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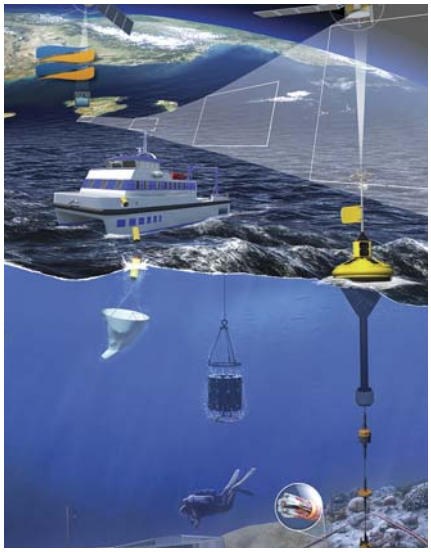
The Breadth of the Marine Technology Society



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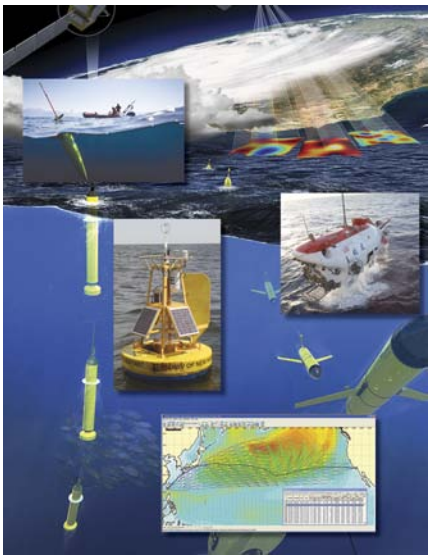

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In This Issue

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PAPER

SOCIB: The Balearic Islands Coastal Ocean Observing and Forecasting System Responding to Science, Technology and Society Needs

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ABSTRACT

New monitoring technologies are being progressively implemented in open-ocean and coastal observatories. The Mediterranean Sea is a well-known, reduced-scale ocean, an ideal natural laboratory to study global ocean processes, in particular those associated with meso- and submesoscale variability, interactions with mean flows and associated ecosystem response. SOCIB, the Balearic Islands Coastal Ocean Observing and Forecasting System, is one of such observatories, a multi-platform distributed and integrated system, a facility of facilities that extends from the nearshore to the open sea. SOCIB profits from 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, and also of societal needs in islands where preservation of the environment is essential to assure both residents' welfare and the competitiveness of the tourist sector. SOCIB is unique in that, from peer-reviewed excellence, its mission and objectives are science-, technology-, and society-driven. These types of new marine infrastructures, because of their critical mass and sustained funding, are presently establishing new ways of international cooperation, leading to major science breakthroughs, innovations in oceanographic instrumentation, and new ways of more efficient and science-based coastal and ocean management. We describe the major elements and structure of SOCIB and present some recent scientific, technological, and society-related results that are of relevance at a global ocean scale.

Keywords: ocean observatories, paradigm change on ocean observation, multi-platform integrated observing and forecasting system, science, technology and society driven mission and objectives, scientific excellence and response to society needs

International Context and Paradigm Change in Ocean Observation

Oceanographic information, combined with integrated predictive models, are increasingly needed to manage national coastal and ocean areas; to portray the state of the ocean today, next week and for the next decade; 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, among other direct applications. However, the ocean changes continuously, and therefore, the ocean must be observed continuously to deliver accurate and reliable ocean services. This, combined with the understanding that we have a responsibility to maintain healthy, resilient and sustainable coasts and oceans and 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 Commission (2010, 2012, 2013) and by most countries that are advanced in marine science research and with economically significant coastal areas (Committee on an Ocean Infrastructure Strategy for U.S. Ocean Research in 2030, 2011). These new observatories, such as Integrated Marine Observing System (IMOS) in Australia, the Ocean Observing Initiative (OOI) and different regional components of the Integrated Ocean Observing System (IOOS) in the United States, Neptune and Venus in Canada, Coastal Observing System for Northern and Arctic Seas (Cosyna) Project in Germany, and Poseidon in Greece, are today discovering new insights into 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 Ocean Observing and Forecasting System (Tintoré, 2010) is one such system, a new facility of facilities, open to international access. SOCIB is a multiplatform, distributed and integrated system (Figure 1) a scientific and technological infrastructure, which since early 2012 has delivered free, open, quality-controlled and timely streams of oceanographic data and modeling services to support operational oceanography in a Mediterranean and international framework. It contributes to the needs of marine and coastal research

FIGURE 1

SOCIB, a new multiplatform observing and forecasting system located in the Balearic Islands (Western Mediterranean).

in the context of global change. In line with EuroGOOS (www.eurogoos.org), operational oceanography is here understood in a wide sense, including both systematic long-term measurements of the seas and their interpretation and dissemination and 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, sea level rise, and ecosystem variability, among others.

SOCIB responds to a twofold change of paradigm in the observation of our oceans and coasts (Delaney & Barga, 2009). First, the observation of the oceans has evolved from being centered on a unique platform, the oceanographic ship, to today's multiplatform and integrated systems (using satellites, ships, gliders, HF radar, drifters, ARGO profilers, moorings and fixed platforms, etc.; Figure 2). There is however a second paradigm change related to data deluge and data availability. Historically, just the teams directly involved in data collection had access to the data and were involved in the analysis. Today, many different kinds of data are quality controlled and available in quasi real time. As a result, scientists and society have direct access to huge amounts of data, by this enlarging the community that supports improved science-based decisions.

New tools for this data analysis are being developed in order for these two paradigm changes to become really effective. This will reenforce a science-technology-society system and a science-to-society transfer as a loop can now be established from new scientific breakthroughs and new scientific questions (presently not yet foreseen, but that we will be prepared to address in the future, e.g., with background baseline data) to new technologies development and to the development of tools for more knowledge-based decision support. The result is a more science- and ecosystem-based ocean and coastal management, with continuous feedback between the three key elements, science, technology development, and society.

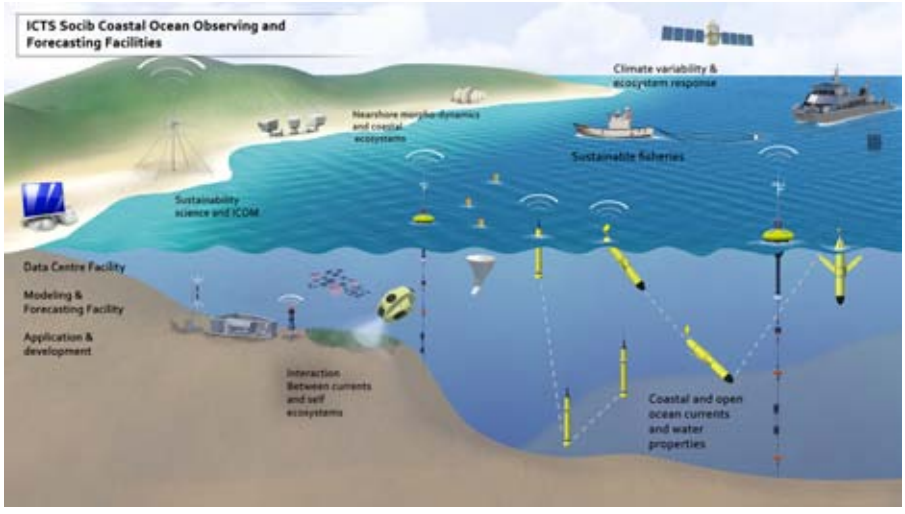
The change in paradigms is now widely recognized and is at the origin of the key drivers identified by SOCIB back in 2009: (1) science priorities, (2) technology development, and (3) response capacity to society needs. Again, this is fully in line with today's approach of the new European Union Horizon 2020 program.

From the initial Board of Trustees meeting in December 2008, there have been three consecutive phases in SOCIB: the Design phase covered from 2009 to July 2010, when the Implementation Plan (2010-2014) was approved. This was followed by the Construction phase, during which the different observing and forecasting systems were established and that ended in December 2012. The Operational phase started during 2012, and several facilities have already started to provide operational data and modeling services that are available through the SOCIB THREDDS catalog (see below). SOCIB activities are funded until 2021 and are included in the Spanish Large Scale Scientific Infrastructures Program (from the Ministry of Economy and Competitiveness) and in the Balearic Islands Regional Research and Innovation Plan.

In this paper, we present SOCIB, the drivers, objectives, and major components and also briefly describe some of the major achievements reached during 2012, focusing on the observing, modeling, and data center facilities. The reader more interested in technology developments and/or applications and tools for coastal and ocean management is referred to SOCIB reports and publications available at www.socib.es (Figure 3).

FIGURE 2

SOCIB major components (adapted from IMOS).



Mission, Drivers, Objectives, and Vision

SOCIB mission is to develop an observing and forecasting system, a scientific and technological infrastructure that provides free, open, quality-controlled, and timely streams of data

FIGURE 3

SOCIB Web page, www.socib.es, multiplatform integrated facilities.

to achieve three missions: (1) Support research and technology development on key internationally established topics such as the role of the oceans in the climate system at interannual scale, interaction between currents and eddies, vertical exchanges and physical and ecosystems variability, variability of nearshore morphodynamics, and sea-level variability in response to climate change. (2) Support longer-term strategic needs from society in the context of global change such as sustainable management, science-based mitigation and adaptation strategies and also policy development and operational tools for decision support. (3) Strengthen 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 but also, by specific interests from the European, Spanish and Balearic Islands societies. The general objective is accordingly twofold: (1) to contribute to address and respond to international scientific, technological and strategic challenges 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 center of excellence.

In the long term, our vision is to advance the understanding of physical and multidisciplinary processes and their nonlinear interactions, to detect and quantify changes in coastal systems, to understand the mechanisms that regulate those coastal systems, and to forecast their evolution and or adaptation under, for example, different International Panel on Climate Change scenarios.

SOCIB specifically addresses the preservation and restoration of the coastal zone and its biodiversity and the analysis of its vulnerability under global change. It also considers new approaches such as science-based sustainable fisheries and/or connectivity studies and marine-protected area's (MPA's) optimal design to advance and progressively establish a more knowledge-based and sustainable management of the oceans and coastal areas.

Strategic Location in the Western Mediterranean

SOCIB activities are largely centered in the western Mediterranean, with focus in the Balearic Islands and adjacent sub-basins (specifically the Algerian and Alborán/Gibraltar) and covering the nearshore, the coastal ocean and the blue open ocean waters and their associated processes. SOCIB takes advantage of the strategic position of the Balearic Island at the Atlantic/Mediterranean transition area, one of the "hot spots" of biodiversity in the 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 www.imedea.uib-csic.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. 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 is a strategic location for the development and implementation of new ICOM-based tools and applications. In addition, the existence of the Cabrera Island National Park (Figure 4), areas of barely disturbed marine ecosystems such as Menorca and areas with sensitive habitats and special interest ecosystems, such the NE of Mallorca, North and South of Menorca, Menorca channel and South 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.

Guiding Principles and Operational Scope

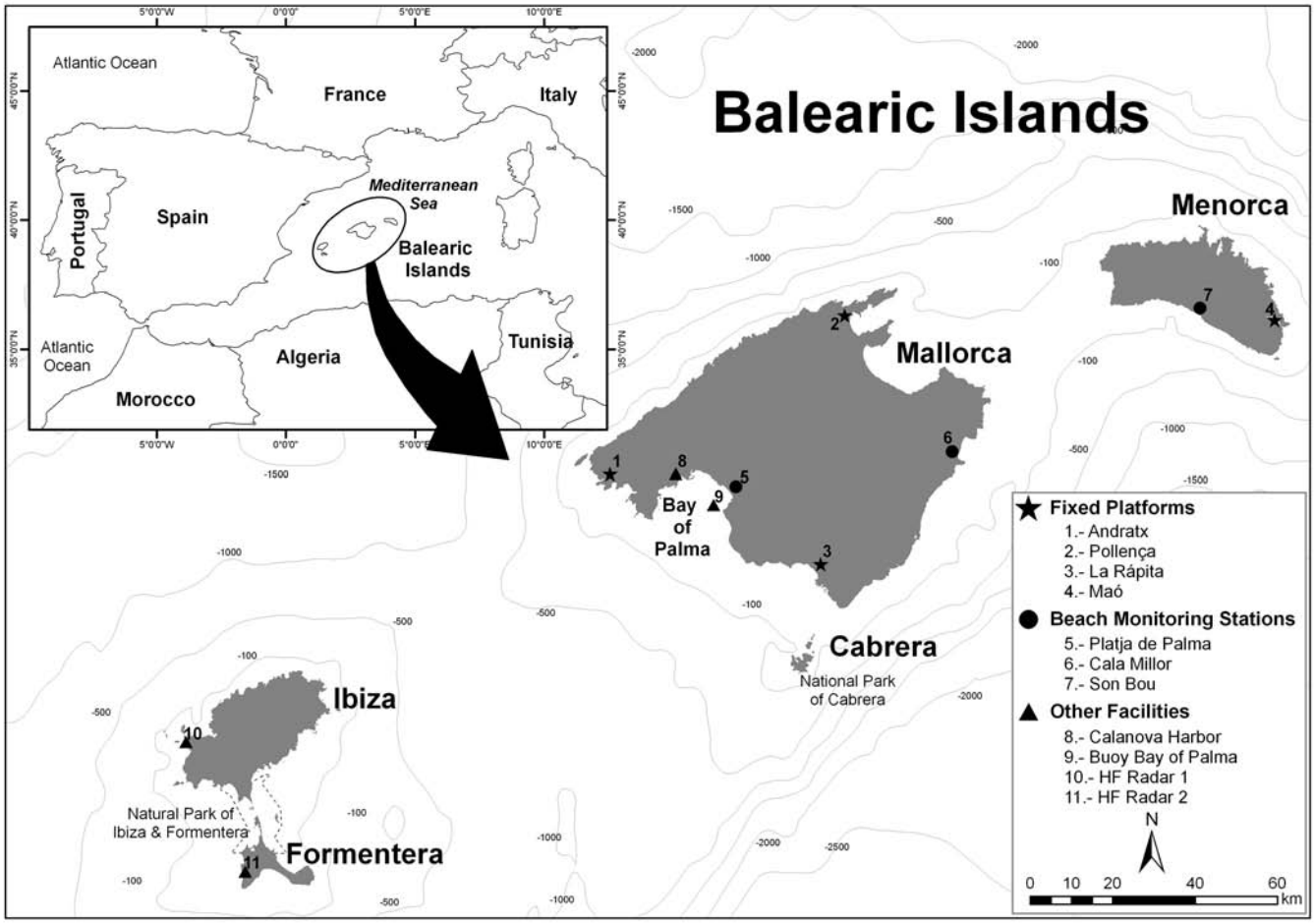
In line with IMOS, a number of well-defined principles have been established from the very beginning. These principles guide the development, decision-making and interaction with SOCIB partners, users and other collaborating institutions. They are:

- 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.

SOCIB was designed to support a sustained approach to ocean monitoring to address state-of-the-art science priorities, enhance technology development

FIGURE 4

The Balearic Islands (Mallorca, Menorca, Ibiza, and Cabrera) in the Western Mediterranean Sea.



and that would be also capable to respond to society needs. Curtin and Belcher (2008) analyzed the conditions for radical innovations to occur in oceanography. They showed the importance of scientific leadership, close work with engineers and sustained funding, very close to the founding elements of SOCIB.

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. 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.

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, implementation and development of new technologies, and response to the strategic interests of Spanish and Balearic Islands society. In other words, SOCIB is science, technology and society driven. A secondary uniqueness of SOCIB is that it extends from the beach and the nearshore to the open ocean (similar to NANOOS, the IOOS regional system on the northwest U.S. coast).

As with other international ocean observing systems, SOCIB has three major infrastructure components: (1) a distributed multiplatform observing system with appropriate instruments and technologies, (2) a numerical forecasting system with different types of predictive models, and (3) a data management and visualization system. The combination of the three elements enables 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, modeling, and data center facilities that respond to science-driven objectives, it is also addressing technology and society-driven needs. Accordingly, SOCIB functional structure (Figure 5) has been established into three main divisions and three services. In this section, we present a brief outline of this general functional structure.

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

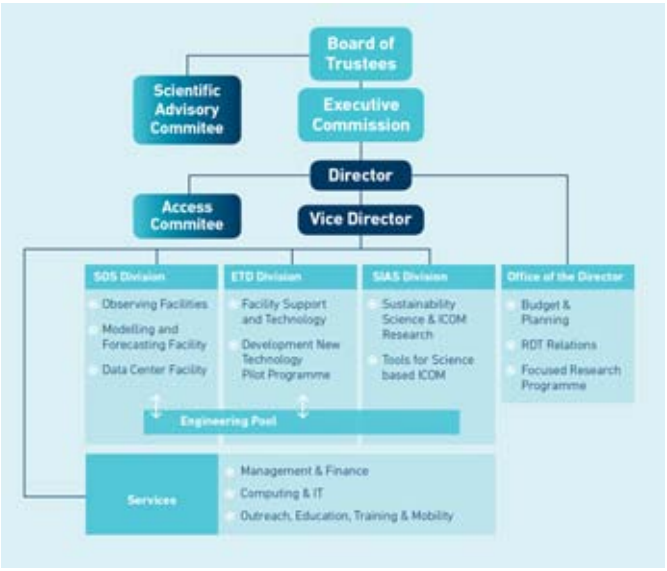
The Engineering and Technology Development Division (ETD Division) provides the engineering and technical backbone to develop and operate the facilities of the Systems Operation and Support Division and is also responsible for the application, development, and testing of new technologies for future observing systems and for developing new analytical tools for the effective management of new, high volumes, of observational data and modeling output.

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

FIGURE 5

SOCIB structure.



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 multidimensional attributes. New scientific approaches such as sustainability science have emerged to address this need and are more interdisciplinary, participative, and problem orientated than before. At the policy level, frameworks such as Integrated Coastal Zone Management and Marine Spatial Planning (we refer to these collectively as Integrated Coastal and Marine/Ocean Management) have been proposed as ways to link scientific assessment, monitoring, and prediction with environmental decision-making.

These science-to-society multidisciplinary activities were initiated in 2005 at the Mediterranean Institute for Advanced Studies (IMEDEA) of the Consejo Superior de Investigaciones Científicas (CSIC) and the University of the Balearic Islands (UIB). They are continued at SOCIB as requested by the Board of Trustees in 2008. This area of activity is again a good example of the capacity of excellent peer-reviewed science to respond to society needs and of cooperation with regional and local institutions.

The output from this division will ultimately provide 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). Also important is the application of new methodologies for coastal zone delimitation and marine spatial planning to well-identified problems such as recreational boating (Balaguer et al., 2008, 2011; Diedrich et al., 2011; Diedrich & Tintoré, 2012).

The establishment of the environmental sensitivity of the coasts of the Balearic Islands is also an important and continuous task at SOCIB. It started in 2004 and is based on the recognition of the different types of coasts of the Islands based on geomorphological, bioecological and socioeconomic characteristics defined in Balaguer et al. (2008), following the coastal sensitivity typologies and ESI (Environmental Sensitivity Index) proposed by the U.S. National Oceanographic and Atmospheric Administration (NOAA) and applied in the Mediterranean by Adler and Inbar (2007) on the coasts of Israel. The maps that have been developed (e.g., Figure 6) cover the entire coastline of the Balearic Islands (around 1,700 km) and comprise approximately 4,500 segments. The adaptation of the standard proposed by NOAA differentiated eight types of shorelines (according to geomorphological sensitivity, divided into 15 subtypes). The establishment of the sensitivity of the coast of the Balearic Islands is an important decision support tool that follows the work described in Beagle-Krause et al., (2010) for responding to oil spill events (Jordi et al., 2006; Balaguer et al., 2011). This tool has been transferred to the government of the Balearic Islands (Directorate General of Emergencies), who actually used it with beneficial results in July 2007 to respond to an oil spill that occurred off the coast of Ibiza.

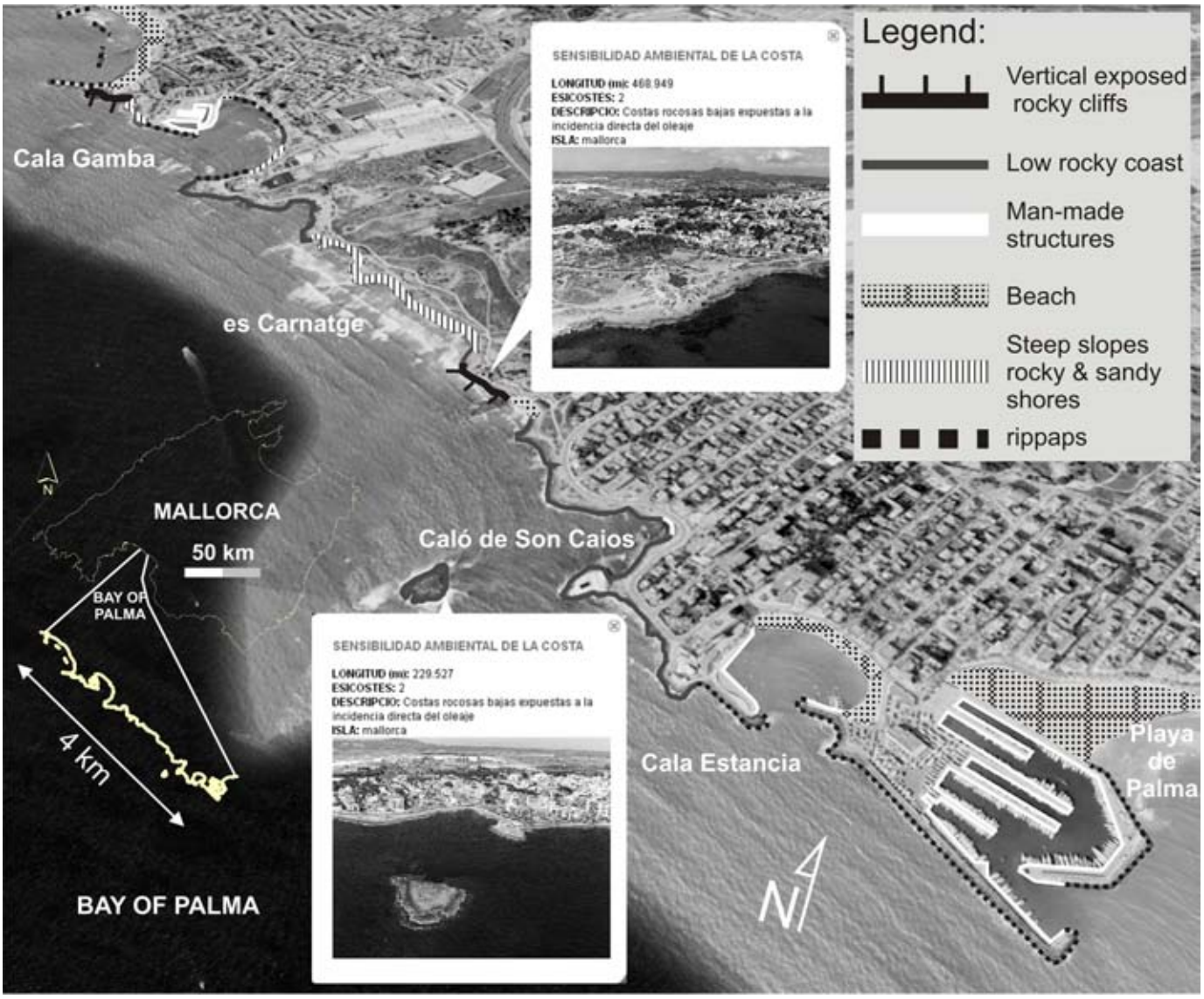
The three "horizontal" SOCIB Services that support the Divisions are Management and Finance; Computing and Information Technology; and Outreach, Education, Training and Mobility (OETM). They are all located at SOCIB offices in the Technological Park (Parc Bit).

Finally, the Office of the Director is responsible for SOCIB strategic direction, budget planning and communication with the consortium's governing bodies. In addition the Office of the Director manages the Atlantic Bluefin Tuna focused program (ABT), led by IEO (Instituto Español de Oceanografía). The Balearic Islands constitute one of the main spawning grounds of ABT eastern stock, the one that spawns in Mediterranean Sea. The ABT SOCIB program started in 2010 in line with previous studies from Alemany et al. (2010) and Reglero et al. (2011). It has focused on the sustainable use of marine living resources, studying the impact of the physical and biogeochemical variability on ABT spawning grounds and population dynamics. Several interdisciplinary cruises have been already carried out from 2010 to 2012 and will be continued in forthcoming years, combining *in situ* monitoring with satellite data (SST, Color, Altimetry) and numerical models.

This ABT Program is another example of the regional problem-solving approach at SOCIB, addressing state-of-the-art problems with global worldwide relevance. One of the main conclusions so far is that the 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, which in the Balearic Sea consist of the convergence between recent low salinity Modified Atlantic Waters (MAW) with more saline Mediterranean Waters (MW) and the existence of significant mesoscale and submesoscale variability that appears to play a key role in the Bluefin Tuna spawning strategies worldwide. Therefore, most of the

FIGURE 6

An example of environmental sensitivity index characterization of the Balearic Islands coastline.



results obtained in the Balearic Sea could be extrapolated at the regional level. Moreover, under the Integrated Marine Biogeochemistry and Ecosystem Research/Climate Impacts on Oceanic Top Predators (IMBER/CLIOTOP) initiative (www.imber.info/cliotop), the ABT team is working in close coordination with the research teams of the NOAA Southeast Fisheries Science Center in the USA and Fisheries Research Agency in Japan, 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.

Systems Operations and Support Division

The SOSD is responsible for operating the observational, numerical, and data management facilities, and we describe below each one of the existing facilities that conform a sustained, spatially distributed, heterogeneous, potentially relocatable and dynamically adaptive network, integrated through data management and numerical methodologies.

Six major observing facilities were in place in 2012: a new coastal catamaran research vessel (strongly needed in the Islands with more than 1.200 km of coastline); HF radar at the Ibiza channel; a fleet of gliders (both Slocum and Seagliders); Lagrangian platforms including Argo profilers and surface drifters (SVP); Fixed stations (including

open ocean moorings, coastal moorings and coastal stations); and a Beach Monitoring facility.

Coastal R/V *Catamaran* Facility

The SOCIB R/V *Catamaran* (Figure 7) was delivered in September 2012 by Rodman Polyships (Vigo) and is presently undergoing sea trials. She is a modern and fast catamaran (an evolution from the NOAA R/V *Manta*) with 23.76 m LOA, 9.00 m beam and 1.75 m draught, that sails at an optimal and fuel efficient cruising speed of 18 knots (total fuel-diesel consumption around 330 L/h for the 2 × 1.622 HP; 500 miles autonomy), allowing rapid transit times between the different Islands and survey sites. She has two labs (wet and dry, with an area of 27 m^2) and can accommodate up to 16 persons for missions of duration between 1 and 5 days (7 crew and 8 scientists for 24-h operations and a reduced crew of 3 for 8-h operations). This R/V *Catamaran* brings new and cost-effective opportunities to both scientists/engineers and the different key oceanography-related institutions in the islands (IMEDEA, IEO, UIB) but also in adjacent regions.

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 ocean's surface are now a mature technology that has been implemented and is routinely operating in numerous locations worldwide. The HF radar system (13.5 MHz) was delivered to SOCIB in July 2012 (one station in Ibiza and the second in Formentera islands) and is presently undergoing extensive calibration and validation actions. At present hourly surface velocity fields in the Ibiza Channel (Figure 8) are available through the SOCIB data center.

Glider Facility

A new glider facility for routine glider operations is operational at SOCIB and has been run in strong collaboration and in-kind support from IMEDEA (CSIC-UIB) since 2010, following the research activities and associated glider developments at IMEDEA (CSIC-UIB) since 2005 (Ruiz et al., 2009a, 2009b, 2009c). SOCIB has improved the existing glider infrastructures by providing new glider units, new electronics, ballasting and operations labs, a new 1,000-m pressure chamber, and a 9.2-m Hurricane Zodiac rigid inflatable boats (RIB) for glider deployment and recovery. The present SOCIB glider fleet (three-in-kind from IMEDEA) consists of five Slocum gliders and two iRobot Seagliders (Figure 9). Additionally, the IMEDEA facilities at Calanova Harbor (Bay of Palma) include a warehouse and coastal laboratory available to support glider operations.

Twenty-eight glider missions have been performed, collecting ~17,000 hydrographic and biogeochemical profiles, which gives a cost estimate of around 30 Euros/glider profile. Gliders combined with satellite altimetry have specifically contributed to better understanding of mesoscale and submesoscale process (1–20 km) in the upper ocean (Pascual et al., 2009b, 2010; Ruiz et al., 2009a), including the coupling between the physical and biogeochemical process of the marine ecosystem (see Ruiz et al., 2012a, for recent revision). Multiplatform experiments combining drifters, ships, gliders and satellites have been also carried out. Bouffard et al. (2010, 2012) and Ruiz et al. (2012b) showed the benefits of this multiplatform approach for characterization of the variability in the coastal ocean. Different types of tools, such as path planning tools (Garau et al., 2009) and thermal lag correction tools, have been also developed (Garau et al., 2011).

Since January 2011, the glider operations have focused on the routine

FIGURE 7

SOCIB coastal catamaran 24 m LOA.

FIGURE 8

Ibiza channel (between Ibiza and the mainland) HF radar coverage and surface currents.

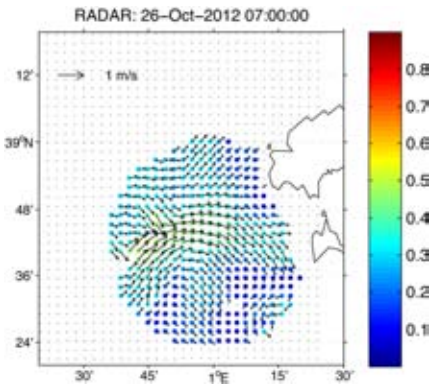


FIGURE 9

Launching a glider off the southern cost of Mallorca.

and sustained operational monitoring in the Ibiza Channel. Heslop et al. (2012) 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. The relevance of the choke points concept will be further exploited.

Fixed Stations Facility

The Fixed Stations Facility is also already operating with one AXIS buoy located in the Bay of Palma and four Coastal Stations that include sea level gages and barographs at key harbors (Andratx, Pollensa, La Rápita, and Maó). Intensive work has been carried out during on the setup of the coastal stations, including quality control procedures. A new deep-water mooring (800 m depth) will be established in the Ibiza channel with physical and biogeochemical sensors in 2013 when a coastal buoy will be installed in the Ibiza-Formentera Natural Park. The data can be visualized in quasi real time from the new SOCIB iPhone App available from the Apple Store.

Lagrangian Platforms Facility

The first four SVP surface drifters were released in September 2011 in collaboration with Med Project TOSCA, where SOCIB was participating. This was followed with four releases in 2012. The plan is to deploy four to eight SVP drifters annually. All the surface drifters are part of the international Global Drifter Program. It is interesting to note that significant speeds higher than 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 permit the observation of long-scale and interannual variability (Vélez-Belchí et al., 2010) and therefore are also a key element in SOCIB. The first three profilers were deployed in 2011, and three additional ones were deployed in 2012. The plan is to release four Argo profilers annually. This activity is part of the Argo-Spain initiative, led by IEO as part of the EuroArgo EC cofunded Infrastructure and the new E-Aims project. The first Argo profilers show interesting features, such as the seasonal flow of Atlantic waters through the Ibiza channel (WMO 6900661) or the flow of the alternative Levantine Intermediate Water (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 the SOCIB web.

Beach Monitoring Facility

Balearic Islands' beaches are a major tourist attraction for the 12.3 millions of tourists that visit the archipelago (population is roughly multiplied by 10 in summer), a classical Mediterranean sun and beach destination. Therefore beach dynamics, sea-level rise, flooding and erosion, as well as users' safety risk issues and beach management associated with recreational and leisure activities are of relevant interest for the Balearic Islands society given the importance to the environmental and socioeconomical context (Tintoré et al., 2009).

The Beach Monitoring Facility is also operational and develops three different activities: real-time data, periodic surveys and historical data (Figure 10). Real-time and continuous monitoring of coastline evolution and nearshore hydrodynamics, using both coastal video monitoring and Acoustic Doppler Current Profilers (ADCP) is at present carried out in three beaches: Cala Millor (May 2011) and Platja de Palma (September 2011) in Mallorca and Son Bou in Menorca (October 2011). The second group of activities relates to a biannual monitoring program of bathymetric surveys and sediment sampling in the former beaches. Finally, the last type of activity concerns the compilation of historical data on shoreline position, sediment features, bathymetries, beach profiles from research projects and publications. The ultimate aim of all these actions is to establish a database from which to obtain baselines to support scientific research and public-private coastal management (Alvarez-Ellacuría et al., 2011 and Gomez-Pujol et al., 2011).

Together with the SOCIB Data Centre, a specific web-based visualizing tool has been established for visualization and discovery of weather stations data and video monitoring products. A map server based on GIS technology enables access to historical and beach data survey program data. All these data sources have in mind meeting the potential uses by public-private beach managers and scientific research or educational purposes.

From a technological point of view, the Beach Monitoring Facility, operated jointly with IMEDEA (CSIC-UIB), has developed an open-source coastal video-monitoring system—SIRENA (Nieto et al., 2010)—and different tools for video-monitoring products management (errors analyses; image geo-referencing) and coastline extraction among others.

FIGURE 10

Nearshore data flow from the different platforms and surveys of the Beach Monitoring Facility (from data capture to dissemination).

Modeling Facility

We describe here only the operational and/or preoperational systems implemented at SOCIB during 2011–2012. The scientific results also obtained (e.g., Renault et al., 2012a, 2012b, following Warner et al., 2010) can be found and are described at the SOCIB web site.

Regional Modeling: The activities formally started in 2010 with the development and implementation of the WMOP current forecasting system that is a regional configuration of the Regional Oceanic Model System (ROMS, www.myroms.org; Shchepetkin & McWilliams, 2005) to forecast ocean currents. The model domain was implemented over an area extending from Gibraltar strait to Corsica/Sardinia (from 6°W to 9°E and from 35°N to 44.5°N), including the Balearic Sea and Gulf of Lion. The grid is 631 × 539 points with a resolution of ~1.5km, which allows good representation of mesoscale and submesoscale features of key relevance in this region because of the dynamical effects and interactions with the mean currents (further details can be found at SOCIB Modeling Facility web site).

WMOP has been running continuously since April 2012. Validation procedures based on intercomparison of model outputs against observations (*in situ* and satellite) are being used. These are comparable to those of previous modeling studies in the area (Onken et al., 2008) and the present MyOcean project standards to assess what level the numerical models are able to reproduce the features observed from *in situ* systems or remote sensing. At the same time, different types of indicators (SST, SSS, KE, MLD, Hc [0-150m], transport) are provided for the WMOP domain and also over the Alborán Sea, Gulf of Lion and Balearic Sea sub-basin regions.

Meteotsunami Preoperational System: Meteotsunamis are long-period oceanic waves that possess tsunami-like characteristics but are meteorological in origin. They occur all over the world, and in the Balearic Sea they are particularly intense in the Ciutadella Harbor (Menorca Island) where they are known as "Rissaga" (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 (Monserrat et al., 1991) and/or to convective pressure jumps (Jansá, 1986; Monserrat et al., 2006). The Meteotsunami forecasting system (Renault et al., 2011) is known as BRIFS (Balearic RIssaga Forecasting System) and makes use of a high-resolution configuration of the Weather Research Forecast (WRF; Skamarock et al., 2007) atmospheric model that has been implemented over the Western Mediterranean to have high-resolution, redundant and self-sufficient atmospheric forcing fields. This configuration is able to reproduce reasonably well the atmospheric pressure perturbations and their propagation from initial synoptic conditions. The oceanic response is then forecasted both over the shelf and inside Ciutadella Harbor using a simple ROMS configuration. The model is able to reproduce the main processes and in particular the harbor oscillations driven by the atmospheric disturbance. The predictive capability of BRIFS was tested during summer 2011 and 2012 (the system started in July 2011). Preliminary results show that the forecast is able to reproduce, in relatively good agreement, both atmospheric pressure oscillations (wave train or pressure jump) and oceanic response into the Ciutadella Harbor, but there are also conditions where the forecast needs to be improved

and work is in progress along these lines.

Coastal Wave Modeling: The *Puertos del Estado* coastal wave operational system has been established for the Southern coast of Mallorca and the Palma Harbor entrance using SWAN, a well-established coastal ocean wave model. The system provides on an hourly basis, wave fields and time series estimates of wind, significant wave height, and other parameters in the area with a 72-h horizon. It is updated twice daily. The model is forced by wind forecasts from the HIRLAM model provided by the Spanish met office (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 Bay of Palma and Dragonera (South of Mallorca).

Remote Sensing: Following the implementation plan, the data are integrated in the Modeling Facility to facilitate the development and integration with model outputs. SOCIB web site facilitates easy access to in house generated products and visualization of ocean remote sensing thematic products. Various satellite data products (altimetry, SST, and ocean color) are acquired and processed by SOCIB, operationally providing data visualization products through a dedicated web portal. The SST and ocean color products are acquired, processed and visualized, both at delayed and real-time lags. Swath and gridded data will be progressively considered at different spatial (1–4 km) and temporal (1–8 days) resolutions. These data will contribute an important data stream that produces high-quality regional 1- to 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, 2009a; Bouffard et al. 2010; Escudier et al. 2011).

Data Center Facility

The Data Centre is the core of SOCIB. Through it, SOCIB is developing and implementing a general data management system to guarantee international standards, quality assurance and interoperability. The combination of different sources and types of information (time series, profiles, trajectories, grids/meshes, images, acoustic data, etc.) requires appropriate methods to ingest, catalogue, display, and distribute this information. The general goal of the SOCIB Data Centre 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 (1) discoverable and accessible, (2) freely available, and (3) interoperable and standardized (Tintoré et al. 2012). These principles are in line with the challenges and opportunities of Open Data (European Commission 2010; Reichman et al., 2011; Urban et al., 2012).

To accomplish the full lifecycle data (from the modeling and observing systems ingestion up to the user), the data center 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, and (7) data viewing.

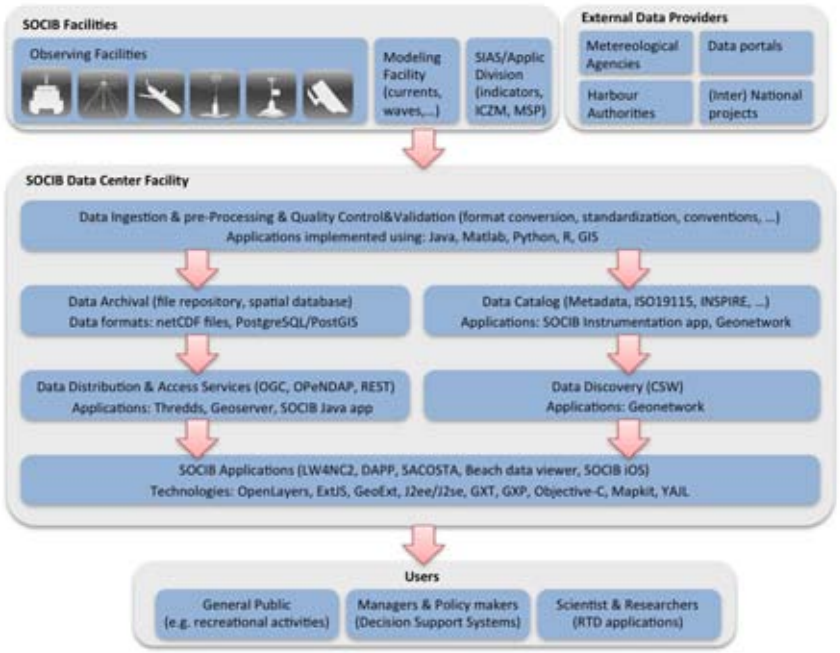
The Data Centre of SOCIB is therefore responsible for directing the different stages of data management, ranging from data acquisition to its distribution and visualization through web applications (Figure 11). The implemented system in the Data Centre relies on open source solutions, following other architectures adopted within the context of marine spatial data infrastructures (Cinnirella et al. 2012).

The main data managed by SOCIB comes from its own observation platforms (e.g., HF radar, gliders, drifters, buoys), numerical models or information generated from the SIAS Division. In addition, the Data Centre also performs the management of data coming from external data providers through various collaborations, for example, with harbor authorities (e.g., Puertos del Estado) or with research groups (e.g., CSIC).

Data processing involves managing different processes such as standardization and data conversion, as well as data validation. Processes include data ingestion, quality controls, generation of new products, and data archival. The generation of metadata follows interoperable and international standards in order to facilitate data discovery, while adopting the European Directive INSPIRE (European Commission, 2007). Data Centre uses different applications for data processing; these include Java, Matlab, R, Python and Geographic Information System (GIS). Data from observation platforms and numerical models are stored in netCDF repositories, while vector data are stored in spatial databases implemented with PostGIS. The management of metadata is done through two main tools. On the one hand, all metadata coming from the SOCIB observation platforms are managed by an internal application. On the other hand, the rest of the metadata is edited and stored using the application Geonetwork.

FIGURE 11

Data Centre Conceptual Structure and SOCIB developed applications.



The distribution and access to data is done through web services (i.e., OGC, REST). THREDDS and Geoserver are used to generate OGC services from the netCDF repository and PostGIS databases, respectively. In addition, the Data Centre has implemented a REST web service, which is called data discovery. These services allow that data generated by SOCIB could be integrated into applications developed by the Data Centre itself or by third parties, thus providing system interoperability. The OGC catalogue service (CSW) is currently implemented with the Geonetwork catalogue. However, further developments are currently underway to harvest the THREDDS catalogue by Geonetwork to integrate all the metadata in a single catalogue service (CSW).

Finally, the SOCIB Data Center also develops specific tools for the different facilities when required. As a result, several web applications have been implemented, responding to interests from a wide range of users. As an example, some applications are designed to manage the instrumentation platforms by the researchers, while other applications are directed to stakeholders and general public by providing a general view of the data produced at SOCIB. These applications have been developed using different technologies (e.g., OpenLayers, KML, iOS). All of them use the web services described above, and some of them can incorporate OGC services provided by external organizations.

Some specific examples of developments are as follows (Figure 12):

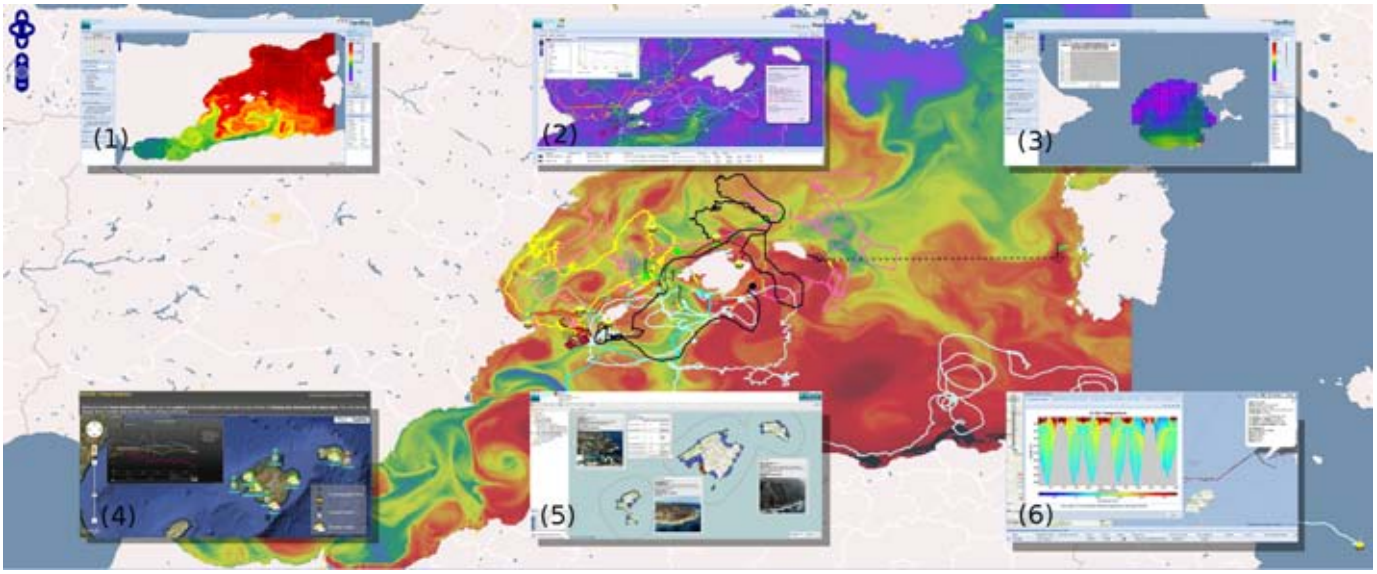
- SACOSTA: web-based map viewer for cartographic data such as environmental sensitivity of the coastline (http://gis.socib.es/sacosta).
- LW4NC2: web application for multidimensional data from netCDF files usually from numerical models (http://thredds.socib.es/lw4nc2).
- BEACH DATA VIEWER: web-based map viewer to display historical and beach survey data (http://gis.socib.es/viewer)
- DAPP: web application to display information related to trajectories from mobile platforms (e.g., gliders, drifter buoys, ARGO profilers; http://apps.socib.es/dapp/)
- SOCIB iOS app for real-time data from fixed stations (oceanographic buoys, sea level stations and coastal weather stations, etc.) and glider trajectories. Available for iPhone and iPad at: http://itunes.apple.com/us/app/socib/id482542716?mt=8

SOCIB Funding and Governance

SOCIB is part of the Spanish Large Scale Infrastructure Facilities (ICTS). 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 Consortium, with legal entity, following a proposal submitted in 2006. Funding up to 36 million Euros was approved, including 13.5 million Euros for scientific equipment and facilities and 2 million Euros/year of running costs through the 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

FIGURE 12

Data and applications developed at SOCIB: (1) Web-based map viewer for numerical models output; (2) Web application for mobile platforms (e.g., gliders, Argo profilers, drifters, etc.); (3) HF radar output; (4) fixed stations web application and SOCIB iOS app; (5) web-based map viewer for cartographic data, ESI, etc.; (6) glider real-time monitoring tool.



initiative. Cooperative agreements with national, regional or international institutions have been also established (Puertos del Estado, Ports de les Illes Balears, IHM, MERCATOR, MONGOOS, 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 MONGOOS and has many similarities with Australia's IMOS in particular, OOI and IOOS initiatives in the United States and several other observational and forecasting systems existing or being designed at present (e.g., Liverpool Bay Coastal Observatory, COSYNA in Germany, MOOSE-Mediterranean Ocean Observation on Environment in France). It is also strongly linked to ongoing EC-funded research projects such as JERICO, TOSCA, PERSEUS, GROOM, MyOcean2, MEDES4MS, and E-AIMS.

Conclusion

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

Acknowledgments

This paper, describing SOCIB, its components, and initial results, is the result of more than 15 years of oceanographic and coastal zone scientific and technological activities in the Balearic Islands (mostly described in the IMEDEA TMOOS 2010–2013 Strategic Plan). As a result, many research projects are at the origin of this activity and should be acknowledged, including EU-funded projects, *Grups Competitius* from the Balearic Government, and the Spanish National Plan for research. JT also kindly acknowledges the invitation from the MTS OOS Committee Chair that gave the opportunity to prepare this manuscript and deeply thanks Reiner Onken for carefully reviewing the manuscript and the MTSJ editor for useful editing and suggestions.

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