REQUEST FOR AN EMI R&D PROJECT 2027–2029

Country/Organisation: Italy

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Project Title: High-resolution modelling of climate-related changes in potential feeding habitats of the North-Western Mediterranean Sea

To make changes to an existing project please submit an amended version of the original form

If this is a continuation of an existing project, please state the computer project account assigned previously.		
Starting year: (A project can have a duration of up to 3 years, agreed at the beginning of the project.)	2027	
Would you accept support for 1 year only, if necessary?	YES ☒	NO ☐

Computer resources required for project year:		2027	2028	2029
High Performance Computing Facility	[SBU]	5 M	15 M	20 M
Graphics Processing Unit Cluster-A	[GBU]			
Graphics Processing Unit Cluster-B	[GBU]			
Accumulated data storage (total archive volume)[2]	[GB]	20 K	60 K	100 K

[1] The Principal Investigator will act as contact person for this EMI R&D Project and, in particular, will be asked to register the project, provide annual progress reports of the project's activities, etc.
[2] These figures refer to data archived in ECFS and MARS. If e.g. you archive x GB in year one and y GB in year two and don't delete anything you need to request x + y GB for the second project year etc.
[3]The number of vGPU is referred to the equivalent number of virtualized vGPUs with 8GB memory.

EWC resources required for project year:		2027	2028	2029
Number of vCPUs	[#]			
Total memory	[GB]			
Storage	[GB]			
Number of vGPUs[3]	[#]			

Continue overleaf.

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Extended abstract

Abstract

This EMI R&D project aims to investigate climate-related changes in potential feeding habitats in the North-Western Mediterranean Sea through a ten-year, high-resolution physical–biogeochemical hindcast based on MITgcm coupled online with BFM (Cossarini et al., 2017). The target configuration will resolve the Ligurian Sea, the Northern Tyrrhenian Sea and the Pelagos Sanctuary region at sub-kilometric resolution (1/128°), with hourly three-dimensional output for the main physical fields and a selected subset of biogeochemical variables (Brandini et al., 2024). The hindcast will be used to quantify climate-relevant variability and emerging trend-like signals in dynamic trophic conditions, with particular emphasis on productive fronts, chlorophyll structures, vertical biogeochemical features, event-driven nutrient supply (Cossarini et al., 2021; Teruzzi et al., 2021), as well as retention areas and other coupled physical–biogeochemical indicators relevant to potential feeding habitats (Tew Kai et al., 2009; Scales et al., 2014; Veatch et al., 2025). To reduce storage demands while preserving the key scientific objectives, the project will adopt a selective output strategy, archiving the main three-dimensional physical fields together with approximately ten key BFM variables (out of the 51 available) at hourly intervals.

Project Overview

This project proposes the production, validation and scientific exploitation of a ten-year, high-resolution physical–biogeochemical hindcast for the North-Western Mediterranean Sea, with the main objective of assessing climate-related changes in dynamic trophic conditions associated with potential feeding habitats. The project aims to generate a physically consistent, multi-year, hourly dataset of three-dimensional hydrodynamic fields and a selected subset of biogeochemical variables. This dataset will provide the basis for analysing coupled physical–biogeochemical variability at scales that are only partly resolved by present basin-scale Mediterranean reanalyses (Escudier et al., 2021; Cossarini et al., 2021). Particular attention will be devoted to trophic-state indicators, productive chlorophyll fronts, vertical biogeochemical structures, event-driven nutrient supply, retention areas and habitat-related diagnostics relevant to potential feeding habitats in the Ligurian Sea, the Northern Tyrrhenian Sea and the Pelagos Sanctuary region (D'Ortenzio and Ribera d'Alcalà, 2009; Teruzzi et al., 2021; De Pascalis et al., 2021). The present proposal is therefore centred on the use of high-resolution physical–biogeochemical modelling to detect and interpret climate-relevant variability and emerging trend-like signals in the dynamical seascape of potential feeding habitats.

The proposed project builds on the previous ECMWF Special Project SPITBRAN, which developed and tested a high-resolution downscaling framework for the north-western Mediterranean using MITgcm coupled with BFM to downscale CMEMS physical and biogeochemical products (Brandini et al., 2024). SPITBRAN demonstrated the feasibility of the modelling framework while highlighting the computational challenges associated with multi-year coupled hindcasts, particularly in terms of I/O and data storage. The complete BFM state will be used during the simulations, while the archived hourly three-dimensional output will include all essential physical variables and approximately ten biogeochemical variables selected during the project, substantially reducing storage requirements without compromising the scientific objectives. The proposed configuration builds on the SHAREMED project computational domain, covering the Ligurian Sea, the Northern Tyrrhenian Sea and the Pelagos Sanctuary, with a horizontal grid of approximately 784 × 336 points and 61 vertical levels.

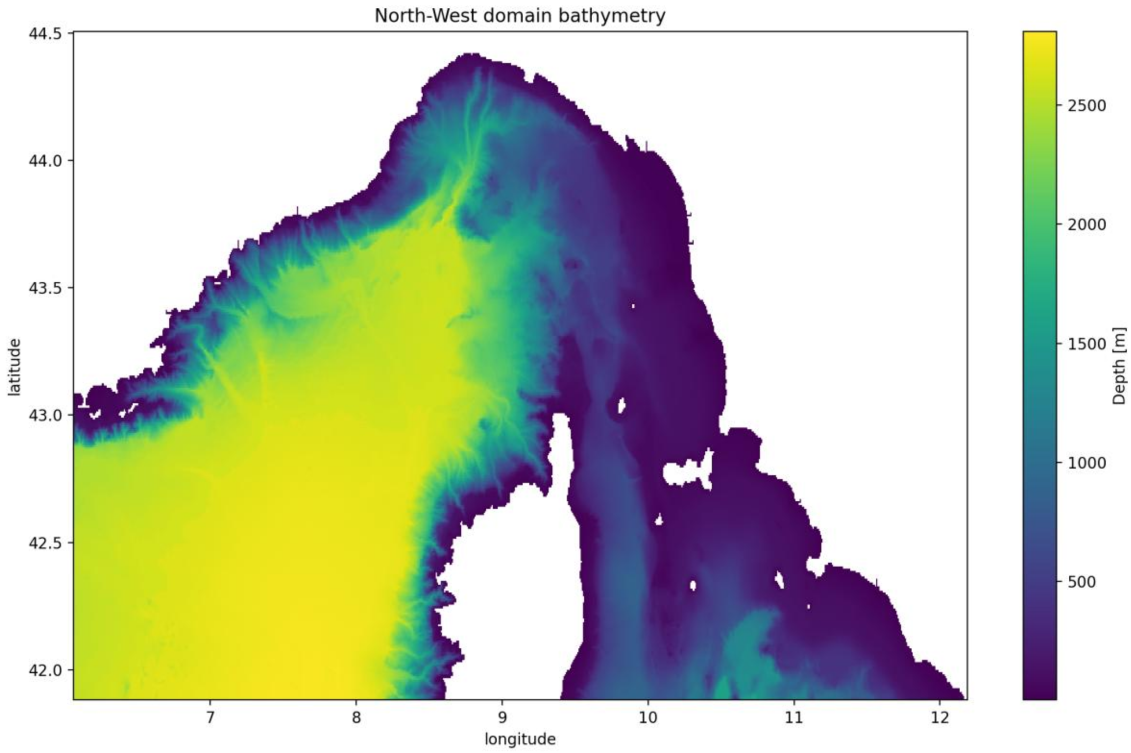

Figure 1: Bathymetry of the domain from the SHAREMED Interreg project used in this proposal.

Scientific Motivation

The North-Western Mediterranean is a dynamically active marginal-sea region where boundary currents, mesoscale eddies, fronts, winter mixing, topographic control and coastal–offshore exchanges interact with a marked trophic gradient (Millot, 1999; D'Ortenzio and Ribera d'Alcalà, 2009). The narrow continental shelf, steep bathymetry and quasi-permanent cyclonic circulation favour intense cross-shelf exchanges and mesoscale activity that strongly modulate nutrient supply and ecosystem functioning. These processes regulate nutrient availability, primary production, oxygen distribution and plankton dynamics. In particular, coherent mesoscale structures can promote biological patchiness by generating transport barriers and incomplete horizontal mixing (Bracco et al., 2000), thereby contributing to the spatial organisation of dynamic trophic conditions. The area also has direct environmental relevance because it includes the Pelagos Sanctuary and a dense observational context, including satellite products, Argo and BGC-Argo profiles, HF radars, gliders, CTD casts and recent regional field campaigns.

Existing Mediterranean physical and biogeochemical reanalyses provide the large-scale reference for this project (Escudier et al., 2021; Cossarini et al., 2021). However, their typical horizontal resolution (about 1/24° in the main CMEMS Mediterranean systems) cannot adequately resolve coastal fronts, shelf–slope exchanges and sub-mesoscale dynamics (1-10km) that regulate vertical nutrient transport, mixed-layer restratification, deep chlorophyll maxima, oxygen variability and ecosystem productivity, all of which are directly relevant to habitat-related diagnostics (Cossarini et al., 2021; Teruzzi et al., 2021).
In this region, processes occurring at spatial scales close to or below the effective resolution of the CMEMS Mediterranean systems are not secondary perturbations, but represent a dominant contribution to the variability of the system, controlling vertical fluxes and ecosystem structure.
Improving the representation of vertical exchanges is also essential for simulating carbon uptake, export production and oxygen ventilation. A ten-year hindcast (e.g. 2015–2024) is required to robustly distinguish seasonal cycles from the interannual variability of frontal structures, including their frequency, persistence, spatial displacement and intensity, which cannot be inferred from shorter simulations or climatological products. This period also benefits from mature satellite observations, operational HF radar measurements, increasing BGC-Argo coverage and recent field campaigns available for model validation. Hourly three-dimensional outputs are required to capture the temporal evolution of fronts, storm-driven vertical exchanges, inertial motions, coastal jet variability and biological responses, whose characteristic timescales (from a few hours to a few days) are therefore lost in daily or monthly averages.

While the resulting dataset will enable further analyses across the range of physical and biogeochemical processes described above, the primary scientific focus of the project will be to detect and interpret climate-relevant variability and emerging trend-like signals in dynamic trophic conditions associated with potential feeding habitats. Particular emphasis will be placed on the frequency, persistence, intensity and spatial organisation of productive fronts, chlorophyll structures, retention areas and other coupled physical–biogeochemical features that may favour prey aggregation and foraging opportunities (Tew Kai et al., 2009; Scales et al., 2014). In this sense, the hindcast is designed not only as a high-resolution numerical archive, but as a tool to assess how climate variability and emerging trends may reshape the dynamical seascape of potential feeding habitats in the North-Western Mediterranean Sea.

Model configuration and input data

The model will use MITgcm as the hydrodynamic core in a regional North-Western Mediterranean configuration (Marshall et al., 1997; Adcroft et al., 2004). MITgcm is appropriate for this application because the target region involves steep topography, shelf–slope exchange, boundary currents, mesoscale circulation, vertical mixing and frontal structures. The biogeochemical component will be BFM, coupled online through BFMcoupler, so that physical advection, mixing and vertical transport act directly on biogeochemical tracers (Vichi et al., 2020; Cossarini et al., 2017).

Physical initial and boundary conditions will be derived from CMEMS Mediterranean physical reanalysis products (Escudier et al., 2021; Copernicus Marine Service, 2026a). Atmospheric forcing will be based on ECMWF/Copernicus reanalysis datasets and, where useful, on higher-resolution regional atmospheric products already available or under development in related activities (Hersbach et al., 2020). The use of high-resolution atmospheric forcing will be evaluated in the first project year, especially for surface heat fluxes, wind-driven events and coastal gradients. Biogeochemical initial and boundary conditions will be derived from CMEMS Mediterranean biogeochemical reanalysis and analysis products (Cossarini et al., 2021; Copernicus Marine Service, 2026b; Copernicus Marine Service, 2026c). These products will also provide the large-scale benchmark for chlorophyll, nutrients, oxygen, carbonate-system variables and primary production. River inputs will be treated as a specific source of uncertainty. During the first phase, river discharge and nutrient loads will be implemented using the best available datasets or climatologies, including EFAS/CEMS hydrological products where appropriate (European Commission Joint Research Centre, 2023). Later sensitivity tests may assess the impact of alternative riverine nutrient forcing on coastal biogeochemical indicators.

The preliminary hourly three-dimensional biogeochemical subset will be selected from variables relevant to trophic-state and potential feeding-habitat diagnostics, such as total chlorophyll, phytoplankton biomass, zooplankton biomass, nitrate, phosphate, silicate, ammonium, dissolved oxygen, dissolved inorganic carbon, alkalinity and carbonate-system diagnostics. The final list of approximately ten archived BFM variables will be defined after the first-year test simulations, based on storage cost, scientific relevance, model stability, validation needs and their contribution to trophic and habitat-related indicators.

Computational workflow

The computational workflow consists of five main stages: (i) retrieval and preprocessing of physical, biogeochemical and atmospheric forcing datasets; (ii) generation of initial and boundary conditions; (iii) execution of the coupled MITgcm–BFM simulations; (iv) post-processing, compression and archiving of selected hourly physical and biogeochemical outputs in NetCDF4 format; and (v) validation against satellite, HF radar, Argo/BGC-Argo and in situ observations.
The simulation workflow is implemented as a modular pipeline spanning preprocessing, model integration and post-processing phases. Long integrations are managed through periodic restart files, enabling job chaining, fault recovery, and robust handling of hardware or software interruptions during multi-year simulations.
The production runs are segmented into restart-controlled execution windows of approximately 24 hours wall-clock time per job, ensuring compatibility with HPC scheduling constraints while accounting for variability in I/O performance and checkpointing overhead. This segmentation provides a practical balance between computational throughput, system reliability and resource efficiency.
Overall, the workflow is designed to be scalable and adaptable, with the ability to adjust core allocation and I/O configuration based on measured performance and system-specific benchmarks.
The computational design of this workflow directly informs the resource requirements described in the following section.

Output strategy and storage justification

For a grid of approximately 784 × 336 × 61 points, one three-dimensional single-precision field requires about 64 MB per output time, excluding metadata and I/O overhead. Archiving all 51 BFM tracers hourly would generate approximately 3.3 GB h^{-1} of biogeochemical output. Including the main three-dimensional physical variables would increase the total hourly output to about 3.7 GB, corresponding to an estimated bound of roughly 324 TB over a ten-year hindcast before compression and additional products.

To reduce storage requirements, the project will archive:

- hourly three-dimensional physical fields;
- hourly three-dimensional output for approximately ten selected BFM variables;
- hourly two-dimensional surface diagnostics for comparison with satellite and HF radar observations (post-processing);

Model outputs will be converted to and archived in compressed NetCDF4 format with optimized chunking (Rew and Davis, 1990; The HDF Group, 1997–2026). Derived indicators will be generated during post-processing, and redundant intermediate files will not be retained after validation. The final archive is expected to require 50–100 TB, depending on compression efficiency, restart frequency and the selected diagnostics.

Computational resources

The final resource request will be refined after benchmark simulations on the selected machine, compiler environment and I/O configuration. The current estimate is based on preliminary benchmarks performed on CINECA facilities and the SPITBRAN experience. The computational estimate performed on the CINECA Leonardo machines is as follows: using a timestep of $\Delta t = 75$ s, a ten-year integration (~4.2×10^6 steps) costs of the order of 10^5 core-hours, i.e. a few million SBU (~19 SBU per core-hour), for the production run alone; the rest of the request covers spin-up, repeated and sensitivity runs, I/O benchmarking and post-processing, to be consolidated by the first-year benchmark. These figures are anchored on the direct predecessor Special Project SPITBRAN (Brandini et al., 2024), which developed the same configuration adopted here — MITgcm–BFM at 1/128° (784 × 336 × 61) over the Pelagos Sanctuary — and reported a measured cost of about 2 500 SBU per simulated day, i.e. of the order of 9 M SBU for a ten-year integration, consistent with the estimate above. SPITBRAN requested 21 M SBU and 12 TB over 2022–2024 and explicitly noted in its final report that data volumes had been overestimated and the corresponding SBUs underestimated. The present request (40 M SBU, 100 TB over 2027–2029) reflects this lesson, the sustained full physical–biogeochemical coupling throughout the ten-year hindcast, and the move to hourly three-dimensional archiving, which sets the storage requirement.

A coupled ten-year production hindcast is expected to be compatible with the scale of an ECMWF/EMI R&D Project, provided that the output strategy remains selective (ECMWF, 2026), and subject to confirmed scalability under the selected HPC architecture and I/O configuration.

The allocation must account not only for the final production run, but also for spin-up tests, failed or repeated runs, sensitivity experiments, I/O benchmarking, pre- and post-processing, and limited weak-constraining or nudging tests on selected variables and time windows.

Project Year	Main activity	SBU request	Accumulated storage
Year 1	One-year free coupled run; preprocessing and post-processing chain; I/O benchmark; final choice of archived BFM variables	5 million SBU	20 TB
Year 2	First multi-year production segment; validation against satellite, HF radar, Argo/BGC-Argo and in situ datasets	15 million SBU	60 TB
Year 3	Completion of the ten-year hindcast; selected sensitivity experiments; selected	20 million SBU	100 TB

	weak-constraining or nudging tests; final archive		

The first year is deliberately designed to reduce uncertainty before the long production phase. The one-year free simulation will quantify wall-clock performance, coupling overhead, I/O load, compression ratios, storage requirements and post-processing cost. The requested computational resources are not only to perform the coupled integrations but also to preserve the temporal evolution of mesoscale and submesoscale physical–biogeochemical processes that shape productive structures, trophic indicators and potential feeding habitats over decadal timescales.

Work plan details

In Year 1, the emphasis will be on technical and physical consistency: stability of the coupled model, boundary forcing, restart strategy, seasonal evolution of SST, mixed layer depth, currents and surface chlorophyll. No data assimilation will be applied during this first phase. The goal is to establish a reproducible free-running baseline and to quantify the model behaviour before introducing additional constraints.

In Year 2, validation will move toward process-oriented metrics, depending on the available datasets. Surface temperature and chlorophyll will be compared with satellite products, including Mediterranean SST and ocean-colour datasets (Copernicus Marine Service, 2026a; Copernicus Marine Service, 2026b). Surface currents will be compared with HF radar observations in the Ligurian and Northern Tyrrhenian Seas (HFR-LaMMA, 2026; Consorzio LaMMA, 2026). Temperature and salinity profiles will be evaluated using Argo, gliders and CTD data. Biogeochemical validation will use BGC-Argo profiles where available, together with satellite ocean colour, in situ data and CMEMS products as large-scale references (Argo, 2026; BGC-Argo, 2026). Metrics will include both pointwise statistics and object-based diagnostics, because high-resolution models can reproduce realistic structures while still showing phase errors at a fixed point. These object-based diagnostics will also support the identification and validation of productive structures, retention areas and habitat-related indicators relevant to potential feeding habitats.

In Year 3, the validated free-running hindcast and the derived trophic and habitat-related indicators will remain the primary deliverables. Depending on the outcome of the validation phase, selected sensitivity or weak-constraining experiments may be performed on limited time windows. These may include SST nudging, satellite chlorophyll constraints, adjustments of selected physical variables, or tests on river nutrient inputs. Their purpose will be to quantify the sensitivity of the hindcast to specific observational constraints and uncertain forcings, rather than to produce a full assimilative reanalysis within this project.

Finally, the project will benefit from recent and ongoing regional initiatives that can strengthen the validation framework and increase the reusability of the modelling workflow. SEAsteMAR field campaigns will provide observations in dynamically active areas, including measurements near oceanographic fronts, CTD profiles and ecological context (SEAsteMAR, 2026). PNRR-MER will contribute to the broader national framework for marine ecosystem monitoring and to the development of reusable analysis tools (ISPRA, 2026; OGS, 2026). In addition, the LaMMA HF radar network in the Ligurian and Northern Tyrrhenian Seas represents a key observational asset, as it provides hourly surface-current fields directly comparable with the temporal resolution of the proposed model output (HFR-LaMMA, 2026; Consorzio LaMMA, 2026).

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