Project: 1313
Project title: Horizon EU-project EPOC [**E**xplaining and **P**redicting the **O**cean **C**onveyor]
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Allocation period: 2024-07-01 to 2025-06-30

Achievements in the previous allocation period

The general objective of EPOC is aimed at generating a conceptual framework of the Atlantic Meridional Overturning Circulation (AMOC), and MPI-M involvement in EPOC is mainly in WP 2, 3, and 4. More specifically:

- WP2 for understanding key processes responsible for maintaining or breaking meridional connectivity of ocean transport
- WP3 to identify processes and drivers of recent change in AMOC and infer role of external forcing,
- WP4 for assessing key processes and feedback for future changes in AMOC

In WP2, MPI-M uses existing MPI-ESM runs and will configure and run very high-resolution coupled simulation (ICON) for the period 1993-2022, with an additional 30-year control simulation to account for model drift. For WP3 and WP4, MPI-M will be producing MPI-ESM-HR and MPI-ESM-ER simulations (historical with fixed GHGs) and use them in conjunction with those from PRIMAVERA to address the respective objectives.

In the last reporting period (July 2023 – April 2024), all simulations with MPI-ESM-HR and -ER were completed on Levante. These simulations will now serve as a basis for WP3 and WP4 of the EPOC project. A PhD student, Maria Jesus-Rapanague, began to analyse the meridional connectivity of the AMOC and its dependence on the ocean grid resolution. First results (Fig.1) indicate that the AMOC connectivity across latitudes is stronger with eddy-rich resolution of 0.1° (ER), compared to eddy-permitting resolution 0.4° (HR) on decadal scales when computed on density-space, but it is not visible on depth space. On interannual timescales, it seems that HR captures a delayed connectivity to the subtropics regardless in depth- or density-space.

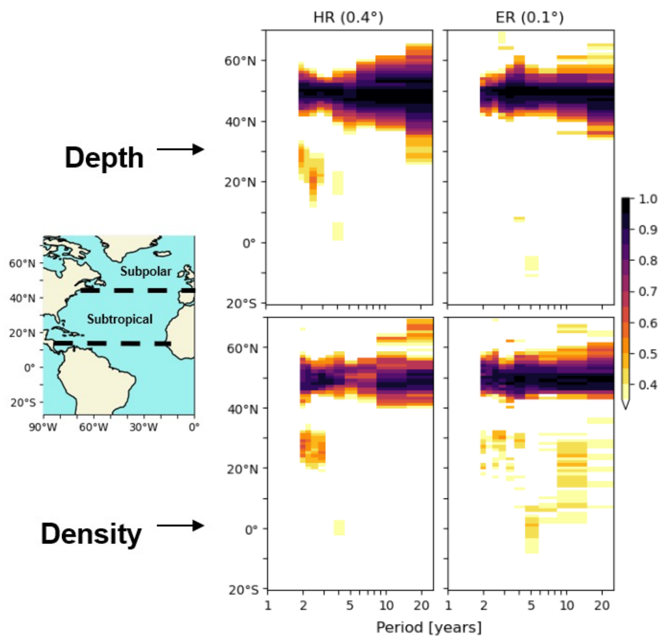

Figure 1: Meridional connectivity of the AMOC in historical simulations with MPI-ESM1-2-HR and ER. The four panels on the right show the squared coherence (spectral equivalent of the cross-correlation) of the maximum AMOC in depth (upper row) and density (lower row) space with the AMOC mean at 1000m averaged over 30° to 40°N (depth space) and at 36.7 kg m^{-3} averaged over 45° to 55°N.

We made a first prototype simulation with the new coupled configuration of ICON-Sapphire for WP2, as described in the last report. This configuration uses now a 5km base grid (R2B9) with telescoping to ~1.25km around Flemish Cap in the North Atlantic (Fig.2a) for the ocean component (ICON-O). In the vertical, the configuration uses now 72 levels in the ocean. Because the atmospheric component (ICON-A) is computationally 3-4 times more expensive compared to the same ocean resolution, ICON-A uses a coarser uniform resolution of 10km (R2B8) with 90 vertical levels.

The simulation allows very high resolution of the ocean (Fig.2b-d), which is in particular important for the dynamics of the boundary currents and of ocean mesoscale eddies (Fig.2c-d). Boundary currents and eddies are thought to be important around Flemish Cap, and are well represented in our ICON coupled simulation (Fig.3). With this improved resolution, submesoscale features around the Flemish Cap can be simulated, allowing a detailed comparison with observational arrays in this area. For this purpose, a new diagnostic for ocean bottom pressure has been implemented into ICON that will become available for all ICON-O users. In addition, a very high resolution is achieved around Greenland and in the Nordic Seas, which are important for the formation of dense water and the AMOC. Recent examples using the ICON-Sapphire simulations are katabatic storms over the Irminger Sea forming dense water (Gutjahr et al., 2022) or polar lows that form dense water in the Iceland and Greenland Sea (Gutjahr and Mehlmann, 2023).

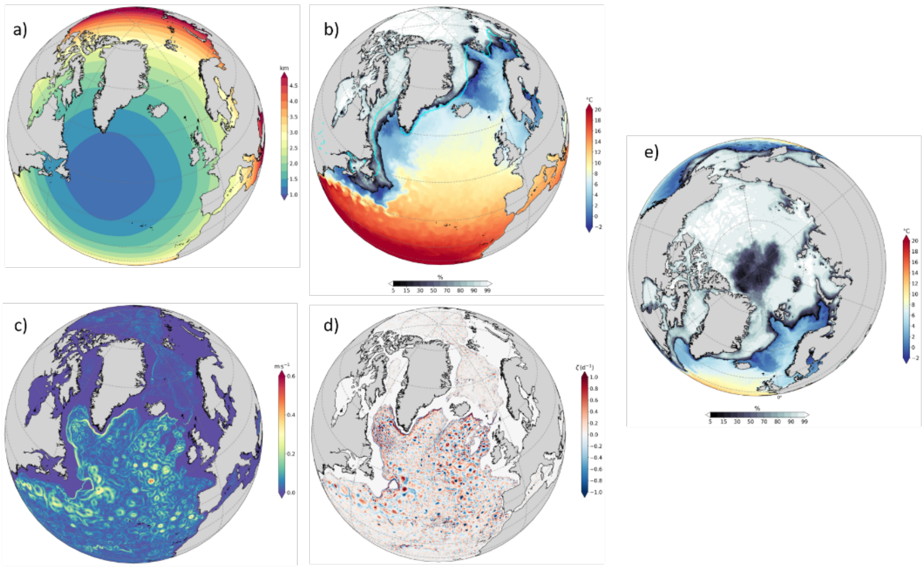

Figure 2: Illustrations of the coupled ICON simulation we use for WP2 of the EPOC project: (a) ocean telescoping grid, (b) sea-surface temperature and sea ice concentration, (c) ocean velocity at 1000m depth, (d) relative vorticity of the ocean velocity, and (e) appearance of an Arctic sea ice 'hole'.

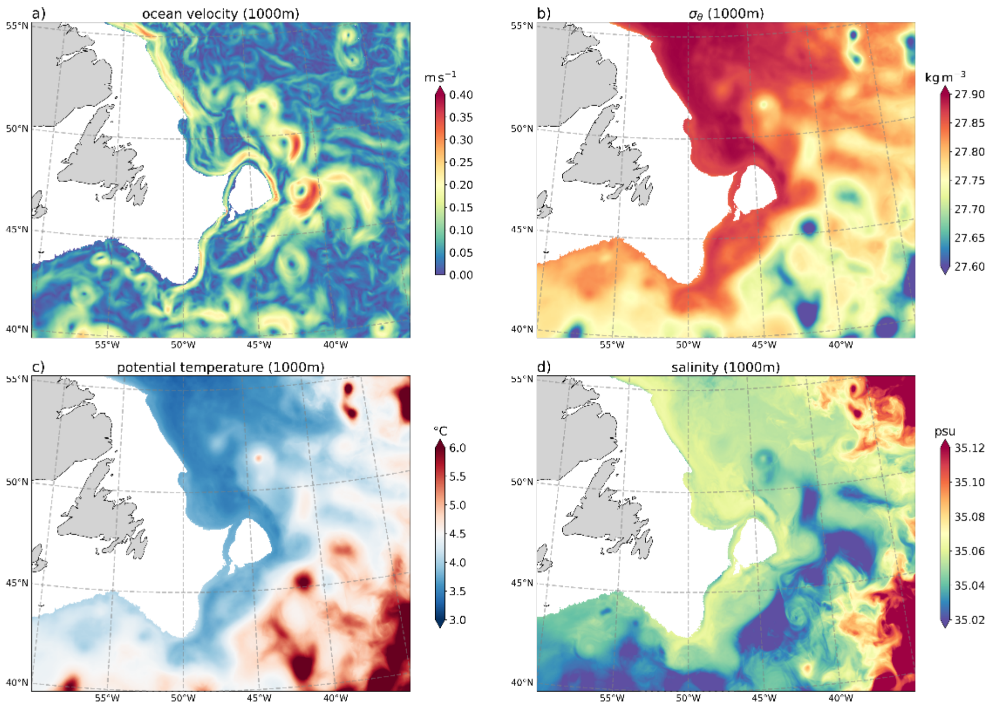

Figure 3: Monthly mean snapshots from the coupled ICON simulation at 1000m depth (March 2026) of (a) ocean velocity, (b) potential density, (c) potential temperature, and (d) salinity.

A major problem that first appeared in the EPOC simulation, but was later also found in the simulations for EERIE and NextGems, was that unrealistically large holes appeared in the winter Arctic sea ice cover (Fig.2e). During the investigation, we also found smaller counterparts in the Antarctic sea ice cover. The search for the cause of these holes took up a large part of the reporting period and we therefore had to stop the EPOC simulation. It was only during the 4th kilometer-scale hackathon at the MPI-M at the beginning of March this year that the cause was found. An error in the ocean code has been active since 2015, which prevented the momentum transferred to the sea ice from being removed from the ocean. In other words, the ocean felt no friction from the sea ice. At coarse resolution this was not a major problem, but once ocean eddies and strong currents are resolved, the sea ice is torn apart by the ocean eddies, leading to the formation of these holes.

This bug has now been fixed, but since it existed since 2015, all tuning efforts were done with this bug in the ice-ocean coupling. We are currently working on retuning the sea ice to represent realistic ice conditions. Once the tuning is done, we will completely restart the EPOC-ICON simulation