Notes on a NEMO Kernel WG

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Objectives

The main objective of the NEMO kernel WG will be to

coordinate implementation of the strategy for the NEMO kernel.

This is likely to include

- agreement of allocation of tasks
- reports on progress and discussion of issues
- discussions to refine/improve the strategy
- discussions of opportunities for funding;

Membership and Meetings

The group will include

- "internal" people working on implementation (such as Gurvan Madec, Jerome Chanut, Andrew Coward, Alex Megann, Dave Storkey, Mike Bell).
- "external" experts who are able to contribute ideas (such as Florian Lemarie, Laurent Debreu, Anne Marie Treguier)
- members of the NDC with specific dynamical expertise/interests (such as David Marshall, Julien le Sommer, Adrian New, Rachid Benshila).

Meetings will be held as needed (once every 6-8 weeks to start with) using Webex. They will be no longer than 60-90 minutes. The agenda is expected to evolve as required to meet the WG objective. To start with it is intended to include one or two 10-minute technical presentations.

Annex: Notes on NEMO kernel

(a) 2-level time-stepping scheme

These notes describe the reasoning behind the transition from a 3-level to a 2-level time-stepping scheme for NEMO. Three types of 2-level scheme will be implemented:

- a forward-backward step (FBS) scheme (useful for 1^{o} climate modelling)
- a 3^{rd} order Runge-Kutta (RK3) scheme
- a compensated time-space scheme (CTS)

The FBS and RK3 will be implemented first as alternative options while the CTS will be implemented later on.

The reasoning behind introducing these new time-stepping schemes is:

(1) a 2-level scheme makes the implementation of AGRIF simpler and cleaner; it enables the 2-way coupling within AGRIF to be perfectly conservative

(2) it similarly simplifies the design of the coarsening of the time-step for passive tracers

(3) it allows larger time-steps to be taken and the computational efficiency to be improved (i.e. the number of calculations per model day to be reduced). For the FBS the time-step can be doubled. With the RK3 scheme (a) the time-step can be 6 times longer (b) only part of the RHS is calculated 3 times per time-step; the expensive viscous, diffusive and monotonic terms are only calculated once. So overall the scheme is 2-3 times more efficient. See additional notes on RK3 below

(4) In order to use these larger time-steps one needs to use (Shchepetkin 2015 Ocean Modelling) an adaptive, Courant number dependent, implicit vertical advection of momentum (u and v) and the active tracers (T and S) . For high resolution ($1/12^o$) global models, Lemarie et al (2015) show that the CFL condition for explicit vertical advection limits the time-step (in a very small number of hot spot regions). Implementation of semi-implicit vertical advection as proposed by Schchepetkin (2015) should be a priority for CMEMS.

(5) A 2-level scheme allows implicit calculation of the top and bottom friction. This is probably important at the upper boundary under sea-ice and ice-shelves and at the bottom in coastal regions. This has been successfully trialled by Jerome Chanut in the fixed volume code. Implementation for the non-linear free surface code should be feasible with the 2-level scheme.

(6) In order to implement the CTS scheme one needs to use the flux form (rather than the vector invariant form) of the momentum equations (vector invariant schemes have not been developed). With the flux form kinetic energy conservation can be achieved calculating e_3 and f only at T points not at vorticity points. Better consistency of the Coriolis term between the 2D and 3D momentum equations can also be achieved. A monotonic advection scheme can also be used for u and v.

(7) A higher order vertical advection scheme should be used and the advective and diffusive fluxes across each face should be added together before limiting them.

Additional notes:

While designing the structure of the code for the 2-level time-step schemes, the following two points need to be taken into account:

(a) applying the limiter to the sum of the advective and diffusive fluxes implies that the fluxes rather than their divergences will need to be stored

(b) if the baroclinic velocity rather than the full velocity field needs to be used there will be significant repercussions for the code structure and the coupling to the ssh and depth integrated flow.

To our knowledge all sea-ice models use an FBS scheme. We do not plan to implement RK3 or CTS in the new sea-ice model.

(b) ALE algorithm

Alistair Adcroft's presentation highlighted some of the difficulties gaining advantage (e.g. reduced numerical mixing) from ALE algorithms. One of the issues is that there is a large difference between iso-neutral and isopycnal density surfaces; the isopycnal surfaces are not the right ones to use.

The z-tilde coordinate has been tested in ORCA025 by Jerome Chanut. Where the thickness becomes small the scheme can become unstable to vertical advection. A positive definite advection scheme would help (as would the semi-implicit advection scheme noted below and the 2-time-level scheme).

In order to avoid excessive numerical mixing from vertical advection, the velocity fields need to be "kept" sufficiently smooth. For example Levy et al. 2010 (Ocean Modelling) show how to obtain a large-scale thermocline structure that is (almost) independent of horizontal resolution. A monotonic momentum advection scheme and/or the viscosity should be chosen in order to achieve this.

One of the first steps to progress beyond the z-tilde coordinate would be to use the finite volume form of the pressure forces described by Adcroft et al. 2008 (Ocean Modelling) with the new equation of state.