REQUEST FOR A SPECIAL PROJECT 2022–2024

MEMBER STATE: Italy

Principal Investigator[1]: Carlo Brandini

Affiliation: Consorzio LAMMA / CNR

Address: Via Madonna del Piano 10

50019 Sesto Fiorentino (Firenze)

Other researchers:
Valerio Capecchi (Consorzio LAMMA)
Michele Bendoni (Consorzio LAMMA)
Alessio Innocenti (Consorzio LAMMA)
Maria Fattorini (Consorzio LAMMA/CNR)
Stefano Querin (OGS)

Project Title:

Numerical investigation of circulation changes in the North Western Mediterranean through downscaling of CMEMS reanalysis data

If this is a continuation of an existing project, please state the computer project account assigned previously.	**SP** ________________	
Starting year: (A project can have a duration of up to 3 years, agreed at the beginning of the project.)	2022	
Would you accept support for 1 year only, if necessary?	YES ☒	NO ☐

Computer resources required for 2022-2024: (To make changes to an existing project please submit an amended version of the original form.)		**2022**	**2023**	**2024**
High Performance Computing Facility	(SBU)	3 000 000	8 000 000	10 000 000
Accumulated data storage (total archive volume)[2]	(GB)	2 000	6 000	12 000

Continue overleaf

[1] The Principal Investigator will act as contact person for this Special 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.

Principal Investigator: Carlo Brandini

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Extended abstract

Abstract

In this Special Project a downscaling of the circulation and biogeochemical reanalysis data available through CMEMS for the period 1987-2021 (physics) and 1999-2021 (biogeochemistry) over the North Western Mediterranean area is proposed. Forcing data derives from a previous special project for the dynamic downscaling of the ERA5 reanalysis data over the North-Western Mediterranenan (SPITBRAN). The downscaling is achieved through the non-hydrostatic MITgcm model (as in this area important convective processes occur) and BFM. This project represents one of the first attempts to realize a high resolution coastal downscaling of the circulation reanalysis models, to better understand the impact of climate change on coastal circulation.

Motivation

In recent years, increasing attention is being paid to variations in global atmospheric and ocean circulation due to long-term climate evolution processes. Only a few studies have been undertaken to try to better understand the changes in ocean circulation on a regional and coastal scale. The resolution adopted for long-term ocean models was usually rather low, and there was also a lack of homogeneous data from which to extract information and support (giving initial / boundary conditions) simulations for limited area models.

The recent vailability of data from European services such as the Copernicus Climate Change Service (C3S), and the Copernicus Marine Service (CMEMS), as well as relevant ECMWF reanalysis datasets, allows to realize, through hindcasts obtained from data of homogeneous quality, an evaluation of the evolution of marine circulation for the latest 30-35 years (since 1987), in particular as regards regional and coastal areas where calibration and validation data for the numerical circulation models are now available.

Regarding the regional / coastal area of interest for this study, the North-Western Mediterranean area has specific characteristics, which need to be better explored especially with regard to possible long-term effects in the circulation regime. This area has a dominant mesoscale circulation component (Pinardi et al, 2013), with an essentially cyclonic character (locally also with modulated by anticyclonic circulation structures).

However, the main feature of this area is a northward boundary intensified current called the North Mediterranean current, sometimes also known as the "Liguro-Provencal-Catalan Current": that is the northern branch of the cyclonic gyre circulation of the northwestern Mediterranean Sea (Millot, 1999). This current originates from the confluence of two currents (flowing along the eastern and western coasts of Corsica), which in turn have a typical seasonal variability. In particular, the Eastern Corsica Current (ECC), which crosses the Corsican channel, flows from the south to the north especially in the winter season, while in the summer the flow tends to be interrupted and sometimes reversed (Astraldi and Gasparini, 1992).

The balance of such mass exchanges it is very important because it is linked to baroclinic dynamics on which it has a great influence the temperature distribution over the entire water column. This baroclinic current is, at first order, in geostrophic balance and flows westward along the continental shelf. During winter and certain upwelling conditions, the Northern Current separates the fresh and nutrient-rich coastal waters from the salty and oligotrophic offshore waters (Barrier et al, 2016).

The North Mediterranean current is one of the most persistent corporate characteristics of the whole Mediterranean, and plays a role, in the Mediterranean, comparable to that of the great ocean currents in the oceans because it conveys the masses of water and closes cyclonically the circulation over the North Weastern Mediterranean area (Pinardi et al, 2013). Moreover this area has a fundamental role in the water mass formation cycle in the Mediterranean as the Western Mediterranean Deep Water (WMDW) is formed in the Gulf of Lion area through convective processes forced by the action of the dominant Mistral wind.

The understanding of any long-term trend in the regional/coastal circulation is important because the Western Mediterranean area hosts the Pelagos sanctuary, a Special Protection Area of Marine Interest (SPAMI) whose waters host, in the summer period, a large number of large Marine vertebrates (cetaceans) that coexist in an area of exceptional biodiversity. This study proposes to use a long-term study on the circulation of the North-Western Mediterranean with the main objective of characterizing the long-term variability of the circulation and in particular of the Mediterranean Northern current that could be used as an indicator of climate change that intervene throughout the Mediterranean.

Unlike other long-term studies, this study proposes:

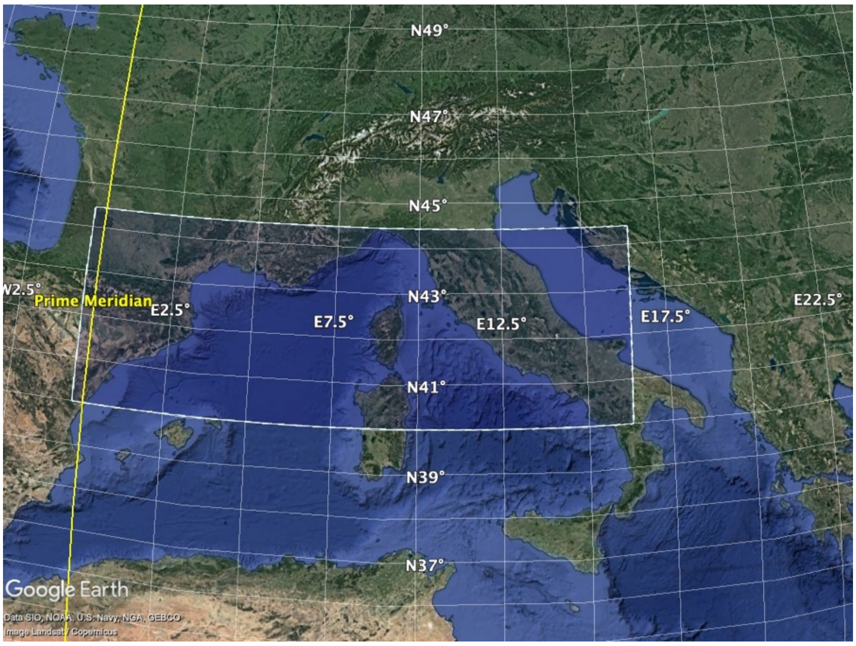
i) a characterization of long-term circulation trends focused in a coastal domain through a limited area model, using high resolution models aimed at downscaling presently available reanalysis data;
ii) the comparison of numerical results with some recently available data including a large number of HF radars implemented in the area during the last 10 years (2012-2021)
iii) the use of a non-hydrostatic circulation model (MITgcm) which is essential to reproduce convection mechanisms at the base of the Deep Water Formation, one of the most important processes that take place in this area
iv) The use of a biogeochemical model (BFM) dynamically coupled with the regional ocean circulation model, to better understand the impact of changes in circulation regimes on biogeochemical fluxes in this area so important for its outstanding biodiversity features.

This project will also benefit from some concurrent initiatives such as:

- the Interreg Med "Sharemed" project on the assessment of environmental threats in the Mediterranean, in which the North-Western Med area was chosen as a pilot area (in collaboration between OGS, MIO and LAMMA) : https://sharemed.interreg-med.eu
- the H2020 SCORE (Smart Control of the Climate Resilience in European Coastal Cities) project, on the theme of the resilience of coastal cities to the environmental threats also caused by climate change : https://cordis.europa.eu/project/id/101003534/it
- the HPC-TRES program and in particular the activity "Study of the evolution of chlorophyll fronts through high resolution models, HF radars and data assimilation" relative to research line A8 of the HPC-TRES scientific plan, still in collaboration between LAMMA and OGS : https://www.inogs.it/en/node/1774

Scientific plan

At a first stage, a regional circulation hindcast will be performed over the North-Western Mediterranean Sea by downscaling existing products available through the Copernicus Marine Service (CMEMS). The reference model chosen for this downscaling is the MIT General Circulation Model (MIT-gcm) a non-hydrostatic numerical circulation model designed for study of the atmosphere, ocean, and climate, developed to to simulate fluid phenomena over a wide range of scales (Marshall et al., 2007). This model was already applied to a wide range of situations, from global scales (Menemenlis et al. 2005), to internal seas such as the Mediterranean Sea (Artale et al., 2009; Reale et al. 2020), up to regional areas within the Mediterranean itself (Cossarini et al., 2017). It is believed that in the high resolution simulation of 3D circulation especially when convective phenomena are so relevant, non-hydrostatic models should be preferred, as convective processes on the kilometer scale are fundamentally non-hydrostatic (Marshall et al., 1997).



The model will be applied in the North-Western Mediterranean area, north of the latitude of 40 ° N. In the same area other circulation models are operational, including the operational ROMS model available from the LAMMA Consortium (http://www.lamma.toscana.it/mare/modelli/correnti). The entire computation domain is thus delimited from -0.4 ° E to 15.4 ° E (in longitude), and from 40°N to 44.5° N (in latitude). It is believed that, on a rather large regional / coastal area like this one, a compromise resolution between accuracy of representation of the main oceanographic processes and computational/storage cost, could be around 1/64 ° which, that at the latitude of the NWMED is equivalent to about 1.5 km. The number of grid points with these assumptions will be around 1024 x 288. To be able to represent even the deepern part of the model domain, we will include at least 60 vertical z-levels. MITgcm uses a regular domain decomposition, and the number of elements in the x and y direction must be divisible by integer numbers.

As regards bathymetric data the latest 2018 EMODnet DTM will be used, that has a grid resolution of 1/16 × 1/16 arc minutes (about 115 × 115 meters). Initial conditions as well as boundary conditions will be obtained from CMEMS data. In particular, the reference dataset is the new Med MFC physical reanalysis product (MEDSEA_MULTIYEAR_PHY_006_004) that is generated by a numerical system composed of an hydrodynamic model, supplied by the Nucleous for European Modelling of the Ocean (NEMO) and a variational data assimilation scheme (OceanVAR) for temperature and salinity vertical profiles and satellite Sea Level Anomaly along track data (Escudier et al, 2020), with a horizontal grid resolution of 1/24˚ (ca. 4-5 km).

River data for the for the main sources present in the area (e.g., Rhone, Ebre, Arno) will be taken from climatological dataset (also available through C3S). As regards to the atmospheric forcing, the dataset obtained from the previous Special Project "Evaluation of coastal climate trends in the Mediterranean area by means of high-resolution and multi-model downscaling of ERA5 reanalysis" will be used, that is a high resolution downscaling of the ERA5 dataset over the whole Mediterranean but with a special focus on the North-Western Mediterranean. The project has been completed in 2021 and forcing data are available from 1979 to 2021 (Vannucchi et al, 2021).

The native-MITgcm output binaries can be converted into NetCDF at the post-processing stage.Indeed, MITgcm has a specific package for dumping NetCDF files

Various data are available in the area for validation and comparison, in particular, starting from 2011, HF radar data collected by various entities including the University of Toulon – MIO, CNR-ISMAR, and by the Consortium itself. LAMMA. These observations, present in various initiatives and projects such as JERICO-3 and SICOMAR-Plus, are very important for the calibration and validation of surface current data.

At a second stage a coupled model between the MITgcm and the Biogeochemical Flux Model (BFM), developed by Cossarini et al (2017), and available through a collaboration with OGS, will be implemented in the same area. The BFM is a bio geochemical model based on plankton functional type formulations, and it simulates the cycling of a number of constituents and nutrients within marine ecosystems. This will allow a complete downscaling in the North-Western Mediterranean area also as regards the current biogeochemical reanalysis products available present on CMEMS for the period. The reference product in this case is the Mediterranean Sea biogeochemical reanalysis at 1/24° of horizontal resolution (ca. 4 km) covers the period 1999-2019 and is produced by means of the MedBFM3 model system (Teruzzi et al, 2021).

Workplan

First year

i) Configuration of the MIT-gcm model for the NWMED
ii) Creation of numerical grids, initial/boundary conditions and forcings
iii) Run of the regional NWMED-MIT model for the last 10 years (2012-2021)
iv) Validation and analysis of the results (comparison with HF-radar, in-situ data and satellites)

Second year

v) Run of the regional NWMED-MIT model for the remaining 24 years (1987-2011)
vi) Analysis of the results for the whole reference period (1987-2021)

Third year

vii) Configuration of the coupled MITgcm–BFM model for the NWMED
viii) Creation of initial/boundary conditions and forcings for the BFM model
ix) Run of the regional coupled MITgcm-BFM model for the NWMED for the last 23 years (1999-2021)

Involved Software

The general documentation for the coupled (hydrodynamic-biogeochemical) model MITgcm-BFM can be found here:

- hydrodynamic model: http://mitgcm.org
- biogeochemical model: https://cmcc-foundation.github.io/www.bfm-community.eu/
- coupler (MITgcm-BFM): https://gmd.copernicus.org/articles/10/1423/2017/

Source code available at:

- https://github.com/MITgcm/MITgcm (hydrodynamic model)
- https://github.com/CMCC-Foundation/BiogeochemicalFluxModel (biogeochemical model)
- https://github.com/gcossarini/BFMCOUPLER (coupler)

Computer resources

The computer-resource requirements have been estimated on the previous experience with the Special Project SPITCAPE and SPITBRAN.

The decade 2012-2021 will be performed during the first year of the Special Project (2022), the remaining period 1987-1997 during the second year (2023). In the third year (2024) a full downscaling of the physical and biogeochemical part for the North-Western Mediterranean will be exploited. The use of the coupled MITgcm-BFM model will require greater computational resources than the use of the uncoupled model because, in addition to the simultaneous execution of multiple numerical models, the data exchange times between models must be added.

For the first year of uncoupled simulation, we estimate a computational cost of about 3 M SBU. Hence the computational cost estimated for the second year is about 8 M SBU, and about 10 M SBU for the third year, when coupled physical-biogeochemical simulations will be performed.

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