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.

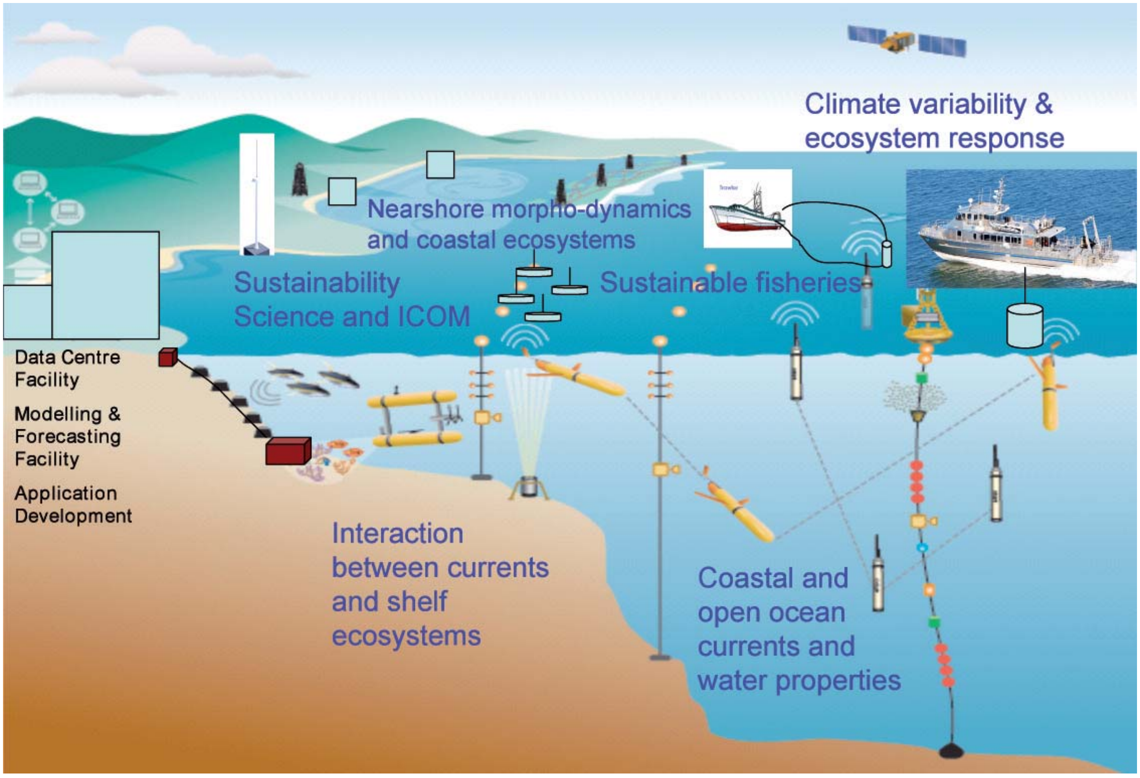

Figure 1. Overview of SOCIB observing and forecasting system (details can be found at SOCIB Implementation Plan at www.socib.eu, adapted from IMOS).

<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.

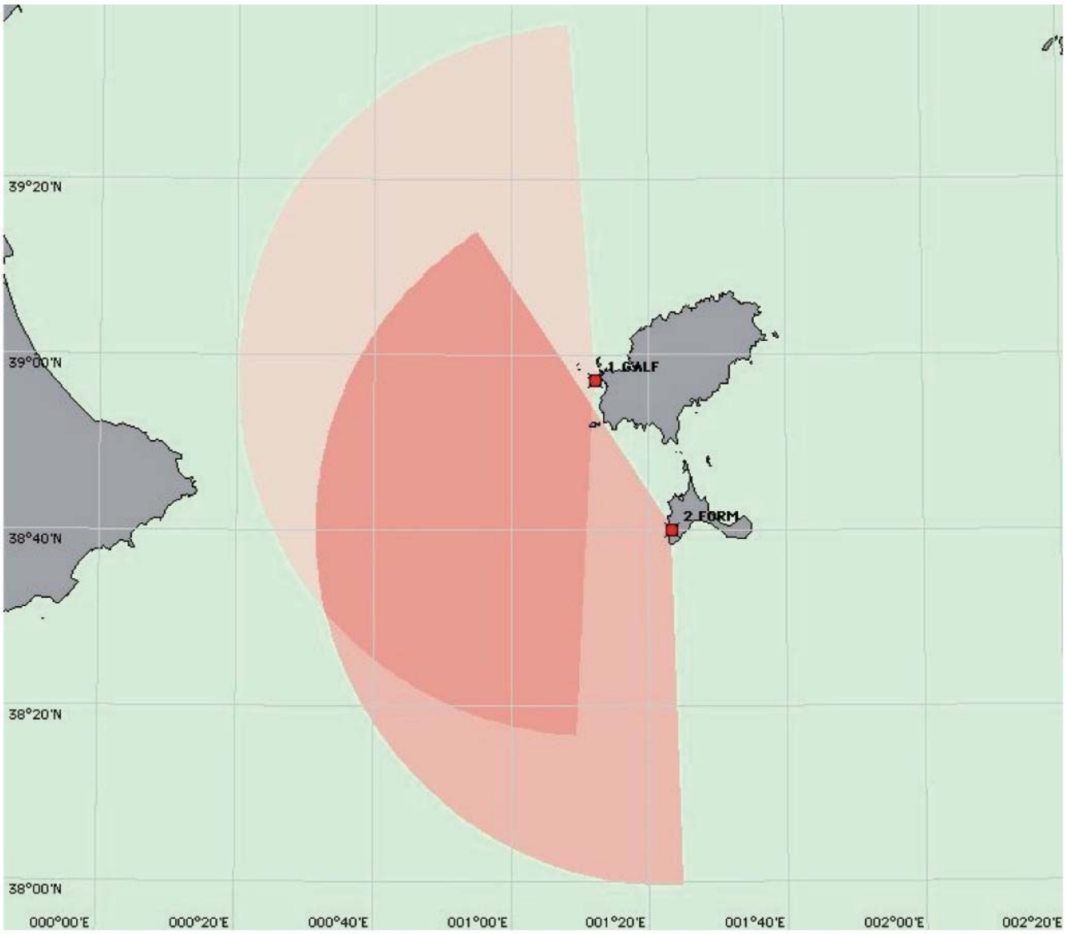

Figure 2. Ibiza channel coverage as designed.

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.

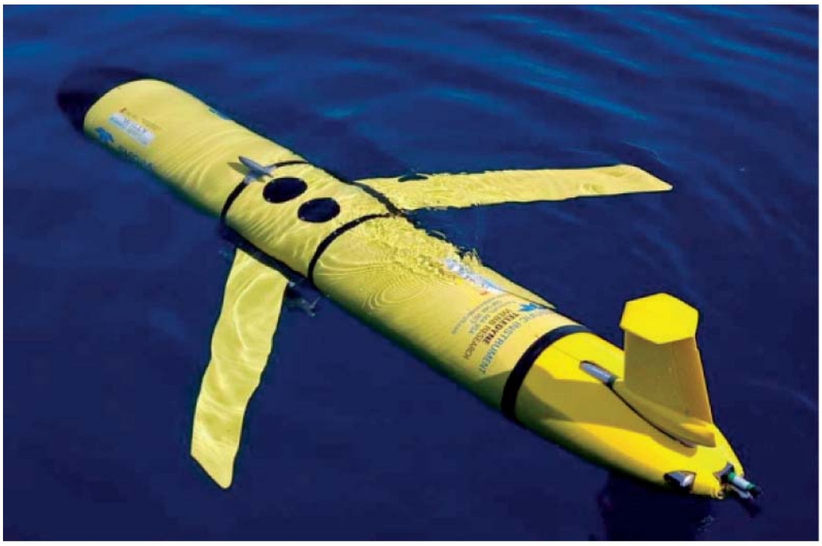

Figure 3. Slocum glider from IMEDEA (CSIC-UIB).

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).

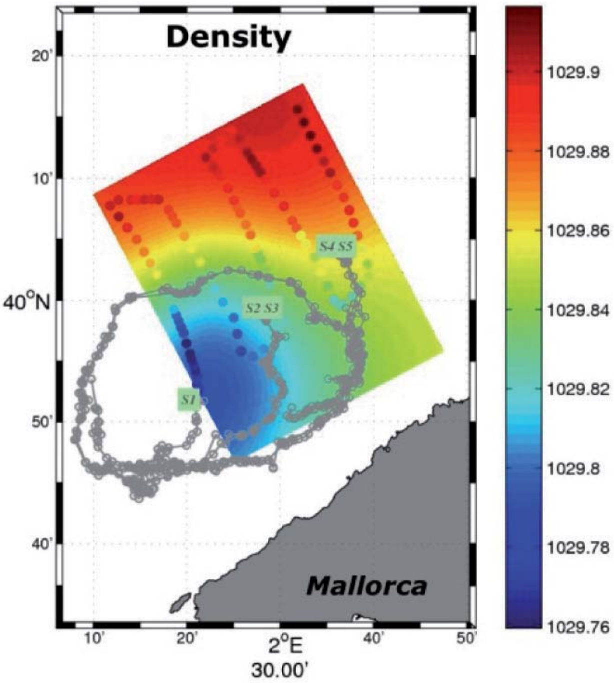

Figure 4. Density field at 75 m obtained during the SINOCOP experiment through optimal interpolation. Colour dots corresponds to values measured by the gliders and CTDs. Grey solid lines and dots are drifter's trajectories. Figure from Ruiz *et al.* (2012).

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.

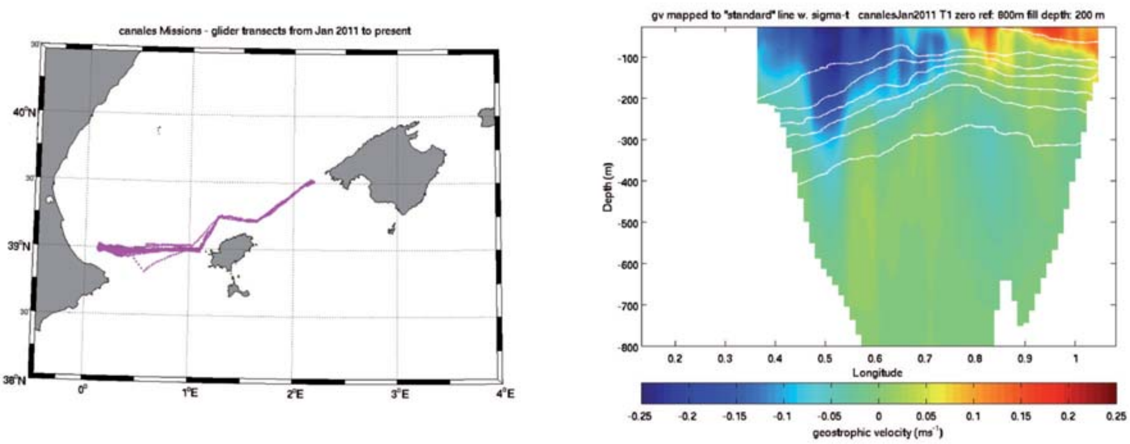

Figure 5. Glider missions from January to September 2011 (left) and Geostrophic velocity across Ibiza channel from January glider mission (right).

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.

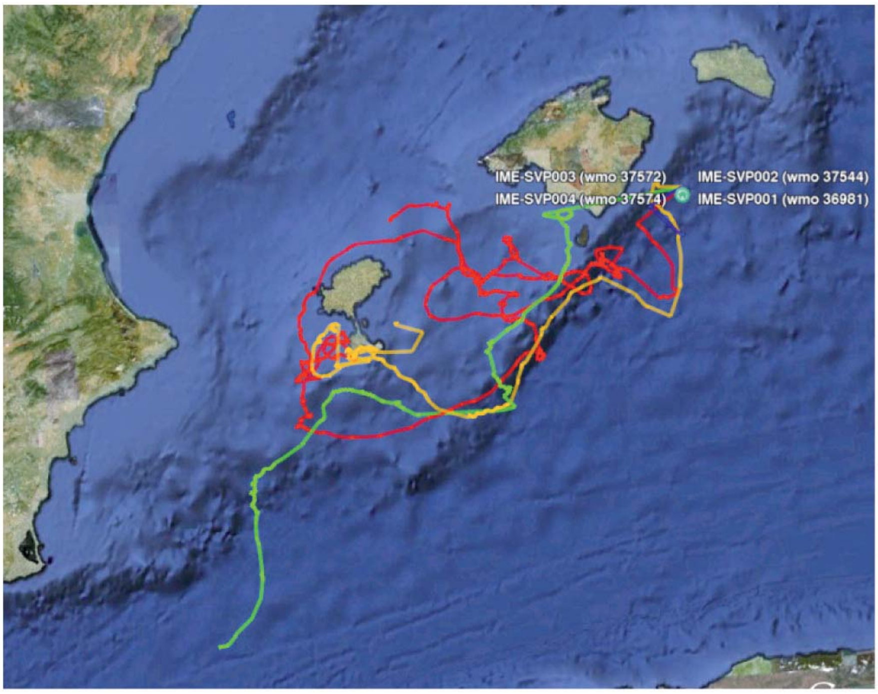

Figure 7. Trajectory followed by the SOCIB surface drifters during September and October 2011 (Source: SOCIB website).

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.

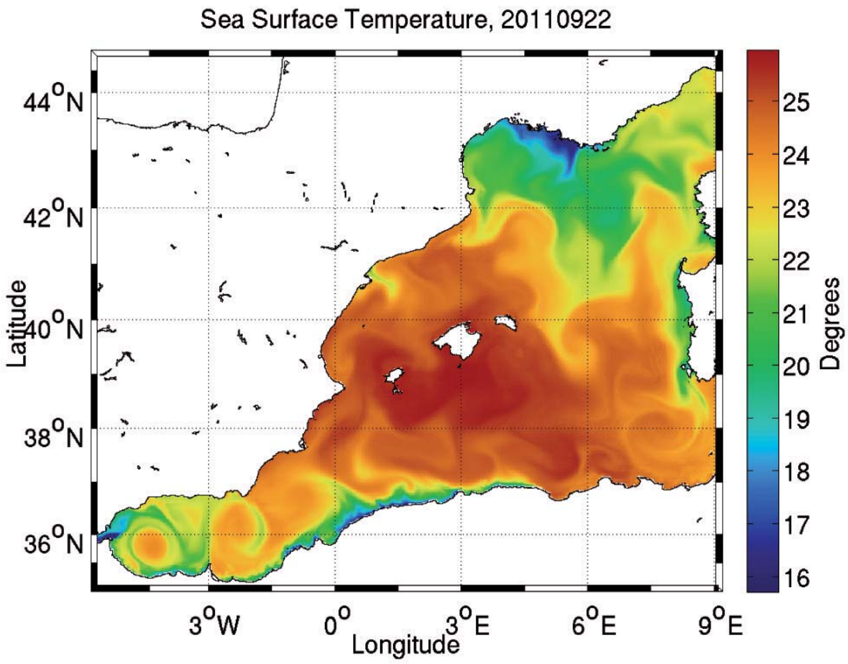

Figure 8. Domain configuration and Sea Surface Temperature Forecast at 2011-05-06 2100h.

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).

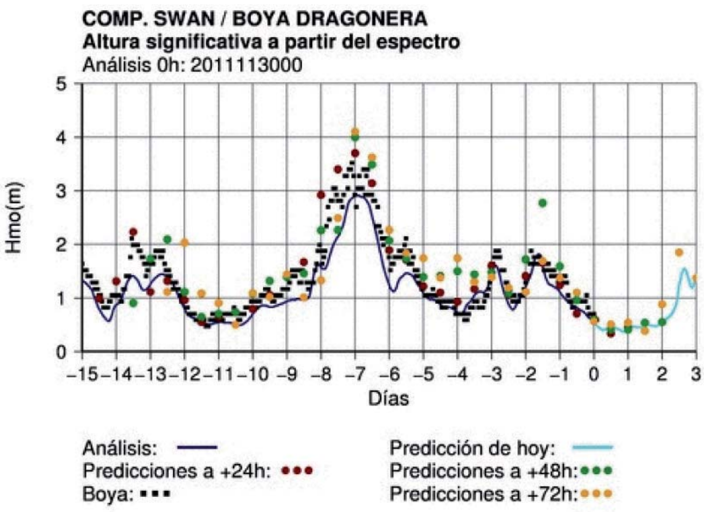

Figure 9. a) SLP Comparisons between simulated significant wave height and observed at Dragonera at 30/11/2011.

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.

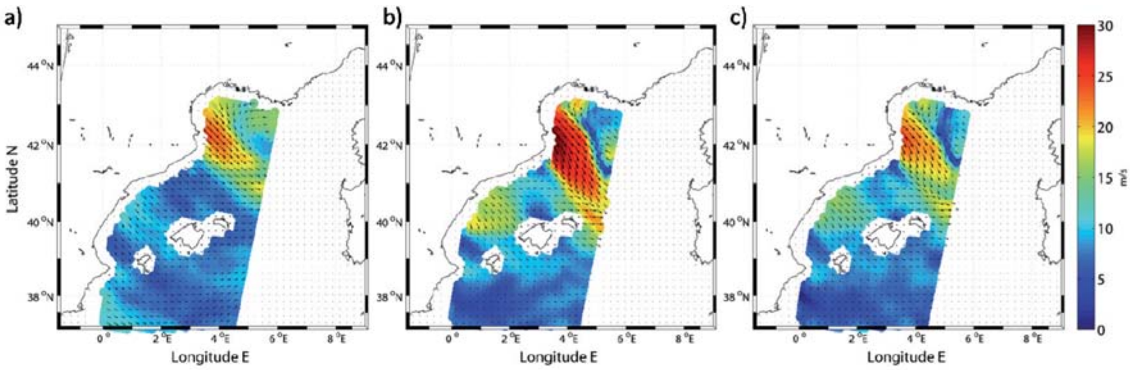

Figure 10. (a) Wind snapshot, 0842UTC 04 May 2010 as observed by ASCAT. The color fields represent the wind speed intensity (m/s) and the arrows the wind speed direction. (b) Same as (a) but for the wind simulated by the uncoupled simulation. (c) Simulated by the full coupled simulation.

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.

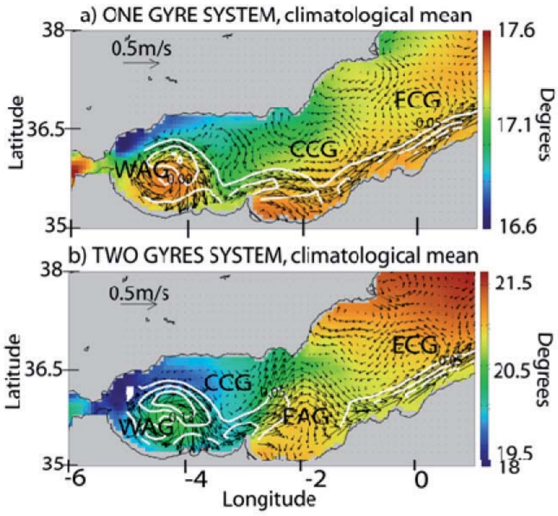

Figure 11. a) Geostrophic current (m s-1) patterns and kinetic energy (m2 s-2, one contour each 0.05 m2 s-2) distributions superimposed on the weekly mean SST fields for the two quasi-persistent modes of the Alborán Sea gyral circulation system. They correspond to (a) one-gyre mode (1G) with moderate 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.

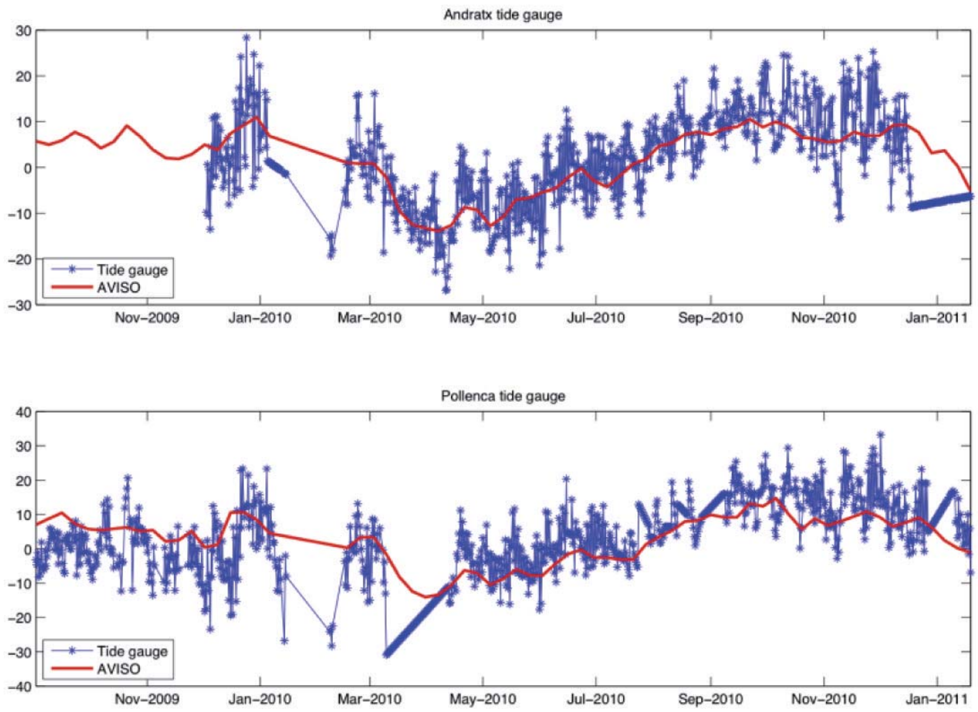

Figure 12. Comparison of altimetry and tide gauge sea level observations at Andratx and Pollensa tide gauges. The good agreement between both data sets allows to perform the combined OI analysis shown in Fig. 11 – Source: Escudier *et al.* (2011).

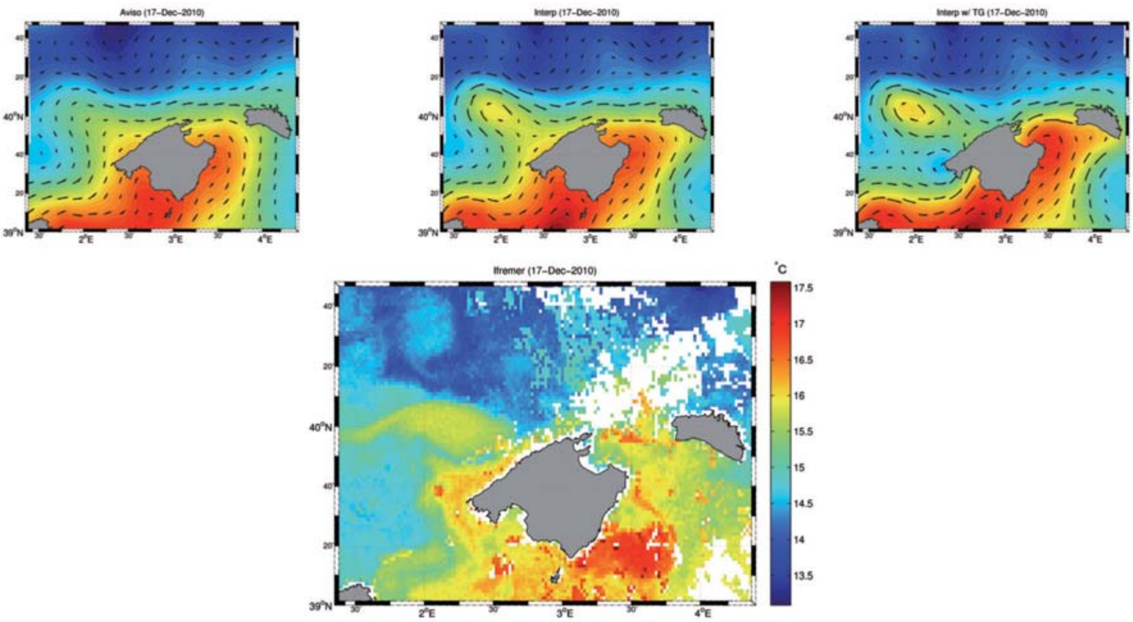

Figure 13. In these figures, the potential of combining altimeter data with tide gauges (TG) located along the Mallorca coast in order to improve coastal features is explored. The eddy revealed by SST (bottom) North-West of Mallorca is better reproduced by the 2steps OI (top center) and even better when 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

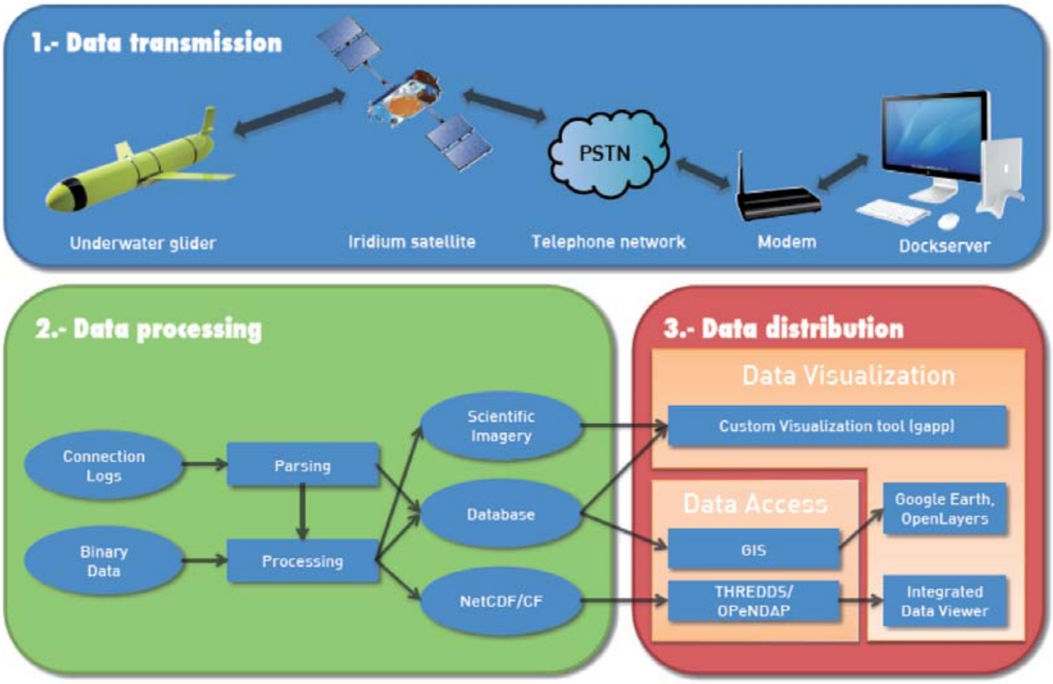

Figure 14. Glider data management workflow at SOCIB.

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.