Sensitivity of the Western North Atlantic circulation to the vertical coordinate system in global ocean models

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Background

• The Western North Atlantic boundary currents system is a major component of the Atlantic Meridional Overturning Circulation (AMOC), including a northward near-surface flow (the Gulf Stream, GS, and the North Atlantic current, NAC) and a deeper compensating southward flow (primarily due to the Deep Western Boundary Current, DWBC).

• Course resolution global ocean models poorly resolve some important oceanic processes, resulting in major well-defined basins, especially along oceanic western boundaries, e.g. the GS separation near Cape Hatteras (Chassignet and Marshall, 2012) or the DWBC strength at depth (Yulander et al. 2014).

Current-topography interactions appear to play a key role for simulating a realistic Western North Atlantic circulation:

• Penduff et al. (2007) described significant improvements on the simulation of the DWBC structure when using a levels with partial steps to better represent the ocean topography in a global ocean 5/4° configuration.

• Eyrer 2016 and Shoucrier et al. 2016 showed that inadequately representing the local interactions between the GS and the bottom topography is one of the main drivers for the GS overshooting Cape Hatteras in numerical ocean models.

Vertical coordinates smoothly following the bottom terrain have a superior ability in representing flow-bathymetry interactions in comparison to geopotential z-coordinates:

What is the impact of using terrain-following levels on the circulation along the Western North Atlantic coast of a 3° global configuration?

Local terrain-following vertical coordinates

• Classical terrain-following coordinates introduce errors in the computation of the pressure-gradient force, making their use in global configurations challenging (e.g., Lemare et al. 2012).

• Bruciaferri et al. 2018 introduced a Multi-Envelope (ME) approach to vertical coordinates where computational surfaces are curved and adjusted to multiple arbitrarily defined surfaces (aka envelopes) rather than following geopotential levels or the actual bathymetry.

• This can allow one to optimize model levels to best represent different physical processes in different sub-domains of the model while minimizing horizontal pressure-gradient errors.

• Bruciaferri et al. 2022 developed a generalised methodology to use ME vertical levels only in local targeted areas of a NEMO global ocean configuration while standard z-coordinates with partial steps were used elsewhere to successfully improve the representation of the North Atlantic overflows at 1/4°.

Results

Numerical experiments using the Met Office NEMO 4.2.4-based GISS9 configuration at 1° resolution with new updated bottom topography (Storkey et al., in preparation). Two identical integrations differing only in the vertical coordinate system (zps against local-ME) spanning the period 2005-2015. Results presented here are in terms of averaged fields computed considering the last 5 years of the simulations.

Conclusions and future work

• We have implemented local ME terrain-following coordinates along the shelf and the continental slope of the east coast of North America in the Met Office NEMO-based 3° GISS9 global ocean configuration to study the sensitivity of the western North-Atlantic circulation to the vertical coordinate system.

• Preliminary results analysing 5-years averages from 10-years long integrations seem to indicate that, at 1° of resolution, local-ME quasi terrain-following levels:

  1. might allow one to obtain some improvements over a model employing a level with partial steps, representing a GS and a DWBC which seem to generally better agree with observations and partially resolving some large temperature and salinity biases on the shelf.

  2. are not to sole to solve the main biases affecting the North-Atlantic circulation – e.g. the GS separation conundrum or the absence of the NAC’s North-west corner.

• Future work will include:

  1. Exploring the sensitivity of our results to the horizontal resolution by implementing a 1/12° global ocean configuration using local-ME terrain-following levels;

  2. Conducting a barotropic vorticity budget analysis to try to unravel some of the mechanisms driving differences between models using different vertical coordinate systems.

References

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