ISSN: 3029-0724

*Research Article*

Journal of Environmental Science and Agricultural Research

# SOCIB: Integrated Multi-Platform Real-Time Ocean Observing in the Balearic Sea

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**Received:** August 08, 2026; **Accepted:** August 17, 2026; **Published:** August 25, 2026

**ABSTRACT**

High-resolution oceanographic monitoring is essential for managing the Mediterranean Sea, a major climate-change hotspot and a hub of socio-economic activity. The Balearic Islands Coastal Observing and Forecasting System (SOCIB) addresses this need through an integrated multiplatform network, including autonomous gliders, HF radars, and metocean buoys. This work describes SOCIB's operational observing framework and evaluates its contribution to assessing the physical and biogeochemical variability of the Western Mediterranean. SOCIB provides real-time metocean data such as currents, waves, and winds essential for optimizing maritime operations, enhancing safety, and supporting regulatory compliance. Furthermore, integrating these datasets into numerical models and AI-based predictive systems improves risk mitigation and early warning systems for coastal hazards. Looking ahead, SOCIB aims to expand its spatial coverage, deploy new autonomous platforms, and contribute to a Digital Twin of the Mediterranean, ensuring safe and sustainable marine operations.

**Keywords:** Monitoring, Measurement Techniques, Data Acquisition and Processing

## Introduction

The Mediterranean Sea is widely recognized as both a climate-change hotspot and a region of intense socio-economic activity. Coastal communities, ports, maritime transport, tourism, fisheries, and emerging blue-economy sectors are increasingly exposed to hazards associated with sea-level rise, extreme storms, marine heatwaves, coastal flooding, and shoreline erosion. Sustained and integrated ocean observations are therefore essential for understanding environmental variability, improving forecasting capabilities, and supporting evidence-based management of marine and coastal resources [1,2].

Recent advances in ocean observing technologies have enabled real-time monitoring of physical and biogeochemical processes from the nearshore zone to the open ocean. These developments have led to the emergence of integrated multi-platform observing and forecasting systems capable of providing high-resolution information across a wide range of spatial and temporal scales. Such systems play a fundamental role in bridging the gap between scientific research, operational services, and societal needs [1,3].

The Balearic Islands Coastal Observing and Forecasting System (SOCIB) since 2010, a Large-Scale National Research Infrastructure, represents a multipaltform observing and forecasting system, from nearshore to open sea and form events to climate. Established to respond simultaneously to scientific, technological, and societal priorities, SOCIB integrates observing platforms, forecasting models, a dedicated data centre, and sector-oriented services into a single operational framework. The system provides high-quality, free, and open-access environmental data following FAIR principles and supports users ranging from researchers and public administrations to maritime industries and coastal managers [4]. Through the transformation of observations into operational products and services, SOCIB contributes to safer marine operations, improved environmental management, and the contribution to development of a future Digital Twin of the Mediterranean Sea [1].

**Citation:** Nikolaus Wirth, Benjamin Casas. SOCIB: Integrated Multi-Platform Real-Time Ocean Observing in the Balearic Sea. J Envi Sci Agri Res. 2026. 4(4): 1-3. DOI: doi.org/10.61440/JESAR.2026.v4.197

## Materials and Methods

The Balearic Islands Coastal Observing and Forecasting System (SOCIB) operates a multi-platform ocean observing and forecasting infrastructure covering the Balearic and Western Mediterranean Seas. The system combines fixed and mobile observing platforms, numerical forecasting systems, and integrated data management services within a coordinated operational framework [1,3].

The observing network includes infrastructures like; coastal stations, moored metocean buoys, high-frequency (HF) radar systems, autonomous underwater gliders, drifting platforms, coastal monitoring stations, and the research vessel B/O SOCIB. Together, these assets provide sustained measurements of oceanographic and atmospheric variables, including currents, waves, temperature, salinity, sea level, and selected biogeochemical parameters. Continuous observations are transmitted to the SOCIB Data Centre, where datasets undergo automated quality-control procedures before being distributed through open-access web services [1].

Particular attention is given to the coastal zone through Beach Monitoring Facilities that combine automated video observations with topobathymetric surveys to quantify shoreline evolution, sediment transport processes, and morphodynamic variability. Offshore observations are complemented by autonomous gliders capable of repeatedly measuring the water column and resolving mesoscale and submesoscale ocean processes that are difficult to observe using conventional techniques.

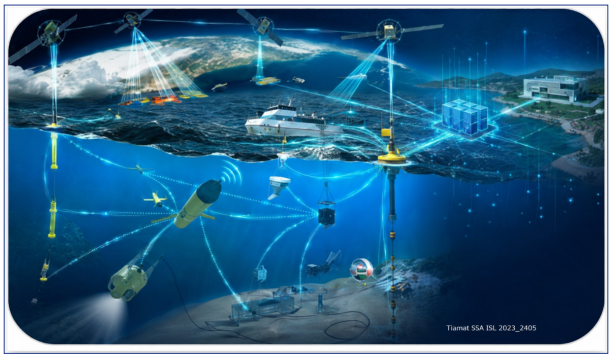


**Figure 1:** SOCIB: a Research Infrastructure, a multi-platform ocean observing & forecasting system

The observational component is integrated with operational forecasting systems. The Western Mediterranean Operational Forecasting System (WMOP) provides three-dimensional forecasts of ocean circulation and hydrodynamic variability, while the SAPO wave forecasting system delivers high-resolution predictions of wave conditions in coastal and offshore areas. Extreme sea-level events are monitored through the BRIFS forecasting framework, which supports early warning of meteotsunamis in the port of Ciutadella, Menorca (rissagues) and other coastal hazards. [4]

SOCIB follows an end-to-end data value-chain approach in which observations, modelling systems, data management infrastructure, and user-oriented applications are fully integrated. This operational framework enables the generation of products and services tailored to scientific research, coastal management, maritime safety, environmental monitoring, and offshore engineering applications.

## Results and Discussion

The integration of real-time observations, forecasting systems, and digital services provides substantial benefits for coastal and offshore engineering activities throughout the Baleric Sea. Continuous monitoring of waves, currents, winds, and sea-level variability supports operational decision-making for port authorities, vessel operators, coastal managers, and maritime infrastructure developers [1].

For port and offshore operations, near-real-time metocean information contributes to safer navigation, optimization of maintenance activities, planning of dredging operations, and assessment of operational risks during adverse weather conditions. High-resolution forecasts of waves and currents improve situational awareness and support preparedness for extreme events, including coastal flooding, storm surges, and meteotsunamis [3].

The value of SOCIB extends beyond data acquisition. By integrating observations with numerical modelling systems and digital delivery platforms, the infrastructure transforms environmental information into operational services that directly support decision-making processes. This approach aligns with SOCIB's broader strategy of converting ocean observations into sector-focused products and services that address the needs of diverse stakeholder communities, including ports and shipping, coastal protection agencies, environmental managers, and maritime protec areas (MPA) like Cabrera National Park [1,3].

Future developments are expected to strengthen the integration of observations, forecasting systems, artificial intelligence methods, and cloud-based data infrastructures. Expanding autonomous observing capabilities, increasing spatial coverage, and improving interoperability between observing systems and digital platforms will enhance forecasting performance and operational service delivery. These advances constitute key building blocks for the development of a regional Digital Twin of the Mediterranean, capable of integrating real-time observations with predictive simulations to support scenario analysis, risk assessment, and adaptive management of coastal and offshore environments.

Overall, SOCIB demonstrates how integrated ocean observing systems can support both scientific understanding and practical decision-making. By providing sustained, high-resolution observations together with forecasting and digital services, the system contributes to safer maritime operations, improved environmental stewardship, and greater resilience of coastal and offshore infrastructure under changing climate conditions.

## Discussion

The future of operational ocean observing is evolving from isolated monitoring platforms toward fully integrated observing, forecasting, and data-service ecosystems. Current developments focus on enhancing the interoperability between multi-platform observations, numerical forecasting systems, advanced data analytics, and emerging artificial intelligence techniques to improve environmental predictions and support operational decision-making. Within this context, SOCIB is advancing a long-term vision based on the integration of real-time observations, modelling capabilities, and digital services across the Western Mediterranean.

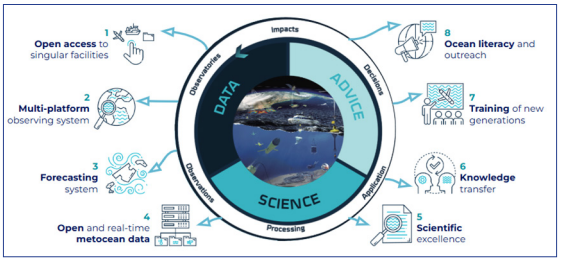


**Figure 2:** Full data value chain: From high-resolution monitoring to actionable advice for decision-makers in the Western Mediterranean

This observation-model synergy directly contributes to the Digital Twin of the Mediterranean currently being developed under the European Digital Twin Ocean initiative (EDITO, www.edito.eu). By seamlessly integrating high-quality observational datasets into the EDITO Data Lake, SOCIB enables a dynamic and comprehensive digital representation of the marine environment. Building upon this foundational infrastructure, we are developing high-resolution, localized digital twins for key coastal areas: MeDITTO Protect (Cabrera National Park), MeDITTO Adapt (Cala Millor), and MeDITTO Alert (Port of Ciutadella). A major focus of these highly detailed local twins is the simulation of complex 'What-If Scenarios', empowering stakeholders to model environmental responses to future climate pressures and extreme events. Ultimately, these advanced predictive capabilities will facilitate robust hazard preparedness and evidence-based management, strengthening the connection between operational oceanography and the need for resilient, sustainable maritime activities.

## Conclusion

Sustained, high-resolution metocean observation provides an essential foundation for resilient coastal and offshore engineering designs. The multiplatform system operated by SOCIB showcases the practical utility of integrating fields of physical data monitoring with numerical forecasting to secure blue economy activities and coastal asset integrity in a changing climate.

## Acknowledgements

The contributions of the entire SOCIB team are gratefully acknowledged. The seamless operation of SOCIB's multi-platform observing and forecasting system is made possible through the collective efforts of all departments and institutional groups, which together constitute a critical component of the marine data value chain. Their sustained collaboration enables the generation, stewardship, and delivery of high-quality environmental observations, data products, and forecasts, providing high-resolution information across environments ranging from the coastal zone to the open ocean and across timescales spanning episodic high-frequency events to long-term climate variability. The observational and processed datasets supporting this study are openly accessible through the official SOCIB data repository at www.socib.es.

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