EMSO Technology Roadmap 2025-2030

Interoperable Deep-Sea Observing Innovations for Climate Resilience and a Sustainable Blue Economy

History of changes

Version	Date	Change	Authors
1.0	08/08/2025	First version	Ingrid Puillat
1.1	23/08/2025	Second version	Ingrid Puillat, Marco Galeotti
1.2	08/09/2025	Final version	Ingrid Puillat, Marco Galeotti

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1. EMSO Scientific and observational strategy

EMSO ERIC: a legal entity

EMSO ERIC is the European Multidisciplinary Seafloor and water column Observatory - European Research Infrastructure Consortium. It is a legal entity since 2016, through Commission Implementing Decision (EU) 2016/1757 of 29th September 2016 (Official Journal of the European Journal, L268), joining 8 Country Members: Italy (host), France, Greece, Ireland, Portugal, Romania, Spain and Norway. It encompasses 14 Regional Facilities (RFs) with 25 Institutions involved, operating in European Seas and open ocean and sea waters from the seafloor to the surface, having its headquarters and statutory seat at Via di Vigna Murata 605, 00143 Rome, Italy.

Its governance structure is composed of an Assembly of Members at the decisional level, an Executive Committee gathering representatives of the operational services distributed in Regional Teams and Service Groups, a Central Management Office (CMO) based in Rome to support the Director General as well as the Executive Committee, and an Advisory Committee.

EMSO Vision

The EMSO vision is twofold, with a non-temporal component and a 2035 target.

"Supporting the sustainable management of our ocean through our integrated capacity to observe, study and understand it from its deepest part to the upper water column on long term. By 2035, EMSO will be recognised as a key European body for the long-term observation and analysis of the European marine environment variability and marine geohazards from the seabed to the water column."

EMSO Mission

"*As a European marine research infrastructure, EMSO ERIC aims to advance knowledge of deep ocean and water column processes in key oceanic regions in the context of global change. The operational scope of EMSO is the provision of services for long-term repeated observations and analysis of Essential Ocean Variables, as well as other physical, biological and environmental variables retrieved by water column and deep-sea observatories*."

EMSO's main objective is to develop services in a wide range of marine disciplines, based on long-term high-quality observation and so-generated time-series at Regional Facilities distributed in the European seas. EMSO ERIC is committed to addressing the user communities' and stakeholders' needs in the scientific macro-areas of the Marine domain and supports investigations on the interactions between Hydrosphere, Biosphere and Geosphere as part of the European environmental research infrastructures.

A society driven scientific strategy

As a marine research infrastructure, EMSO supports researchers and society in addressing issues related to four main societal and economic challenges that are interconnected, a characteristic that guides its vision and strategy in the long term:

- Climate change and ocean variability across spatio-temporal scales
- Geohazards and operational early warning systems
- Marine biodiversity loss
- Global ocean carbon cycle, warming and acidification.

Aligned with these four main Societal Challenges, EMSO tailors its scientific strategy around four driving scientific topics and processes with a cross cutting observing capacity that enables EMSO to play a unique role (left part of figure 1). Connected to these topics, four Key Scientific Questions – KSQs (central part of figure 1) are driving the research activities supported by the EMSO infrastructure (central part of figure 1).

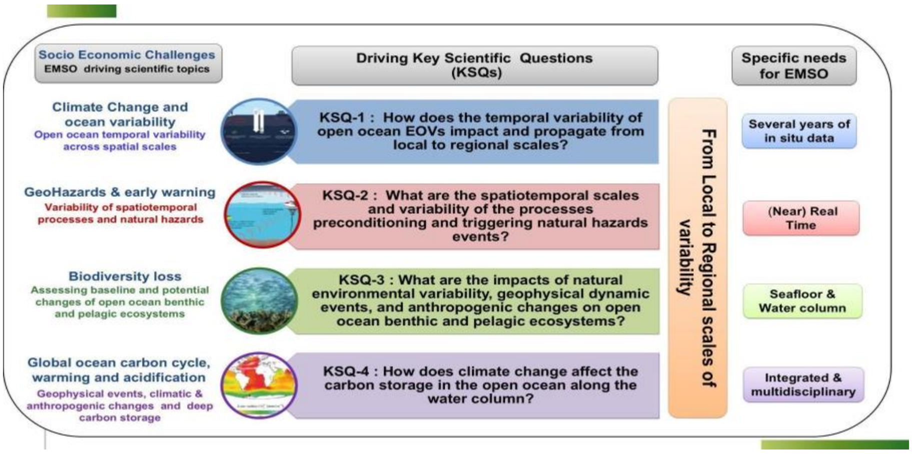

Figure 1 – Related to four general socio-economic challenges(left part of the figure, blue-grey lines), the EMSO scientific strategy is based on four driving scientific topics and processes (left part of the figure, coloured lines) aligned on four Key Scientific Questions (central part of the figure)

Uniqueness of the EMSO observing strategy

EMSO has deployed various long-term marine observing systems, i.e. at least several years to acquire a time series of repeat measurements. To support early warning systems the EMSO infrastructure operates (Near) real-time systems. To study marine ecosystems dynamics and their effects on the carbon cycle EMSO enables investigation of the water column and the seafloor through an integrated and multidisciplinary approach.

The currently deployed technologies

Currently, EMSO consists of 14 observing Regional Facilities, for 21 sites with the following key features:

- Acquisition of about 125 in situ observation marine variables in deep and open ocean of the European area.

- Accessible observations, data and information come from 20 deep-sea sites, of which 5 are in the Nordic Seas Regional Facility, 3 in the South Adriatic, 4 in the Ligurian Sea, 4 in the Ionian basin, 1 in the Aegean Sea, 1 in the Black Sea, and 2 in the north-east Atlantic.
- Four deep-sea platforms are cabled to shore (Ligurian Ouest, Nice, Western Ionian Sea, Hellenic Arc).
- Easy access to three shallow water sites, designed to test equipment items, methodologies and procedures and for training. These sites are also conducting observations aligned with the EMSO Strategy.

Sensors are usually mounted on platforms that provide power to the sensors, remote logging by the operator and data transmission. The platforms can have various features, mostly depending on the site and on the target area of the ocean (surface, water column, seabed).

The EMSO community has also consolidated a set of core observational parameters including conductivity, temperature, pressure, dissolved oxygen, turbidity, optical backscatter, current velocity and direction, and underwater sound. These parameters are now systematically measured across all Regional Facilities. This effort led to the development of specifications for the EMSO Generic Instrument Module (EGIM)[1]. EMSO's organisational structure has been strengthened with specific working groups (WG) for sensors and equipment, developing best practices guidelines and sharing knowledge. This was made possible through engineering advancements funded by EU projects such as TRIDENT and GEORGE.

Currently, the main categories of platforms operating in EMSO measure the geosphere-hydrosphere interaction and consist of

i) seafloor multiparameter monitoring stations and landers;

ii) mooring lines;

iii) moored profilers for the water column monitoring;

(iv) and surface buoys for the air-sea interaction and data transmission.

In some of the EMSO sites, mobile platforms are included in repeat sections. In addition, some of the most innovative platforms recently introduced the Smart Cable and Cabled Crawler, but these observational facilities need further integration.

2. The EMSO technology strategy and roadmap

Technological challenges

At this stage, for EMSO, it is essential to optimise the already existing capabilities and to introduce and develop new technologies to enrich the observational capacity of the EMSO facilities. This is hindered by several challenges inherent to deep-sea environments, that include the limited durability of sensors under extreme pressure and corrosive conditions, the difficulty of maintaining reliable and long-lasting power supply solutions, issues surrounding the precision and stability of measurements over extended periods, and the constraints of data transmission technologies, which often struggle with bandwidth and latency issues in remote, submerged locations.

[1] https://www.frontiersin.org/journals/marine-science/articles/10.3389/fmars.2022.801033/full

More specifically, the following are the most urgent technological challenges to be tackled:

1) Technical aspects of sensor and equipment development and maturation durability, reliability and resistance to environmental conditions (temperature, pressure, biofouling, corrosion, wave energy).
2) Metrology aspects of sensors development and maturation; accuracy stability.
3) Power supply and storage (industry-driven process, ongoing outside EMSO).
4) Bi-directional data transmission, efficiency and bandwidth capacity (either bottom/surface/shore, or horizontal between distant seabed stations, or local with ROV).
5) Spatial coverage (vertical and horizontal), very limited footprint..
6) Increasing data flow due to big data flow (imagery, acoustic and cable sensing).
7) Observatories evolution/customisation: prepare for specific or new requirement (for the observation of new variables or in situ processing), integration of cutting edge and future technologies.
8) To apply embedded AI techniques for a more efficient data acquisition (for example underwater imagery).

<u>The EMSO technology strategy</u>

To further develop the EMSO technological capacities aligned with the four driving scientific topics and connected Key scientific Questions, EMSO will include the most recent sensors and methodologies such as biology sensors: metabarcoding, eDNA, imaging (combination with automatic classification), ocean sound and bioacoustics. Passive acoustic monitoring provides valuable insights into geophysics, biodiversity, ecosystem health, climate-driven soundscape changes, and anthropogenic impacts such as noise pollution and vessel collisions with marine mammals.

To face the increased cost of the energy and to progress on the decarbonisation of research infrastructures, we need more sustainable and less maintenance demanding systems such as Smart cables and fibre optic sensing technologies in submarine telecommunication cables (DAS and SOP[2]), where the EMSO community has strong interests and the wish to establish EMSO as a reference player, introducing more autonomous systems in energy and mobility. The next version of cable technology will integrate more sensors and communication technologies (such as wireless one).

EMSO will redesign a Smart, Greener and Lower cost infrastructure and integrate the emerging technologies.

<u>The EMSO technology roadmap</u>

By 2035, EMSO activities will focus on:

i) EMSO legacy by setting the harmonisation technology of the EMSO Generic Instrument Module (EGIM) as a key asset for its expansion.
ii) Development of sustainable and low-maintenance systems, such as autonomous samplers, sensors and systems easier to operate, including those measuring ocean surface parameters in support of the satellite community, and the future generation of Smart submarine cables.
iii) Smart submarine cable technologies and distributed fibre optic sensing technologies in submarine telecommunication cables (DAS and SOP).

[2] DAS (Distributed Acoustic Sensing) and SOP (State of Polarization)

iv) Upgrade of Autonomous Unmanned Vehicles (AUVs) and resident robotics for extending the coverage of fixed-point observation in specific regions and potentially in between RFs.

v) Biology sensors: metabarcoding, eDNA, imaging (combination with automatic classification),

vi) Ocean sound and bioacoustics: an interdisciplinary theme that integrates across the Hydrosphere, Biosphere, and Geosphere. Passive acoustic monitoring provides valuable insights into geophysics, biodiversity, ecosystem health, climate-driven soundscape changes, and anthropogenic impacts such as noise pollution and vessel collisions with marine mammals.

vii) Digital Innovations for Ocean Observation with new tools and methodologies to enhance the long-term ocean monitoring, to improve data accuracy, accessibility and processing. This includes AI, data classification tools and machine-learning (ML) techniques for real-time analysis to deal with large datasets, of which time series data are a priority for EMSO, including images and acoustic data.

viii) Technologies for wireless data transmission in deep water, optimisation of energy consumption and storage capacity.

Synthesis of the EMSO Technology strategy

Category	Common to scientific topics	Biodiversity specific	Geophysics
Sensing		• Autonomous eDNA and in-situ sequencing of eDNA. • Long-term conservation of samples. • Autonomous smart video-camera with AI Embedded.	• Hazards Sensing Stack (BPR + OBS).
Robotics, mechanics and platforms	• Resident robotics and marine .autonomous systems to expand spatial coverage and reduce global maintenance. • Adaptive autosampling and semi-resident robot to address environment variability in near real-time. • Usage of DAS in biodiversity, geology and oceanography research. • Inductive Real Time Mooring. • New version of Smart cable sensor nodes.	• Integration of sensors such as hydrophone fixed arrays in fiber optics underwater cables. • Deployment of a Remote Access-Sampler (RAS) to collect samples for biological and biogeochemical parameters.	
Software and IT	• Optimization algorithms to better distribute the sensors, sampling rate.	• AI-driven bioacoustic monitoring of biodiversity.	

Electronics	• Improve RT data transmission along the water column for moorings using inductive cables. • Energy availability. • Bi-directional data transmission, increase efficiency and bandwidth capacity (either bottom/surface/shore, or horizontal between distant seabed stations, or local with ROV...). • Exploiting IoT as a backup system for low-power low-capacity telemetry.		

Table 1 - Developments categorised per technological area.