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Formation of dense water over the North Atlantic subpolar gyre in a hierarchy of climate models

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Introduction

The Atlantic Meridional Overturning Circulation (AMOC) is a key component of the global climate by carrying dense water equatorward. OSNAP observations have recently revealed that dense water is mainly formed over the eastern subpolar gyre and have highlighted the dominant role of the buoyancy forcing in the formation of dense water over the Irminger and Iceland basins. The short length of the OSNAP timeseries, however, limits conclusions over longer time scales. To investigate a wide range of temporal scales, we explore the representation of the mean overturning and buoyancy-induced transformation (WMT) in three 100-years long coupled simulations of HadGEM3-GC3.1, at resolutions ranging from ~130 km atmosphere and 1° ocean (LL) to 25 km atmosphere and 1/12° ocean (HH).

The WMT over the eastern SPG does not increase with resolution

The overturning convergence over the Irminger and Iceland basins increases from low (8.9 Sv) to medium and high resolutions (12.9 Sv), while the WMT is smaller at high (6.4 Sv) than at medium resolution (8.7 Sv) : a stronger diapycnal mixing explains half of the dense water formation over the Irminger and Iceland basins at high resolution

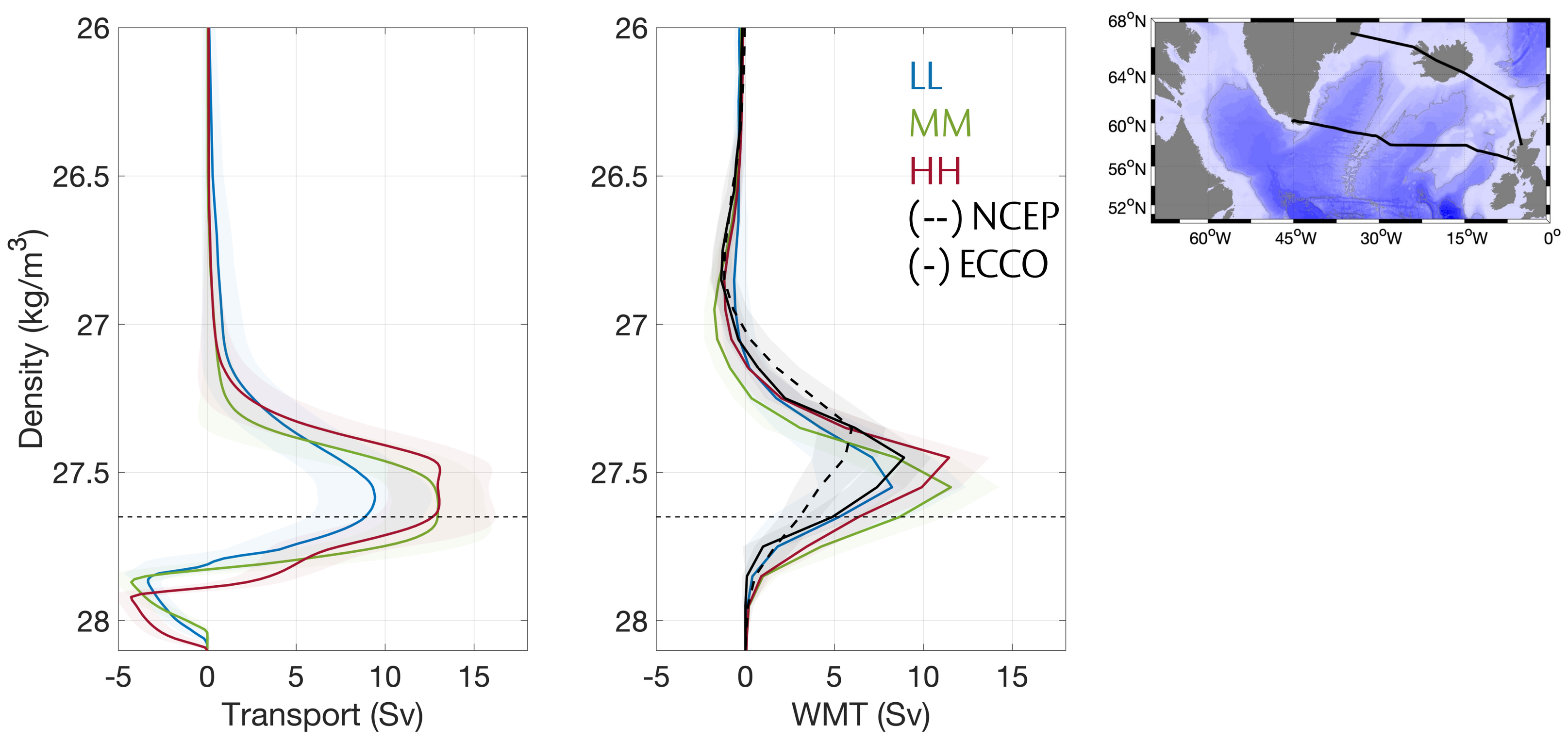

Fig. 1: Averaged (left) overturning convergence between the Greenland-Scotland Ridge and OSNAP East and (right) WMT over the Irminger and Iceland basins for the models at low (LL), medium (MM) and high (HH) resolutions. The WMT estimated with the atmospheric reanalysis NCEP/EN4 and ECCOv4 are in black.

The overturning and WMT over the Labrador Sea increase with resolution

The increase in overturning is consistent with the increase in WMT over the Labrador Sea, but the WMT is more than twice larger at medium (3.4 Sv) and (5.1 Sv) high resolutions than estimated from atmospheric reanalysis (1.1-2 Sv)

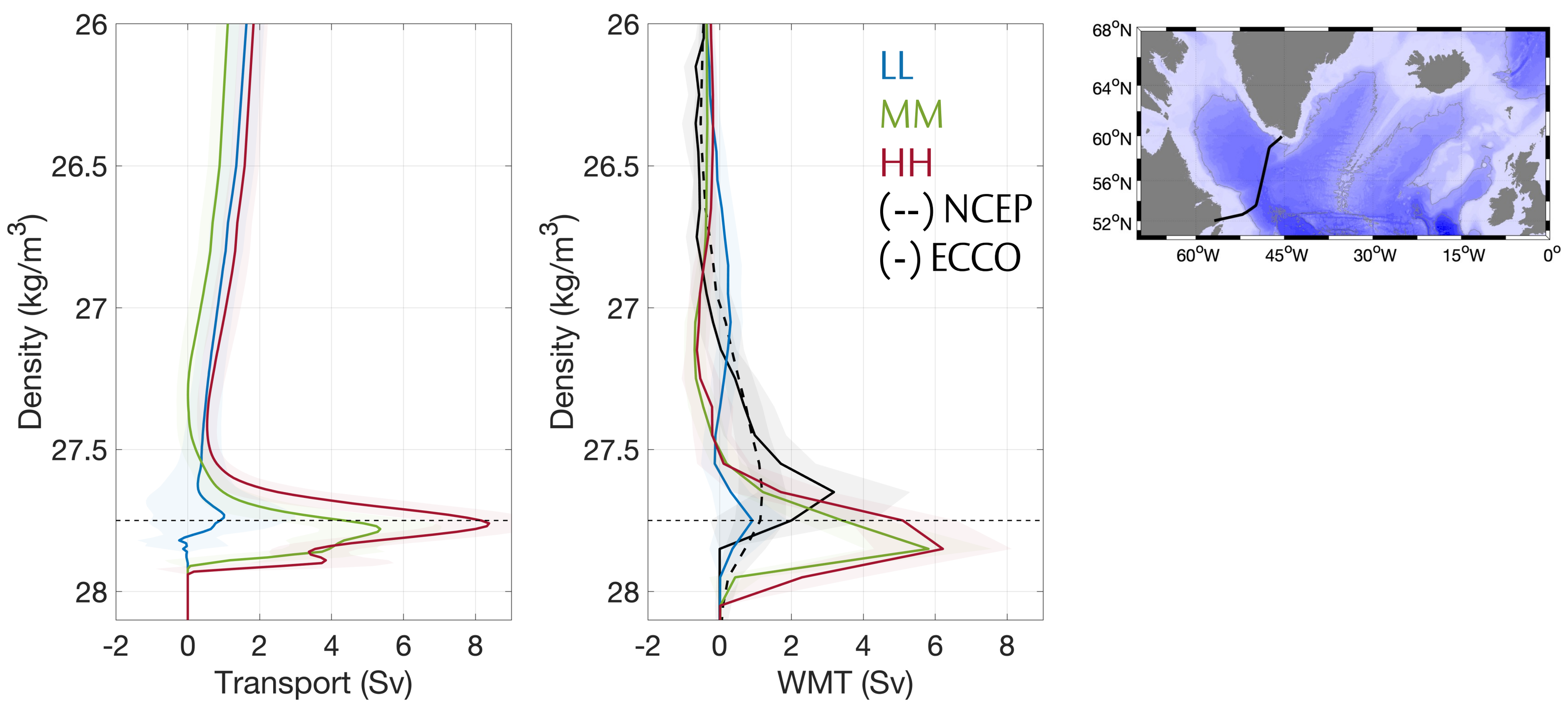

Fig. 2: Averaged (left) streamfunction at OSNAP West and (right) WMT over the Labrador Sea for the models at low (LL), medium (MM) and high (HH) resolutions. The WMT estimated with the atmospheric reanalysis NCEP/EN4 (--) and ECCOv4 (-) are in black.

Shift in the spatial distribution of the WMT at medium and high resolutions

Contrary to observation-based estimates, the WMT at $\bar{\sigma}_{MOC}$ is stronger along the boundary currents of the Labrador Sea whereas denser waters (27.8-28 kg m^{-3}) are formed in the interior of the basins

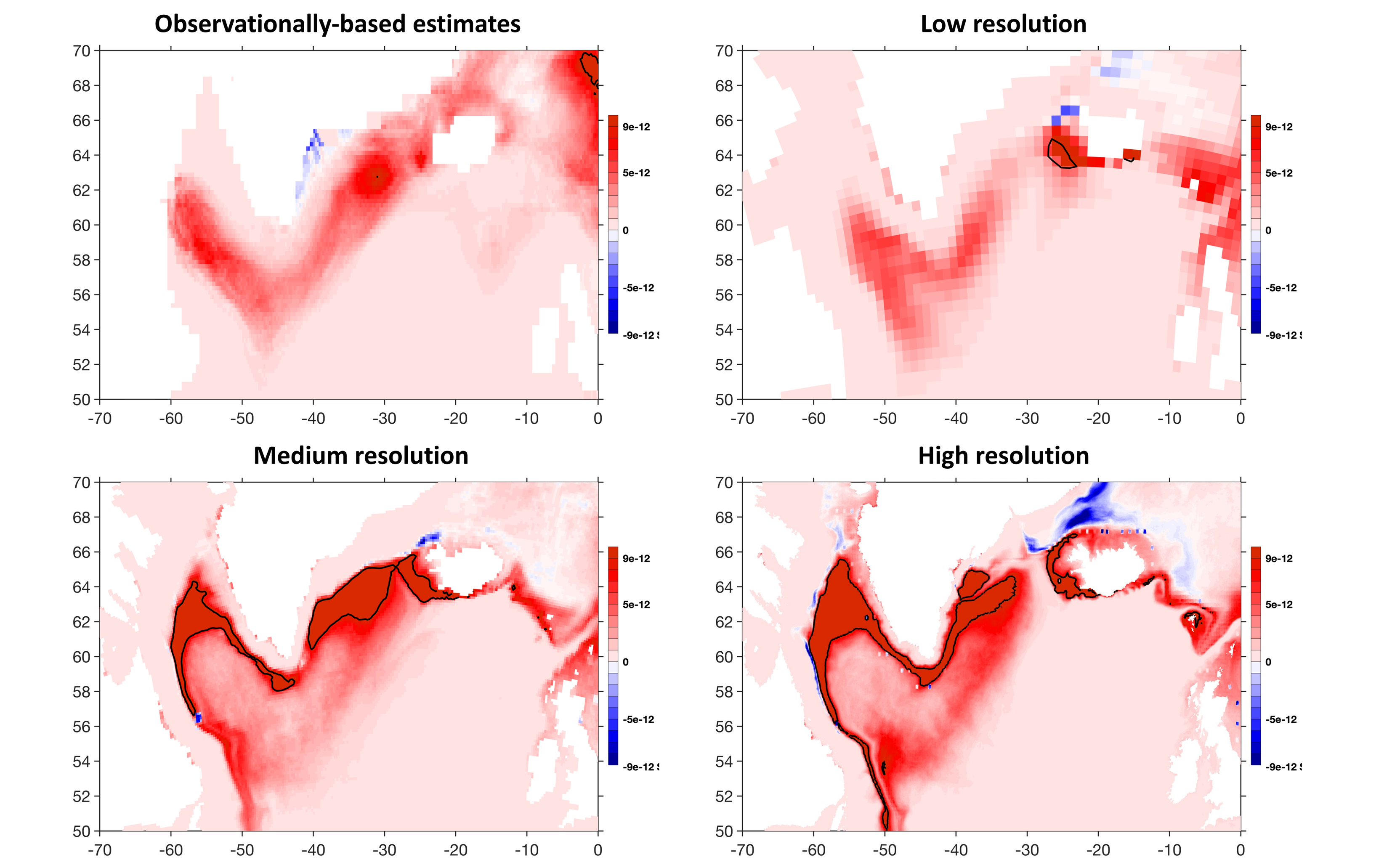

Fig. 3: Spatial distribution of the averaged WMT (Sv/m^2) at 27.75 kg m^{-3}, the density of maximum overturning at OSNAP West, for the three models (1950-2050) and the atmospheric reanalysis NCEP/EN4 (1980-2018).

A bias in surface density is reinforced by small marginal sea-ice over the Labrador Sea

The outcropping area of the density bin 27.65-27.75 kg m^{-3} shifts along the boundary currents at medium and high resolutions

Small marginal sea ice allows too much air-sea heat exchange along the boundary currents at medium and high resolutions

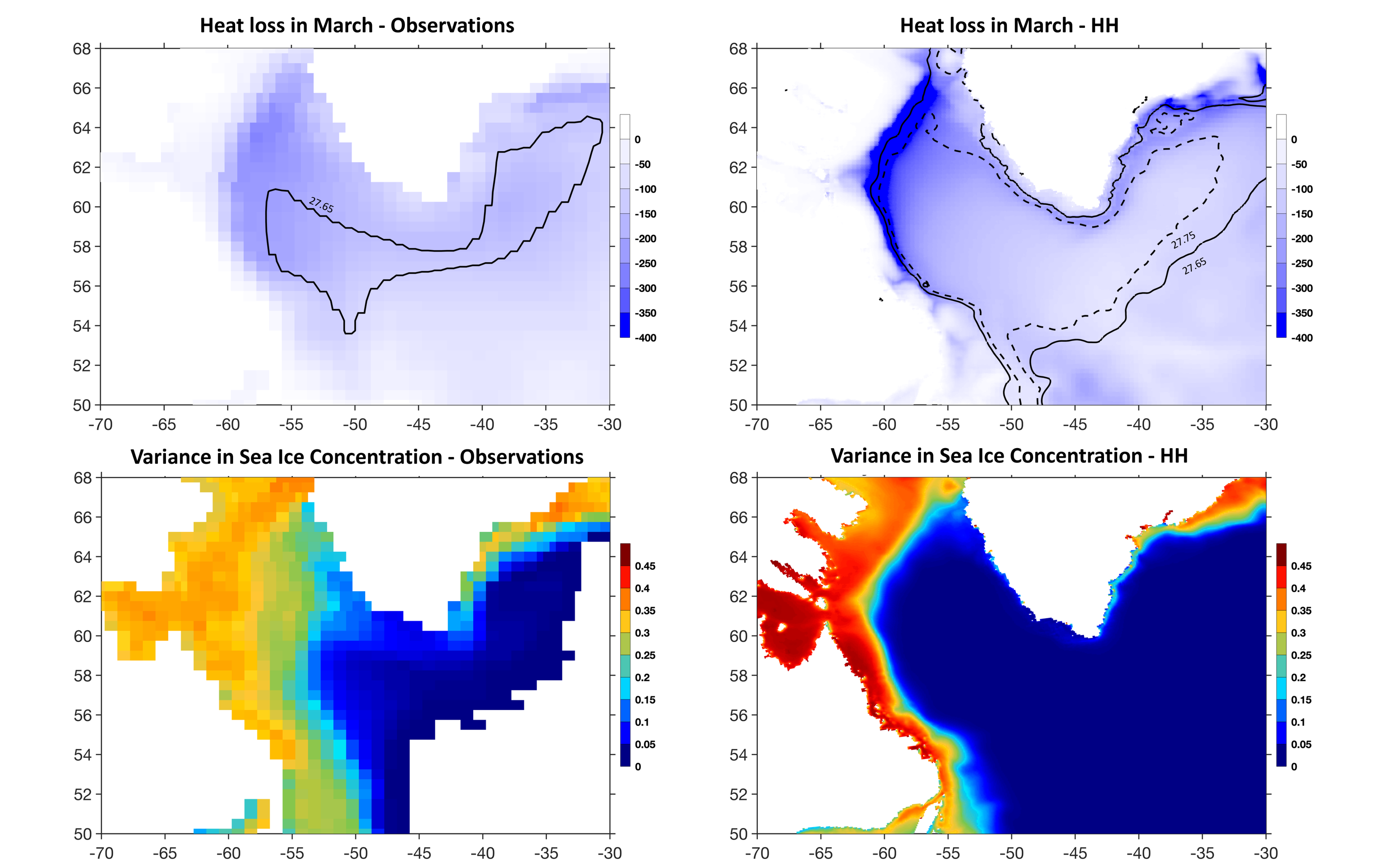

Fig. 4: (upper panels) Heat loss (W m^{-2}) in March for the observations ECCOv4 and the model at high resolution HH. The plain and dashed lines indicate the outcropping isopycnals 27.65 kg m^{-3} and 27.75 kg m^{-3} in March, respectively. (lower panels) Monthly variance in sea ice concentration for the observations ECCOv4 and the model at high resolution HH.

- The overturning over the subpolar gyre increases with resolution in HadGEM3-GC3.1 and is too large in MM and HH as compared to observations
- The WMT alone does not account for the large overturning over the eastern subpolar gyre in HH, but is consistent with the increase in overturning over the western subpolar gyre
- The large WMT at $\bar{\sigma}_{MOC}$ over the Labrador Sea is explained by a bias in surface density and is reinforced by small marginal sea ice that allows too much air-sea heat exchange along the boundary currents