# <u>LATE</u> REQUEST FOR A SPECIAL PROJECT 2021–2023

**MEMBER STATE:** Italy

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**Project Title:** NEMO4 sensitivity experiments

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|---|---|---|
| If this is a continuation of an existing project, please state the computer project account assigned previously. | **SP** ___________________ | |
| Starting year:<br>(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 the years:**<br>(To make changes to an existing project please submit an amended version of the original form.) | | **2021** | **2022** | **2023** |
|---|---|---|---|---|
| High Performance Computing Facility | (SBU) | - | 8,600,000 | 9,500,000 |
| Accumulated data storage (total archive volume)[2] | (GB) | - | 36,500 | 59,000 |

*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 an annual progress report of the project's activities, etc.
[2] 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.

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# Extended abstract

**Overview**

In this special project, we plan to perform sensitivity experiments with NEMO4 to reproduce the strength and low-frequency variability of the Atlantic Meridional Overturning circulation to different vertical mixing parameterizations. This special project will help to design the tuning experiments with EC-Earth4. EC-Earth4 is the new version of the EC-Earth climate model that is currently under development and will participate in the next phase of the Coupled Model Intercomparison Project, CMIP7.

**1. Introduction**

***1.1 General context and current status***

EC-Earth is an Earth System Model (ESM) collaboratively developed by the EC-Earth Consortium, which involves more than 20 institutions from several European countries. The model's current generation is the EC-Earth3 (Doscher et al., 2021), and it participated in the Coupled Model Intercomparison Project, Phase 6 (CMIP6). The atmospheric component of EC-Earth3 is constituted by a modified version of cycle 36r4 Integrated Forecast System (IFS; ECMWF, 2009) that includes the land-surface scheme H-TESSEL (Balsamo et al., 2009). The ocean component is represented by the Nucleus for European Modelling of the Ocean (NEMO; Madec, 2008) version 3.6, and the Louvain la Neuve (LIM3; Vancoppenolle et al., 2012) sea-ice model. The OASIS3-MCT (Valcke, 2013) coupler version 3.0 exchanges fields between the atmosphere and ocean components.

EC-Earth3 contributed to CMIP6 in different configurations. With TL255L91 resolution in the atmosphere and ORCA1L75 ocean grid, the standard one shows a multi-centennial variability in the Atlantic Meridional Overturning Circulation (AMOC; Doscher et al., 2021) that is also reflected in many other variables of the climate system in the pre-industrial experiments. Moreover, this low-frequency variability is reported in different climate models that share the same ocean component NEMO (Jiang et al., 2021), suggesting that it could be associated with some inherent property of the ocean model.

A new version of the EC-Earth model, the EC-Earth4, is currently under development for participating in the next phase of CMIP, CMIP7. The atmospheric component IFS will be replaced by OpenIFS cy43, and the ocean component will be updated to NEMO4.

***1.2 Objective and expected contributions to the field***

This special project aims to study the sensibility of the AMOC (both in its strength and its low-frequency variability) modelled by NEMO4 to a set of parameters associated with vertical mixing. This study would help to a) understand the model sensitivity to such parameters and b) better design the tuning experiments that will be performed during the development phase of EC-Earth4.

## 2. Methodology

### *2.1 The models*

Most of this project will be carried out with version 4 of the global ocean model NEMO, standing for "*Nucleus for European Modelling of the Ocean*". The main component of NEMO, the *Ocean Engine* (NEMO-OCE, 2019), computes the ocean dynamics and thermodynamics by solving the primitive equations. NEMO-OCE is interfaced with a sea-ice model, the *Sea Ice Modelling Integrated Initiative* (SI3, 2019), which resolves the sea ice dynamics and thermodynamics, brine inclusions and subgrid-scale thickness variations. NEMO-OCE can also be coupled with passive tracer and biogeochemical models and with atmospheric circulation models via the OASIS coupler.

NEMO uses a curvilinear orthogonal grid in the horizontal direction and a full or partial step *z*-coordinate, or *s*-coordinate, or a mixture of the two, in the vertical direction. The distribution of variables is a three-dimensional Arakawa C-type grid, and several physical choices are available to describe ocean physics. We plan to use the ORCA1 grid configuration (around 1ºx1º horizontal resolution) for the experiments.

The second year of the project will be carried out using the new version of the EC-Earth climate model, EC-Earth4, which will have a low-resolution configuration based on the Tco95L91 atmospheric grid coupled with the ORCA1 ocean configuration.

### *2.2 The experiments*

The experiments proposed here aim at evaluating the model sensitivity in reproducing the strength and low-frequency variability of the AMOC. With this purpose, we will test the different choices to compute the vertical eddy viscosity ($A_u^{vm}$, $A_v^{vm}$) and diffusivity ($A^{vT}$, $A^{vS}$) coefficients for temperature and salinity, respectively. The Amoc index at different latitudes, the Atlantic meridional streamfunction and the Atlantic total transports of heat and freshwater will be analysed.

During the first year of the project, it is planned to run standalone ocean experiments with NEMO4, ORCA1 configuration. Each experiment will last 250 years and will be set as follows:

<u>*A) Sensitivity to the vertical mixing*</u> (total of 4000 model years)

A.1) Constant mixing (*ln_zdfcst*). This is the crudest way to define the vertical ocean physics and we want to test it with constant values of $A_u^{vm} = A_u^{vm} = 1.2 \text{x} 10^{-4}$ $m^2s^{-1}$ and $A^{vT} = A^{vS} = 1.2 \text{x} 10^{-5}$ $m^2s^{-1}$ (total of 250 yrs).

A.2) Richarson number dependent (*ln_zdfric*). The vertical mixing coefficients depend on the local Richarson number and are diagnosed from the large scale variables computed by the model. This scheme will be tested in two versions (total of 500 yrs):

- with enhanced mixing in the Ekman layer (*ln_mldw*);
- without enhanced mixing in the Ekman layer.

A.3) Turbulent Kinetic Energy (TKE) closure (*ln_zdftke*). The vertical eddy viscosity and diffusivity coefficients are computed from a TKE turbulent closure model based on a prognostic equation for the turbulent kinetic energy and a closure assumption for the turbulent length scales. This scheme will be tested in different configurations (total of 1500 yrs):

- with the turbulent length scale bounded by the distance to surface and bottom (*nn_mxl=0*);
- with the turbulent length scale bounded by the local vertical scale factor (*nn_mxl=1*);
- with the turbulent length scale computed as the first vertical derivative of mixing length bounded by *nn_mxl=0* with the same upward and downward length scales (*nn_mxl=2*);
- as before but with distinct dissipative and mixing length scale (*nn_mxl=3*);
- with the penetration of the TKE below the mixed layer (*nn_etau=1*);

- with the penetration of the TKE just at the base of the mixed layer (*nn_etau=2*).

A.4) Generic Length Scale closure (*ln_zdfgls*). This is a turbulent closure scheme based on prognostic equations for the turbulent kinetic energy and for the generic length scale. The different predefined closure types will be assessed (total of 1000 yrs):

- Mellor and Yamada, 1982 *(nn_clos=0*);
- Rodi, 1987. (*nn_clos=1*);
- Wilcox, 1988 (*nn_clos=2*);
- Umlauf and Burchard, 2003; Kantha and Carniel, 2003 (*nn_clos=3*).

A.5) OSMOSIS boundary layer scheme (l*n_zdfosm*). It refers to how to specify the Stokes surface drift and penetration depth. We will test 3 options (total of 750 yrs):

- the Stokes drift is assumed to be parallel to the surface wind stress, with magnitude consistent with a constant turbulent Langmuir number *(nn_osm_wave=0*);
- the Stokes drift is assumed to be parallel to the surface wind stress, with a magnitude as in the classical Pierson-Moskowitz wind-sea spectrum. (*nn_osm_wave=1*);
- the Stokes drift is taken from ECMWF wave model output, though only the component parallel to the wind stress is retained (*nn_osm_wave=2*).

*B) Sensitivity to convective processes* (total of 500 yrs)

B.1) Enhanced vertical diffusion (*ln_zdfevd*). In this case, the vertical eddy mixing coefficients are set to be very large in regions where the stratification is unstable (total of 250 yrs).

B.2) Non-penetrative Convective algorithm (*ln_zdfnpc*). It mixes downwards instantaneously the statically unstable portion of the water column until the density structure becomes neutrally stable (total of 250 yrs).

During the second year of the project, it is planned to run coupled ocean experiments with EC-Earth4. Depending on the results obtained during the first year, we will evaluate the coupled response to selected parameters. In particular, we will choose the five parameters that show the highest sensibility in the standalone configuration. Each experiment will last 100 yrs with a total of 500 model years.

**3. Justification for the resources requested**

From scaling tests, each model year of NEMO4-ORCA1 standalone costs around 1900 SBU, whereas each model year of the coupled EC-Earth4 costs around 19000 SBU. Therefore, for running 4500 model years (see Section 2.2) with NEMO4 standalone during the first year of the special project, we estimate that it will be needed about 8.6 million of SBU. Besides, for running 500 model years of the coupled version of EC-Earth4, we need roughly 9.5 million of SBU.

With regards to the storage, the requirements for the storage are around 8.1 GB/model-year for NEMO4 standalone and 45 GB/model-year for EC-Earth4. This will imply 4500x8.1GB = 36.5 TB for the first year and 500x45GB +36.5 TB = 59 TB at the end of the second year.

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