initial phases of implementation. It is anticipated that a thorough testing of the ability of the system to satisfy the needs of the principal drivers – science, technology and society – will take place concurrently and that this will result in some revisions after the current 5-year Implementation Plan. Over the longer term SOCIB will continue to test and adapt its system to the changing needs through consultation with the community and stakeholders.

In line with IMOS, a number of well-defined principles have been established from the very beginning. These principles guide the development, decision-making and interaction with SOCIB partners, users and other collaborating institutions. They are:

- Scientific and technological excellence through peer review,
- Science, technology and society driven objectives,
- Support to R&D activities in the Balearic Islands,
- Integrated, coordinated multiplatform,
- Multidisciplinary and sustained monitoring,
- Partnership between institutions, and
- Free, open and quality controlled data streams, with data in adherence to scientific community standards.

Activities are well coordinated with regional, national and/or European observatories as shown by the participation of SOCIB team in different on-going topic related research projects.

SOCIB is designed to support and prioritize a sustained approach to ocean monitoring that is responsive to science, technology and society. The initial focus in the development of SOCIB is on physical variables and progressively later some biogeochemical variables, reflecting both the present state of sensor technology and the importance of the impact of physical processes on driving biogeochemical and ecological responses (see Annex 6 SOCIB scientific themes as stated in the original SOCIB Proposal)[2]. New biogeochemical sensor technologies are advancing rapidly and will be incorporated into the SOCIB observing network that will enhance the long term sustained monitoring of chemical and biological properties.

5. SOCIB structure, major components and facilities

SOCIB is unique among coastal ocean observatory systems in that our mission, vision and structure respond to three main drivers: state of the art research priorities, implement and develop new technologies and respond to the strategic interests of Spanish and Balearic Islands society. In other words SOCIB is science, technology and society driven. As with other international ocean observing systems SOCIB has three major infrastructure components:

(1) A distributed multi-platform observing system with appropriate instruments and technologies.

(2) A numerical forecasting system.

(3) A data management and visualization system.

The combination of the three elements will enable real time monitoring of the state of the ocean and the coastal zone and the prediction of its spatial and temporal evolution.

SOCIB structure is original in that apart from the observing, modelling and data centre facilities that respond to science driven objectives, it will also need to address technology and society driven questions. Accordingly, SOCIB structure has been established in three main Divisions and four Services responsible for providing the support to the Divisions, in accordance to SOCIB's mission. In this section we briefly present the general structure and focus later on the Observing, Forecasting and Data Centre initial plans, results and major on-going activities.

[2] Memoria científica del proyecto ICTS-SOCIB (2006)

The observing, forecasting and data centre components configure the **Systems Operation and Support Division (SOS Division)** that will be described in further detail in the next section**.**

The second Division, the Engineering and Technology Development Division (or ETD Division), provides the engineering and technical backbone to develop and operate the facilities of the Systems Operation and Support Division and is also responsible for the application, development and testing of new technologies for future observing systems and for developing new analytical tools for the effective management of new, high volumes, of observational data and modelling output. This division is the result of the technological activities that originated at IMEDEA around year 2000 with physical oceanography monitoring capabilities and the introduction at that time of beach monitoring activities and initial development of marine technologies development by 2003 (that expanded later in 2005 with the new IMEDEA labs).

Major activities during 2010 and 2011 concentrated on recruitment and formation of engineers and technicians, re-organisation and upgrade of SOCIB laboratories at IMEDEA (in kind CSIC contribution to SOCIB, in particular the glider that includes includes balancing facilities, the new 1.000 m pressure chamber, and the technology lab), preparation of tenders' specifications and follow-up as well as the initial field operations, mostly related to the glider facility and the beach monitoring facility setup monitoring system (two beaches in Mallorca and one in Menorca).

The third Division, the Strategic Issues and Applications for Society (SIAS Division), is designed to develop applications and operational tools for science-based management of the coastal and marine environment, within the general frame of sustainability science, thus supporting the development and transfer of strategic knowledge to meet the needs of society in the context of global change.

The sustainable management of coastal and marine ecosystems is a significant international challenge, which is becoming increasingly urgent with the prevalence of global change. There is no panacea for solving sustainability problems, rather, there is a need for scientific research aimed at developing innovative, adaptive approaches to understanding and managing social-ecological systems with variable, complex, and multi-dimensional attributes. New scientific approaches such as sustainability science have emerged in order to address this need and are more interdisciplinary, participative, and problem oriented than before. At the policy level, frameworks such as Integrated Coastal Zone Management and Marine Spatial Planning (within our group we refer to these collectively as Integrated Coastal and Marine Management) have been proposed as ways to link scientific assessment, monitoring, and prediction with environmental decision-making.

In the Balearic Islands, the sound management of the coastal zone is of utmost importance to guarantee the quality of life of residents and the competitiveness and sustainability of the economic activity in the Balearic Islands. These science to society multidisciplinary activities were initiated in 2005 at IMEDEA (CSIC-UIB) and they continued at SOCIB as requested by the Board of Trustees in 2008. This area of activity is again a good example of the capacity to respond to society needs and of cooperation with regional and local institutions.

The output from this division will ultimately provide key science-based decision support tools and sustainable policy insight for Balearic, Spanish and International ICOM managers in the marine and coastal environment. As an example, the development of science based but society endorsed (Social and Economic Council, CES) indicators for sustainable management of the coastal zone, is among the most significant achievements (Diedrich *et al.*, 2010; 2011). Even more relevant is the on-going implementation of this system of indicators in the Island of Menorca, in cooperation with CES, IBESTAT (Balearic Islands Statistical Institute) and OBSAM (local observatory from Menorca), with 17 indicators having been already established by 2011. Also important is the application of new methodologies such as Marine Spatial Planning to well identified problems such as recreational boating (Balaguer *et al.*, 2011; Diedrich *et al.*, 2011).

The three 'horizontal' SOCIB **Services** support the Divisions, Management & Finance, Computing & IT, and Outreach, Education, Training & Mobility (or OETM) and they are located at the Parc Bit offices close to the UIB Campus. They are essential elements of SOCIB activities and only a very brief outline can be provided here. Management and Finance is responsible for the day-to-day activity as well as preparing the annual balances and reports that have been successfully audited in 2010 and 2011. Computing and IT has established the communications, storage and computing needs for the data centre and the different facilities: the mainframe computer is an SGI Altix XE, a cluster of 8 computing nodes. Each computing node contains 2 Intel Xeon X5560 hexacore (2.8 GHz) and 48GB RAM which makes there are 96 computing cores with 384 GB RAM (being expanded to 512 cores and 3TB) interconnected by a 4xQDR Infiniband network. Disk space is on a NAS server with 40 TB and a scratch system disks with 10 TB. Finally, the Outreach and Education Service has been also active, with for example, the presence of SOCIB at major regional science fairs (once a year in different Balearic Islands, Menorca, Mallorca and Ibiza), the regional Technological Forum (Forotech, in 2010 and 2011) and /or the preparation of a Glider documentary that has been shown on TV several times. Also important is the agreement with UIB LADAT (www.ladat.es) for state of the art visualization and animation of SOCIB activities and results.

The final component of the SOCIB structure is the **Office of the Director**. This Office is responsible for SOCIB strategic direction, budget planning and the communication with the consortium's governing bodies. In addition the Office of the Director manages the SOCIB Focused Research Programs, which initially encompass one research programme, Atlantic Bluefin Tuna (ABT), leaded by IEO (COB - Mallorca)and with active involvement also of IMEDEA (TMOOS).

The ABTis one of the most emblematic top predator species in the world's ocean, exploited and studied by the human beings since antiquity, both for its impressive biological traits and economic value. In the last decades, excessive fishing pressure lead the Atlantic stocks to collapse, to the point that it was proposed to include it in the CITES Convention. Traditional management approaches are mostly based on data from the fisheries sector (which are sometimes considered by different authors as being partially unreliable) and do not take into account the environmental influence on the recruitment variability. These management approaches have been shown many times to be ineffective to ensure the sustainability of exploited fish populations. In this context, taking advantage of the fact that the Balearic Islands constitute one of the main spawning grounds of ABT eastern stock – the one which spawns in the Mediterranean Sea – the COB/IEO led in the '90s the TUNIBAL project, to study the ABT larval ecology, with the aim of modeling the environmental influence both on the location of spawning sites and larval survival rates.

The main goal of the ABT SOCIB Focused Research Programme follows all this previous work (see for example Alemany *et al.*, 2010 or Reglero *et al.*, 2011), and is therefore a clear application of operational oceanography in support of fisheries ecology and sustainable management. Given the environmental and socio-economic importance of this species we briefly describe below the major elements considered as well as the on-going activities.

The ABT SOCIB Programme has focused on the sustainable use of marine living resources, studying the impact of Mediterranean natural physical and biogeochemical variability on ABT spawning grounds and population dynamics. The specific objectives are: (1) Identification of spawning sites location and environmental characterization; (2) Predicting larval survival; (3) Forecasting of tuna spawning location (spawning habitat) based on environmental variability; (4) Forecasting of larval recruitment index based on environmental variability and associated predicted survival rates. To achieve these objectives, several cruises have been already carried out during 2010 and 2011 and will be continued in forthcoming years, combining *in situ* monitoring with satellite data (SST, Colour, Altimetry) and numerical models.

This ABT Programme is an example of the problem solving approach of SOCIB, regional problems with global relevance. In this case, despite we are working only off the Balearic Islands, we are considering also the results from other spawning sites in the Mediterranean Sea (Central Mediterranean, Cyprus, etc.). One of the main conclusions so far is that these different ABT spawning areas present common features, since all of them are highly oligotrophic, located in the vicinity of islands and present complex hydrodynamic scenarios resulting from the interaction of different water masses (in the Balearic Sea, convergence between recent low salinity Modified Atlantic Waters-MAW- with more saline Mediterranean Waters-MW-) and the existence of a significant mesoscale and submesoscale variability (that appears also to play a key role in the bluefin tuna spawning strategies worldwide). Therefore, most of the results obtained in the Balearic

Sea could be extrapolated at regional level. Moreover, under IMBER/CLIOTOP initiative (www.imber.info/cliotop.html), the ABT team is working in close coordination with SEFSC/NOAA (USA) and FRA (Japan) research teams, which are also carrying out similar projects in the main western ABT stock and Pacific Bluefin tuna spawning areas, Gulf of Mexico and Nansei islands respectively.

The responsibilities and main functions of the Divisions, Services and Office of the Director are detailed in Annex 2 from SOCIB Implementation Plan. Significant activities have taken place during 2011 in ETD Division, ASIS Division and the different Services but we will here focus in the next section on the major components and results from the SOSD Facilities during 2011.

6. Systems Operations and Support Division

The Systems Operations and Support Division is responsible for operating the observational, numerical and data management facilities.

Facilities: SOCIB observing components will be progressively constituted by a sustained, spatially distributed, heterogeneous, potentially re-locatable and dynamically adaptive network that will be integrated through data management and numerical methodologies.

Six major observing facilities will be initially considered, a new technology advanced coastal catamaran research vessel (strongly needed in the Islands with more than 1.200 km of coastline), HF radar at the Ibiza channel, gliders, open ocean moorings and coastal moorings and stations, Argo and surface drifters, and finally nearshore monitoring of beaches and harbours.

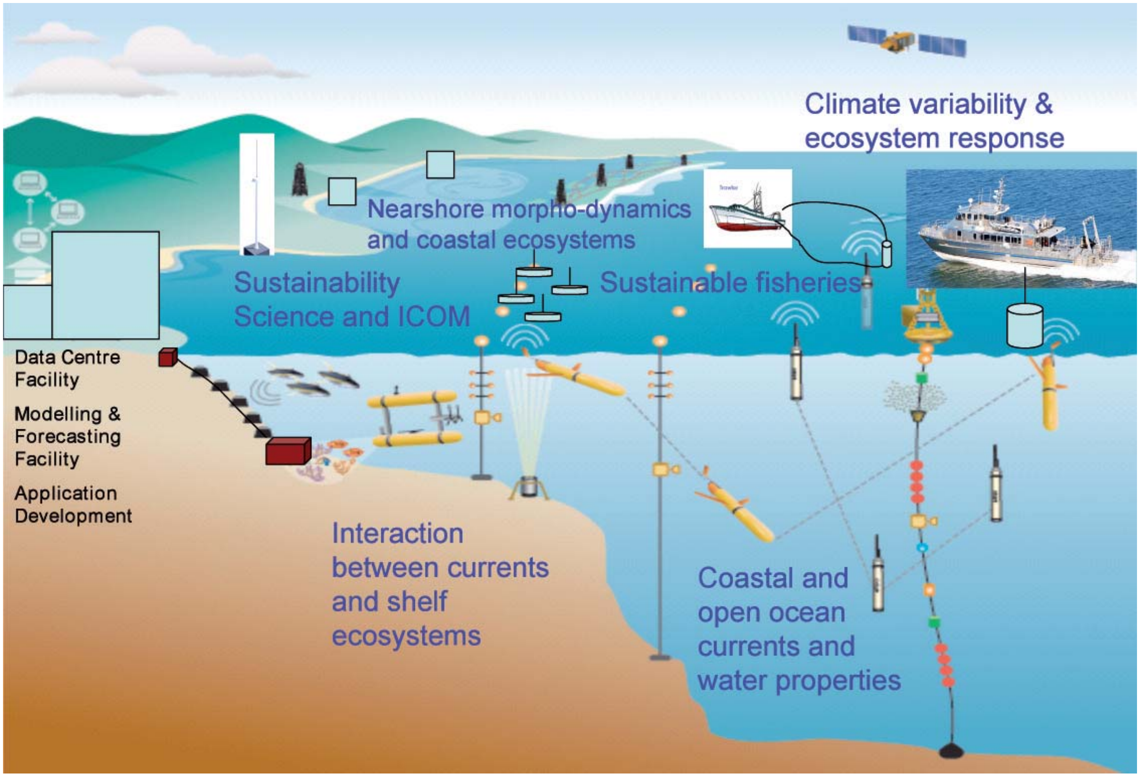

Figure 1. Overview of SOCIB observing and forecasting system (details can be found at SOCIB Implementation Plan at www.socib.eu, adapted from IMOS).

<u>Coastal R/V Catamaran Facility:</u>

The construction of SOCIB R/V catamaran started in June 2011 at Rodman Polyships shipyards in Vigo. The catamaran will be one of the key observing platforms at SOCIB. She is a modern and fast catamaran with 24 m length, 9 m beam and 1,75 m draught, that will sail at a cruising speed

of 22 knots, allowing rapid transit times between the different Islands and survey sites. She will have two labs (wet and dry, with an area of 27 m2) and will be able to accommodate up to 16 persons for missions of duration between 1 and 7 days.
She was designed to be efficient for coastal ocean operations, responding to scientific, technological and societal needs. She will be well equipped with winches, A frame, space for a two 10' container, as well as continuous surface seawater analyser (thermo-salinograph, Seabird SB21) and Turner fluorometer, Rosette CTD SeaBird 911, MultiNet MOCNESS Plankton net, PortaSal salinometer and Helix10 water purification system, SIMRAD hydrographical sounder 12 kHz and hull mounted RDI Teledyne Doppler profiler 150 kHz. As of October 2011, the hull mould has been constructed and is being laminated, as can be seen online cameras at www.socib.eu. This R/V catamaran is an important platform for the Balearic Islands that will bring new and cost effective opportunities to both scientists/engineers and the different key oceanography related institutions in the islands, IMEDEA, COB IEO, UIB, etc.

HF Radar Facility

Surface currents are identified as a high priority product for coastal ocean observing systems. Shore-based high-frequency (HF) radars that broadcast and then observe back-scattered radio signals from the oceans surface are now a mature technology that has been implemented and is routinely operating in numerous locations worldwide. The tender for the long range HF radar system (12 MHz) was awarded in summer 2011 and two stations, one located in Ibiza and the second in Formentera are being installed at the end of 2011. It is expected that the system will start operating in 2012, with continuous hourly monitoring of the surface velocity field in the Ibiza Channel and will be contributing to the scientific objectives as described initially in the Implementation Plan.

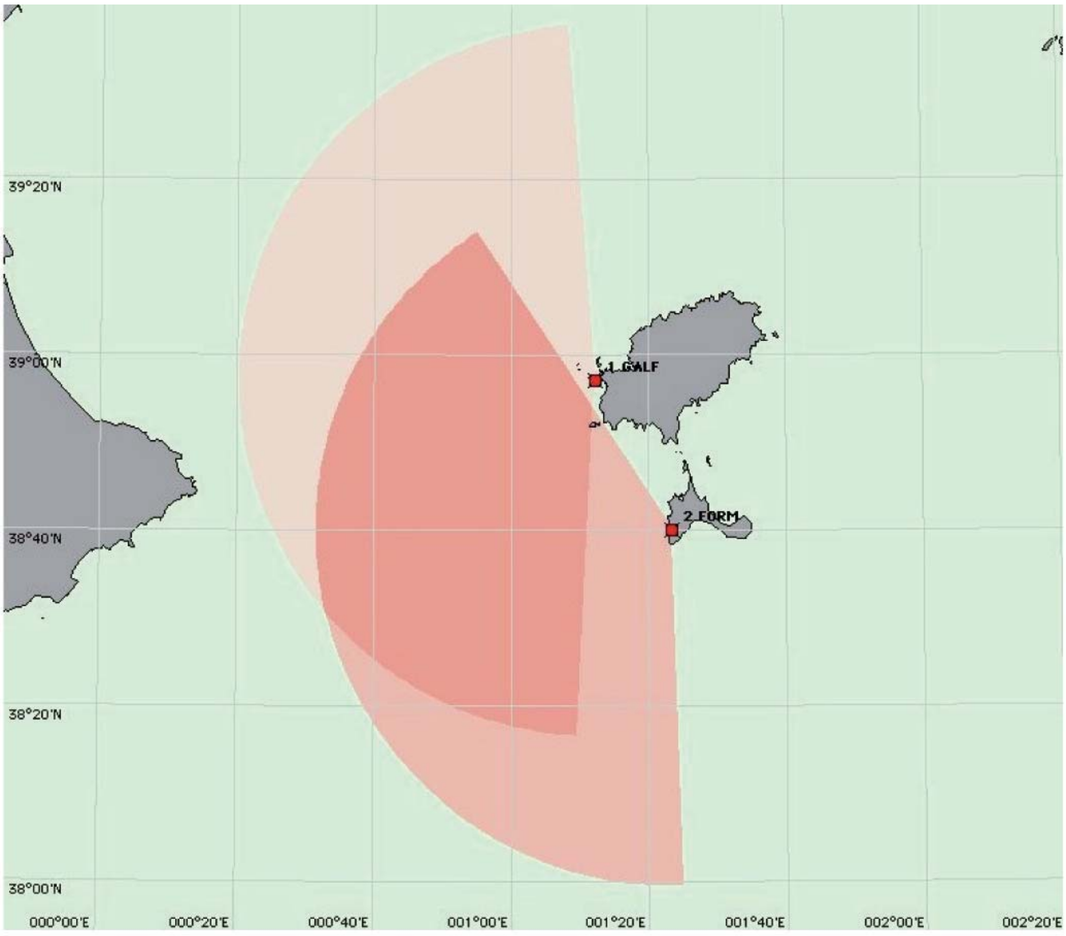

Figure 2. Ibiza channel coverage as designed.

The Glider Facility at SOCIB:

A new glider facility for routine glider operations is operational at SOCIB and runs in strong collaboration and in kind support from IMEDEA (CSIC-UIB) 2010, following the research activities and associated glider developments at IMEDEA (CSIC-UIB) since 2005 (Ruiz *et al.*, 2009 a,b,c). SOCIB has improved the existing glider infrastructures providing new glider units, new electronics, ballasting and operations labs, a new 1000 m pressure chamber as well as a coastal 9,2 m cabined Hurricane Zodiac rib for glider deployment and recovery. The present IMEDEA/SOCIB glider fleet consists of 5 Slocum gliders and 2 iRobot Seagliders. Additionally, the IMEDEA facilities at Calanova harbor (Bay of Palma) include a coastal ship and a warehouse/coastal laboratory available to support glider operations.

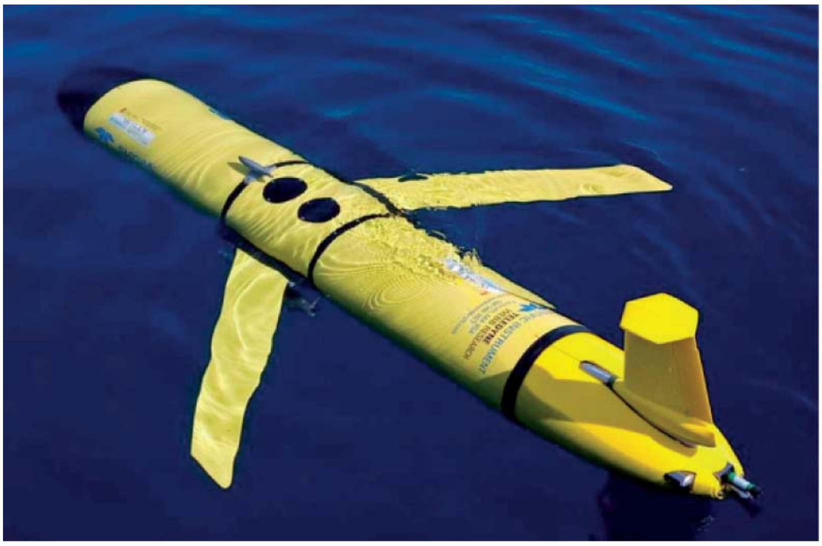

Figure 3. Slocum glider from IMEDEA (CSIC-UIB).

The IMEDEA/TMOOS team that is at the origin of the Glider Facility has since 2005 carried out a major effort to assess and demonstrate the use of gliders for routine and operational ocean monitoring at key control points or sections, in the frame of different mostly EU and Spanish funded research projects (among others, MERSEA, COOL, ECOOP, SESAME, MyOcean). More than 20 glider missions have been performed, collecting ~15.000 hydrographic and biogeochemical profiles. Gliders have specifically contributed to better understanding of mesoscale and sub-mesoscale process (1-20 km) in the upper ocean (Figure 4, Pascualc *et al.*, 2009b; Pascualc *et al.*, 2010; Ruiz *et al.*, 2011), including the coupling between physical and bio-geochemical marine processes. In combination with remote sensing, high-resolution glider data have also improved coastal altimetry results (Bouffard *et al.*, 2010) and path planning tools (Garau *et al.*, 2009) and thermal lag correction tools have been also developed (Garau *et al.*, 2011).

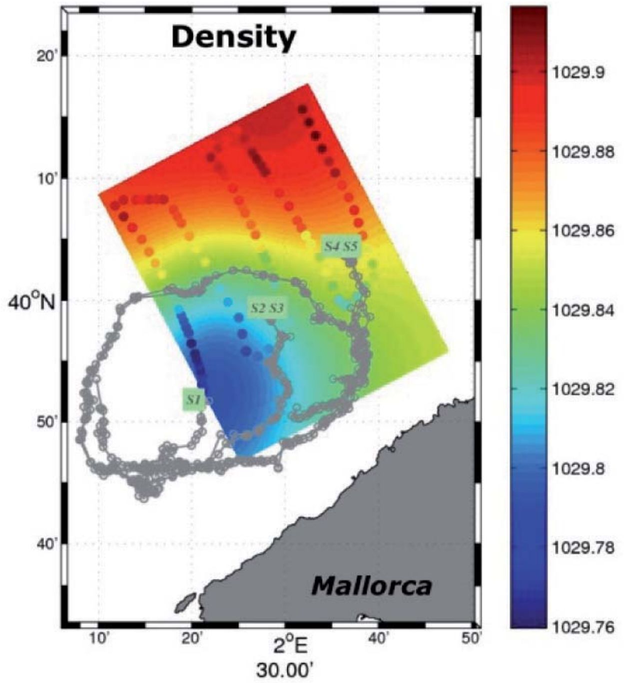

Figure 4. Density field at 75 m obtained during the SINOCOP experiment through optimal interpolation. Colour dots corresponds to values measured by the gliders and CTDs. Grey solid lines and dots are drifter's trajectories. Figure from Ruiz *et al.* (2012).

Since January 2011, the SOCIB/IMEDEA glider operations have focused on the routine and sustained operational monitoring in the Ibiza Channel (Figure 5). First results have reported a new view of the temporal and spatial variability of the Atlantic and Mediterranean N/S exchanges through the channel. This Ibiza channel glider track will be maintained on a routine basis and additional permanent glider sections will be progressively considered in the Balearic, Algerian and Sardinian sub-basins in strong collaboration with international partners.

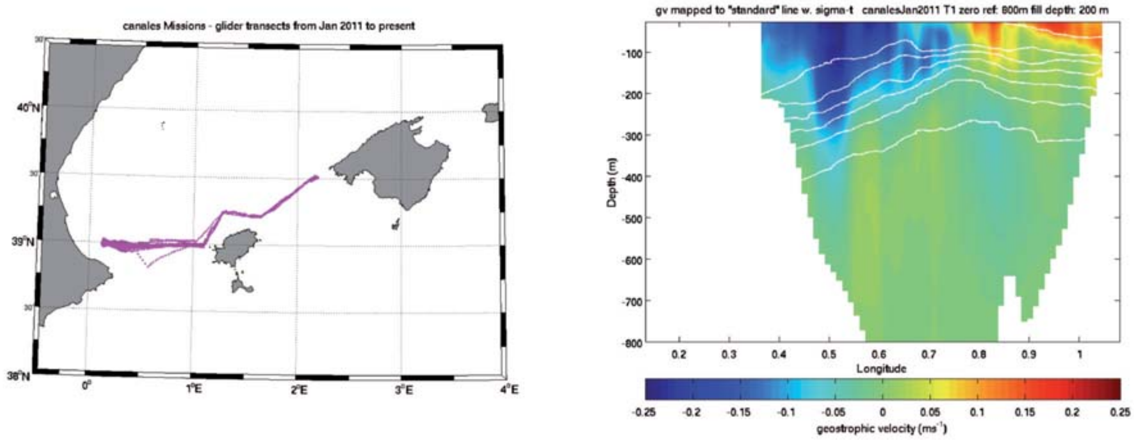

Figure 5. Glider missions from January to September 2011 (left) and Geostrophic velocity across Ibiza channel from January glider mission (right).

Moorings and Coastal Stations Facility

The Mooring Facility is also already operating in 2011 with one coastal buoy (in kind from IMEDEA/TMOOS) and four new sea level gages and barographs located at different key harbours (Andratx, Pollensa, La Rápita and Maó). Figure 6 shows an example of sea level time series from Andratx. Intensive work has been carried out during 2011 on the setup of the coastal stations, including quality control procedures in line with EU funded project MyOcean WP15 (*in situ* TAC). A new deep-water mooring (800 m depth) will be established in the Ibiza channel with physical and biogeochemical sensors in late 2011/early 2012. A coastal buoy will be installed in the Ibiza-Formentera Natural Park, SE of Espardell Island. The data can be visualised in quasi real time from the new SOCIB iphone App available from the Apple Store.

Figure 6. Sea level time series at Andratx mooring facility. Source: SOCIB website.

ARGO and Surface drifter Facility

The Argo and surface drifter Facility is also active. The first 4 SVP surface drifters were released in September 2011 (Figure 7) in collaboration with Med Project TOSCA, where SOCIB is participating. The plan is to deploy 8 SVP drifters annually. All the surface drifters are part of the international Global Drifter Program. It is interesting to note that significant speeds higher that 50 cm/s can be estimated from the drifter trajectories at different times, such as for example off the western coast of Ibiza, along the slope, where sustained velocities around 50 and 60 cm/s where registered by IME-SVP003 (WMO 37572) during the first week of November 2011.

Argo profilers, among others, permit to observe long-scale and inter annual variability (Vélez-Belchí *et al.*, 2010) and therefore are also a key element in SOCIB. The first three profilers were deployed in 2011 (one more to be launched at the end 2011), with plans to deploy four Argo profilers annually. They are included in the ArgoSpain initiative, led by IEO as part of the EuroArgo EC co-funded Infrastructure. The first Argo profilers show interesting features, as the seasonal flow of Atlantic waters through the Ibiza channel (WMO 6900661) or the flow of the alternative LIW path at the southern shelf break of Mallorca (WMO 6900660).

The evolution, visualization and data for the Argo profilers and SVP drifters are accessible from SOCIB Web.

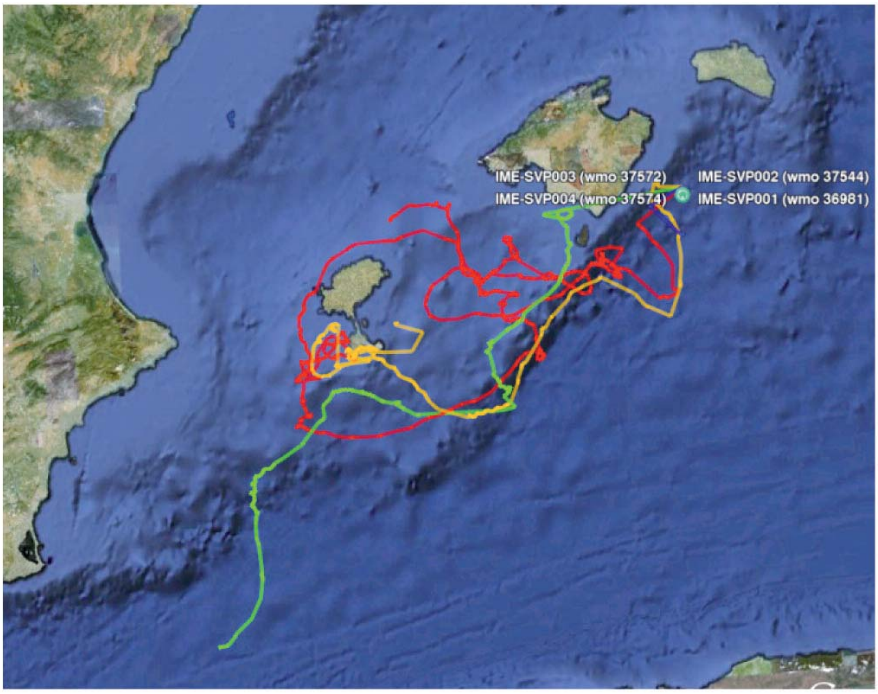

Figure 7. Trajectory followed by the SOCIB surface drifters during September and October 2011 (Source: SOCIB website).

Beach Monitoring Facility

The (Marine and Terrestrial) Beach Monitoring Facility is one of the more relevant facilities for the Balearic Islands society given the importance of beaches on the environmental and socio-economical context of the islands. The facility has started its implementation during 2011 in three beaches: Platja de Palma and Cala Millor in Mallorca and Son Bou in Menorca in line with the scientific, technological and societal objectives described in the Implementation Plan.

The Modular Beach Integral Monitoring Systems (MOBIMS) enable the autonomous and sustained collection of physical data on coastline evolution, hydrodynamics, sediment budgets and sediment transport. Each one of the MOBIMS consists of a coastal video monitoring system (SIRENA; Nieto *et al.*, 2010; Gómez-Pujol *et al.*, 2011), an Acoustic Doppler Current Profiler (ADCP) and a programme of bathymetric surveys and sediment sampling. This system is modular in order to gradually expand the number of beaches under observation to cover different types of energetic input.

The installation of the video-monitoring cameras and the baseline data obtained through detailed *in situ* monitoring in the three sites during 2011 has also been accomplished, following the road map provided by the Implementation Plan, (Cala Millor in early 2011, Platja de Palma in July and November 2011 and finally Son Bou in October 2011). An important accomplishment is that snapshots and other statistical products (i.e. image mean, variance and time-stacks), as well as the meteorological data are received in real time at SOCIB and can be visualized and downloaded from SOCIB Web as of September 2011. Additionally tools for coastline extraction (Álvarez-Ellacuría *et al.*, 2011) and image management and error analysis have been developed.

Modelling Facility

The activities from the Modelling Facility started in 2010 with the development and implementation of the WMed/balOp (WMBAL) forecasting system that is a regional configuration of the Regional Oceanic Model System (ROMS, http://www.myroms.org, Shchepetkin and McWilliams, 2005) to forecast ocean currents. ROMS is a 3D, free-surface, split-explicit primitive equation ocean model with Boussinesq and hydrostatic approximation. The model domain was implemented over an area extending from Gibraltar strait to Corsica/Sardinia (from 6ºW to 9ºE and from 35ºN to 44.5ºN), including Balearic Sea and Gulf of Lion (Figure 8). The grid is 631 x 539 points with a resolution of ~1.5km, which allows good representation of mesoscale and submesoscale features (first baroclinic Rossby radius ~10-15 km) of key relevance in this region because of its dynamical effects and interactions with the mean currents. The model has 30 sigma levels, and the vertical σ coordinate is stretched for boundary layer resolution. Bottom topography is derived from the Smith and Sandwell product (Smith and Sandwell, 1997). Advection for momentum is integrated using a third order upstream scheme (Shchepetkin and McWilliams, 1998), while advection for tracers is integrated using a MPDATA family scheme (Margolin and Smolarkiewicz, 1998). The pressure gradient term is solved by a density Jacobian with cubic polynomial fits (Shchepetkin and McWilliams, 2003). Parameterization of the vertical mixing follows the generic length scale approach (Umlauf and Burchard, 2003), with gen parameters coded in ROMS as described by Warner *et al.* (2005). Open boundary conditions are applied to tracers and baroclinic velocity using a combined Orlanski-type radiation conditions and nudging (Marchesiello *et al.*, 2001) to MFS/MOON MyOcean Mediterranean System daily fields. The free surface and depth-integrated velocity boundary conditions applied at the open boundary following Flather (1976) also come from MFS fields. The configuration is forced by atmospheric conditions derived from AEMET/Hirlam atmospheric model (Unden *et al.*, 2002) each 3 hours using a bulk formulation (Fairall *et al.*, 2003).

WMBAL is running continuously since January 2011. Validation procedures based on inter-comparison of model outputs against observations (*in situ* and satellite) are being used in line with My Ocean standards to assess at what level the numerical models are able to reproduce the features observed from *in situ* systems or remote sensing.

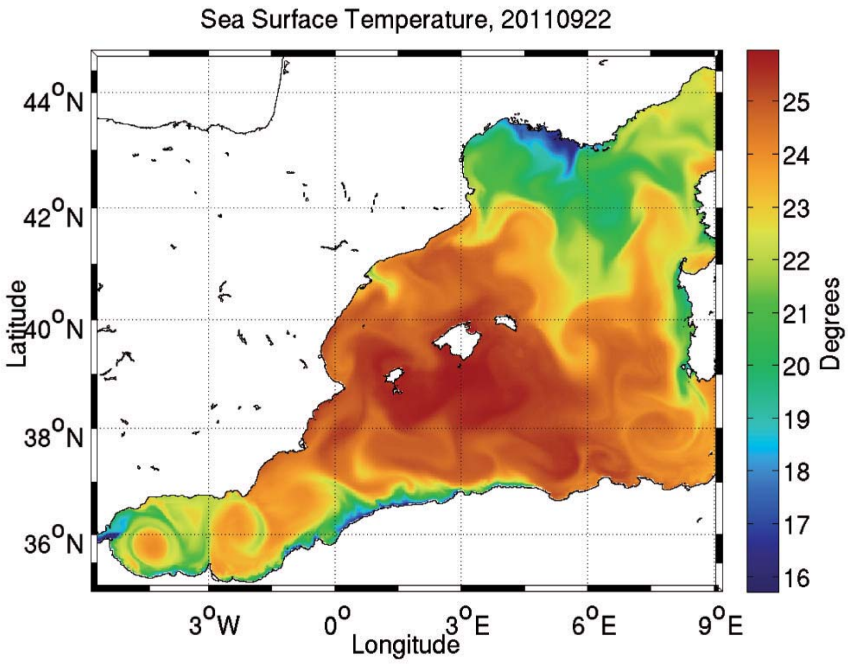

Figure 8. Domain configuration and Sea Surface Temperature Forecast at 2011-05-06 2100h.

At the same time, a Meteotsunami pre-Operational Forecasting System (MOFS) has been developed, based on the configuration detailed in Renault *et al.* (2011). Meteotsunamis are long-period oceanic waves that possess tsunami-like characteristics but are meteorological in origin. They occur in oceans all over the world, usually under their local names such as "Rissaga" (Ramis and Jansá, 1983; Tintoré *et al.*, 1988; Gomis *et al.*, 1993). The sea level oscillation during a Rissaga event corresponds to the oceanic response to some atmospheric gravity waves (Ramis and Jansá, 1983; Monserrat *et al.*, 1991) and/or to convective pressure jumps (Jansá, 1986; Monserrat *et al.*, 2006). MOFS makes use of a high-resolution configuration of the Weather Research Forecast (WRF, Skamarock and Klemp, 2007) atmospheric model that has been also implemented over the Western Mediterranean Sea in order to also have high resolution, redundant and self-sufficient atmospheric forcing fields. Results show that this configuration is able to reproduce reasonably well the atmospheric pressure perturbations from initial synoptic conditions. The oceanic response is then forecasted both outside and inside Ciutadella harbour (Menorca Island, Spain) using a simple ROMS configuration and is able to reproduce the main processes and in particular the harbour oscillations driven by the atmospheric disturbance (Renault *et al.*, 2011). The predictive capability of MOFS has been tested during summer 2011. The forecasting system started from July 2011. Five Meteotsunamis events (not extreme) occurred from the forecasting system start. Preliminary results show that the forecast was able to reproduce in relatively good agreement both atmospheric pressure oscillations (wave train or pressure jump) and oceanic response into the Ciutadella harbour.

In relation to wave modelling, two parallel initiatives have been undertaken. First, we have implemented SWAN, a well-established coastal ocean wave model that is being used in the wave operational system established jointly by SOCIB and *Puertos del Estado* for the Southern coast of Mallorca and the Palma harbour entrance. The system, presented in 2011 to the Port Authority of the Balearic Islands, provides on an hourly basis wave fields and time series estimates of wind, significant wave height, etc. in the area with a 72 hours horizon and is being updated twice daily (Figure 9). The model is forced by wind forecasts from the HIRLAM model provided by the AEMET and the deep ocean Mediterranean wave model from *Puertos del Estado*. This system also includes a validation procedure with near real-time measurements registered by the oceanographic buoys located at Enderrocat/Bay of Palma and Dragonera. This application is part of the Local Wave Forecast System at the Port Authorities (SAPO) and in this particular case the system implemented by SOCIB is focused on the Port of Palma, belonging to the Port Authority of the Balearic Islands. Over the coming months, SOCIB plans to increase the domain of the wave forecast to cover the Balearic Islands coastline and complemented with the predictions of surface currents and even reaching the bathing areas (http://socib.es/sapo/d.sapo/sapo.html).

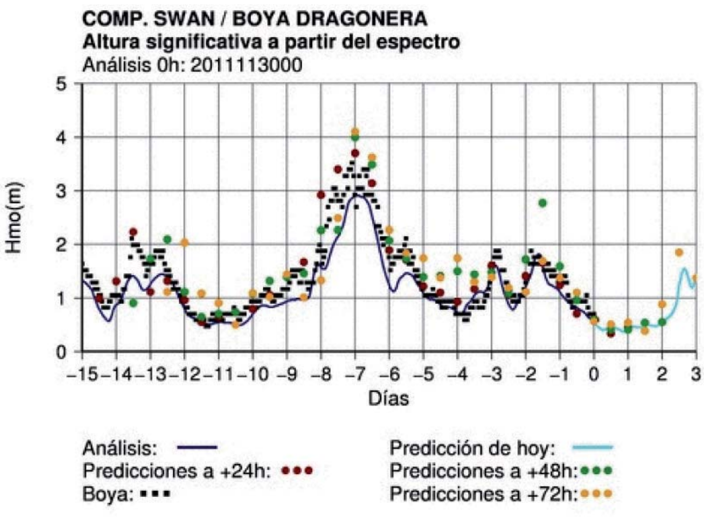

Figure 9. a) SLP Comparisons between simulated significant wave height and observed at Dragonera at 30/11/2011.

At the same time, a WAM based Balearic Sea forecast system is also being implemented with different nested domains covering the four islands. This system shows its ability to simulate the main variability of the sea state.

To better identify the significant air-sea-wave interactions, we used (in cooperation with NURC, WHOI/USGS and PE) the Coupled Ocean-Atmosphere-Wave-Sediment Transport (COAWST, Warner *et al.*, 2010) Modelling System, which is comprised of the Model Coupling Toolkit to exchange data fields between the ocean model ROMS, the atmosphere model WRF and the wave model SWAN (Booij *et al.*, 1999). A severe storm occurred in May 2010 over the western Mediterranean Sea with intense ocean/atmosphere interactions. This storm has been selected as suitable case study for a first implementation of the coupled system at SOCIB/IMEDEA (refer to Renault *et al.*, pers. comm.). In this study, uncoupled and coupled simulations over the Western Mediterranean Sea were carried out. This event is well reproduced by the different simulations showing a cyclogenesis starting on 03 May 2010 close to the Balearic Islands and that turning on to the Gulf of Lion. This event induced an intensification of both Mistral and Tramontane winds up to 28 m s-1 generating rough sea state with significant wave height up to 5m. As observed by *in situ* measurements, the simulated oceanic response to the storm is a significant sea surface cooling (up to 2 degrees) over the Gulf of Lion, mostly confined to the Tramontane zone intensification and along the storm track. Comparison with available atmospheric and oceanic observations showed that the use of the full coupled system provides the most skillful simulation, illustrating therefore the benefit of using a full coupled ocean-atmosphere–wave model system for the assessment of the storm event (see Figure 10). The performance of the modeling system is indirectly suggestive of the relevance of the inclusion of the impact of the sea state on air-sea interactions and the associated increased momentum stress. The realism of the full coupled simulations is encouraging and provides a road map for further hypothesis testing and toward a coupled forecasting system.

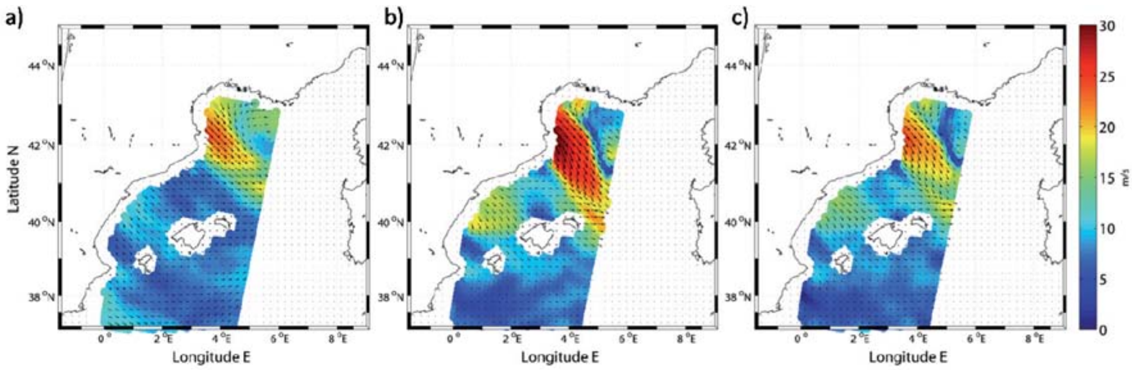

Figure 10. (a) Wind snapshot, 0842UTC 04 May 2010 as observed by ASCAT. The color fields represent the wind speed intensity (m/s) and the arrows the wind speed direction. (b) Same as (a) but for the wind simulated by the uncoupled simulation. (c) Simulated by the full coupled simulation.

Finally, the ecosystem variability is being addressed in collaboration with ICMAN (CSIC) through the development and implementation of coupled bio-physical models (ROMS/NPZD) that started in 2011. As described in the Implementation Plan, SOCIB considers of strategic importance the understanding of ecosystem response and variability associated with physical variability, mostly related to fronts and mesoscale and/or submesoscale eddies. In this context, SOCIB continues the interest from IMEDEA/TMOOS in an area such as Alborán Sea where this type of relationship is more evident due to the strong signals. Along these lines, we concentrated on studying the basis for the observed different states (one gyre, no gyre, two gyres) of the circulation in the Alborán Sea using satellite data and numerical models (see Figure 11). A detailed study of 936 weekly Alborán Sea absolute dynamic topography (ADT) - altimetric derived surface geostrophic current maps for 1993-2010- has shown the existence of two distinct semi-annual signals representing the predominant variability of the data (Renault *et al.*, pers. comm.). The Western Anticyclonic Gyre (WAG) and the Central Cyclonic Gyre (CCG) characterize the winter-spring phase. This single anticyclonic gyre regime apparently develops under moderate ranges of net transport rate across the Gibraltar strait and/or upper layer transport rate. The double anticyclonic gyre regime occurs in the case of an additional development of the Eastern Anticyclonic Gyre (EAG), and prevails during the summer – autumn period under relatively strong upper layer transport from the Gibraltar strait. Associated with this study, a three dimensional modelling process study has been also carried out (Oguz *et al.*, 2011) to provide quantitative support for the existence of this observed bistable semi-annual upper layer circulation regime of the Alborán Sea. Results show that their development may be explained, to a first order, by varying Gibraltar transport rates that are developed in response to the depth averaged current prescribed at the western open boundary of the model and the horizontally uniform but vertically stratified two different water mass structures initially prescribed for the Alborán Sea and Gibraltar Straits.

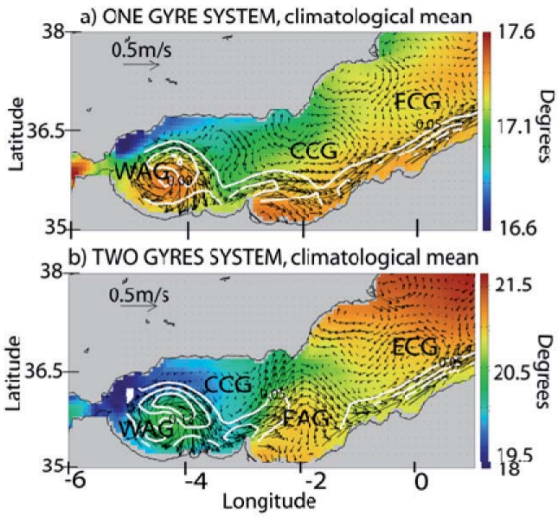

Figure 11. a) Geostrophic current (m s-1) patterns and kinetic energy (m2 s-2, one contour each 0.05 m2 s-2) distributions superimposed on the weekly mean SST fields for the two quasi-persistent modes of the Alborán Sea gyral circulation system. They correspond to (a) one-gyre mode (1G) with moderate rate of Atlantic inflow, (b) two-gyres mode (2G) with high rate of Atlantic inflow. The colorbars on the right represent the SST ranges in ºC. The respective positions of the Western Anticyclonic Gyre (WAG), Central Cyclonic Gyre (CCG), Eastern Anticyclonic Gyre (EAG) and Eastern Cyclonic Gyre (ECG) are indicated by the respective acronyms.

Remote Sensing: in relation to remote sensing data, following the implementation plan they are integrated in the Modeling Facility to facilitate the development and integration with the model outputs. SOCIB will facilitate easy access to in house generated products and visualization of ocean remote sensing thematic products. Various satellite data products (altimetry, SST and ocean color) will be acquired and processed by SOCIB, operationally providing data visualization products though a dedicated web portal. The SST and ocean color products will be acquired, processed and visualized, both at delayed and real time lags. Swath and gridded data will be considered at different spatial (1-4 km) and temporal (1 day -8 days) resolutions. These data will contribute as an important data stream producing high-quality regional 1-2 km resolution near real time forecasts. Altimetry data and products will benefit from the expertise of IMEDEA researchers in developing improved and tailored satellite altimetry products for coastal and mesoscale applications (Pascual *et al.*, 2007; Pascual *et al.*, 2009a; Bouffard *et al.*, 2010; Escudier *et al.*, 2011). The specific tasks foreseen will include:

- Development, and implementation of methods for the combination of different sensors (including the estimation of geostrophic velocities close to the coast imposing a boundary condition). This task has been started in 2011 by using a two step optimal interpolation scheme with smaller correlation scales than the standard AVISO product and using both the bathymetry and tide gauges information to constrain surface currents along and not perpendicular to the slope (Figures 12, 13);

- Estimation of a high resolution mean dynamic topography (MDT). The MDT will be built as a combination of sea surface height data derived from satellite altimetry, space gravity missions (GOCE), numerical model outputs and *in situ* oceanographic (T, S profiles and drifter currents) data. This task will be performed in collaboration with CLS starting in 2012.

- Development of indicators (satellite and model based) indicators for sustainable fisheries, for example, combining ocean colour data (through an empirical algorithm linked to primary production) and combining with SST, Altimetry, and physical variables from model outputs.

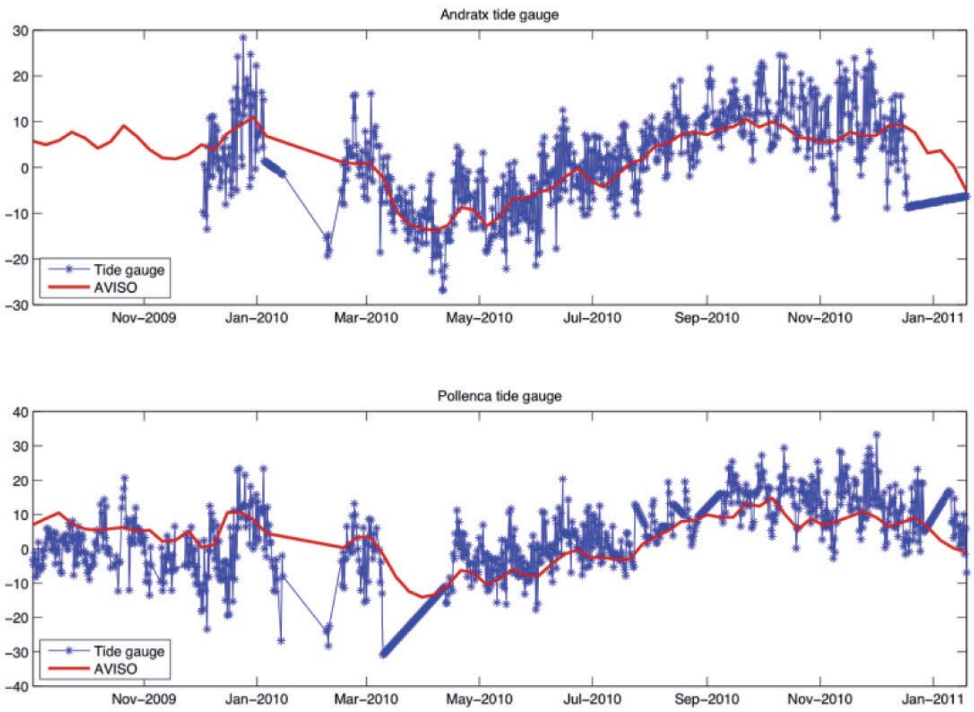

Figure 12. Comparison of altimetry and tide gauge sea level observations at Andratx and Pollensa tide gauges. The good agreement between both data sets allows to perform the combined OI analysis shown in Fig. 11 – Source: Escudier *et al.* (2011).

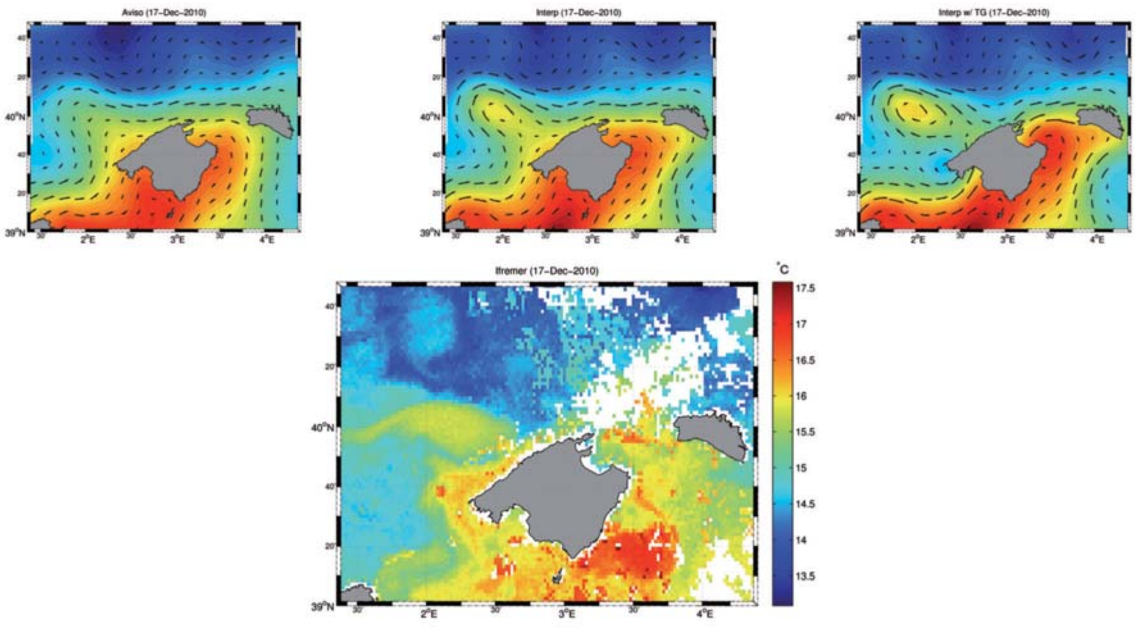

Figure 13. In these figures, the potential of combining altimeter data with tide gauges (TG) located along the Mallorca coast in order to improve coastal features is explored. The eddy revealed by SST (bottom) North-West of Mallorca is better reproduced by the 2steps OI (top center) and even better when adding tide gauge (top right) information in comparison with standard AVISO (top left) – Source: Escudier *et al.* (2011).

Data Center Facility

The Data Centre is the core of SOCIB and is developing and implementing a general data management system to guarantee international standards, quality assurance and inter-operability. It is also performing specific developments and tools for the different facilities when required. Its main functions and capabilities range from data reception to its distribution and visualization (via web services and THREDDS/OPeNDAP protocols), passing through processing, quality control, documentation, standardization and archiving (NetCDF format and CF conventions), and data discovery (based on OGC protocols).

During 2011 the Data Centre of SOCIB, in conjunction with the different facilities, has developed several applications for oceanographic data management. Those applications are intended to cover the needs of SOCIB, following its implementation plan. In order to do that, the team members of the Data Centre Facility have been working in the different data management process steps, from acquisition and processing, storage, to visualization and distribution.

The general goal of the Data Centre Facility is to provide users with a system to locate and download the data of interest (near real time and delayed mode) and to visualize and manage the information. Following SOCIB principles, data need to be:

- Discoverable, accessible, 'collect once, use many' (data and metadata),
- Freely available,
- Interoperable, standardization and sharing guarantee.

To accomplish the full lifecycle data (from the modelling and observing systems ingestion up to the user), the data centre has defined seven steps for the Data Management Process:

1. Platform management and communication,
2. Quality Control assurance,
3. Metadata Aggregation and Standardization,
4. Data Archive,
5. Data Search and Discovery,
6. Data Policy and distribution,
7. Data Viewing.

The data management system created for gliders, Fig. 14, is an example of the new capabilities for real time definition of mission planning, including adaptive sampling and real time monitoring using a Web tool that allows quick visualization and download (http://apps.socib.es/gapp/).

Also important are the new Apps that are being developed for smartphones and that are already available for iPhone.

Some specific examples of developments are:

- Multi-platform management: gliders, drifters, moorings, beach monitoring cameras and more, with real time monitoring capabilities
- Data Archive: informatics' infrastructure to securely archive data and metadata, and retrieve them on demand
- Distribution: interoperability through OPeNDAP, WMS, HTTP, FTP…
- Catalog: THREDDS to organize data and metadata for automatic harvesting
- Discovery: RAMADDA to search and find data sets of interest
- Analysis and Visualization: IDV, custom web applications and others to provide

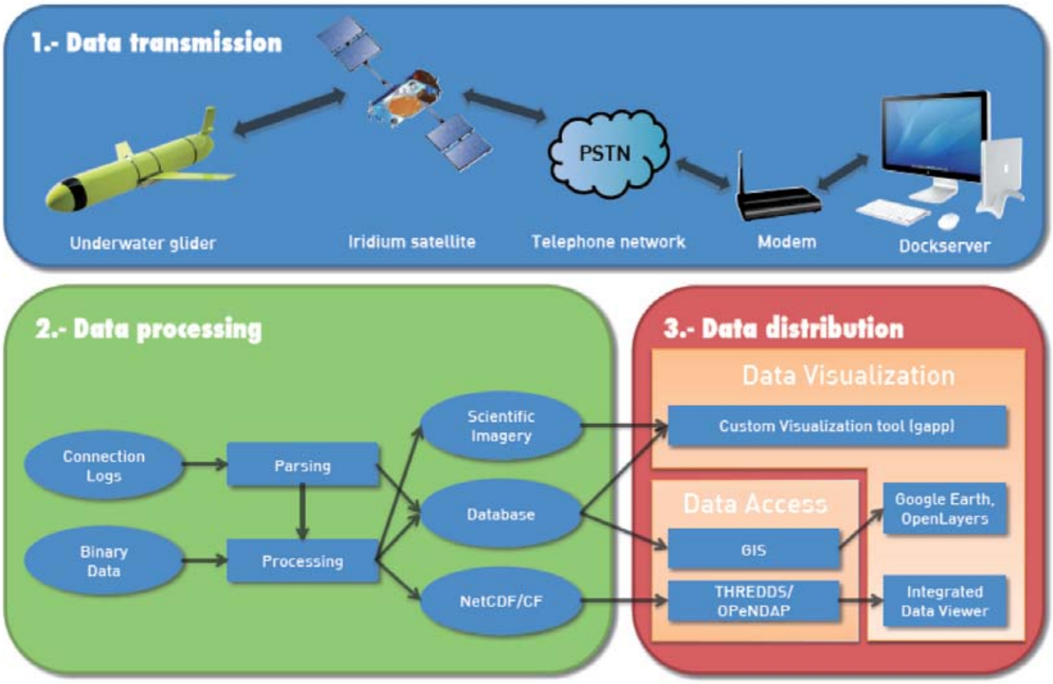

Figure 14. Glider data management workflow at SOCIB.

7. SOCIB Funding and Governance

SOCIB is part of the Spanish Large Scale Infrastructure Facilities (ICTS). An international scientific advisory committee will be responsible for the implementation of a peer review evaluation process following the highest quality standards. Formal agreement between the Spanish Government (Ministry of Science and Innovation) and the Balearic Islands Regional Government (Ministry of Economy, Finance and Innovation) was reached in 2008 to establish, in the Balearic Islands, this new Coastal Ocean Observing and Forecasting System, SOCIB, a new Consortium (formally known as SOCIB also) with legal entity, following a proposal submitted in 2006. Funding, up to 36 million Euros was approved, including 13,5 million Euro for scientific equipment and facilities, and 2 million Euros/year reaching year 2021. Activities formally started in 2009 with the preparation of the detailed implementation plan that was finally approved in July 2010 and the formal participation in the Consortium of key partners in the Balearic Islands, such as CSIC, IEO and UIB. Strong and active involvement and partnership between all key players is essential for the success of this initiative. Co-operative agreements with national, regional or international institutions have been also established (Puertos del Estado, Ports de les Illes Balears, IHM, MERCATOR, among others) and will continue.

SOCIB is a new way to fund R&D activities and represents a very significant change in marine and coastal observing in the Balearic Islands (and also at European level), moving to an oriented, strategic regional approach with a view to establishing a sustained marine and coastal system. It is a pilot initiative at regional level that will be later extended at national and/or European level. SOCIB is a specific contribution to MOON[3] and is also in line with IMOS[4] in Australia (with which many similarities exists), OOI and IOOS initiatives in USA[5] and several other observational and forecasting systems existing or being designed at present (Liverpool Bay Coastal Observatory[6], COSYNA[7] in Germany, MOOSE-Mediterranean Ocean Observation on Environment in France

[3] http://www.moon-oceanforecasting.eu/
[4] http://www.imos.org.au/
[5] http://www.oceanleadership.org/ocean_observing/initiativehttp://ioos.noaa.gov/
[6] http://cobs.pol.ac.uk/
[7] http://www.gkss.de/institute/coastal_research/structure/operational_systems/KOK/projects/ICON

(with which active coordination is envisioned in particular in the northern sub-basins) and will be also linked to ongoing European projects such as PERSEUS and operational initiatives such as MyOcean and MyOcean2, the Marine Core Service in the Mediterranean and other GMES actions.

8. Conclusion

SOCIB is an example of a new type of sustained and operational marine and coastal infrastructure. Theses infrastructures, combining new technology developments and careful scientific analysis will allow new ways of international cooperation leading to major science breakthroughs and new ways of science based coastal and ocean management.

Acknowledgements: this paper describing SOCIB, its components and initial results is the result of more than 10 years of oceanographic and coastal zone scientific and technological activities in the Balearic Islands (mostly described at IMEDEA TMOOS 2010-2013 Strategic Plan) and as a result, different and many research projects are at the origin of this activity and should be acknowledged (EU funded MERSEA, ECOOP, SESAME, MyOcean and PERSEUS, CICYT funded COOL, etc.). SOCIB is formally a consortium from the Spanish Ministry of Science and Innovation and the Balearic Government whose support is gratefully acknowledged. JT also kindly acknowledges the invitation from CIESM that gave the opportunity to prepare this manuscript in the frame of present and future physical oceanographic activities in the Mediterranean.

Origin of *Dinoiphysis* species bloom in the Northeastern Adriatic Sea

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Abstract

Occurrence of *Dinophysis* species in relation to hydrographical data in the northeastern Adriatic Sea has been investigated in a period from 2001 to 2005. *D. caudata* appeared in the community during stratified summer period. *Dinophysis* species abundances show significant correlation with surface and bottom salinity differences (Δs). Higher abundances of *Dinophysis* species and its longer persistance in the phytoplankton community have been recorded at the offshore station in relation to inshore stations. More abundant *Dinophysis* population in offshore area is associated with higher salinity differences between surface and bottom layer. These findings suggest that offshore conditions in association with higher surface salinity are more favorable to bloom origin than inshore conditions.

Introduction

Species belonging to *Dinophysis* genera can produce toxic compounds, which can through the food web affect human health. This genus due its economic and public importance and its influence on shellfish industry has gained great scientists interest. Detailed exploration of the ecophysiology, biology, and toxicology of *Dinophysis* species started in recent times after these species has been obtained in culture. In the Croatian waters 13 *Dinophysis* species has been recorded out of which seven species appeared regularly with defined seasonality (Ninčević Gladan *et al.*, 2008). Species *D. fortii* and *D. caudata* are associated with shellfish toxicity events in the northern and southern Adriatic Sea (Ninčević Gladan *et al.*, 2011). This paper analyzes data of *Dinophysis* species abundances in relation to physicochemical parameters at stations placed in northern Adriatic.

Materials and methods

The investigated area is located along the western coast of the Istrian peninsula, comprising inshore stations IP1 (11 m) and IP2 (8 m) and offshore station IP3 (18 m) (Figure 1). The inshore stations are located 4-5 km south of the Mirna River estuary, without significant freshwater and sewage water inflow.

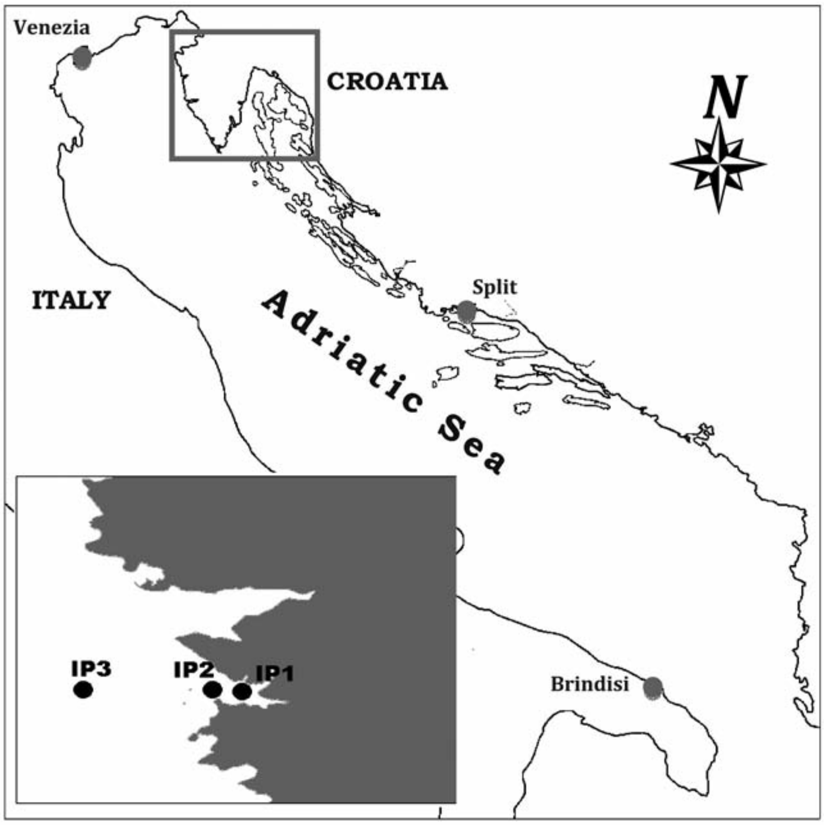

Figure 1. Study area with sampling stations.

Field surveys were conducted from January 2001 to December 2005. In the colder part of the year (from November to March) sampling was performed on a monthly basis. In the warmer period from April to October sampling was done every two weeks. Phytoplankton samples were collected with a plankton net (mouth diameter 29 cm, mesh size 20 μm) towed vertically from near bottom to the surface. The results were expressed as no. cells m^{-2}. Phytoplankton species were identified and counted under the inverted microscope (Olympus IX50) according to Üthermöhl method (Üthermöhl, 1958). For *Dynophysis* spp. abundance determination, the whole chamber bottom was scanned for cells. Temperature and salinity in the surface and bottom layers were recorded with the YSI Model 63 handheld pH, salinity and temperature probe.

Results and Discussion

Much higher abundances of *D. caudata* and *D. fortii* were repeatedly recorded at offshore station IP3 than at inshore stations IP1 and IP2.

Dinophysis caudata was first recorded at stations IP3 and IP1 in relation to station IP2 where this species has been recorded month later. These species remain in the community much longer at offshore station IP3 in relation to inshore stations. Among these four years the longest bloom prolongation has been in 2002 which is characterized by extremely rainy summer and autumn period.

Dinophysis caudata with higher abundances occured in the seawater in summer period, which is characterized by thermal stratification and low precipitation. The highest abundances of *D. caudata* were recorded in August of 2004, which was according to Croatian Metorological and Hydrological Service extremely dry. Despite dry condition at the offshore station halocline condition has been recorded in that period.

Dinophysis appearances at all stations coincide with halocline existence. Mean monthly salinity along the western Istrian coast ranged from 36.6 to 38.5 in July and January, respectively. The lowest surface salinity was recorded during summer period. During investigation period, differences between surface and bottom salinity (Δs) were higher at offshore IP3 station in relation to inshore stations. Significant relations have been observed between abundances of *D. caudata* and *D. fortii* species and Δs ($N = 164$, $r = 0.27$, $p<0.05$; $N = 47$, $r = 0.40$, $p<0.05$).

The distribution of physicochemical and biological properties in the Northern Adriatic is driven by ocean currents. According to Orlić (1989) during the summer season when a stratified water column occurs, less saline waters from the Italian rivers flow above the pycnocline not only along the western coast, but also towards the northern and eastern coasts. Our salinity data confirm this view. We hypothesize that this water mass favors *Dinophysis* spp. growth or even spreading to the eastern part. The *Dinophysis* bloom in the inshore waters is supported by intensive precipitation, halocline formation and accumulation of *Dinophysis* species. General accepted theory is that stability of the water column is a critical condition for the accumulation of *Dinophysis* cells and its dense patchy distribution (Maestrini, 1998).

Cyclonic gyre obtained by the POM model (Princeton Ocean Model) in the northern Adriatic mean monthly current field could enable surface transport of the river-influenced water from the western coastal area towards the Istrian coast during summer stratified conditions (Figure 2). These results support our hypothesis obtained through the analysis of *Dinophysis* abundance and salinity values.

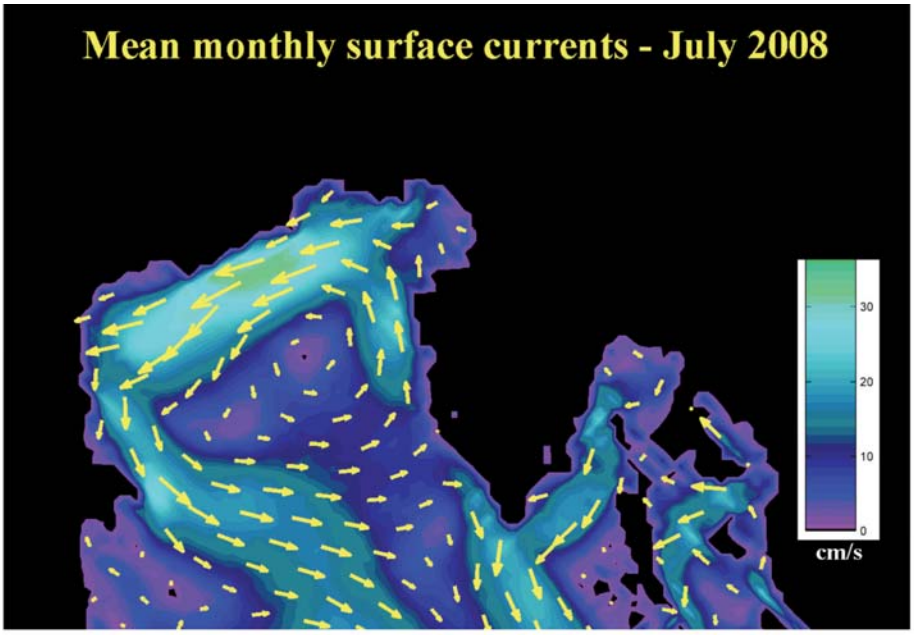

Figure 2. Mean monthly surface currents for July 2008 obtained by POM model forced with Aladin surface momentum, heat and water fluxes and river discharges.

During the five-year investigation period, we observed differences in the frequency of toxicity events. In 2002 and 2003, there were no events of DSP shellfish poisoning; in 2001 and 2004 there were a few toxicity events. In 2005, a year characterized by unusually high precipitation quantities, significant DSP toxicity events were recorded. Toxic events recorded in 2005 occurred after rainy periods except in the summer (Figure 3). That summer toxicity event could be the results of *Dinophysis* species brought in surface current from the western coast.

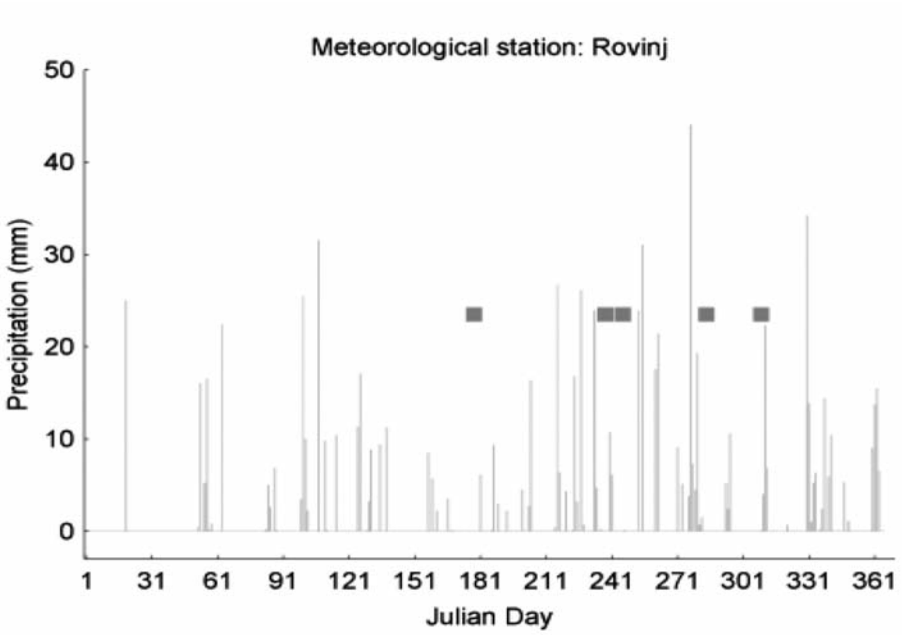

Figure 3. Precipitation quantity in 2005 year (grey squares depict periods of DSP toxicity events).

Phytoplankton bloom forecasting is an important component of many projects due its contribution to better understanding of phytoplankton dynamic behavior and management of coastal waters. To test the hypothesis expressed in this study, determination of physico-chemical parameters and phytoplankton community during stratification period in a transect from the river Po estuary to the Istrian coast should be done.

SESAME Proposed WOCE-TYPE Stations in the Mediterranean and Black Seas

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Introduction

It is obvious that in the Mediterranean and Black seas many monitoring stations already exist. Yet, it is considered imperative to obtain long time-series from a few more stations in the open sea of the SES, in order to contribute to the study not only of the state, but also the variability of the ecosystem both in seasonal and interannual time-scales. Under the SESAME Project, funded by the European Commission under the 6th Framework Programme, ten (10) oceanographic research vessels simultaneously conducted multinational cruises across the Med and Black Sea in March-April (Umit Ünlüata cruises) and August-September 2008 (Fig. 1). New observations were thus gathered during these multidisciplinary, multiship oceanographic cruises. Furthermore, the SESAME-IP project prepared the background for the monitoring of both seas, by proposing WOCE (World Ocean Circulation Experiment) -type stations at selected transects. Such stations will be established for the first time in the Basin and are destined to be sampled after the duration of the project, creating information to be used in the future. The selection of certain stations in the SES

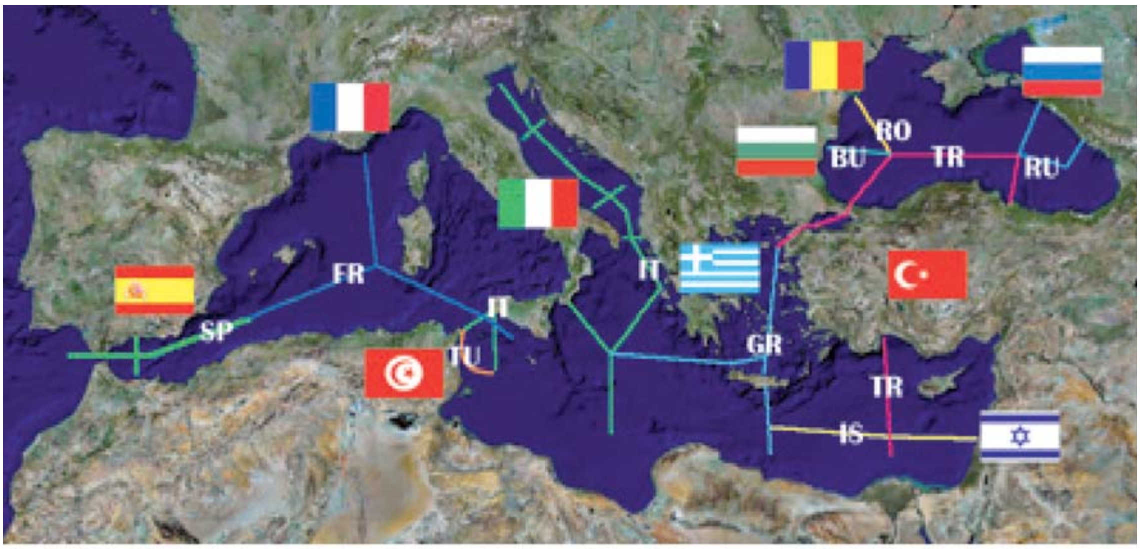

Fig 1. SESAME Cruises in spring and autumn 2008.

is based on existing information and the new data gathered from the SESAME cruises. The choice of the sampled parameters will be decided with respect to their significance for understanding of ecosystem functioning, particularly for understanding of the processes that are not well known and in connection with climate change effects. Parameters include those with hydrographic information (T and S), as well as standard biogeochemical parameters such as inorganic nutrients, DO, Chl-a and plankton.

Identification of SESAME monitoring stations

The Mediterranean and Black Seas are monitored routinely by oceanographic research vessels of the coastal states and international missions occasionally or regularly by visiting. Similarly, coastal states have developed networks for continuous observation of the marine environment in the frame of national and international research programs. Following the same idea, coastal states and foreign missions release drifting instruments to measure various parameters as temperature and salinity, occasionally dissolved oxygen, and dynamic parameters as for example surface currents. The maps below present observational networks that have been developed, where continuous, long-term measurements of different parameters of Mediterranean deep waters in key areas (e.g. CIESM Hydrochanges Program- Fig. 2; MOON Network – Fig. 3; and Multisensor Moorings- Fig. 4).

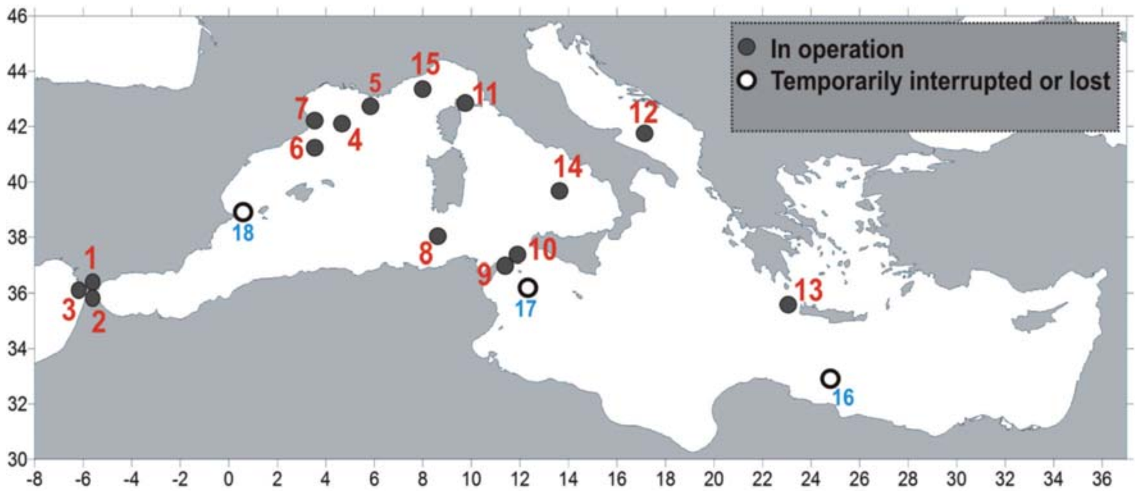

Fig 2. CIESM Hydrochanges Network (taken from CIESM webpages).

Fig. 3. MyOcean validation network (national real-time transmitting fixed stations/buoys).

Fig. 4. Multi-sensor moorings (yellow circles) and cabled seafloor observatory NEMO-SN1 (red square) in the Mediterranean Sea.

SESAME WOCE-TYPE Stations: selection criteria

The proposed WOCE-Type stations have been selected based on: (1) their scientific relevance, being representative of sub-basin scale processes area in terms of hydrographic and biogeochemical conditions, (2) the coverage of the whole Mediterranean and Black Sea basin, (3) focusing, as far as possible, on areas in the open sea (as coastal stations are being covered under national level) which could be visited more easily by the international scientific community. Such characteristics make the stations suitable for becoming SESAME monitoring stations that have been maintained in the past and could be maintained in the future. Furthermore, the availability of past multidisciplinary data already obtained help to make a thorough review, maximizing the use of past and concurrent research data collections.

SESAME WOCE-TYPE Stations: proposition

Based on the above criteria, expert opinion and SESAME information during the Work Package 2 campaigns, seven (7) stations are selected to represent, in addition to national monitoring, the network of stations that could cover changes in the future. These stations will add the information to the existing structures already in place (as for example the monitoring of the Greek Seas by POSEIDON network). Five stations (Fig. 5) are proposed for the Mediterranean Sea and two in the Black Sea (Eastern and Western cyclones). Here follows their description:

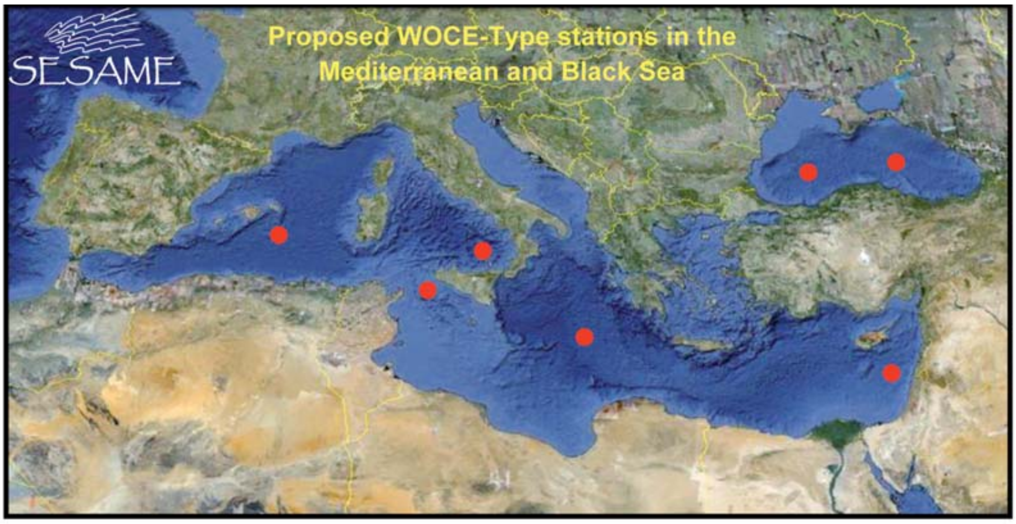

Fig. 5. SESAME-IP Proposal for monitoring (WOCE-Type) stations.

WOCE-TYPE STATIONS:

1. **Eastern part of the Levantine basin** aiming mainly to monitor the fluctuation of the warmest and saltier core eddy of the Mediterranean. The South Eastern Levantine is the most saline and warmest surface water in the Mediterranean. Salinity of the Levantine surface water in this region has significant interannual fluctuations defined by intensity of cyclonic circulation in the Levantine basin. Low level of circulation leads to stagnation of LSW and increase of salinity. Intensification of the cyclonic circulation after stagnation leads to advection of anomaly saline water in regions of intermediate and deep water formation. Therefore salinity of LSW can be considered as predictor for intensification of deep water formation in the Aegean Sea.
2. **The Ionian Sea station** to monitor one of the deepest basins of the Mediterranean that has a long record of sampling through recent years and during the SESAME WP2 cruises. In the Ionian site a deep sediment trap mooring has been established and receives also dust from the Sahara (with southern winds), which may play an important role in the ecosystem functioning.
3. **The Sicily channel station** to monitor the exchange of waters between the east and the west basins. The Sicilian site has been regularly sampled by CNR-ISMAR and CNR-IAMC during the past years and is close to two long-term moorings at the western sill managed by CNR-ISMAR. In addition a long term coast to coast transect has been monitored (between Mazara, Sicily, and Cape Bon, Tunisia).
4. **The Tyrrhenian Sea station** well placed to receive signals of changes from the Eastern Mediterranean. This station has been regularly sampled in the framework of the Italian VECTOR project during the past years and since April 2007 there is a deep sea mooring managed by CNR-ISMAR in collaboration with the Parthenope University of Naples and ENEA. In addition a repeated coast-to-open sea transect is monitored (between the deep station and the Gulf of Naples.
5. **The deep water station in the western Mediterranean basin**, which together with the coastal station (observing systems already in operation in France and Spain) will give an overall picture of changes occurring in the western basin.
6. & 7. In the Black Sea **two fixed regions** (rather than stations) are proposed, one in the western and one in the eastern deep part of the sea (Fig. 6). The proposed monitoring regions are centered at the SESAME WP2 joint stations, at the intersections of the SESAME WP2 cruise tracks (Fig. 6). Each Region is a square of about 30 by 30 miles.

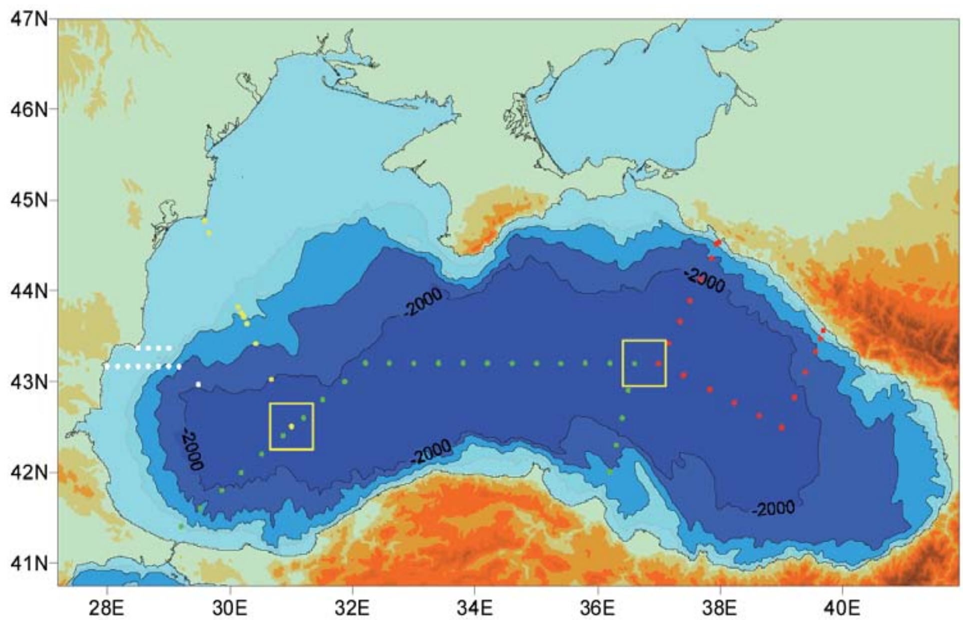

Fig. 6. The proposed WOCE Regions (yellow line squares) are located at the crossroads of the SESAME WP2 Black Sea sections.

The choice of the SESAME monitoring Regions in the Black Sea complies with three major important criteria:

1) Both Regions represent the quietest central part of the Black Sea, where high-frequency noise due to the horizontal advection is at its minimum. The SESAME Regions are located near the centers of the western and eastern sub-basin circulation gyres, where the black lines with arrows indicate the main patterns of horizontal circulation, the dashed line shows the position of the near shore convergence zone, small circles with arrows – near shore eddy-like structures.

2) The SESAME Regions are adjacent to the Black Sea countries' EEZs borders. This considerably facilitates logistics and performance of multi-disciplinary measurements in "national" cruises. In the eastern Region, three countries, Russia, Turkey, and Ukraine can carry on their oceanographic stations freely within their respective EEZs. The western Region overlies the Turkish, Bulgarian and Romanian EEZs.

3) In the eastern Region, a long record (about 50 years) of regular hydophysical and hydrochemical data does exist. Hence, the prolongation of observations is strongly recommended. In the coming few years, P.P. Shirshov Institute of Oceanology, Rusian Academy of Sciences (SIO RAS) is going to maintain, in addition to cruises, an anchored automatic profiling system (CTD+current velocity) at the eastern SESAME Region. This system, equipped by near real time data transmission via satellite, will provide the oceanographic community by hydrophysical information all year around.

Conclusions

It is believed that the proposed WOCE-Type stations will enhance the information in the Mediterranean and Black Seas and create a long term dataset of hydrological, biogeochemical and ecological properties against which future changes could be assessed. The SESAME consortium is determined to maintain the operation of these stations beyond the duration of the project. All interested bodies and Institutes could use the acquired information as the data will be incorporated into the SESAME database. The latter will be maintained also after the end of the project as all data will be transferred to a public domain database.

Considerations for the implementation of a Med-SHIP program

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Abstract

As the Mediterranean is often considered a reduced model of the ocean, it may be thought easy to adapt the strategy of the Global Ocean GO-SHIP program by a simple scaling down. But the Mediterranean is a sea where variability is extremely high in both space and time. Following a brief review of the sources of variability, recommendations are suggested for what could be the backbone of a Med-SHIP program. That the efficiency of Med-SHIP will be clearly linked to the possibility to improve and extend the various monitoring networks (existing or future) at the whole Mediterranean scale.

1. General picture of the Mediterranean

The Mediterranean can be regarded as a machine that transforms the lighter water incoming at the surface in the strait of Gibraltar from the Atlantic (Atlantic Water: AW) into denser Mediterranean waters (MWs), that will eventually exit at depth through Gibraltar (Figure 1; see Millot and Taupier-Letage, 2005b for a review). The formation of the dense MWs occurs during wintertime through deep convection processes in the northern parts of both basins*:* off the Gulf of Lions (potentially west of the Strait of Bonifacio too, see Fuda *et al*., 2002) for the Western Basin, and in the southern Adriatic, southern Aegean and "Rhodes gyre" for the Eastern Basin. The winter conditions vary from one year to another: the convection does not reach the bottom every year. Therefore there is a strong interannual variation in the characteristics and the depth of the water formed (e.g. Rubino and Hainbucher, 2007; Schroeder *et al.*, 2010a, and Schroeder *et al.*, this volume). In the same way, when the waters involved in the convection vary, the resulting deep water varies too, as observed for a few years now in the Western Basin. And finally the origin of the denser water formed may also vary. This was the case during the episode called the Eastern Mediterranean Transient (EMT), when the water originating from the Aegean became denser than the water formed in the Adriatic, replacing the latter in the deeper part of the Eastern Basin (for a review see Roether *et al*., 2007, and Kress *et al.*, this volume).

At all depths all the water masses (i.e. AW and MWs) circulate along the local isobaths (Figure 1). When the seafloor is flat, the denser water masses tend to circulate mainly alongslope, in a general counter-clockwise circuit too. This means that, after their initial spreading and downstream of their formation area, the most recent/less modified deep water masses are to be found and sampled rather alongslope. However there are (sub-)mesoscale processes that interplay to increase variability (Testor and Gascard, 2003). In the same way, when the seafloor is very rough as in the

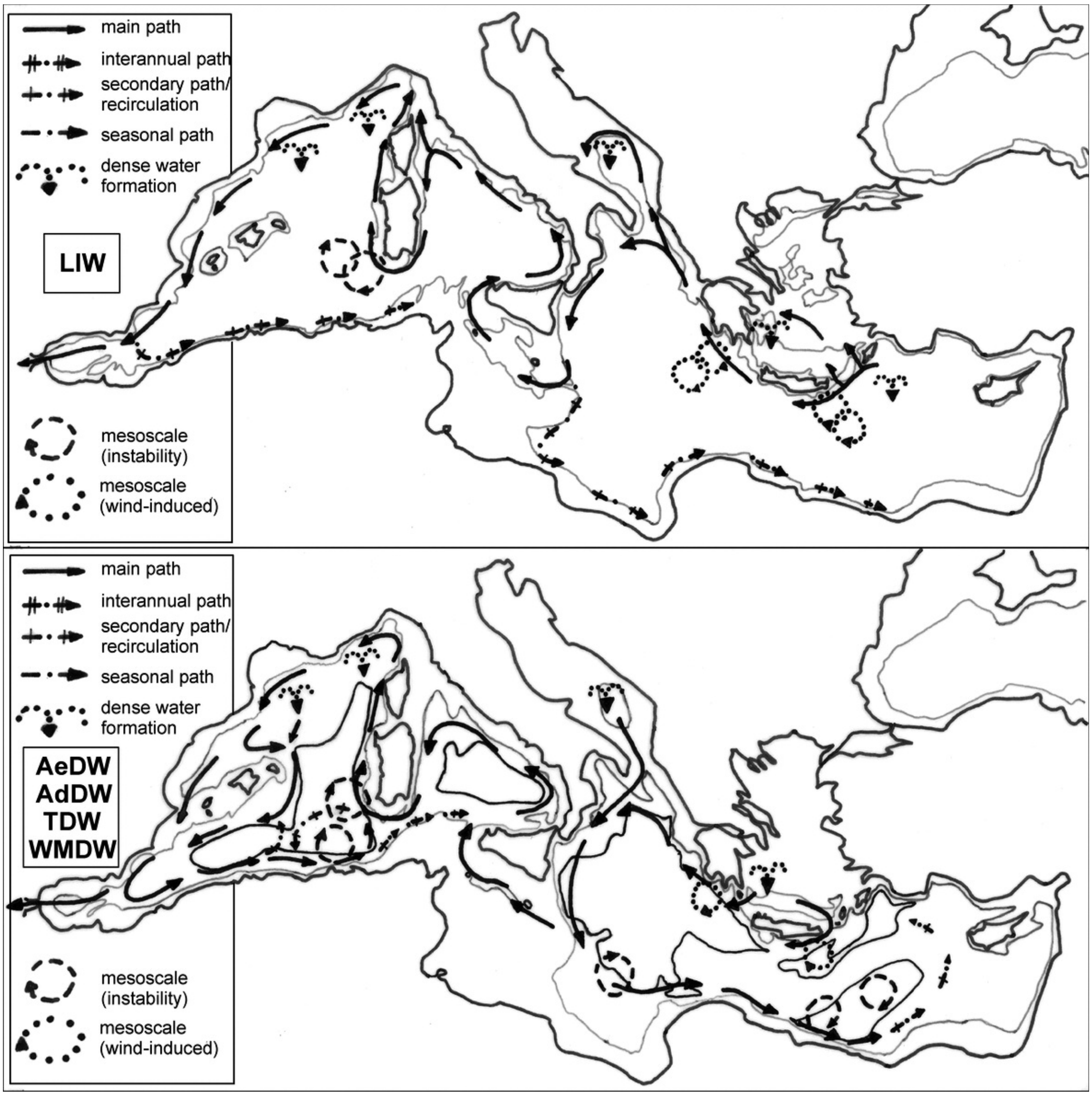

Figure 1. General circulation diagram of Mediterranean water masses: a) Intermediate (LIW); b) Deep waters. (from Millot and Taupier-Letage, 2005b).
The circulation diagram of surface waters by same author will be found on p. 25 of CIESM Monograph 27 (2005).

Eastern Basin, the densest waters are channelled by the bathymetry, which results in a very high spatial heterogeneity above the seafloor (Figure 2; Taupier-Letage and Millot, 2010).

As for the densest-waters-to-date, they are trapped in the large troughs that are found in the Tyrrhenian, the southern Adriatic, the central Ionian, and the Levantine off Egypt (Herodotus trough, and south of Crete), until a denser water is formed. Therefore there is no simple relationship between the age of a water mass and its depth. Indeed, the oldest /most homogeneous waters are found at ~1000 m deep in the central part of the Eastern Basin (Schneider *et al.*, 2010).

The lighter AW enters the Mediterranean at Gibraltar and defines the surface circulation which consists of two counter-clockwise circuits in both basins. In the southern parts, the alongslope flow of AW is unstable: the Algerian Current and the Libyo-Egyptian Current both generate meanders and eddies. Only the anticyclonic ones are long-lived. The eddies, embedded in the current, first propagate alongslope downstream (eastward) at a few km/day. Eventually they can detach from the current and drift in the open-sea. These (mesoscale) eddies have diameters ranging

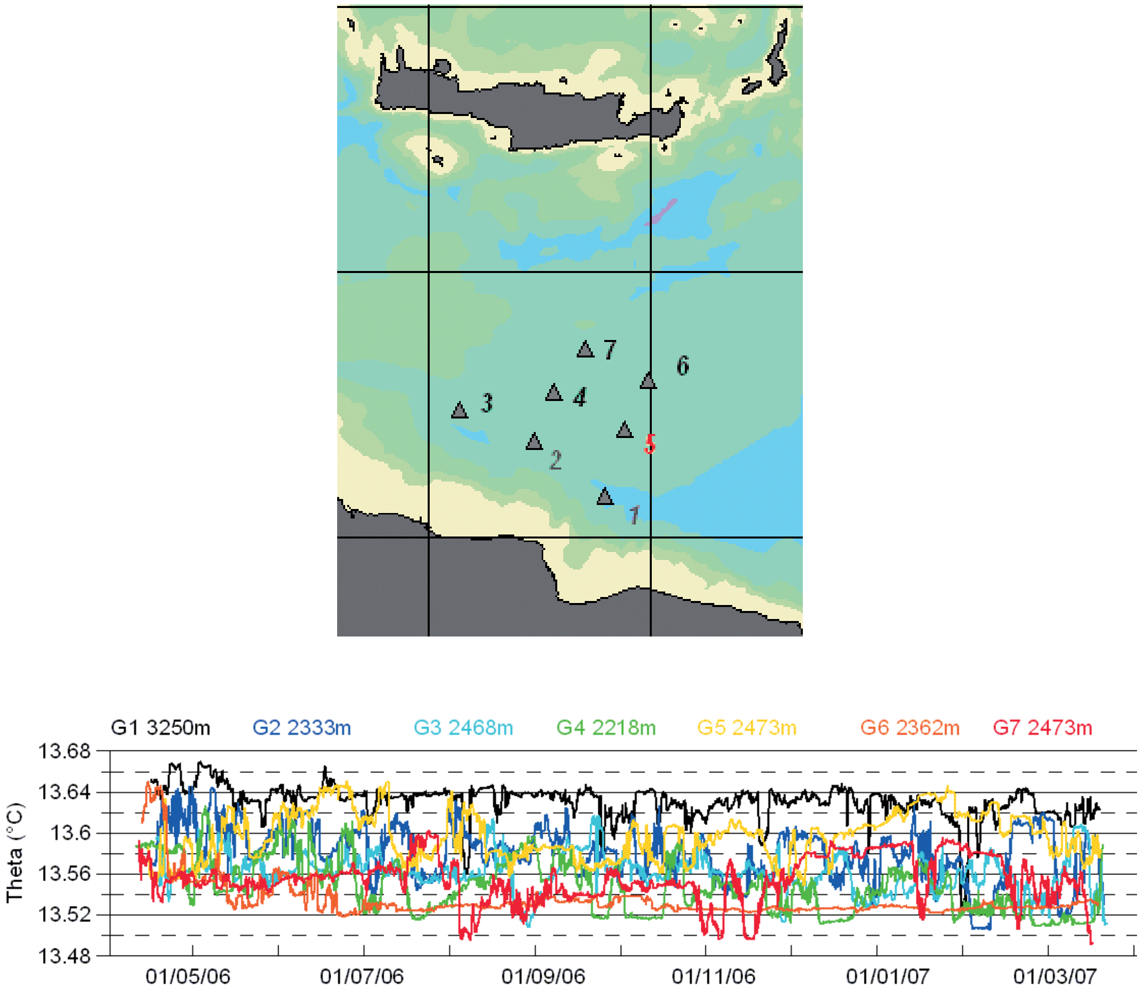

Figure 2. Time series of the potential temperature recorded a few meters above the seafloor at the seven moorings (G1-G7) of the EGYPT project (Eddies and GYres Path Tracking, www.ifremer.fr/lobtln/EGYPT/). Respective depths are indicated on top of the frame.

from 50 to 150 km (up to 250 km), vertical extents from 100s to 1000s of meters (down to the bottom: ~3000 m; see Figure 2; Millot and Taupier-Letage, 2005a; Taupier-Letage and Millot, 2010), and lifetimes from month to year (up to three years at least; Puillat *et al.*, 2002; Hamad *et al.,* 2005; 2006).
In the northern parts of both basins AW flows alongslope as a permanent current (the Northern Current). It displays a strong seasonal variability: its mesoscale activity increases during wintertime, mainly generating meanders (up to small eddies -diameter 10-20 km- in the Eastern Basin), which propagates downstream (see Figure 15 of Stemmann *et al.*, 2008; Oszoy and Aydogdu, this volume).

The importance of the mesoscale activity raises two main concerns relevant to a Med-(GO)-SHIP-like program. The first one is that both Algerian and Libyo-Egyptian eddies can have a significant impact on the general circulation. These eddies interact very frequently with their parent current, and can divert recent (little mixed) AW offshore (e.g. Taupier-Letage *et al.*, 2003; Taupier-Letage, 2008; Millot and Gerin, 2010). In the same way, eddies can entrain intermediate and deep waters (Millot and Taupier-Letage, 2005a; Testor and Gascard, 2003; Testor *et al.*, 2005) off their normal paths -that is along the local isobaths in a general counter-clockwise circuit (Figure 3). The second one is the variability of immersion of the various isolines (isotherms, isohalines, isopleths...) induced by the structure of the eddies, when most of them are likely to be used for latter calculations of carbon-related parameters. As an illustration let's take the case of the anticyclonic eddy called Ierapetra, created during the summertime 2005 and sampled in April 2006. The difference of immersion of the isotherms and % saturation O2 (taken as examples) between the central zone and the edges (precisely determined thanks to a sampling interval of ~5 to 10 miles) reaches ~400 m (Figure 4). Additionally, although Ierapetra was offshore, it was entraining recent AW northward on its western edge, and newly-formed LIW on its eastern one and central zone. The distance between both types of stations is ~50 km, that is about the sampling interval used for zonal pan-Mediterranean transects. With such a complex structure and high variability, what is at stake is the correct interpretation of "sparse" data and of their derived parameters.

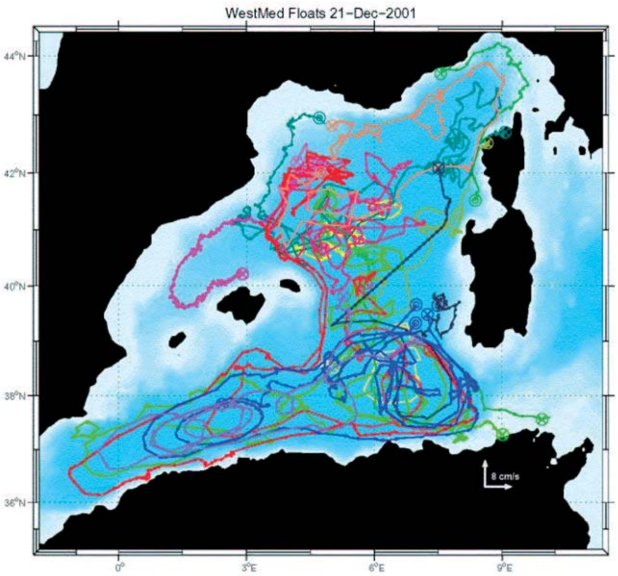

Figure 3. Trajectories of floats drifting between ~1000 and 2000 m during ~1 year (courtesy P. Testor and U. Send).

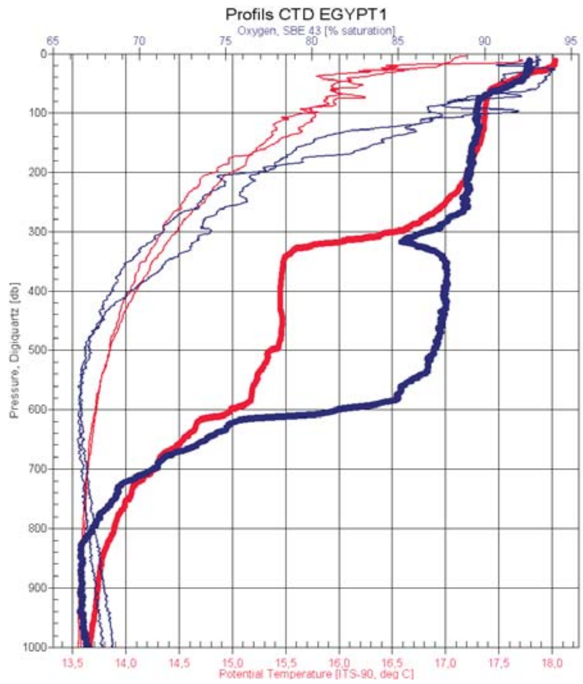

Figure 4. CTD casts made across an anticyclonic eddy (Ierapetra 2005) in April 2006 (EGYPT project). Thick lines: cast in the center; thin lines: on both western and eastern edges. Parameters: potential temperature (red), oxygen saturation (blue); plots cut at 1000 m.

On top of these difficulties (mesoscale + interannual + decadal variabilities) we also have to consider that our knowledge of the climatology of the Mediterranean is clearly questionable, at least in the central and southern parts of both basins, where few data are available. For example a data set, when quasi-unique, can exaggerate the weight of one situation or episode. We also know that some data come from cruises which have considered calibrating their CTDs by adjusting their deepest profiles with the one taken exactly at the same location a few months before, which we now know is not relevant (see Figure 2).

2. The main factors to take into account:

- Interdependence of the two basins
    - ⇨ Sample both basins
- Dense Water Formation processes + related events (EMT, WMT...)
    - ⇨ Abrupt changes
    - ⇨ High interannual variability
    - ⇨ Whole water column
- Mesoscale phenomena ubiquitous and permanent
    - ⇨ Very high spatial and temporal variability

3. Optimum characteristics for a Med-SHIP program/transect:

- Transects in both Western and Eastern Basins
- Cross-basin
- Cross the circulation of all the water masses, i.e. from slope to slope
- Cross the circulation perpendicularly in a coastal band ~50 km wide => transects perpendicular to the local coastlines/isobaths are more likely to get the full current section
- Cross the main areas of DWF
- Cross the central and southern areas
- Cross the deepest areas
- Yearly repetition
- Optimal period: from late spring to summer
- Sampling interval: ~10 miles
- Full depths casts

4. Recommendations

The main concerns with a unique pan-Mediterranean zonal transect are that some waters will not be sampled, and that it might be difficult to establish the continuity with the previous one, all the more if performed at a decadal scale: the correct understanding of the outcome of the dense water formed and of the carbon sequestered might be at stake.

However the previous characteristics are clearly unrealistic for the type of work requested for a GO-SHIP program and transect, in terms of funding required, sampling effort and analyses.

An efficient (minimal) trade-off could be to design two north-south transects across the Western and the Eastern Basins (transects W and E, resp.), as schematized on Figure 5, plus a third one west-east across the northern Ionian (transect I). This way the main water masses would all be sampled (perpendicularly), the DWF areas (or very close downstream) too, as well as several deepest parts of the Mediterranean. These transects should have Med-SHIP full-depth casts (every 20-30 miles) interleaved with CTD-only casts down to ~1000 m, to ensure the correct description (and hence understanding) of the mesoscale. The adaptation or development of profiling sensors for parameters related to GO-SHIP issues should be fostered, so that these no-bottle- sampling-casts would be even more efficient.

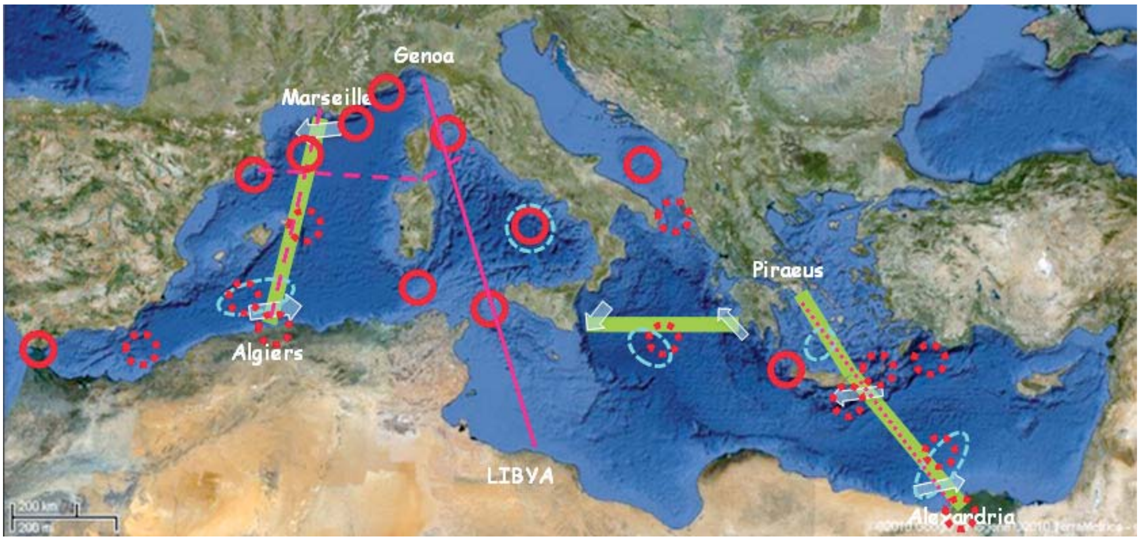

Figure 5. Suggested backbone for a Med-SHIP program (thick transects), and synergy with the monitoring programs HydroChanges (circles: existing stations, dotted circles: suggested complementary stations), and Transmed (thin transects; plain: existing, dashed: completion planned before late 2012; dotted: suggested). The arrows represent the local general circulation. The dashed ellipses represent the deepest areas.

The repetition rate for the Med-SHIP transects cannot be high, but it should not exceed five years *a priori*. In-between, the synergy with other programs should provide the information to establish the continuity. Namely a yearly hydrological monitoring of these Med-SHIP transects at least (program to create yet), the network of moored CTD's HydroChanges (http://www.ciesm.org/marine/programs/hydrochanges.htm), the (near-future) network of thermosalinometers Transmed (http://www.ifremer.fr/lobtln/TRANSMED/), and the potential network of gliders.

For the hydrological monitoring with CTD (+ auxiliary sensors), even though some transects are performed on a quasi-regular basis in the Western Basin (see Schroeder *et al.*, this volume), and used to be in the Adriatic (past Adricosm program), no comprehensive or coordinated program is secured yet, not even with XBTs. This remains an open issue, where one solution might be a modified EUROFLEETS call to encompass work coordinated at the Mediterranean scale.

The HydroChanges network of moored CTDs (Figure 5) is running for now (for examples of the hydrological time series provided by these moorings and results see papers in CIESM, 2009, http://www.ciesm.org/online/monographs/Malta.html). New moorings should be added, especially to sample along the Med-SHIP transects: at the foot of the slope off Menorca and Algiers, in the strait East of Crete and at the foot of the slope off Alexandria, off the Peloponnese and in the channel of Otranto. In the same way new moorings should be installed in the deepest areas of Alboran, Algerian and Ionian, off Rhodes and in the Herodotus trough (the deepest area of the Tyrrhenian is already equipped, see Figure 5).

The installation of low-cost autonomous thermosalinometers on ships of opportunity allows the monitoring at high temporal resolution (~weekly) of the temperature and salinity of the sea surface, and provides a synoptic picture at basin scale. At present the Transmed network has equipped one container ship from Genoa to Malta and Libyan harbours. The route from Marseille to Algiers (see Figure 5) will be included shortly within the program HYMEX (www.hymex.org), the one from Barcelona to Rome will follow. The system is very cheap and cost- efficient, and could be easily implemented on the route from Piraeus to Alexandria at least. More details and the potential final network, crossing all DWF areas, and basins and sub-basins, can be obtained from http://www.ifremer.fr/lobtln/TRANSMED/index.html. One main development should be a more sophisticated system which allows auxiliary sensors relevant for GO-SHIP (e.g. for pCO2), with capability for drawing water samples. Such systems exist in the North Sea and Baltic Sea (see http://www.ferrybox.org/).

5. Conclusion

The downscaling of GO-SHIP to a REGional- or Med-SHIP implies heavy adaptations to meet the requirements imposed by a very high variability in both space and time. As the GO-SHIP sampling is extremely demanding, the Med-SHIP transects cannot meet the frequency and sampling interval that would be optimum. Thus synergy with other monitoring programs is compulsory. However the implementation of a Med-SHIP program together with that of multi-platform monitoring programs it international funding framework dedicated to monitoring programs. Any sustained effort for monitoring is presently funded at the national or even regional/ provincial level, or if funded at EU level is extremely short-lived (three years).

Another issue to solve prior to/along with designing a Med-SHIP (Mediterranean-wide) program is the maritime jurisdiction claims for Exclusive Economic Zones (EEZ), that some countries extend unilaterally. A Mediterranean-wide agreement for scientific sampling at least should be sought as soon as possible, with the aim of obtaining in a near future presenting an homogeneous dense cover of stations as in Figure 5.

The Ocean Data Network (ODN)
A model of data management for a sustained hydrographic program

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Abstract

The Mediterranean is characterized by a North-South data divide. For the MedSHIP program, the data management strategy proposed is built upon the ODN (Ocean Data Network) model. This model is organized around a data assembly center linked to NODC's by a strong cooperation and coordination, and moving toward a basin-wide data capability, sharing capacity, and data management standards.

1. Introduction

Data management is likely to be the most challenging issue for the MedSHIP program, particularly regarding the important data divide between the North and South of the Mediterranean. In fact, contribution of the southern Mediterranean's ocean community to the previous global oceanographic programs was low (Mallard *et al.*, 2004). The planning activities of the MedSHIP program will address data management, data sharing and products development issues in the Mediterranean context, with regard to the general strategy proposed (Hood *et al.*, 2009) for the global GO SHIP program.

The general strategy proposed by the Workshop is built upon the IODE/IOC/UNESCO model, with a central data assembly center, playing also the role of a communication and coordination center, as the backbone of the new regional Ocean Data infrastructure, linked to a well established ODN (Ocean Data Network), by a strong cooperation and coordination with NODCSs. This strategy move toward a basin-wide data capability, sharing capacity, and data management standards.

A task team is created to propose ways and solutions to improve technology and data policies, particularly in south Mediterranean countries, to release data in a more timely manner; to coordinate with other international programs, and to propose a mechanism for products development and data synthesis.

2. Data management, sharing and products development

2.1 The ODN [Ocean Data Network] as a model

When implementing an international collaboration in ocean science, with data sharing arrangements, involving partners at different levels in data management practices, sharing policies like MedSHIP, we gain learning from past experiences. The MedSHIP Workshop recommended the ODN [Ocean Data Network] model, shaped by UNESCO/IOC through the IODE [International Oceanographic Data Exchange], which has more than 40 years on managing aspects of data and information flow at national, regional and international level. Technical issues relating to data collection, storage, dissemination, referencing, etc., have been addressed since the earliest years of IOC's existence. However, data exchange policy issues have only come to the fore in the past two to three years, with creation of formal working groups on data exchange policy (Longhorn, 2003).

The ODN model was built on the consideration that, in ocean sciences, any capacity program for the developing world should be one that will not only build indigenous capacity but also develop and improve national, sub-regional and regional capacities and capabilities with the involvement, cooperation and coordination with all agencies with mandate for ocean (Ayinla, 2009) ODINAFRICA, was one of the networks created, in a process of more than 25 years [1989-2013] (Pissierssens, 2010).

The program provided support to operate National Oceanographic Data Center and develop products. The focus was made on national requirements but also identifies similar needs across the region and, develops regional products and services that serve all participating countries in a region. The approach adopted recommend to not develop data centers as isolated facilities, but ensure that these centers provide services and products that are needed by users; and ensure that the project is driven by stakeholders as representatives of users and involve these stakeholders as much as possible in the governance of the project. At the end of the process, 25 African countries construct a Pan-African observing system; data products (Atlas)/ national and regional work plans multi-sectoral data; share data (cooperation in OceanDataPortal), and integrated in global programs such as GOOS, WOCE, etc.

2.2 The data management and sharing policy AND Data assembly centers

The data management is organized on a distributed model, where NODCs maintain control of their data resources, and are responsible for data collection, analysis, documentation, quality control (QC) archiving, and ii) the data assembly center is responsible for data merging, online dissemination and documentation, etc.

The MedShip Workshop recommends that the data-release guideline of the GO-SHIP program should be adopted to be in harmony with the global program:

- Preliminary dataset released within 6 weeks,

- 6 months for final physical data,

- 1 year for final data of all other variables.

While in the North part of the basin, where frameworks for data sharing are well established, the strategy and the guidelines proposed for the global GO SHIP program could be adopted without constraint, meaning that quick data release, real-time or near-real time and a broader coverage [more variables exchanged (CDT, SST, salinity, etc.) principles, to produce scientific products on a shorter time scale could be respected. In many south Mediterranean countries, governments are still considering publicly funded research data either as secret or commercial commodities, the absence of a clear policy and legislative framework at the national level can seriously disturb the effective implementation of the basin-wide data sharing objectives.

Many international centers/projects related to the oceanographic data management were implemented in the Mediterranean during the last decade [MEDAR/MEDATLAS, SeaDataNet, EMODNet, etc.), which enhanced regional co-operation and advanced communication and interaction between the various Mediterranean NODCs. This network must be strengthened by building capacities for advanced data production. The strategy of the ODN model is built to develop and improve national, sub-regional and regional capacities, with the involvement, cooperation and coordination with all hydrographic stakeholders.

2.3 Existing data management centre/infrastructure

During the last decade, many projects related to oceanographic data and information management in the Mediterranean were conducted. These projects allowed the establishment of a pan-Mediterranean network of data centres and specialized marine institutions, they also permitted the development of several oceanographic and marine metadata directories for the Mediterranean Sea, which were updated and expanded within the SEASEARCH project (Mallard *et al.*, 2004). They also permitted to establish a data format and data management quality control standards compatible with existing international ones.

- **MyOcean** is a pan-European project (60 partners in 28 countries), it is the Ocean Monitoring and Forecasting component of the GMES (Global Monitoring for Environment and Security) Marine Core Service. It provides the users with the main variables needed to depict the ocean state: *Temperature*, *salinity*, *currents*, *sea level*, *ice coverage and thickness*, or *primary ecosystem characteristics*. MyOcean products include both observational data from satellites and *in situ* observing systems as well as numerical analysis and forecasting services.

- **EMODNet** (European Marine Observation and Data Network) is actually in a pilot phase, and will be a network of existing and developing European observation systems, linked by a data management structure covering all European coastal waters, shelf seas and surrounding ocean basins. EMODnet has a portal that provides users with hydrographic data collated for a number of Mediterranean regions in Europe, such the Western Mediterranean, the Ionian Sea and the Central, Mediterranean Sea, Adriatic Sea, Aegean and Levantine Sea.
EMODNet must facilitate long-term and sustainable access to the high-quality data necessary to understand the biological, chemical and physical behavior of seas and oceans. EMODNet is coordinated at EU level with the INSPIRE directive and large-scale framework programs on European and global scales (**GMES and GEOSS**), that urge access to, and exchange of, environmental data and information.

- **SeaDataNet:** is built on the IODE/IOC/UNECO model of ODN (Ocean Data Network) SeaDataNet is a Pan-European infrastructure for managing, indexing and providing access to ocean and marine data sets and data products, from more than 35 National Oceanographic Data Centers (NODCs) and international organizations (IOC/UNESCO, ICES, EU-JRC) from European and Mediterranean countries. SeaDataNet established standards for interconnecting the data centers enabling the provision of integrated online access to comprehensive sets of multi-disciplinary, *in situ* and remote sensing marine data, metadata and products.

- The MEDAR/MEDATLAS: a multi-parameter database of high quality oceanographic and marine data sets for the Mediterranean. It includes bio-chemical parameters and climatology data, and greatly improved the spatial and temporal resolution of the statistics.

- The MEDATLAS Project provided the user community with an updated and fully quality-controlled data base of temperature and salinity profiles of the Mediterranean Sea and compiled a revised climatological statistics for the region.

- MOON (Mediterranean Operational Oceanography Network): which brings together twenty six marine research and operational agencies, to implement and develop the ocean observing and forecasting system in the Mediterranean Sea. One of the missions of MOON is to improve and harmonize observation and information systems.

- Mediterranean Ocean Data Base (MODB): a comprehensive data set of temperature and salinity profiles for the Mediterranean Sea.

- The EU/MATER (Mass transfer and ecosystem Response) database consists of a great diversity of data types.

2.4 A national framework

There are still many barriers to overcome, if data sharing objectives that are central to the GO SHIP program will be implemented, particularly in countries with no clear statement of data access policy and supporting legislative framework at the national level, These difficulties were identified when dealing with spatial data in GIS projects, for land and resources management. "*The GIS* *community has now gained support at different governmental levels. A spatial data community is growing, and the concept of National Spatial Data Infrastructure is making its way to the decision making sphere*" (Longhorn, 2003).

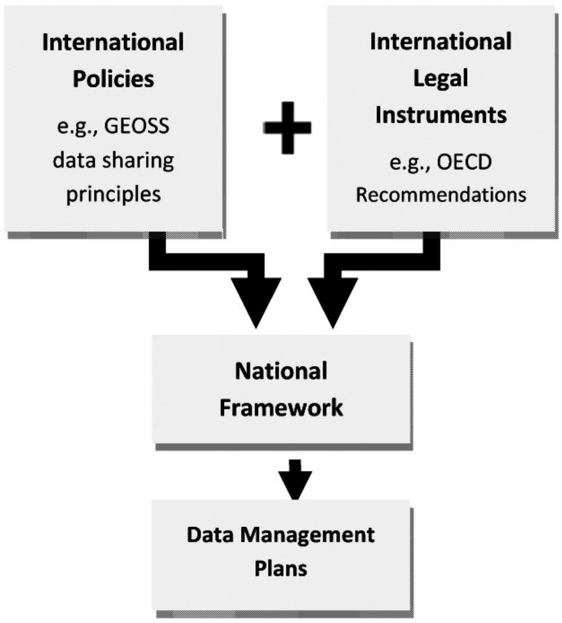

Figure 1. A regulatory framework for data-sharing arrangements (Fitzgerald *et al.*, 2010).

The key of success, in implementing a long-term and basin-wide hydrographic program, lies on the implementation of a coherent policy and legal framework that promote access and reuse of data at all levels in order to facilitate information flows, and support the international principles (see Figure 1).