Agenda Item	Preparatory document for Sessions on Science Strategy on 11 March 2025
Purpose	This cover document introduces the above referred session of the EMSO strategic workshop with a summary of the EMSO achievements so far, the strategic options the EMSO community shall think about and the questions asked to the EMSO community.
Reference documents	Annex: EMSO preliminary Science Strategy Document
Expected outcomes	- Snapshot on the already strong enough scientific synergies, common needs, common research topics , some preliminary inputs on the needed EMSO future services. This will start to feed day 3. - Snapshot on the not strong enough scientifc synergies to further develop on with the potential implementation of new EMSO Ocean Observatories - Some preliminary discussion on the neededstrategy and technologies to better progress from observation dedicated to study local scale processes to regional ones. This will feed day 2. - A discussin on how to implement the future EMSO internal scientific committee that would deal with the above.
Version date and lead person.	05 March 2025 Dominique Lefèvre (CNRS-MIO, France), Laura Beranzoli (EMSO ERIC) and Ingrid Puillat (EMSO ERIC DG)

Background Considerations

The main EMSO objective is to develop scientific services in a large range of disciplinary sectors, based on long-term high quality time-series collected at the Regional Facilities distributed in the European seas. It has been acknowledged that EMSO could not answer to the many potential expectations and needs across a so large range of sectors and that a scientific strategy shall be elaborated to refine its scope and scientific objectives.

The ESFRI monitoring feedback received in April 2024 pointed out several importants points with regards to the geographical extension and basin representativity of the EMSO infrastructure versus its PAN-EU relance. These are key comments to take on board the future EMSO strategy.

- *Capability to expand to cover shallower waters, possibly in conjunction with other RIs.*
- *Open question as to whether the science output already reflects representativity for the regional marine conditions*
    - ⇨ *selection criterion for observation platforms, i.e. whether regional or wider studies benefit sufficiently from the EMSO offer.*

- *The true interlinkage of data over large spatial scale would involve modelling (e.g. flexible grid model FESOM), and EMSO should examine how stronger collaboration with marine modelling community can improve the integration of data into marine hydrographic and weather models.*
- *With its focus on deep-sea oceanic environments, EMSO most probably has a unique contribution to wider oceanic issues at basin scale.*

The increasing financial contrains faced in Europe is implying the need for a collaboration between research infrastrucures to optimise the scientific and technical strategies.

The scientific document presented in Annex 1 has been drafted with the EMSO Science Service group in view of the elaboration of the Science Strategy of EMSO 2025-2034. The EMSO Science Strategy shall address some of the mainly acknowledged marine environmental and socioeconomic challenges. To do so the EMSO Science Strategy shall feed the upgrade of EMSO services towards different types of users, such as provision of new quality-assessed data acquired at EMSO facilities, validated and accessible through EMSO Data Portal, and further development of data products and work in cooperation with other ERICs and Research Infrastructures.

Summary of key achievements

The elaboration of this document roots in the EMSO achievements and followed a stepwise process with several intermediate considerations and conclusion to build upon.

It has been agreed that nowadays EMSO ERIC is committed to addressing the user community's and stakeholders' needs in the scientific macro-areas of the ***Marine Domain*** at the intersection between the Earth's domains: Ocean, Biosphere and Geosphere ***as reported in Section 1.*** Discussion amongst the scientists involved across the 14 EMSO Regional Facilities (RFs) pointed that the inclusion of emerging interdisciplinary fields, such as bioacoustics and ocean sound will strengthen EMSO's capacity to address both fundamental scientific questions and applied societal challenges. The Leader of the Science Service group and scientific officer of the EMSO Central management office proposed to work on the definition of an EMSO Science strategy based on a set of Key Scientific Questions (KSQs) and subsequent questions that would help tackle some scientific and Societal challenges. These questions have been discussed and reviewed with the scientific community. As a result, the most recent formulation comprises four KSQ plus one fifth that is targeting the elaboration of the EMSO Technology roadmap (not dealt with in this document). **These four KSQ as well as the corresponding scientific and societal challenges are presented in Section 2 of the annexed document** whereas the fifth one will be introduced on the second day of this workshop.

Points of attentions and asked questions to the attendees

During the workshop Regional Facility teams will firstly present their contributions to these KSQs and subsequent questions with objective to foster discussion on the commonalities and specificities in EMSO. This is the indispensable third step to draw the EMSO synergy that would help design the future EMSO infrastructure to better monitor and study the regional scale of marine environmental processes and their variability, including its observational capabilities, services and products. Specific contributions provided by certain regional Facilities are also key to fill gaps, bring not enough yet spread expertise.

Expected outcome

- Snapshot on the already strong enough scientific synergies, common needs, common research topics , some preliminary inputs on the needed EMSO future services. This will start to feed day 3.
- Snapshot on the not strong enough scientifc synergies to further develop on with the potential implementation of new EMSO Ocean Observatories
- Some preliminary discussion on the needed strategies and technologies to better progress from observation dedicated to study local scale processes to regional ones. This will feed day 2.
- A discussin on how to implement the future EMSO internal scientific committee that would deal with the above.,

Organisation of the session

1. Introdcution to the KSQs by the Science group Leader
2. Each Regional Facility teams will firstly present contributions to KSQs and subsequent questions with objective to foster discussion on the commonalities and specificities in EMSO.
3. Discussion session about RF contribition to KSQ (short, open Q& A)
4. Interactive session to review the tables given in table 3 of Annex 1
5. Discusion to conclude on the current synergies, strengths and weaknesses of EMSO per KSQ, needed technoloies and observatories to better answer the regional scale of variabilities. I

Annex: EMSO preliminary Science Strategy document

ANNEX

EMSO preliminary Science Strategy document

Version: 6 March 2025

Executive Summary

The main EMSO objective is to develop scientific services in a large range of disciplinary sectors, based on long-term high quality time-series collected at the Regional Facilities distributed in the European seas. It has been acknowledged that EMSO could not answer to the many potential expectations and needs across a so large range of sectors and that a scientific strategy shall be elaborated to refine its scope and scientific objectives.

In view of the *EMSO Strategic Workshop 2025*, the purpose of this document is to explain the way initiated to elaborate the EMSO Scientific strategy in a stepwise process with several intermediate considerations and conclusions to build upon. The main content of this document has been prepared with a collaborative approach by collecting inputs from the EMSO scientists. The Science Strategy shall address the main urgent acknowledged challenges and draw a roadmap to design, develop and deliver reliable services for the different types of users such as provision of new quality-assessed data acquired at EMSO facilities, validated and accessible through EMSO Data Portal, and further development of data products and work in cooperation with other ERICs and Research Infrastructure.

Stepwise process and content of the document:

It has been agreed that nowadays EMSO ERIC is committed to addressing the user community's and stakeholders' needs in the scientific macro-areas of the ***Marine Domain*** at the intersection between the Earth's domains: Ocean, Biosphere and Geosphere ***as reported in Section 1.*** Discussion amongst the scientists involved across the 14 EMSO regional Facilities (RFs) pointed that the inclusion of emerging interdisciplinary fields, such as bioacoustics and ocean sound will strengthen EMSO's capacity to address both fundamental scientific questions and applied societal challenges. The Leader of the Science Service group and the scientific officer of the EMSO Central management office proposed to work on the definition of an EMSO Science strategy based on a set of Key Scientific Questions(KSQs) and subsequent questions, that would help tackle some scientific and Societal challenges. These questions have been discussed and reviewed with the scientific community. As a result, the most recent formulation comprises four KSQs plus one fifth that is targeting the elaboration of the EMSO Technology roadmap. **The four KSQs are presented in Section 2** of this document whereas the fifth one will be introduced on the second day of this workshop.

During the workshop Regional Facility teams will firstly present their contributions to these KSQs and subsequent questions with objective to foster discussion on the commonalities and specificities in EMSO. This is the indispensable third step to draw the EMSO synergy that would help design the future EMSO infrastructure to better monitor and study the regional scale of marine environmental processes and their variability, including its observational capabilities, services and products.

Specific contributions provided by certain regional Facilities are also key to fill gaps, bring not enough yet spread expertise. To initiate this job, a core group of EMSO scientists preliminarily assessed current contributions of the Regional Facilities to each Key Scientific Question per EMSO macro area of the Marine domain. The gathered information is structured in one table per KSQ as in **Section 3 of this document**. It is considered as a draft and preliminary version.

In an interactive session scientist will be requested to review this table to conclude on the current synergies, strengths and weaknesses of EMSO per KSQ. In a further step it will help prioritise the effort to reach our objectives.

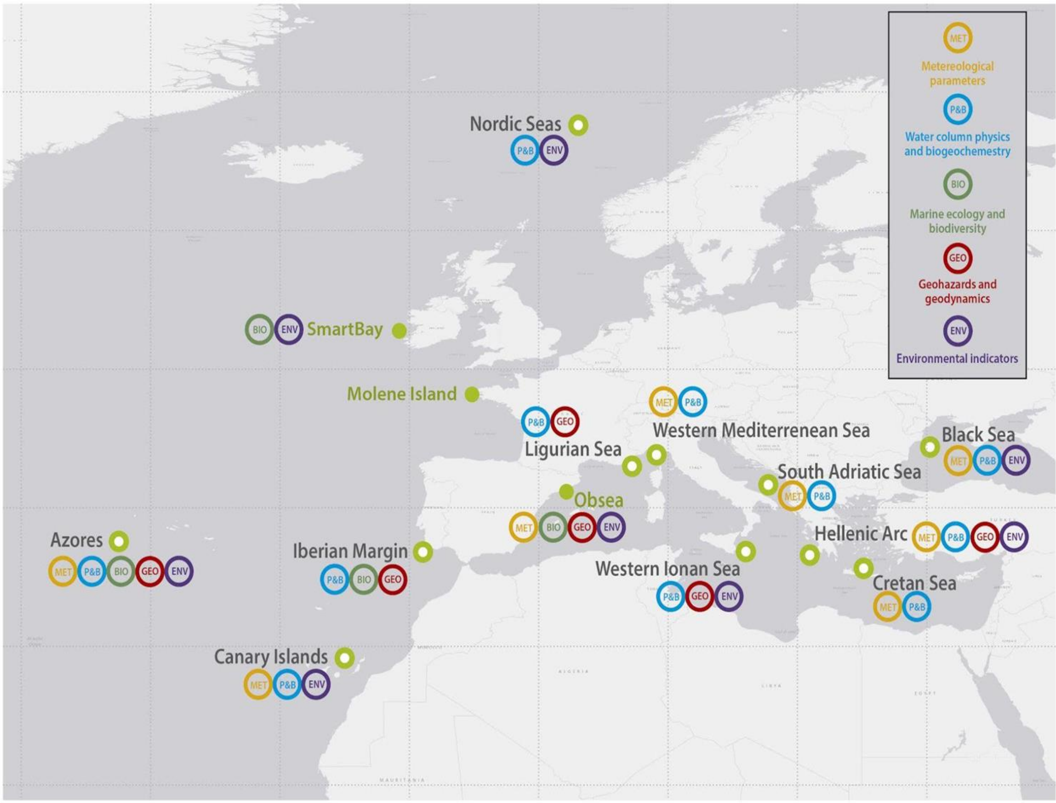
Content

1. Rationale for the scientific strategy

The main EMSO objective is to develop scientific services in a range of Marine disciplines, based on long-term high quality time-series collected at the Regional Facilities distributed in the European seas. The scientific services support the investigations on the interactions between the Earth's domains: Ocean, Biosphere and Geosphere. Recently, the inclusion of emerging interdisciplinary fields, such as bioacoustics and ocean sound, has been considered to strengthen EMSO's capacity to address both fundamental scientific questions and applied societal challenges.

EMSO ERIC is committed to addressing the user community's and stakeholders' needs in the scientific macro-areas of the ***Marine Domain:***

- Hydrodynamics and hydrology (Hydrosphere) – Understanding of deep physical dynamics—including ocean currents, diapycnal mixing, and vertical diffusion—is crucial for linking deep-sea processes with water column variability. This, in turn, improves our ability to assess climate variability, ocean circulation, and the impacts of extreme weather events on the entire water column.
- Biogeochemistry, biology and ecology (Biosphere) - Investigating the biogeochemical cycles, biological productivity, and ecosystem dynamics that regulate ocean life, including the biodiversity monitoring and the effects of anthropogenic stressors such as pollution and climate change
- Geology and geophysics (Geosphere) - Investigating seafloor processes, geohazards, tectonic activity, and sediment transport mechanisms to enhance the understanding of the sub-seabed processes and their implications for marine ecosystems.
- Ocean sound and bioacoustics – An interdisciplinary theme that integrates across the Hydrosphere, Biosphere, and Geosphere. Passive acoustic monitoring provides valuable insights into biodiversity, ecosystem health, climate-driven soundscape changes, and anthropogenic impacts such as noise pollution and vessel collisions with marine mammals.
- Technological Innovations for Ocean Observation – Developing new tools and methodologies to enhance the long-term ocean monitoring, to improve data accuracy, accessibility and processing. Integrating AI and machine learning techniques for real-time analysis.



Almost 10 years after EMSO ERIC establishment, it is relevant to map the scientific activities and update the EMSO scientific questions including the most urgent scientific topics and the stakeholders current expectations to EMSO.

2. Challenges and related EMSO Key Scientific Questions

2.1 Challenge 1: Open ocean temporal variability across spatial scales

Lead: Vanessa Cardin (OGS), Daniel Toma (UPC), Nadia Lo Bue (INGV)

Current monitoring efforts of open ocean variability is fragmented, making it difficult to assess long-term trends and understand the interactions between various processes acting at various scales. It is essential to measure and study the thermohaline variability, acidification, deoxygenation and human-induced stressors on long term.

KSQ-1 : How does the temporal variability of open ocean EOVs impact and propagate from local to regional scales?

KSQ1.1: How do long-term trends influence the open ocean environment and lead to long-lasting (or irreversible) impacts at regional and local scales?

KSQ 1.2: What are the effects of changes in the frequency of extreme events from regional to local scales?

KSQ 1.3: How do regional-scale changes and extreme events interact with basin-scale variability in the open ocean environment?

KSQ 1.4: How do regional open ocean variabilities affect the coastal processes?

2.2 Challenge 2: Spatiotemporal process variability and natural hazards

Lead: Sebastien Garziglia (Ifremer), Davide Embriaco (INGV), Pierre Henry (CNRS-Cerege)

Changes in the open ocean can modify erosional patterns, sediment dynamics, fluid flow activity and stress state with poorly understood consequences for natural hazards such as submarine landslides, earthquakes and tsunamis. Understanding hazard interactions at the monitoring timescale is essential for the modelling of processes over longer timescales and making accurate assessments and predictions. Monitoring processes in the open ocean helps with the early and reliable detection of tsunamis. Monitoring also provides insight into how hazards make their way into the sedimentological record, and thus how this record may be interpreted.

KSQ.2 What are the spatiotemporal scales and variability of the processes preconditioning and triggering natural hazards events?

KSQ 2.1: How do climate change, sedimentary and geodynamic processes interact at local and regional scales ?
KSQ 2.2: How water column processes can be detected and their consequences better anticipated ?
KSQ 2.3: What are the processes and scales of variability that affect fluid flow and seepage to the water column ?
KSQ 2.4: How to resolve the various processes leading to catastrophic events ?

2.3 Challenge 3 : Assessing baseline and potential changes of open ocean benthic and pelagic ecosystems

Lead: Silvana Neves (PLOCAN), Daniel Toma (UPC), Roberto Bozzano (CNR), Costas Frangoulis (HCMR), Marjolaine Matabos (IFREMER)

Marine ecosystems are complexed and shaped by various environmental and biotic processes that interact across a wide range of spatial and temporal scales. Understanding their dynamics and the underlying processes is essential to disentangle natural variability from long-term changes resulting from human activities.

Marine ecosystems are experiencing rapid biodiversity loss or shifts in communities composition due human activities, including climate change, resource exploitation and pollution, impacting ecosystem functions such as productivity, nutrient cycling, and biogeochemical fluxes. Loss of species, particularly in key functional groups, reduces ecosystem resilience, alters food web structures, and affects carbon sequestration mechanisms.

Furthermore, ecosystem connectivity plays a crucial role in species (including alien ones) migration, population dynamics, and genetic exchange, particularly in marine environments with strong larval dispersal and large-scale oceanographic connectivity. Coastal and deep-sea ecosystems rely on functional biodiversity to maintain carbon cycling, predator-prey interactions, and primary production, with key species influencing overall ecosystem functionality

KSQ 3: What are the impacts of natural environmental variability, geophysical dynamic events, and anthropogenic changes on open ocean benthic and pelagic ecosystems?

KSQ 3.1: What mechanisms drive ecosystem responses to environmental variability and disturbances, and how do local productivity and biogeochemical fluxes propagate through the surrounding benthic and pelagic ecosystems?

KSQ 3.2:How do scales of environmental variability affect biological processes and ecosystem functioning such as larval dispersal, colonization processes, species growth, distribution and behavior, biotic interactions, microbial activity and trophic interactions?

KSQ 3.3 How do anthropogenic pressures such as climate change, deep-sea mining, fisheries, and pollution influence (or may influence) the functioning, connectivity and resilience of benthic and pelagic communities across different spatial scales?

KSQ 3.4 How can integrated, long-term observational data from EMSO infrastructures improve predictions of ecosystem shifts in response to natural and human-induced changes?

2.4 Challenge 4 : Geophysical events, climatic and anthropogenic changes and deep carbon storage

Lead: Stefano Miserocchi (CNR-ISP), Costas Frangoulis (HCMR), Nadia Lo Bue (INGV)

The ocean is a vital carbon reservoir, storing approximately 40,000 billion tonnes of carbon, primarily as dissolved inorganic carbon—50 times the amount in the atmosphere. This carbon is unevenly distributed, with significantly higher concentrations in deep ocean layers, where its dynamics remain still poorly understood. While inorganic carbon in the surface layer directly interacts with the atmosphere, regulating CO_2 exchange, the processes governing the physical pump, biological pumps, and vertical sedimentary transfer in deeper layers are still not fully elucidated. A comprehensive, distributed observation network is essential to accurately assess the ocean's carbon inventory and improve our understanding of these complex, interconnected mechanisms.

KSQ 4: How does climate change affect the carbon storage in the open ocean along the water column?

KSQ 4.1: How is the physical pump affected by medium and long term variability of the atmospheric forcing?

KSQ 4.2: How are the biological pumps (organic and carbonate/inorganic) affected by variability at different time scales?

KSQ 4.3: How does marine biodiversity and ecosystem dynamics influence carbon cycling through the biological carbon pumps?

KSQ 4.4: Carbon deep storage assessment with respect to thermohaline variability.

Strengths of EMSO to address the 4 Key Scientific Questions

KSQ-1 : How does the temporal variability of open ocean EOVs impact and propagate from local to regional scales?

Table : Scientific sub Key questions versus processes to be studied and phenomenon

Scientific Sub Key Challenges	Hydrodynamics and hydrology processes	Biogeochemistry, biology and ecology processes	Geology and geophysics processes
KSQ 1.1: How do long-term trends influence the open ocean environment and lead to long-lasting (or irreversible) impacts at regional and local scales?impacts at regional and local scales?	EMSO-Azores: local monitoring of water mass away from hydrothermal influence W1M3A: Investigate how changing weather patterns and climate variability affect pollutant fluxes. EMSO-WIS: local monitoring of the physical properties of the deep sea and water column, along with the study of processes driving their variability EMSO-SA & EMSO-LIG: Warming and salinification trends at intermediate and deep layers	W1M3A: Examine how radon progenies in the marine boundary layer serve as tracers for airborne pollutant deposition into the ocean. Study the deposition of heavy metals, microplastics, and other airborne pollutants into the ocean. EMSO-LIG: Impact of the deep convection on DO ventilation, nutrients and acidification trends. EMSO-SA: Mid-long term dynamics of the carbon system variability induced by warming trend EMSO-Canarias:	

	EMSO-LIG: Evolution of the convection process vs. stratification in the NW MedSea EMSO-Canarias: How does long-term oxygen variability at ESTOC reflect changes in ocean ventilation and water mass dynamics Future:How does long-term variability in oxygen and temperature at ESTOC reflect broader climate change patterns? Hellenic-Arc (operations on stand-by): meteorological and hydrological characteristics (entire water column)	How is long-term ocean acidification affecting primary production and carbonate chemistry in the Canary Basin? What are the long-term ecological implications of persistent plastic pollution in marine environments Future:How does long-term ocean acidification at ESTOC impact carbonate chemistry and biological processes Hellenic-Arc (operations in stand-by): nutrients, Chla, O2, CO2, pH, CH4 (only bottom), plankton and mammals (hydrophone) variability EMSO-WIS : DO monitoring at Seafloor and water column and CO2 periodic sampling along the water column	
KSQ 1.2: What are the effects of changes in the frequency of extreme events from regional to local scales?	W1M3A: Monitor and analyze marine heat waves (MHWs) to assess their drivers, persistence, and impacts from open ocean to coastal regions. EMSO-LIG: Monitor the dense water formation spreading in the NW MedSea region EMSO-SA: Monitoring the duration of dense water forming events caused by shelf and open convection processes in the Adriatic Sea.	EMSO-Canarias How do increases in the frequency and intensity of nutrient pulses (e.g., simulated upwelling events) affect plankton respiration and carbon export, and what implications does this have for local biogeochemical processes under more frequent extreme conditions? What is the biogeochemical response of the open ocean to pulses of atmospheric dust deposition?	EMSO-WIS monitoring the volcanic ash fallout of Mt. Etna through turbidity measurements at deep open ocean site;

	EMSO-Canarias How do episodic Saharan dust deposition events influence regional hydrodynamics and water column stratification at ESTOC? Hellenic-Arc (operations on stand-by): heat waves, storm and dust extreme events, meteotsunamis EMSO-WIS how do local hydrodynamic conditions influence sedimentation processes of volcanic ash volcanic fallout during Etna pyroclastic activity Monitoring of MHW-related signals through the water column including impact and spreading at the deep layer (through observatories and smart cable)	Hellenic-Arc (operations on stand-by): effects on Chla, O2, plankton, CO2, pH, CH4 (only bottom), mammals (hydrophone)	

KSQ 1.3: How do regional-scale changes and extreme events interact with basin-scale variability in the open ocean environment?	W1M3A: Investigate teleconnections between Mediterranean-wide anomalies and local-scale observations. EMSO-SA: Changes in the Northern Ionian Gyre (NIG) circulation and its impact in the SA and Mediterranean. Changes in intensity and spreading of dense water formed by shelf and open convection events in the Adriatic Sea. EMSO-Canarias How do decadal basin-scale climate oscillations, such as shifts in major climate modes, drive regional differences in ocean conditions (e.g., oxygen levels), and what factors account for the variability in local responses?. How do large-scale climate modes (NAO, AMO) influence temperature, salinity, and circulation at ESTOC? Future:How does climate-driven variability in water mass properties influence the deep-water carbon cycle? Hellenic-Arc (operations on stand-by): hydrological observations combined with other Med observatories. Modelling at Med scale	Hellenic-Arc: Modelling at Med scale	

	EMSO WIS: Processes such as the Adriatic outflow, the formation and spreading of LIW, and EMDW are interconnected play a key role in driving variability in the circulation and hydrography (NIG activity) Iberian Margin: Monitor mediterranean outflow characteristics at the northwestern region of the Gulf of Cadiz. Observe the upper water column structure, its variability and coastal circulation patterns, as it exchanges EOVs with the open ocean (upwelling filaments, contorted upwelling front, eddy activity in coastal transition zone…)		
KSQ 1.4: How do regional open ocean variabilities affect the coastal processes?	EMSO-Canarias How do hydrodynamic processes in the Canary Current system influence coastal upwelling and nutrient transport near ESTOC? How Climate-driven shifts in open-ocean conditions can alter coastal upwelling intensity Hellenic-Arc (operations on stand-by): meteo and hydrological multiplatform (Supersite) observations in open ocean and coasts	Hellenic-Arc (operations on stand-by): nutrients, plankton variability multiplatform (Supersite) observations in open ocean and coasts	

KSQ.2 What are the spatiotemporal scales and variability of the processes preconditioning and triggering natural hazards events?

	Hydrodynamics and hydrology processes	Biochemistry,biology ecology processes	Geology and geophysics processes
KSQ 2.1: How do climate change, sedimentary and geodynamic processes interact at local and regional scales ?	EMSO-CANARIAS How does long-term hydrographic variability at ESTOC relate to climate-driven changes in water mass properties? Hellenic-Arc (operations on stand-by): sea level rise EMSO-SA: Better understand how air-sea interactions trigger meteotsunamis, and their consequences on the dynamics of the water column		EMSO-Ligure-Nice: Monitoring pore fluid pressure and temperature EMSO-Canarias: Future:How do variations in dynamic ocean pressure (measured by tsunami meters) impact regional sedimentation Hellenic-Arc (operations on stand-by): seismicity, gas events EMSO-SA: Changes in sediment export from shelf to deep basin.
KSQ 2.2: How water column resonances can be detected and their consequences better anticipated ?	Better understand how air-sea interactions trigger meteotsunamis, and their consequences on the dynamics of the water column (also W1M3A) Hellenic-Arc (operations on stand-by) storm extreme events, meteotsunamis		Use information from small meteotsunami events to better forecast damaging tsunamis resulting from earthquakes, landslides and volcanic eruptions Hellenic-Arc (operations on stand-by): seismic tsunamis Iberian Margin: combine OBS and absolute pressure gauges data for calibration and validation of transfer

			function between strain and ground motion EMSO WIS: sea bottom pressure recorders provide real time data on sea level which is essential for tsunami detection in open sea.
KSQ 2.3: What are the processes and scales of variability that affect fluid flow and seepage to the water column ?	How efficiently are released fluids mixed within the water column and what are the resulting fluxes to the atmosphere ? EMSO-Azores: monitoring bottom, water column currents over space and time	What is the impact of fluid emissions on water column chemistry, oxygenation, and life ? (also EMSO-Azores) EMSO-Azores: monitoring fluid chemistry in space and time	What is the impact of concurrent rises in sea level and temperature on the dynamics of free gas and gas hydrates in sediments ? on hydrothermal systems ? How do fluid pressure and fluid fluxes at shallow depth vary as a consequence of tectonic and magmatic processes and events? EMSO-Azores:monitoring fluid temperature in space and time, EMSO-Ligure-Nice: Monitoring pore fluid pressure and temperature

KSQ 2.4: How to resolve the various processes leading to catastrophic events ?			What are the connections and triggers between primary and secondary hazards? What is the time lag between an earthquake and the triggering of a submarine landslide ? How small but regular events impact slope stability (hardening vs cumulative effect) ? How do catastrophic events make (or not) their way into the geological record? EMSO-Ligure-Nice: Monitoring pore fluid pressure and temperature EMSO-CANARIAS How do catastrophic geodynamic events, such as volcanic eruptions, drive rapid environmental changes, and what processes govern the subsequent habitat formation and recolonization dynamics. EMSO WIS: Seismic data recorded at sea helps identification of earthquake sources, provides information on events not detected by the land network, provide information on possible submarine landslide

KSQ 3: What are the impacts of natural environmental variability, geophysical dynamic events, and anthropogenic changes on open ocean benthic and pelagic ecosystems?

	Hydrodynamics and hydrology	Biochemistry, biology, ecology	Geology and geophysics
KSQ 3.1: What mechanisms drive ecosystem responses to environmental variability and disturbances, and how do local productivity and biogeochemical fluxes propagate through the surrounding benthic and pelagic ecosystems?	EMSO-Azores: How hydrothermal plume interact with local topographic features and submesoscale/tidal currents and impact larval dispersal? Hellenic-Arc (operations on stand-by): meteorological and hydrological characteristics, heat waves, storm and dust extreme events	EMSO-Azores: • (future): impact of microbial production associated with hydrothermal plumes on geochemical cycles and trophic networks in the deep ocean • Role of chemical variability on biological communities (microorganims and fauna) W1M3A: Examine potential stress responses (e.g., altered vertical migration, changes in metabolic rates) Iberian Margin: (future) Is there a discernible disturbance related to climate change and/or anthropic influence in deep benthic habitats (VMEs)? Hellenic-Arc: Med basin scale ecosystem model, Hellenic-Arc (operations on stand-by): nutrients, Chla, O2, CO2, pH, CH4 (only bottom), plankton and mammals (hydrophone) variability.	EMSO-Azores: influence of geological features and fluid circulation on species distribution and biodiversity

KSQ 3.2: How do scales of environmental variability affect biological processes and ecosystem functioning such as species growth, distribution and behavior, biotic interactions, microbial activity and trophic interactions?	Hellenic-Arc (operations on stand-by): Mixed layer depth, upwelling and deep water formation impact on plankton production and distribution	EMSO-Azores: ● Growth (video, experiment), behavioral study (video) ● Ecological soundscape (future): use of passive acoustic for biodiversity,biological rhythm and interactions ● Characterisation of biological rhythms and how they control species behaviour and community dynamics? ● Experimentation to assess colonisation: larval dispersal and recruitment. EMSO-Canarias: How do variations in upwelling intensity and nutrient pulses reshape plankton community structure, and in turn, alter carbon flow, trophic interactions, and overall ecosystem functioning How do interannual changes in chlorophyll concentration at ESTOC reflect broader shifts in phytoplankton communities and productivity? Cetacean behaviour through bioacoustics. Soundscape - use of passive acoustic for biodiversity assessment EMSO-SA: Mixed depth dynamics variability influences vertical zooplankton migration. Assessment of mesozooplankton assemblages. EMSO-SA: Improving knowledge on fin whale acoustic occurrence.	EMSO-Azores (future): Role of venting soundscape on larval behaviour and recruitment?

		Hellenic-Arc (operations on stand-by): Chla, plankton composition/biomass and vertical migration (ADCP) EMSO WIS: Marine mammal behavior, detected through bioacoustics, serves as a valuable marker of environmental variability, providing insights into changes in ecosystem dynamics and habitat conditions	
KSQ 3.3 How do anthropogenic pressures such as climate change, deep-sea mining, fisheries, and pollution influence (or may influence) the functioning, connectivity and resilience of benthic and pelagic communities across different spatial scales?	EMSO-SA:	W1M3A: Investigate how different sound levels and frequencies influence zooplankton movement, feeding, reproduction, and survival. EMSO-Canarias: How do ferry routes impact cetaceans, and how can collisions be mitigated? How can pump-based sampling reveal plastic pollution's long-term ecological impact? How do offshore wind farms sound levels affect marine ecosystems? EMSO-Azores: • Impact of research activity on habitat and species distribution • impact of light (video analysis and sampling) (Deep-Sea mining and Research activity) • Impact of sampling/habitat destruction on on habitat and species distribution (repeated surveys)	

		• Experimentation for assessing impact to induced disturbance Iberian Margin: How is shipping noise impacting sound sensitive species? Hellenic-Arc (operations on stand-by): hydrophone EMSO WIS: monitoring of anthropogenic noise levels through detection of sound pressure at different frequency band (MSDF) and its impact on marine mammals behaviour	
KSQ 3.4 How can integrated, long-term observational data from EMSO infrastructures improve predictions of ecosystem shifts in response to natural and human-induced changes?	EMSO-WIS-EMSO-SA: by providing in situ hydrological data for forecast and reanalysis models	Iberian Margin: How to improve the estimation of cetaceans distribution densities with passive acoustics in a significant noise field generation area? Hellenic Arc: Med Basin ecosystem model supported by observational data EMSO-WIS: Sound pressure noise measurements integrated with marine traffic data to assess the impact of human activities on ecosystem shifts.	

KSQ 4: How does climate change affect the carbon storage in the open ocean along the water column?

	Hydrodynamics and hydrology	Biochemistry,biology, ecology	Geology and geophysics
KSQ 4.1: How is the physical pump affected by medium and long term variability of the atmospheric forcing?	EMSO-SA: Air sea interactions and convection events, mixed layers development, meteorological regimes EMSO-Canarias How does variability in ocean ventilation and mixing at ESTOC influence CO2 uptake and storage? Future:How does the interaction between atmospheric CO2 levels and ocean mixing drive changes in carbon uptake at ESTOC? Hellenic-Arc (operations on stand-by): Air sea interactions , mixed layer depth, meteorological regimes, deep water formation, upwelling EMSO WIS: Monitoring CO_2 variability along the water column, linked to local hydrodynamics, reveals key mechanisms of the physical pump for	EMSO-LIG: Air-sea O2 and CO2 fluxes in the Ligurian Sea EMSO-SA: Dissolved Carbon fluxes variability Hellenic-Arc (operations on stand-by): CO2 air-sea exchanges,	

	carbon transport and sequestration in marine ecosystems		
KSQ 4.2: How are the biological pumps (organic and carbonate/inorganic) affected by variability at different time scales?	Hellenic-Arc (operations on stand-by): hydrological characteristics influencing the biological pump	EMSO-SA:Nutrients availability, biodiversity, phenology, vertical carbon fluxes by sediment trap EMSO-LIG: Monitor the POC fluxes in relation to the PP and zooplankton biodiversity EMSO-CANARIAS How do decadal climate shifts impact the biological carbon pump and deep carbon export?. 【4】 What seasonal and interannual factors control the biological carbon pump efficiency at ESTOC? Hellenic-Arc (operations on stand-by): Chla, CO2, pH, CT, TA, plankton composition/biomass and vertical migration (ADCP), carbon composition/fluxes by sediment traps	

KSQ 4.3: How does marine biodiversity and ecosystem dynamics influence carbon cycling through the biological carbon pumps?	Hellenic-Arc (operations on stand-by): Mixed layer depth, upwelling and deep water formation impact on plankton production and distribution	EMSO-CANARIAS:How do plankton shifts affect carbon export and sequestration? Future:Cetacean-mediated carbon sequestration EMSO-LIG: Biological gravitational carbon pump EMSO-SA: Biodiversity from mesozooplankton assemblages and carbon fluxes connection through the biological carbon pump Hellenic-Arc (operations on stand-by): Chla, plankton composition/biomass and vertical migration (ADCP), plankton products composition/fluxes by sediment traps	
KSQ 4.4: Carbon deep storage assessment with respect to thermohaline variability.	EMSO-SA:Thermohaline circulation, mixing and convection Hellenic-Arc (operations on stand-by): hydrological characteristics	EMSO-SA:Dissolved component of carbon EMSO-Canarias:How do thermohaline shifts affect deep ocean CO_2 sequestration?	EMSO-Azores: Hydrothermal Venting and Volcanic Activity Hellenic-Arc (operations on stand-by): seabottom CO2, pH, CH4