Design of an improved time-stepping algorithm for the NEMO ocean model (H2020 IMMERSE)

Location: LJK (Jean Kuntzmann Laboratory UMR5224), Grenoble University Campus – France
Starting date: as soon as possible (the position will remain open until a suitable candidate is hired)
Contract Duration: 12 months initially and renewed for 12 additional months by mutual agreement
Gross Salary per month: between 2653€ and 2936€ (according to the experience)
Scientific advisors: Florian Lemarié (Inria), Laurent Debreu (Inria)
External collaborations: Mike Bell (MetOffice, Exeter, UK), Gurvan Madec (LOCEAN, Paris, France)

Team Presentation: the general scope of the Inria AIRSEA project-team (http://team.inria.fr/airsea/) is to develop mathematical and computational methods for the modeling of oceanic and atmospheric flows. The mathematical tools used include both deterministic and statistical approaches. The areas of application range from climate modeling to the local prediction of extreme events. The proposed work will be part of an EU H2020 Innovation action entitled "IMMERSE " (Improved Models for Marine EnviRonment SErvices).

CONTEXT: a goal of the IMMERSE project is to develop a new time-stepping algorithm within the NEMO (Nucleus for European Modelling of the Ocean; *Madec, 2012*) ocean model for improved accuracy and stability. NEMO is a flagship European modeling framework developed by 5 European partners. The numerical kernel is currently based on a Leapfrog (3-level) scheme that provides a good combination between simplicity and efficiency for low-resolution global simulations provided an adequate filtering of its computational mode; e.g. via a Robert-Asselin (RA) filter. However, it is well known that the RA filter increases phase errors, dissipates the physical mode and affects stability (e.g. *Lemarié et al., 2015*). Moreover, Leapfrog can be combined only with centered advection schemes because it is unconditionally unstable for diffusive process. As a consequence, monotonicity or positive-definiteness (either for tracers or layer thickness) comes at a substantial cost and complication. The relevance of Leapfrog for fine-scale simulations and/or with an ALE vertical coordinate is thus questionable (e.g. *Klingbeil et al., 2018*). The overall ambitious objective is to jointly improve the quality, flexibility, and efficiency of the NEMO time-stepping algorithm to broaden its domain of application. Note that NEMO is a primitive equations model discretized on a structured Arakawa C-grid.

DESCRIPTION OF THE WORK: it is proposed to study the evolution toward a two-level time-stepping for the NEMO three-dimensional baroclinic (internal) mode both in the form of a Forward-backward scheme (useful for low-resolution paleoclimate modelling) and of a multi-step Runge-Kutta (RK) scheme. Such approach offers many advantages including the absence of computational mode, good efficiency defined as the ratio between the stability limit and the number of rhs computations, simplified time-refinement for grid embedding techniques, vast literature on energy-conserving, strong stability preserving, or total variation diminishing RK schemes, etc (e.g. *Gottlieb et al., 2001* ; *Sanderse, 2012*).

The first part of the proposed work is to design a Runge-Kutta scheme offering a good compromise between accuracy and stability jointly for advection, internal gravity waves propagation, and treatment of Coriolis term. This task will be carried out considering that both space and time dimensions are discretized whereas numerous studies of time-stepping algorithms assume an exact discretization in space (e.g. *Shchepetkin & McWilliams, 2005*). Such approach allows a more accurate estimate of amplitude and phase errors. As far as the treatment of the barotropic mode is concerned, a recently designed framework to study the stability of mode-splitting will be used to design the time-stepping of the barotropic (external) mode in agreement with the one used for the baroclinic mode (*Demange et al., 2018*).

The second part is to illustrate the expected gain associated to the revised time-stepping compared to the original Leapfrog using a series of idealized testcases. Such testcases will be designed both in a 2D x-z slice model and in a 2D x-y shallow-water model to study a wide range of physical processes and to test all aspects of the dynamical kernel. Note that the actual implementation of the proposed time-stepping algorithm in the NEMO code will be done by the NEMO consortium.

REFERENCES:

- Demange J., L. Debreu, P. Marchesiello, F. Lemarié, E. Blayo, C. Eldred : *Stability analysis of split-explicit free surface ocean models : implication of the depth-independent barotropic mode approximation*, J. Comp. Phys., 2018, submitted
- Gottlieb, S., C.-W. Shu, E. Tadmor : *Strong stability preserving high order time discretization methods*. SIAM Rev. 43(1), 89-112, 2001.
- Klingbeil K., F. Lemarié, L. Debreu, H. Burchard : *The numerics of hydrostatic structured-grid coastal ocean models: state of the art and future perspectives* , Ocean Modell., 2018
- Lemarié F., L. Debreu, G. Madec, J. Demange, J.-M. Molines, M. Honnorat : *Stability constraints for oceanic numerical models: implications for the formulation of time and space discretizations*. Ocean Modell., 2015
- Madec, G.: *NEMO ocean engine*, in: Note du Pole de modélisation No. 27, Institut Pierre-Simon Laplace (IPSL), France, 2012
- Sanderse B. *: Energy-conserving Runge-Kutta methods for the incompressible Navier-Stokes equations*, J. Comp. Phys., 2012
- Shchepetkin A., J. C. McWilliams : *The Regional Oceanic Modeling System : A split-explicit, free-surface, topography-following-coordinate ocean model*, Ocean Modell., 9, 2005

SKILLS AND EXPERIENCE: required qualities

Essential :

- Fortran programming skills
- Good knowledge of discretization techniques and in numerical analysis

Desired :

- Experience with a numerical oceanic or atmospheric dynamical kernel

Applicants must have a PhD in Applied mathematics, or, if not, in atmospheric/oceanic sciences with good background in numerical analysis.

APPLICATION: Please send your detailed Resume, a covering letter showing your interest and letters of recommendation by email to : Florian Lemarié – Inria researcher - florian.lemarie@inria.fr. Consideration of applications will begin immediately.

Formal application must be done through the Inria Jobin platform
<https://jobs.inria.fr/public/classic/en/offres/2018-01144>