REQUEST FOR A SPECIAL PROJECT 2019–2021

MEMBER STATE: France

Principal Investigator[1]**:** Yves Morel

Affiliation: CNRS/LEGOS

Address: OMP/LEGOS, 14 avenue Edouard BELIN, 31400 TOULOUSE (France)

Other researchers: Florent Lyard (CNRS/LEGOS, Toulouse, France), Benoit Tranchant (CLS, Ramonville, France), Loren Carrere (CLS, Ramonville, France)

Project Title:

Improvement of the barotropic tide in the 1/12° global ocean NEMO model

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.)	2019	
Would you accept support for 1 year only, if necessary?	YES ☒	NO ☐

Computer resources required for 2019-2021: (To make changes to an existing project please submit an amended version of the original form.)		**2019**	**2020**	**2021**
High Performance Computing Facility	(SBU)	1,100,000	4,200,000	N/A
Accumulated data storage (total archive volume)[2]	(GB)	2,450	7,350	N/A

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] 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: Yves Morel (CNRS/LEGOS)

Project Title: Improvement of the barotropic tide in the 1/12° global ocean NEMO model

Extended abstract

The completed form should be submitted/uploaded at https://www.ecmwf.int/en/research/special-projects/special-project-application/special-project-request-submission.

All Special Project requests should provide an abstract/project description including a scientific plan, a justification of the computer resources requested and the technical characteristics of the code to be used.

Following submission by the relevant Member State the Special Project requests will be published on the ECMWF website and evaluated by ECMWF as well as the Scientific and Technical Advisory Committees. The evaluation of the requests is based on the following criteria: Relevance to ECMWF's objectives, scientific and technical quality, disciplinary relevance, and justification of the resources requested. Previous Special Project reports and the use of ECMWF software and data infrastructure will also be considered in the evaluation process.

Requests asking for 1,000,000 SBUs or more should be more detailed (3-5 pages). Large requests asking for 10,000,000 SBUs or more will receive a detailed review by members of the Scientific Advisory Committee.

Abstract

Simulating an accurate barotropic tide solution in a global ocean high resolution (1/12°) model is challenging. The tide modelling in an ocean global model is complex which is mainly due to the presence of high frequency processes and to the sensitivity of bathymetry variations.
The main focus of this study is on the implementation of a new barotropic tide solution in order to ensure an accurate barotropic tide without disrupting the eddying general circulation. To do so, different solutions will be tested. The first, classical, one is to modify/improve the tide dynamics in the model (bathymetry, bottom friction, tide loading and tide dissipation via internal tide generation). A second solution is through assimilation of data coming from the state of the art tide model FES2014 (see below). It is the essential step before doing realistic simulation of baroclinic tides.
The NEMO model (Nucleus for European Modelling of the Ocean (https://www.nemo-ocean.eu) is a platform for ocean modelling developed by a European consortium, Madec (2008). The NEMO model is widely used in the CMEMS framework in an operational context for short term ocean forecasting but also for longer ocean reanalysis.
This project will use the global configuration at 1/12° named MFC-GLO used in CMEMS that explicitly solve the barotropic tides from an astronomical tide potential.
This study will also use FES2014 (Carrere et al., 2016) which is the last version of the FES (Finite Element Solution) tide model developed in 2014-2016.

1. Detailed description of the study

This project aims to improve the barotropic tide solution in the global NEMO model. Different solutions are proposed in this study and detailed below. The improvement will be tested in the global configuration at 1/12° named MFC-GLO used in CMEMS, based on comparison with observations.

1.1. Bathymetry changes

First, we will improve the bathymetry that is a crucial parameter for the tide accuracy and particularly on the continental shelf. For oceanic tide purpose, the LEGOS laboratory maintains and periodically updates a global bathymetry dataset that we will use and interpolate on the NEMO grid.
An optimization work will be done on the (i) NEMO bathymetry, (ii) the coastline and (iii) the sea/land mask in particular areas of interest where tidal wave propagation is important.

1.2. Self-attraction and Loading (SAL)

The second improvement deals with the Self-attraction and Loading (SAL) effects driven by the tidal forcing itself, see Hendershott et al., (1972). In a global configuration, these effects have to be taken into account in order to achieve a reasonable accuracy for the sea surface elevation variations associated with tides. The SAL effects can be calculated from the ocean model mass field at every time step. However, solving for the SAL at every time step is extremely expensive for a hydrodynamic time-stepped model, as discussed by Stepanov and Hughes (2004). In this study, we plan to use a self-consistent method similar to the one used in Ngodock et al., (2016) to compute the SAL effects. It consists of applying a first guess of the SAL determined by a calculation based on earth elasticity model coupled to a tide atlas such as FES2014. This gives a first surface elevation that is then used to compute the final SAL to be applied. The final elevation field is then corrected from this SAL effects.

1.3. Wave drag parameterization

The third improvement deals with an accurate estimation of internal tide energy loss near rough bathymetry by the linear topographic internal wave drag parameterization (see Arbic et al., 2010). Indeed, a 1/12° ocean model is able to generate 70% of observed internal waves (Nugroho et al. 2017, Niwa and Hibiya 2011). Thus 30% of the tidal energy dissipation by internal tide generation is not solved. In addition internal waves are often dissipated numerically at the wrong places (Nugroho et al. 2017). In this study, we will take into account an accurate estimation of internal tide energy loss and implement a wave drag parameterization coming from FES2014 in the NEMO model.

1.4. Assimilation/projection of the FES2014 solution

The last development concerns a new methodology. It is based on an original idea that consists in the modification of the tide generator (the astronomical tidal forcing but also the dissipation terms) so as to reproduce a solution close to the FES2014 solution, which are the state of the art tide solutions in the oceanographic community. The FES 2014 solution will first be projected on the NEMO grid and the tide generator will be modified so as to exactly reproduce the projected FES2014 velocity fields and the associated free surface variations. This method has no overhead CPU cost and allows a better separation of the slow and rapid (tide) ocean motions, so that different bottom drag can be applied to the slow circulation. In classical methods, this requires time filtering of the total currents, a step requires additional computations, which will be avoided here.

2. System description

2.1. Ocean Model configuration

The NEMO model (Nucleus for European Modelling of the Ocean (https://www.nemo-ocean.eu) is a platform for ocean modelling developed by a European consortium, see Madec (2007). The NEMO model is widely used in the CMEMS framework in an operational context for short term ocean forecasting but also for longer ocean reanalysis.

This project will use the global configuration at 1/12° named MFC-GLO used in CMEMS that explicitly solves the barotropic tides from an astronomical tide potential.

Two global ocean configuration of NEMO will however be used in this study: one with 1/12° (3–9 km) horizontal grid spacing (ORCA12) and one with 1/4° (10–27 km) grid spacing (ORCA025), the latter being used for quicker tests of the assimilation/projection method. Both configurations have 75 z-levels in the vertical direction with thicknesses ranging from 1 m at the surface to 480 m near the bottom at a maximum model depth of 7 km. The bathymetry used in these configurations is based on GEBCO08 and has been interpolated on the NEMO grid without any smoothing. The bathymetry has been locally modified by hand editing mainly in the straits and passages where the sill depths have a major influence and constrain the transports.

The model is forced at the surface with three-hourly atmospheric fields from ERAinterim reanalysis (ECMWF), which is converted to surface fluxes using the bulk formulae coming from IFS model. Coastal and rivers freshwater inputs are a monthly runoff climatology built from (Dai and Trenberth, 2002).

The model includes atmospheric pressure forcing and tidal forcing for 11 tidal constituents, the latter are applied to NEMO as additional atmospheric pressure forcing. The 11 tidal constituents are made up of two long-period tides (***Mf*** and ***Mn***), the four largest diurnal (***K1, O1, P1*** and ***Q1***), the semidiurnal (***M2, S2, N2*** and ***K2***) and one non-linear (***M4***) tidal constituents.

This NEMO configuration uses the non-linear variable volume (VVL) scheme for the free surface. The k-ε turbulence closure, implemented inside GLS (Generic Length Scale) formalism (Umlauf and Burchard, 2003) is used for vertical mixing. The LIM 3 ice model will be used (Rousset et al., 2015).

2.2. Tide solution

FES2014 (Carrere et al., 2016) is the last version of the FES (Finite Element Solution) tide model developed in 2014-2016. FES2014 is based on the resolution of the tidal barotropic equations (T-UGO model/ http://sirocco.omp.obs-mip.fr/ocean_models/tugo) in a spectral configuration. It is an improved version of the FES2012 model (Carrère et al., 2012).

3. Planning

3.1. First year 2019

Some preliminary tests will be done during the first year in order to validate/test the barotropic solution (2D) of NEMO. Different simulations will be done to test:

- The new bathymetry
- The SAL effects
- The wave drag parameterization

All test simulations will have a 1-month duration to test the barotropic tide solution and should not exceed 3 months, both with ORCA025 and ORCA12.

The total duration should not exceed 1 year for the ORCA025 simulations and 6 months for the ORCA12 simulations.

3.2. Second year 2019

The new approach, i.e., the FES2014 solution projected on the NEMO grid will be mainly tested with ORCA025.

Finally, a one-year simulation of ORCA12 (the best solution) should be produced in order to validate both the 2D and 3D fields.
The total duration should not exceed 2 years for the ORCA025 simulations and 1 year for the ORCA12 simulation.

4. Numerical cost

4.1. SBU

As mentioned above, two model configurations will be used. ORCA025_LIM3 (global NEMO model at 1/4° and LIM3 ice model) will be used for basic tests, and ORCA12_LIM3 (global NEMO model at 1/12° and LIM3 ice model) is the target configuration. The two model configurations will be used with the same vertical discretization of 75 levels. The computational cost of the ORCA025_LIM3 configuration is 100,000 System Billings Units (SBU) per year simulated. The ORCA012 computational cost is about 40 times greater than ORCA025 which gives approximatively 4,000,000 SBU per year.

4.2. Storage

In order to validate the barotropic tide in NEMO, all experiments planned within this project with the ORCA025 configuration will have a time duration of 3 months at the most. Some test experiments with the ORCA12 configuration will have a time duration between 1 and 3 months but the target experiment (second year) is at least a one-year experiment.
The NEMO output will be saved hourly for SSH, barotropic velocities and SST. 3D variables such as U, V, T and S will be saved daily (average), yielding ~4,6 TB for one year with the ORCA12 configuration.
The storage space estimated for a 1-year (cumulated test simulations) of ORCA025 simulation is 150Gb for hourly 2D fields.

The table hereafter summarizes the costs (SBU and storage):

ORCA025	year 1	year 2		Storage for 2 years (Gb)	
SBU	100,000	200,000		Year 1	year 2
Duration of experiments	1 year	2 years		150Gb	300Gb
ORCA12	year 1	year 2		Storage for 2 years	
SBU	1,000,000	4,000,000		year 1	year 2
Duration of experiment	6 months	1 year		2,300Gb	4,600Gb
TOTAL SBU	1,100,000	4,200,000	TOTAL storage	2,450 Gb	4,900 Gb

References

Arbic, B. K., A. J. Wallcraft, and E. J. Metzger (2010), Concurrent simulation of the eddying general circulation and tides in a global ocean model, Ocean Modell., 32, 175–187, doi:10.1016/j.ocemod.2010.01.007.

Carrère L., F. Lyard, M. Cancet, A. Guillot, L. Roblou, FES2012: A new global tidal model taking taking advantage of nearly 20 years of altimetry, Proceedings of meeting "20 Years of Altimetry", Venice 2012.

Carrere L., F. Lyard, M. Cancet, D. Allain, Y. Faugere, R. Baghi, S. Dupuy, A. Guillot and N. Picot " Final version of the FES2014 global ocean tidal model, which includes a new loading tide solution", presentation OSTST La Rochelle, Nov 2016.

Dai, A., and K.E. Trenberth, (2003), New estimates of continental discharge and oceanic freshwater transport, AMS Symposium on Observing and understanding the variability of water in weather and climate, 9-13 Feb. 2003, Long Beach, CA.

Hendershott, M. C. (1972), The effects of solid earth deformation on global ocean tides, Geophys. J. Astron. Soc., 29, 389–402.

Madec, G., NEMO ocean engine, (2008), Notes de l'Institut Pierre-Simon Laplace (IPSL) - Universite P. et M. Curie, B102 T15-E5, 4 place Jussieu, Paris cedex 5.

Ngodock, H. E., Souopgui, I., Wallcraft, A. J., Richman, J. G., Shriver, J. F., & Arbic, B. K. (2016). On improving the accuracy of the M 2 barotropic tides embedded in a high-resolution global ocean circulation model. Ocean Modelling, 97, 16-26

Niwa, Y., Hibiya, T., 2011. Estimation of baroclinic tide energy available for deep ocean mixing based on three-dimensional global numerical simulations. North 1–15. http://dx.doi.org/10.1007/s10872-011-0052-1.

Nugroho, D., A. Koch-Larrouy, P. Gaspar, F. Lyard, G. Reffray and B. Tranchant, Modelling explicit tides in the Indonesian seas: An important process for surface sea water properties, Mar. Pollut. Bull. (2017)

Rousset, C., Vancoppenolle, M., Madec, G., Fichefet, T., Flavoni, S., Barthélemy, A., Benshila, R., Chanut, J., Levy, C., Masson, S., and Vivier, F.: The Louvain-La-Neuve sea ice model LIM3.6: global and regional capabilities, Geosci. Model Dev., 8, 2991-3005, https://doi.org/10.5194/gmd-8-2991-2015, 2015.

Stepanov, V.N., Hughes, C.W., 2004. Parameterization of ocean self-attraction and loading in numerical models of the ocean circulation. J. Geophys. Res. 109, C03037.doi:10.1029/2003JC002034.

Umlauf, L. and Burchard, H.,: A generic length-scale equation for geophysical turbulence models, J. Marine Res. 61, 235–265, doi:10.1357/002224003322005087, 2003.