

## Notes from 1<sup>st</sup> meeting on more generic vertical coordinates for NEMO: 4 Nov 2020

**Present:** Amy, Andrew Shao, Diego, Florian, Gurvan, Jerome, Laurent, Mike, Sibylle

**Apologies:** Alex

This group is a sub-group of the NEMO kernel WG.

Andrew talked through key points from sections 4 and 5 of the primer on vertical Lagrangian remapping (VLR) by Griffies, Adcroft and Hallberg.

S M. Griffies, Alistair Adcroft, Robert W. Hallberg 2020: A primer on the vertical Lagrangian-remap method in ocean models based on finite volume generalized vertical coordinates. JAMES

<https://doi.org/10.1029/2019MS001954>

Particular points that were discussed in some detail are:

- In NEMO most of the physical terms (e.g. pressure gradient, Coriolis acceleration, isopycnal diffusion) are calculated using the same fields as input (e.g. the “now” fields). The exceptions are terms that are calculated (at least partly) implicitly. In MOM6 **outside the dynamics** the default is to calculate a term and add it to the basic state before calculating the next term. This operator or process splitting is not made symmetric in time (by doing the steps in one order on one timestep and then in reverse order on the next timestep)
- The VLR scheme splits advection into a horizontal component calculated using an Eulerian approach and a vertical component calculated using a Lagrangian approach
- For a given vertical remapping scheme there is an equivalent Lagrangian vertical advection scheme
- Florian analysed the stability of Eulerian horizontal and Lagrangian vertical advection for a number of time-stepping methods in section 2.1.2 of this first year IMMERSE deliverable. He found that both a leapfrog scheme and an RK2 scheme in which the vertical remapping is done on each of the two substeps are unconditionally unstable. If the remapping is done once after two horizontal advection sub-steps he found the scheme to be stable (when the horizontal advection is stable). **In MOM6 the horizontal advection and vertical advection are done at the same frequency but for thickness 8 horizontal advection steps are performed for each vertical remap.**
- Laurent said that the advection did not need to be split into components in the way it is done in this paper. However, an unsplit version of the ALE method is either not stable or not accurate. So one has to rely on a splitted version as presented in the paper but then we have to take care of splitting errors (see the points above). An alternative which should not be difficult to implement in NEMO would be to start from the adaptive vertical advection option (Shchepetkin) and to treat in a semi-lagrangian way (or remapping) only the part of the vertical velocity which exceeds the CFL (this part is currently handled with an (inaccurate) Euler Backward upwind scheme). This would however be at the price of two vertical advection steps instead of one. Laurent’s notes give further details on this point.
- Andrew noted that the dia-surface velocity of the grid is not actually calculated in the VLR scheme. It is implied by the vertical remapping and can be diagnosed from it but it is not actually calculated. Laurent noted that if one was using a Lagrangian scheme in place of a remapping scheme one would calculate it. One of the advantages of relying on a remapping scheme (instead of a semi-lagrangian advection “à la” Lin and Rood) could be to share model-independent remapping libraries among the community.
- Jerome raised the issue of how to deal with vanishing layers. Laurent replied that for a pure advection problem, this should not be an issue if the Lipschitz condition (i.e.  $dt \cdot dw/dz \leq 1$ ) is satisfied (basically that the trajectories of particles do not cross). This condition is most of

the time must be less stringent than a CFL stability condition. However, Jerome mentioned that several other terms in the NEMO code do not support too small layer thicknesses. He suggested that a penalization method (i.e. keeping a minimum thickness for every layer but adding strong friction) could be appropriate to prevent from vanishing layers.

We agreed to invite Knut Klingbeil to talk about the Hofmeister et al paper and Gibson to talk about his PhD thesis. We'll aim to meet again in mid December or January. The date will depend on the speakers. We will probably need to ask Angus if we can record his session to enable Andrew to hear it.

**Action:** Andrew to invite Angus Gibson

**Action:** Florian to invite Knut Klingbeil