Uncertainty in future Euro-Atlantic large-scale circulation influenced by ocean mean state biases

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PhD SDC

1. Motivation

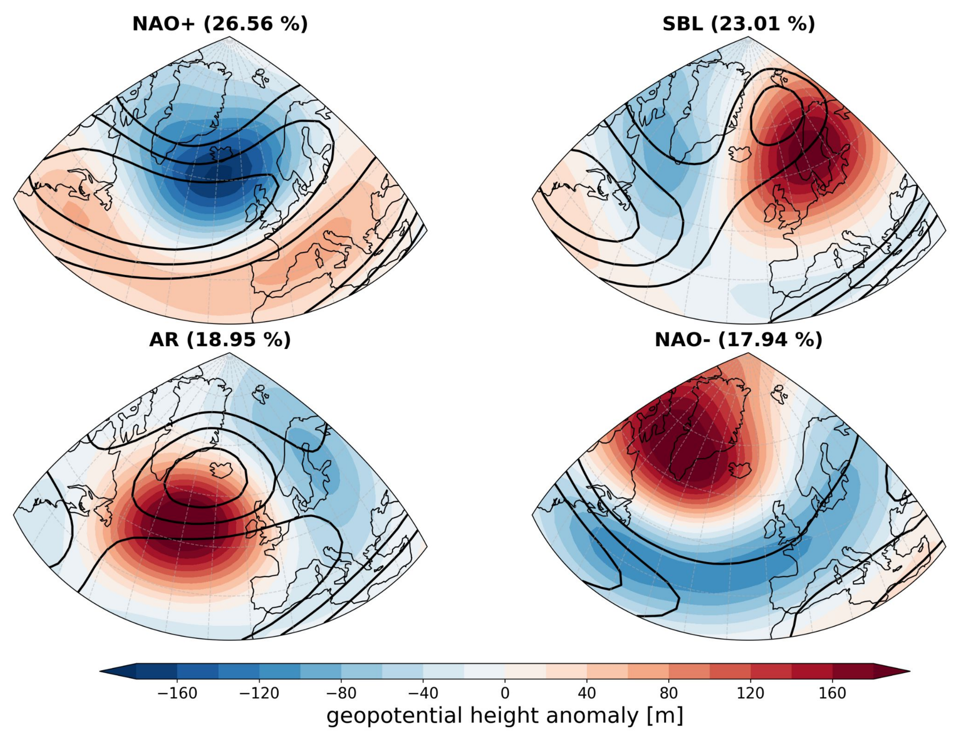
The Atlantic Meridional Overturning Circulation (AMOC) is projected to weaken under anthropogenic forcing, albeit with a wide spread among models. Reduced oceanic heat convergence affects the baroclinicity of the Euro-Atlantic atmosphere and thus large-scale weather patterns (Vacca et al., in preparation).

- Do ocean mean state biases influence the AMOC decline?
- How does this affect projections of wintertime Euro-Atlantic large-scale atmospheric circulation?

2. Data and Methods

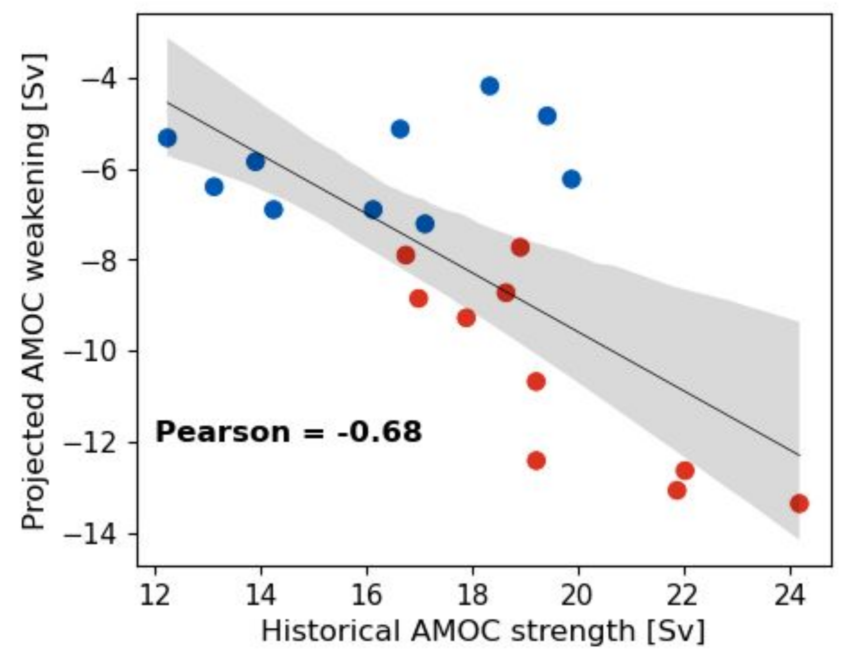
- **20 CMIP6** climate change simulations under the **SSP5-8.5 scenario**.
- **ERA5** and **World Ocean Atlas 2018** as observational references.

Euro-Atlantic Weather Regimes



Weather Regimes computed from ERA5. Superimposed contours are the composite of the low-level zonal wind, indicating the position of the North Atlantic Eddy-driven jet.

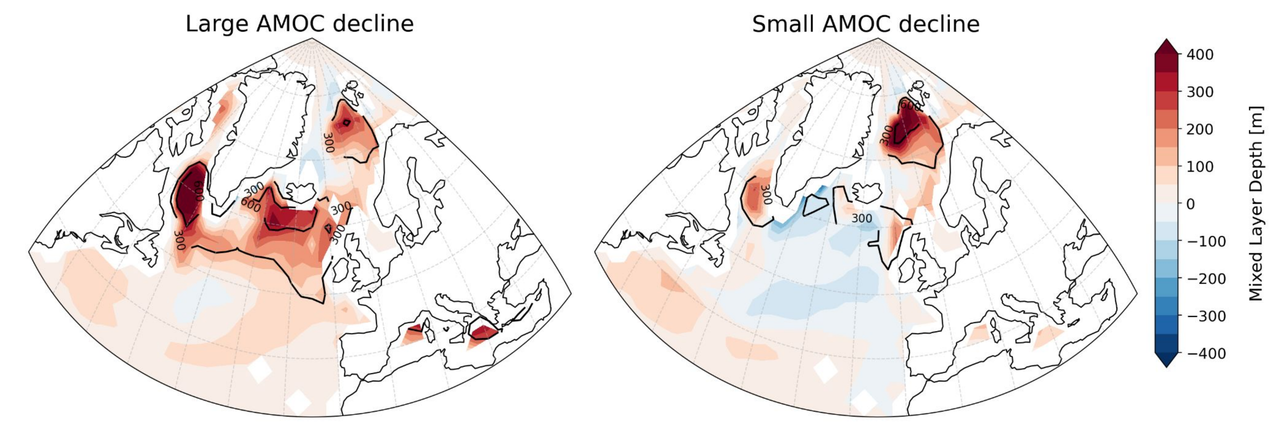
AMOC decline dependence on the mean state



- Model ensemble splitted into **Large AMOC decline group** and **Small AMOC decline group** based on the projected AMOC strength anomaly at the end of the century.
- **Weather Regimes** framework: each 500 hPa wintertime daily geopotential height pattern is classified into one of the four Euro-Atlantic Weather Regimes: the positive phase of the North Atlantic Oscillation (NAO +), the Scandinavian Blocking (SBL), the Atlantic Ridge (AR) and the negative phase of the North Atlantic Oscillation (NAO-).

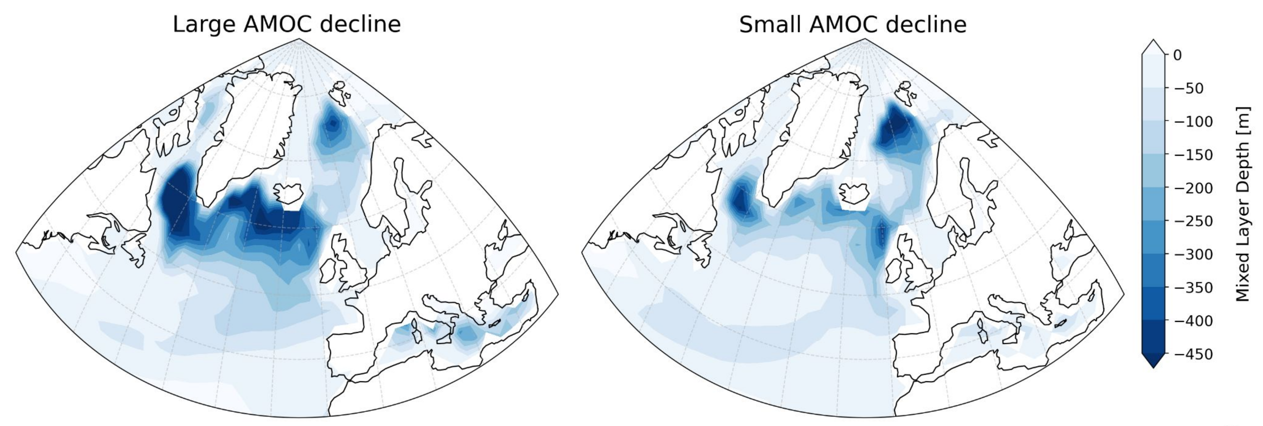
3. Results

Mixed Layer Depth mean state bias



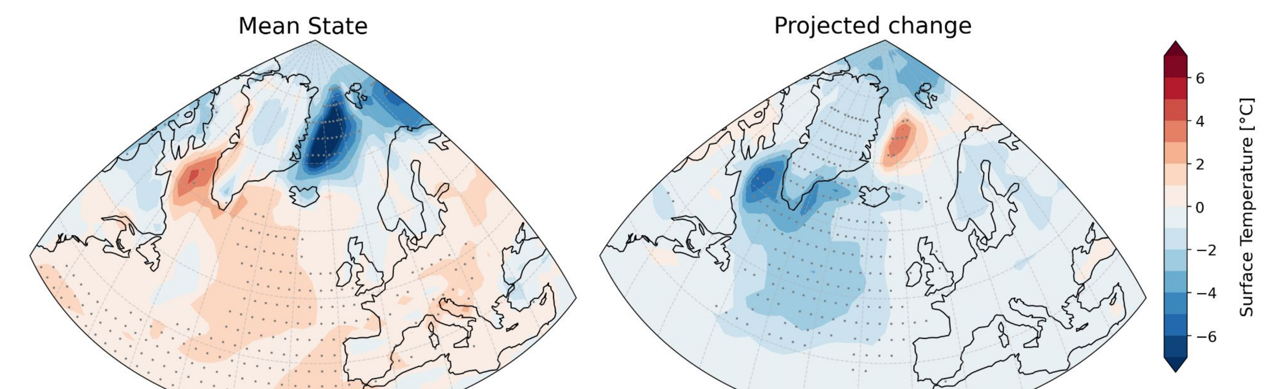
Models that project a larger AMOC decline feature deep convection mainly in the Labrador and Irminger seas, while models that project a smaller AMOC decline feature deep convection mainly in the GIN seas (contours). However, all models show a too deep mixed layer depth in their regions of deep water formation (shading).

Mixed Layer Depth projected change



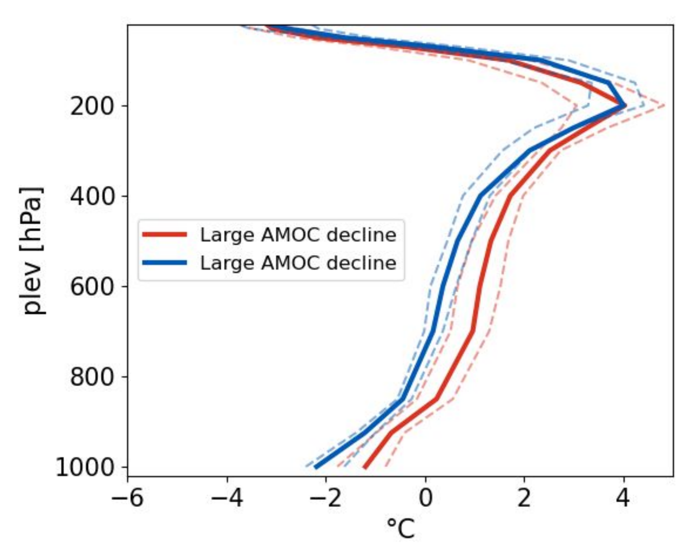
At the end of the century, mixed layer depth decreases in the respective regions of deep water formation, which is different in the two groups (see above)

Surface Temperature difference (Large AMOC decline - Small AMOC decline)



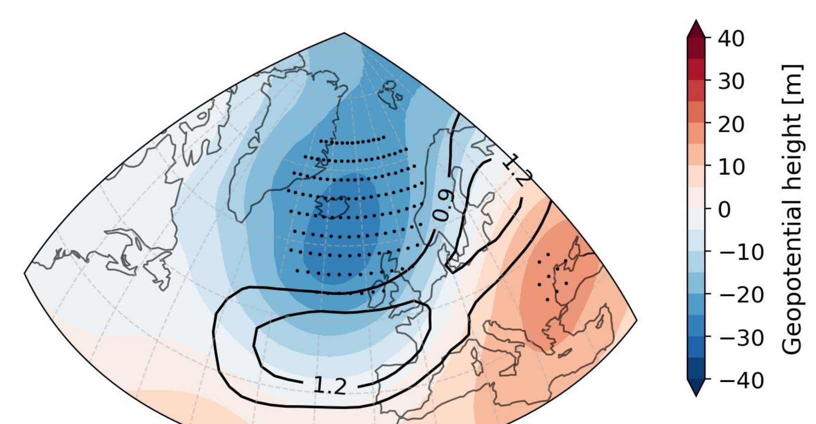
Already in the mean state (left) the stronger mean AMOC strength in the Large AMOC decline group leads to a relatively warmer SST in the Labrador and Irminger seas, and relatively colder SST in the GIN seas. (Right) Because of the larger AMOC decline, the Large AMOC decline group shows an enhanced North Atlantic Warming Hole (NAWH).
→ **Increased low-level Meridional Temperature gradient**, directly related to the North Atlantic jet stream.

Meridional Temperature Gradient change



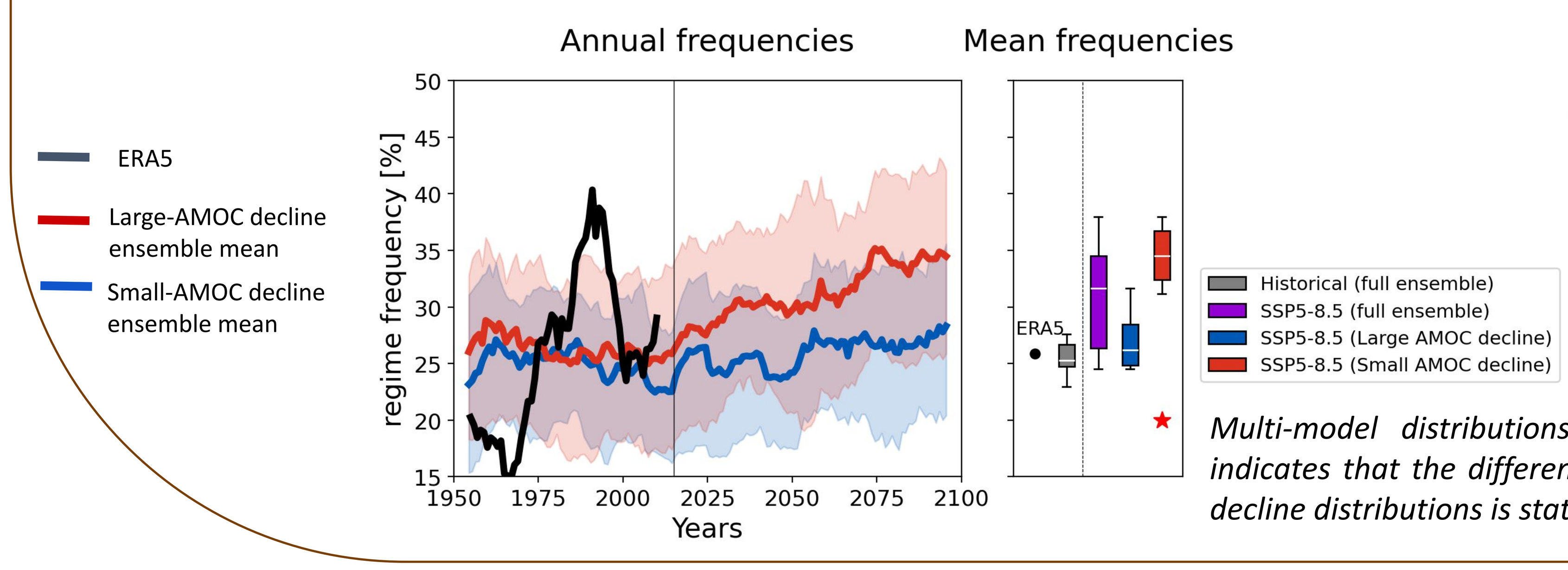
Mean circulation change at 500hPa

Large AMOC decline - Small AMOC decline



- Mid-latitude jet stream is projected to be more intensified in Large AMOC decline models (black contours).
- Consistent with a larger decrease in geopotential height at 500 hPa in the Large AMOC decline group due to the enhanced NAWH (shading).

NAO+ regime frequency



Multi-model distributions of mean frequencies. The red star indicates that the difference between the Large and Small AMOC decline distributions is statistically significant at the 95% level.

- NAO+ regime projected frequency significantly higher in larger AMOC decline models.

4. Key takeaways

- Differences in the models deep convection mechanisms seems to affect the response of the AMOC under climate change (possible emergent constraint).
- Larger positive biases in the Labrador and Irminger seas lead to larger AMOC decline and a more pronounced North Atlantic Warming Hole.
- Future intensification of the jet and increased NAO+ frequency simulated in models with larger AMOC decline.
- Constraining ocean circulation in the mean state helps in reducing uncertainty of future climate change impacts over the North Atlantic.

Main References:

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2. Fabiano, F., Meccia, V. L., Davini, P., Ghinassi, P., & Corti, S. (2021). A regime view of future atmospheric circulation changes in northern mid-latitudes. Weather and Climate Dynamics, 2(1), 163-180.
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4. Gervais, M., J. Shaman, and Y. Kushnir, 2019: Impacts of the North Atlantic Warming Hole in Future Climate Projections: Mean Atmospheric Circulation and the North Atlantic Jet. J. Climate, 32, 2673–2689, https://doi.org/10.1175/JCLI-D-18-0647.1.

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