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

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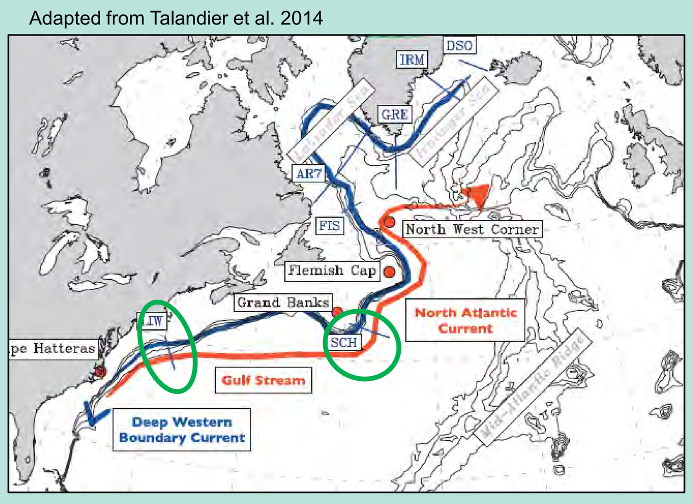
Background

Adapted from Talandier et al. 2014



- 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).
- **Coarse resolution** global ocean models poorly resolve some important oceanic processes, resulting in major well-known biases, especially along oceanic western boundaries, e.g. the GS separation near Cape Hatteras (Chassignet and Marshall, 2013) or the DWBC strength at depth (Talandier 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 z-levels with partial steps to better represent the ocean topography in a global ocean 1/4° configuration.
- Ezer 2016 and Shoonover 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.

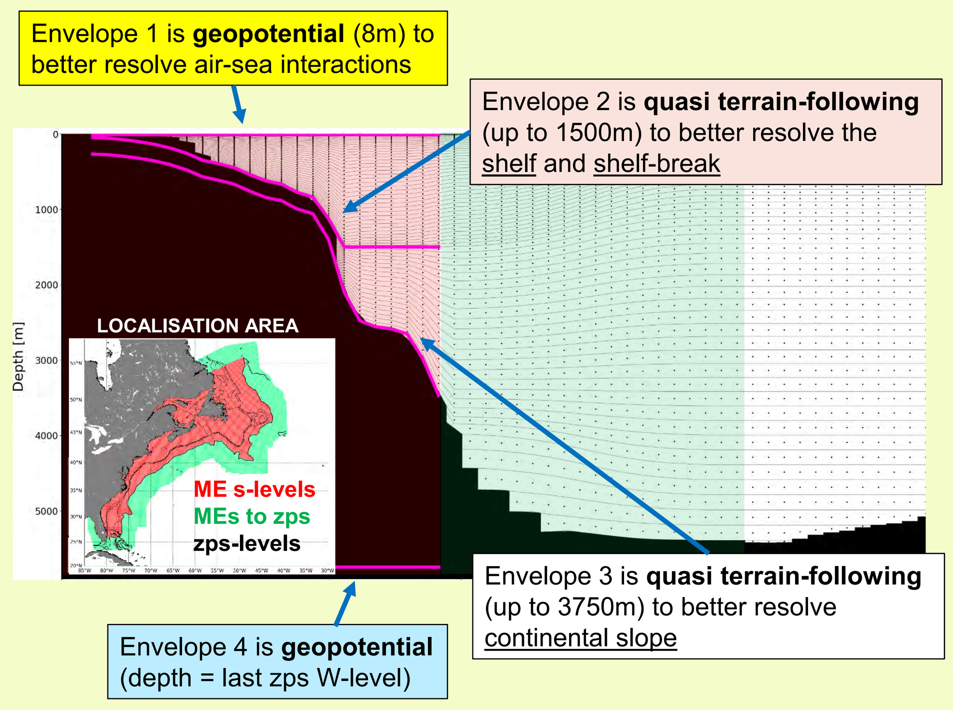
Vertical coordinates smoothly following the bottom terrain have a superior ability in representing flow-bathymetry interactions in comparison to geopotential z-coordinates :

What is the impact of using terrain-following levels on the circulation along the Western North Atlantic coast of a ¼° 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., Lemarie 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 optimise model levels to best represent different physical processes in different sub-domains of the model while minimising 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 Nordic overflows at 1/4°.

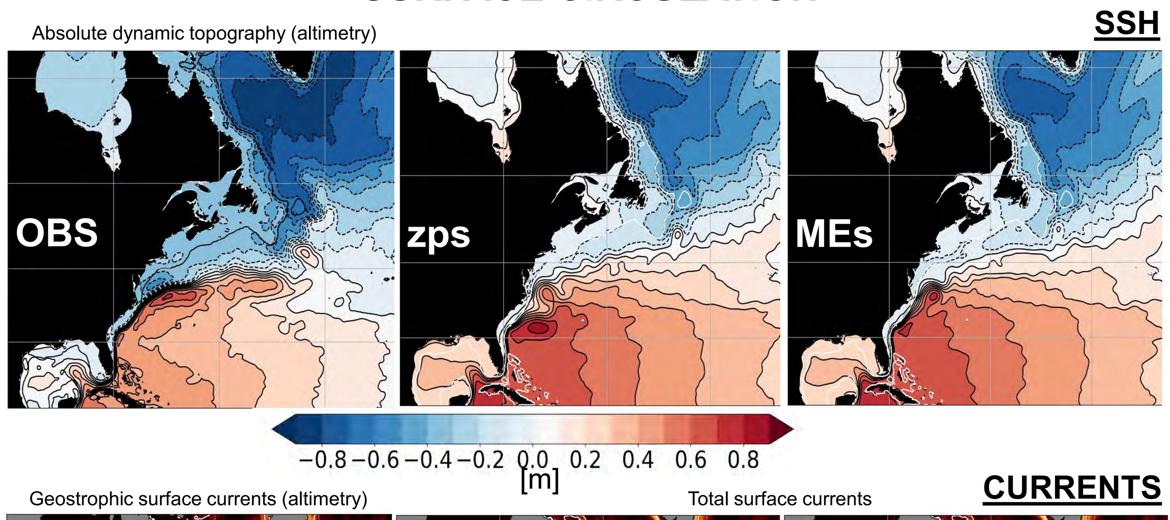
Here, we apply the same methodology to localise ME terrain-following levels along the shelf and the continental slope of the east coast of north America. Our local-ME setup uses 4 envelopes:

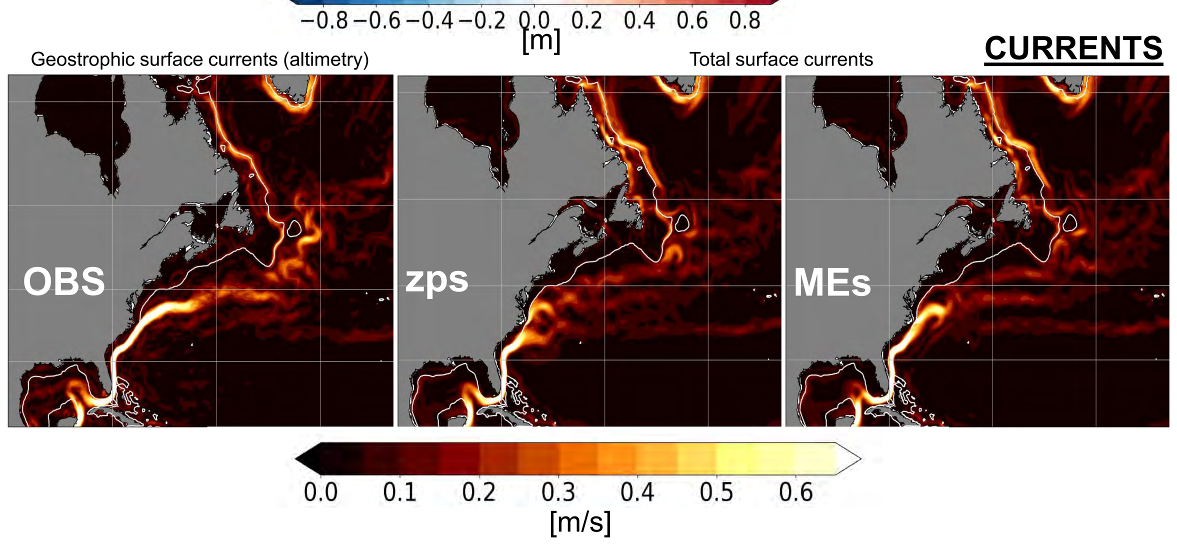


Results

Numerical experiments using the Met Office NEMO4.0.4-based GOSI9 configuration at ¼° 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.

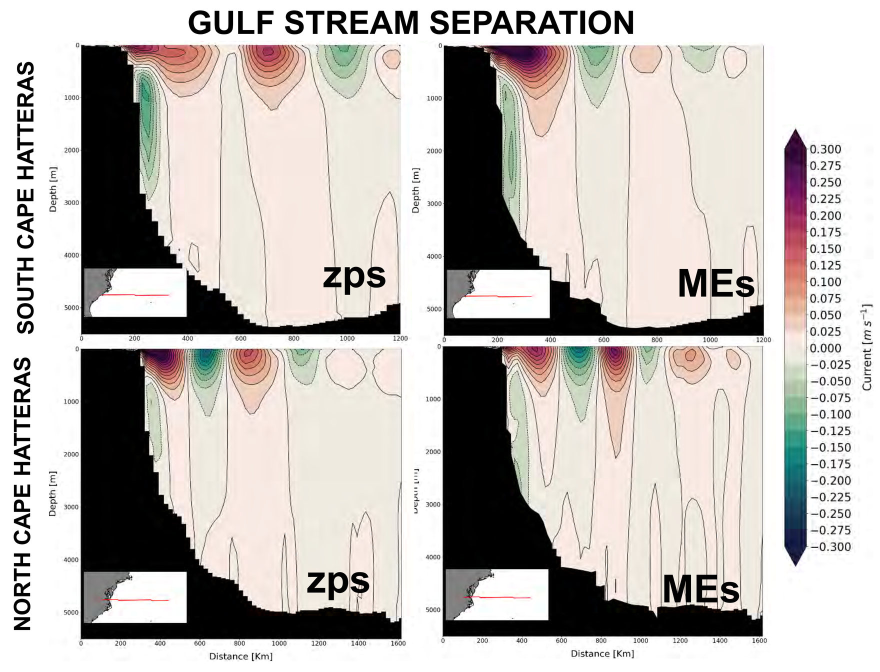
SURFACE CIRCULATION





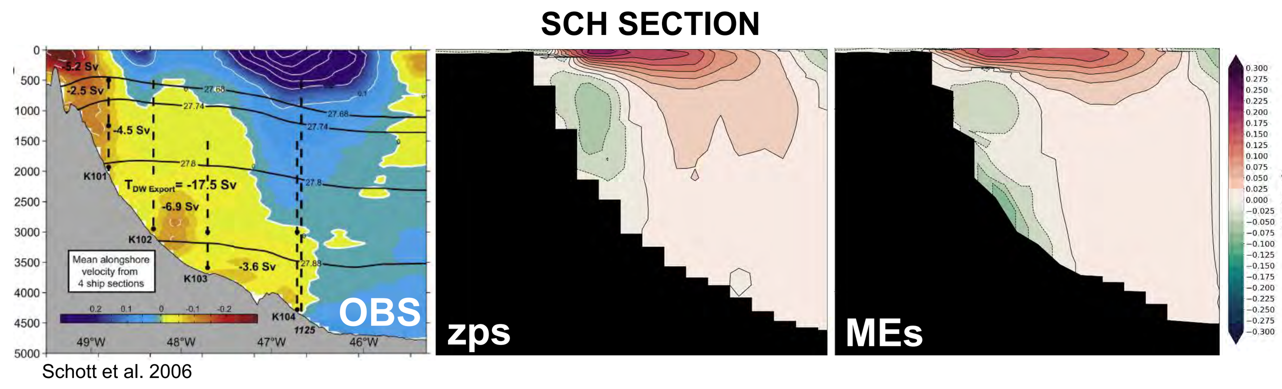
When compared to observations, both models seem to represent a GS separating far north from its observed separation latitude and a weaker NAC flowing eastward offshore Grand Banks (no North-West Corner).

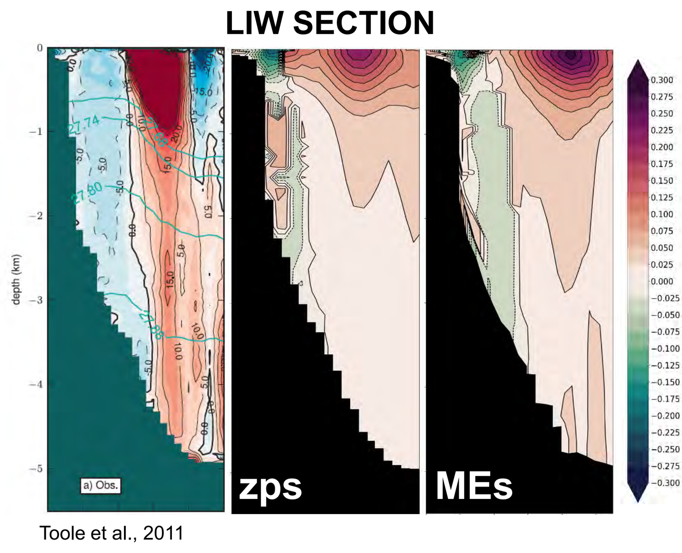
GULF STREAM SEPARATION



Models' solution differs mostly in the representation of the GS: the zps model presents a bifurcation in the proximity of Cape Hatteras while the local-ME model simulates a more coherent jet-like flow structure. Maps of SSH standard deviation (not shown here) show that the zps solution presents higher variability than the ME one, which is more stable.

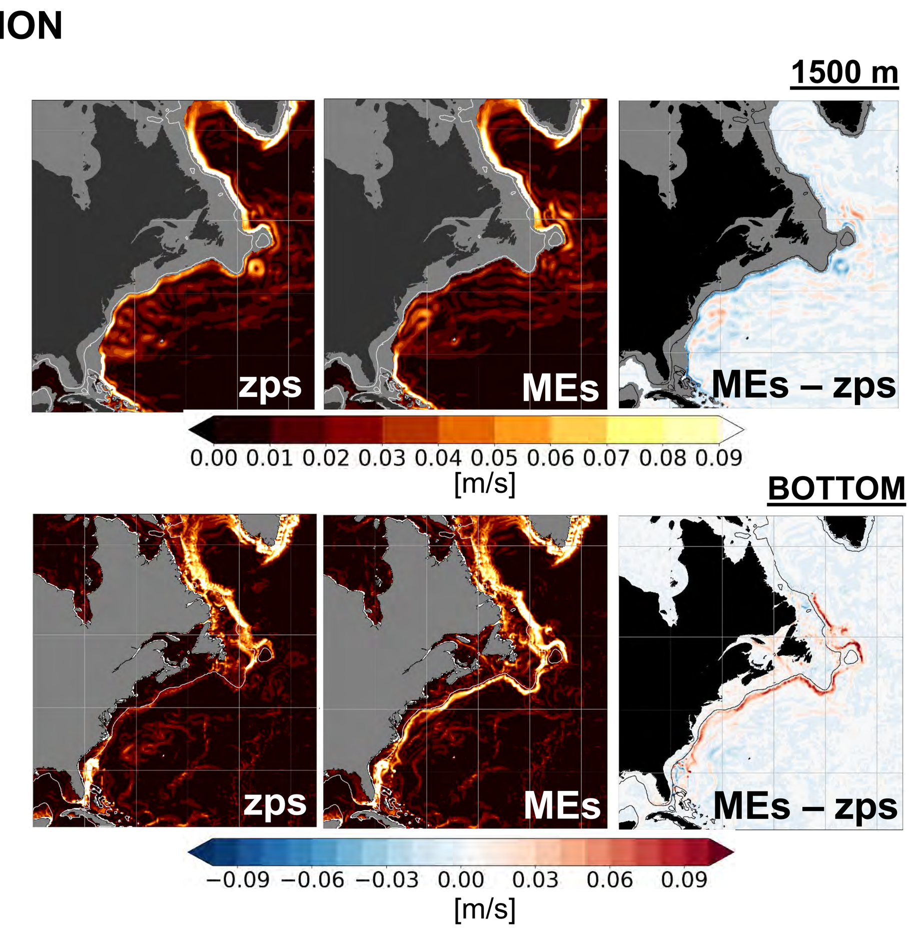
DEEP CIRCULATION





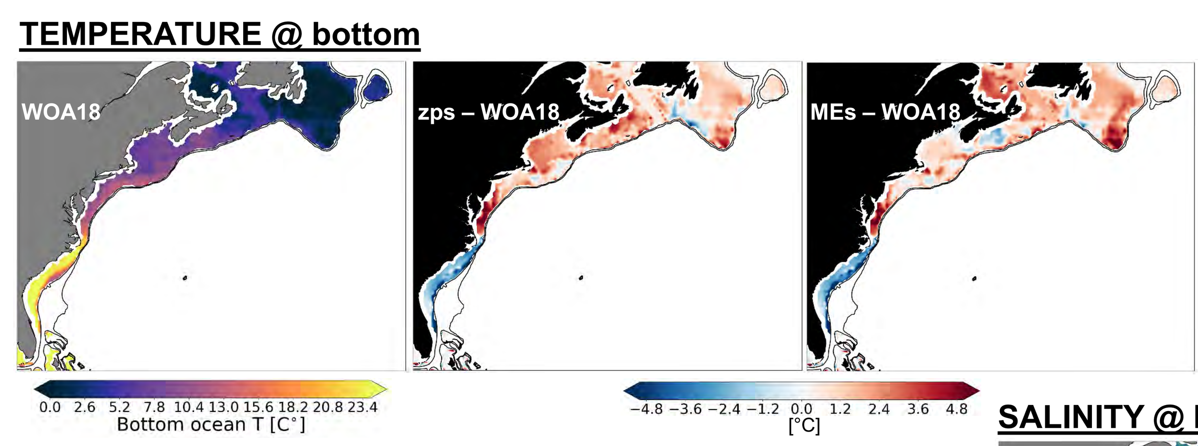
The DWBC represented by the zps model has a core centred around 1000–1500 m with an average value of ~5 cm/s and peaks around 8-9 cm/s, while at the bottom presents weaker currents around 3 cm/s.

In the case of the local-ME model, the DWBC has a more barotropic structure, with average speed of ~3-5 cm/s at 1500m and some intensified currents at the bottom around 3000 m with average values of ~7-8 cm/s .



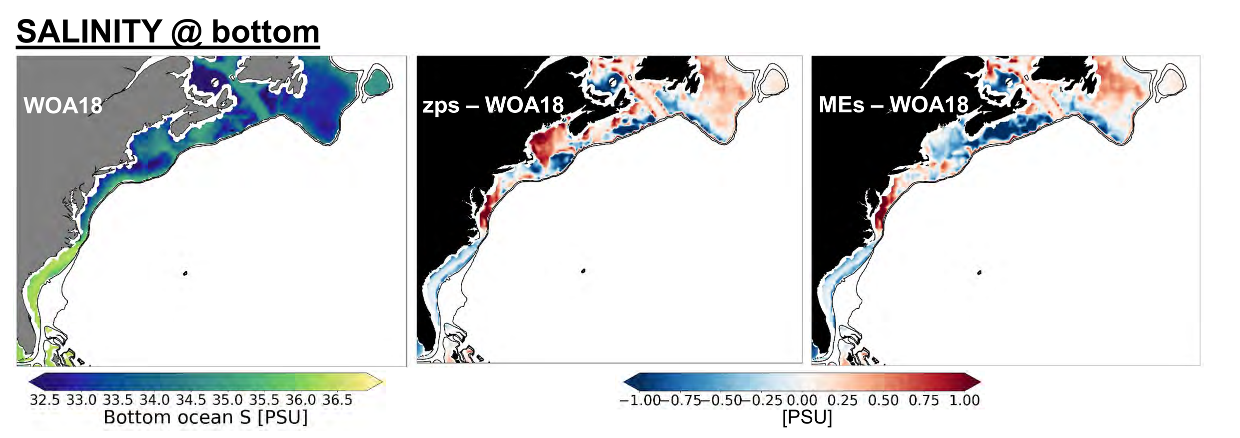
Observational cross-sections describe a DWBC extending along the water column with an average speed of approximately 4-5 cm/s and intensified currents of ~5-6 cm/s near the bottom around 3000-4000 m, which seems to agree better with the local-ME solution.

SHELF HYDROGRAPHY



When compared to WOA18 climatology, both models present a too warm and salty tongue of water on the continental shelf just north of Cape Hatteras, a clear signature of a GS separating far too north from the continental slope.

I general, the local-ME model seems to be able to reduce some of the large biases affecting the zps simulation for both active tracers, especially in the shelf area between Cape of May and the Bay of Fundy.



In some areas, the local-ME model seems to exacerbate the differences with WOA18 climatology – a fresh bias on the continental shelf off Nova Scotia and too warm water around Grand Banks shelf.

Some of the differences in models' biases can be probably explained considering the different vertical resolution of the two configurations in those areas.

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 ¼° GOSI9 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 ¼° of resolution, local-ME quasi terrain-following levels
  1. might allow one to obtain some improvements over a model employing z-level with partial steps, representing a GS and a DWBC which seem to generally better agree with observations and partially reducing some large temperature and salinity biases on the shelf.
  2. are not able 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.

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