## Program LEFE/ MANU-GMMC

**Project Title**

**CHRONOS**

**Years 2013–2015**

<table>
<thead>
<tr>
<th>PI: Florian Lemarié, Laboratoire Jean Kuntzmann, Grenoble, <a href="mailto:florian.lemarie@inria.fr">florian.lemarie@inria.fr</a></th>
<th>Other funding sources: ANR COMODO and INRIA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Participating laboratories: LJK, Mercator-Océan, Ifremer et Laboratoire d’aérologie</td>
<td></td>
</tr>
</tbody>
</table>

### Objectives:

The CHRONOS project is dedicated to the study of time-stepping algorithms in primitive equations oceanic models. The aim is first to study the constraints on the numerics in terms of stability and accuracy for a given application, and then to propose alternatives to existing time-stepping schemes used in global models.

### Main results:

- It is essential to study numerical schemes in a space-time approach to get accurate estimate of the CFL criteria.
- Time-step of eddying global models with an Eulerian vertical coordinate is often restricted by vertical advection.
- Space-time discretizations must be robust and stable for advection and diffusion to maintain good efficiency.
- Coupled space-time schemes offer an efficiency factor that is unrivaled especially when high-order accuracy is required.

---

(Left, a) Maximum time-step allowed for advection depending on the space-time discretizations; (Left, b) Maximum time-step allowed for each process among diffusivity, viscosity, rotation, advection and internal gravity waves using a hierarchy of ORCA configurations. Results are obtained for a third-order upwind scheme in the horizontal and a second-order centered scheme in the vertical. The acronyms are LF=leapfrog, RA=Robert-Asselin filter, AM=Adams-Moulton, AB=Adams-Bashforth, RK=Runge-Kutta, IGW = Internal Gravity Waves. (Right) Map of the process locally limiting the time-step for the $\frac{1}{2}^\circ$ (top) and $\frac{1}{4}^\circ$ (bottom) configurations among rotation (blue), three-dimensional advection (green), and internal gravity waves propagation (black). In both cases, the baroclinic time-step is set by advective processes located at a few hotspots nearshore.
Future of the project: thanks to the CHRONOS project several alternatives to existing algorithmic choices used in state-of-the-art oceanic models have been proposed and thoroughly studied at a theoretical level. Moreover the important properties that the numerical kernel of a given model should satisfy have been emphasized. The next steps are the following:

1. Assess the relevance of the theoretical work on increasingly difficult testcases (particularly the testcases designed during the ANR COMODO project). This work has been initiated in the framework of a collaboration between the LJK and the NEMO system team (Paris) thanks to the hiring of Mustafa Inanoglu (funded by the IPSL from October 2014 to October 2015). The objective is to proceed to an intercomparison between different numerical kernels for the representation of Kelvin and Rossby waves propagation as well as internal gravity waves.

2. The main outcome of the CHRONOS project is the complete redesign of the numerical kernel of the NEMO oceanic model (supported by INSU). This redesign will occur in 2015-2016 notably thanks to frequent long-term visits of Gurvan Madec (CNRS, scientific leader of the NEMO code) in Grenoble.

Main publications

- Lemarié F., L. Debreu, G. Madec, J. Demange, J.M. Molines and M. Honnorat, 2015: stability constraints for oceanic numerical models: implications for the formulation of time and space discretizations. Ocean Modeling, accepted (Preprint available at [https://hal.inria.fr/hal-01065979](https://hal.inria.fr/hal-01065979))

- Demange J., L. Debreu, F. Lemarié, P. Marchesiello and E. Blayo, 2014: numerical representation of internal waves propagation. Tech. Rep. RR-8590, INRIA, [https://hal.inria.fr/hal-01063417](https://hal.inria.fr/hal-01063417)

- Demange J., L. Debreu, P. Marchesiello, F. Lemarié and E. Blayo, 2014: On the use of a depth-dependent barotropic mode in ocean models: impact on the stability of the coupled barotropic/baroclinic system. Tech. Rep. RR-8589, INRIA, [https://hal.inria.fr/hal-01063414](https://hal.inria.fr/hal-01063414)
