SPECIAL PROJECT PROGRESS REPORT

All the following mandatory information needs to be provided. The length should *reflect the complexity and duration* of the project.

Reporting year	2026…………………………………………………………
Project Title:	Freshwater influence on the Atlantic Meridional Overturning Circulation
Computer Project Account:	spiesemm…………………………………………….……
Principal Investigator(s):	Tido Semmler
Affiliation:	Met Eireann
Name of ECMWF scientist(s) collaborating to the project (if applicable)	N/A…………………………………………….…… ……………………………………………………….……
Start date of the project:	01.01.2024……………………………………….……
Expected end date:	31.12.2026………………………………………….……

Computer resources allocated/used for the current year and the previous one

(if applicable)
Please answer for all project resources

		Previous year		Current year	
		Allocated	Used	Allocated	Used
High Performance Computing Facility	(units)	116,727,028	116,741,832	1,000,000	15,141
Data storage capacity	(Gbytes)	480,000	333,152	480,000	333,152

Summary of project objectives (10 lines max)

Since the fate of the Atlantic Meridional Overturning Circulation (AMOC) is very crucial for the climate of Northwestern Europe, it is imperative to include the influence of the increasingly melting Greenland ice sheet and its freshwater contribution on the ocean circulation. Since it is known that the ocean model resolution plays a major role in how the additional freshwater is distributed in the main convection areas Labrador Sea and Nordic Seas, this project aims to address the sole influence of the additional Greenland ice sheet freshwater contribution on these convection areas and the wider ocean circulation in a very high resolution of 4-5 km in these key areas. Since the AMOC is part of the global ocean circulation and known to be influenced by Antarctic ice sheet melting in addition, also the influence of the Antarctic ice sheet melting will be investigated.

Summary of problems encountered (10 lines max)

In the second half of 2025, no further problems have been encountered and AWI-CM3 has been running without any problem. Since very interesting results came out of the realistic Greenland freshwater input experiment for 1950-2022 and of the high versus low resolution simulations until 2200, it is worth publishing the results first. Because of staffing issues, the two papers are still in preparation, and except few very minor tests, no additional simulations have been run in the first half of 2026. The staffing issues persist, and therefore most of the units (179 million SBU out of 180 million SBU) have been given back for 2026 to be used in other special projects that might need extra resources during the second half of the year. For 2027, after publication of the results, a new computing time application will be uploaded before 30th of June, 2026.

Summary of plans for the continuation of the project (10 lines max)

Within the second half of 2026, the publication on the realistic Greenland freshwater input experiments will be finalised and submitted. Furthermore, the paper about AMOC stability in low versus high resolution simulations until 2200 is in preparation (experiments had been run in 2024 and 2025), and it will be finalized and submitted within the second half of 2026.

List of publications/reports from the project with complete references

N/A

Summary of results

Various caveats of state-of-the-art CMIP6 simulations have been addressed with the aim of narrowing the uncertainty of processes contributing to a possible AMOC slowdown in the future. Two major caveats of CMIP6 simulations have been addressed: the resolution helping to resolve the narrow boundary currents and overflows over the Greenland – Iceland – Scotland ridge (Fig. 1), and the prescription of realistic Greenland liquid water runoff and solid ice discharge estimates from Mankoff et al. (2025) which are often only very rudimentarily represented in state-of-the-art CMIP6 simulations.

a) b) c)

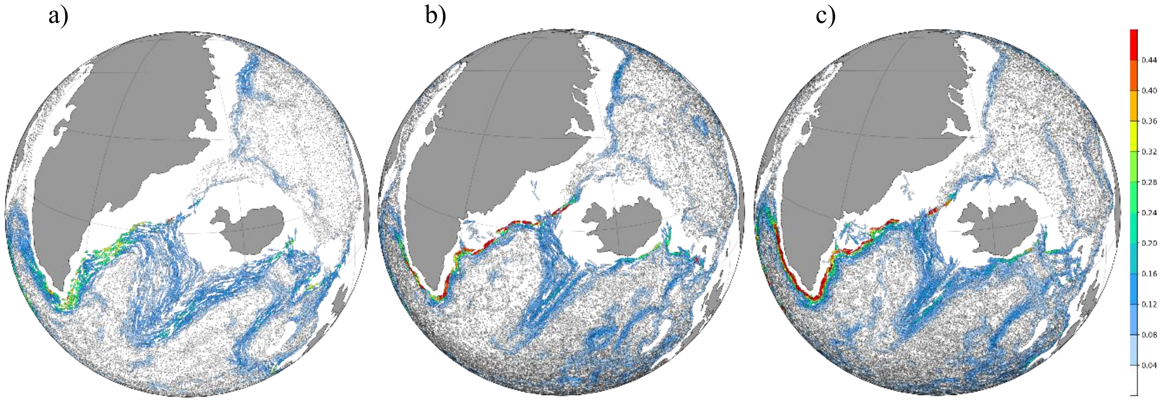


Fig. 1: Velocity vectors 500 m depth (m/s), climatology 1993-2016. a) LR (low resolution), b) GLORYS reanalysis (best estimate of the reality), and c) HR (high resolution). It can clearly be seen that the low resolution boundary currents are too broad and too weak compared to the reanalysis data while the high resolution captures both the narrow boundary currents and the intensity of overflows over the Greenland – Iceland – Scotland ridge.

In our case, the sum of liquid runoff and ice discharge is about five times as large as the liquid runoff that was prescribed in the standard AWI-CM3 simulations (Fig. 2a). Not only the magnitude, but also the regional distribution of the liquid runoff and solid ice discharge has been adjusted. Mouginot et al. (2019) has defined 7 main catchment areas for Greenland (Fig. 2b). Mankoff et al. (2025) provide the Greenland freshwater data for each of these catchment areas in a monthly time resolution for the liquid runoff, and in a yearly time resolution for the solid ice discharge.

a) b)

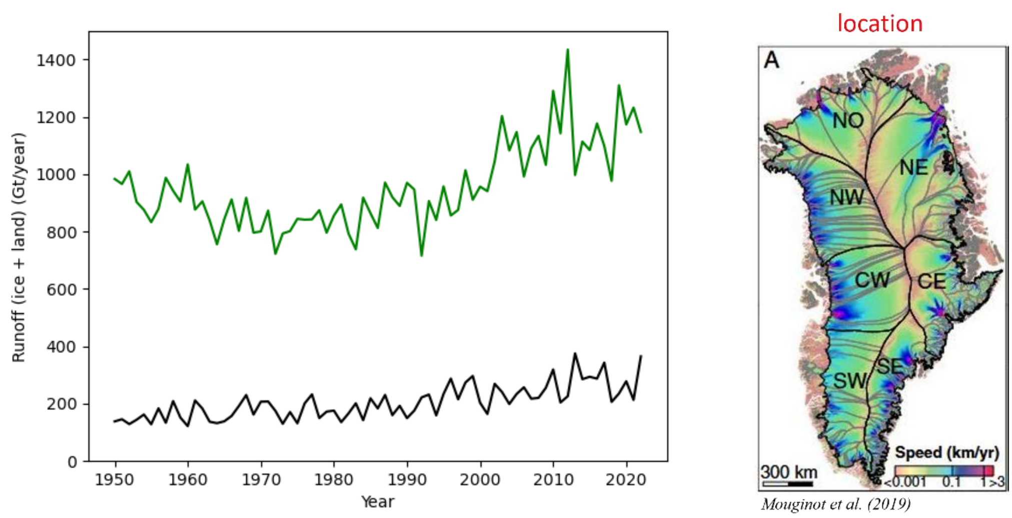
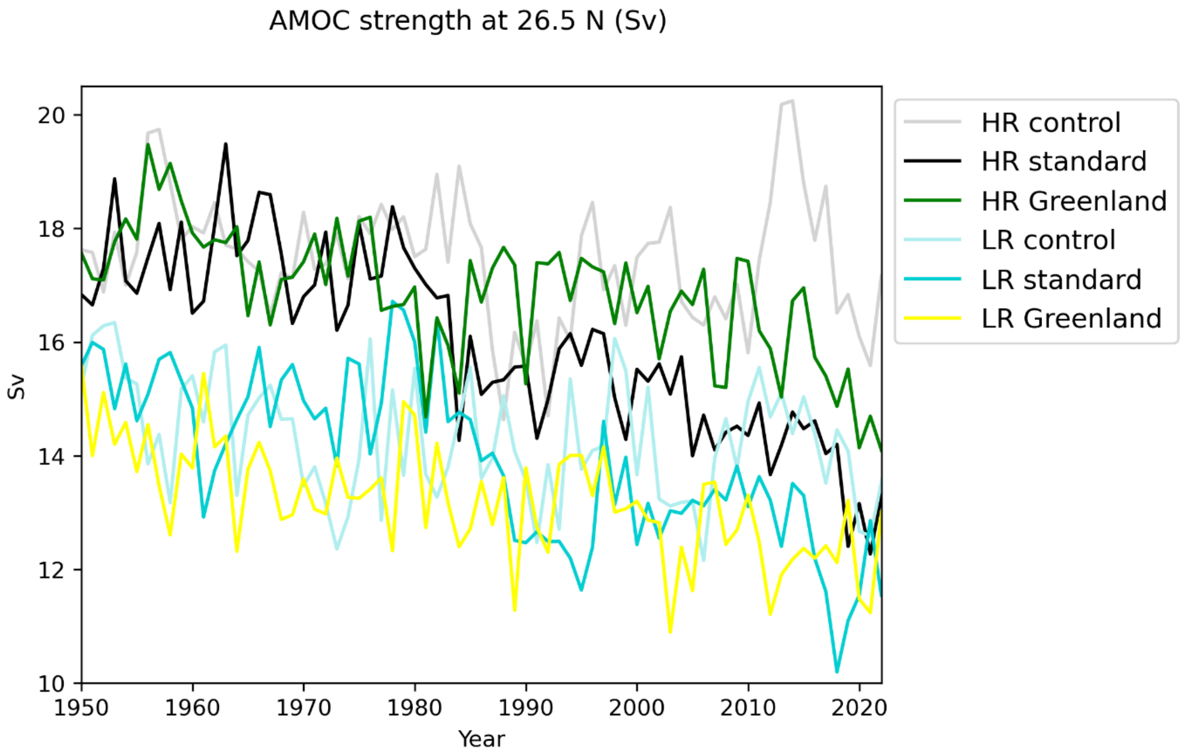


Fig. 2: a) Liquid runoff from AWI-CM3 (black line, standard historical simulation) and sum of liquid runoff and solid ice discharge prescribed from Mankoff et al. (2025), version 6 (green line, Greenland simulation). b) 7 main catchment areas defined by Mouginot et al. (2019). The sum of liquid runoff and solid ice discharge from Mankoff et al. (2025) is about five times larger than in the original AWI-CM3 simulation.

Fig. 3a shows the development of the maximum AMOC strength below 500 m over the ~70 simulation years from three different low resolution (LR) and three different high resolution (HR) simulations: The control simulations with constant 1950 greenhouse gas and aerosol concentrations, the standard simulations with historical increasing greenhouse gas and varying aerosol concentrations, and the Greenland simulations with the same historical greenhouse gas concentrations as in standard but with the liquid runoff and solid ice discharge from Mankoff et al. (2025). The maximum AMOC strength is reasonably constant in the control simulations, especially in the HR configuration; the LR configuration shows a slightly declining trend even in the control simulation. Both LR and HR standard simulations show a declining trend of the AMOC strength, in line with many CMIP6 simulations. While in LR there is no large difference between the three simulations, with LR standard and LR Greenland tending to have slightly less overturning strength than LR control, differences do evolve between the three HR simulations starting from around 1980. Surprisingly, the HR Greenland simulation constantly shows a stronger AMOC strength after around 1985 compared to the HR standard simulation. Towards the end of the simulation time period a more realistic value of 14 to 15 Sv is simulated in HR Greenland than the low value of around 12 to 13 Sv in HR standard. Generally, the HR simulations show higher values of maximum AMOC strength compared to the LR simulations.

Since the Greenland freshwater input is released much further to the north than the low latitude of 26.5 N that is typically used to determine the AMOC strength due to the location of the RAPID array, the AMOC strength at 55 N is depicted in Fig. 3b. Strong interannual variability makes it difficult to see any systematic differences. It is a surprising result that especially the high latitude overturning does not seem to be systematically affected by resolution differences and by such strong differences in the Greenland freshwater input.

a)



b)

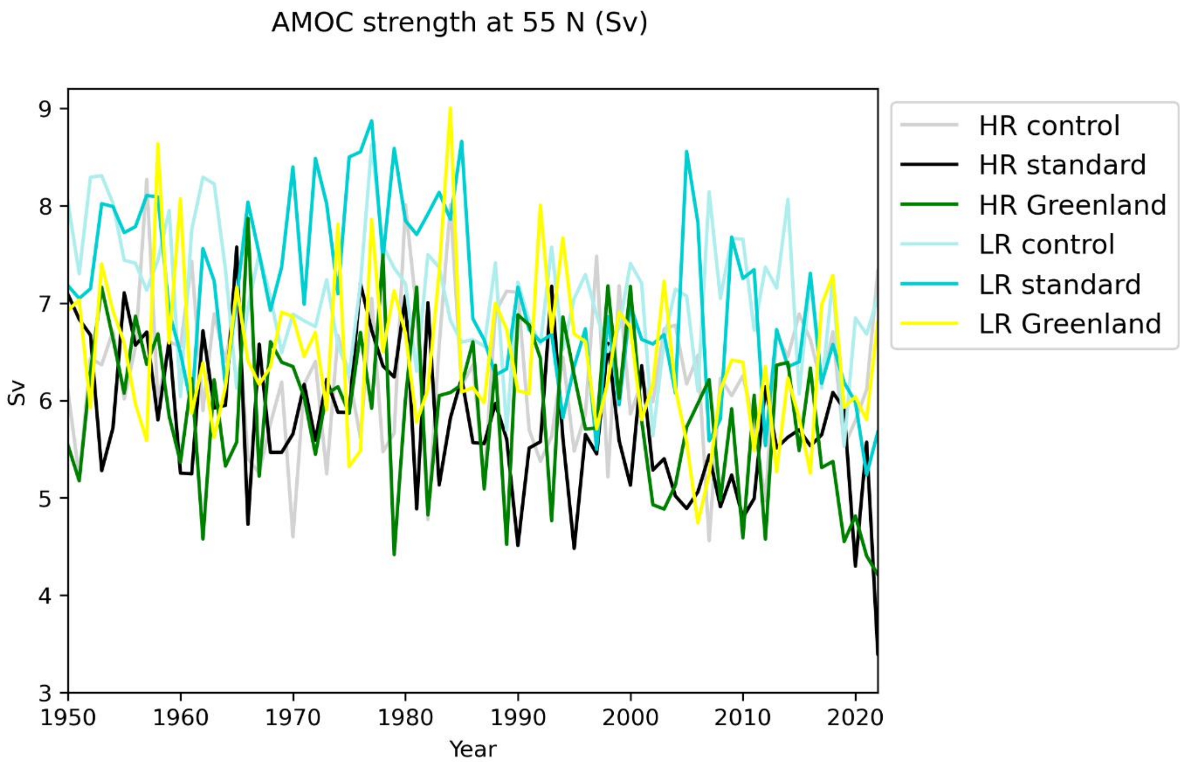
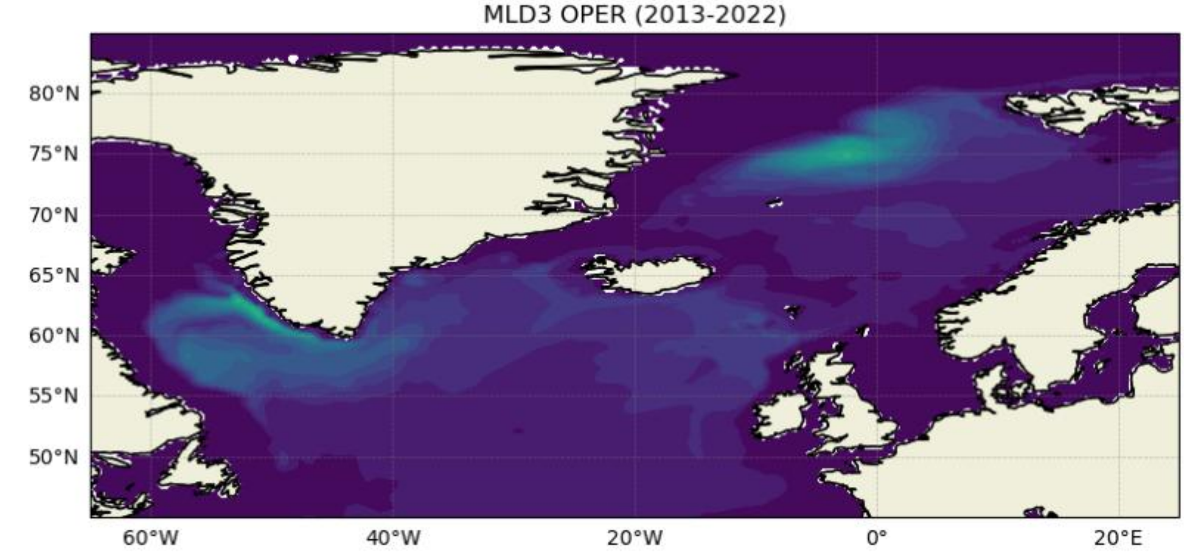


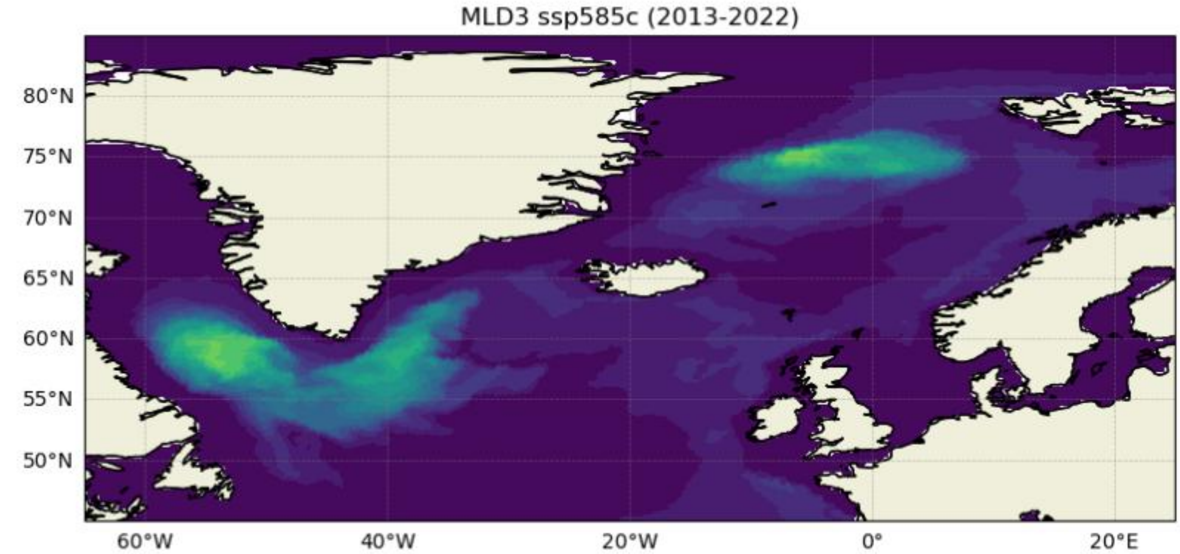
Fig. 3: Maximum AMOC strength in (a) 26.5 N and (b) 55 N

Fig. 4 shows the mixed layer depth from ORAS5 reanalysis and AWI-CM3 simulation data, averaged over 2013-2022, the last 10 years available from our simulations. Mixed layer depth is often used as a proxy for convection. Furthermore, it indicates the major deep water formation areas. In the ORAS5 reanalysis data (Fig. 4a), there are two convection areas, the Labrador Sea / Irminger Sea, and the Nordic Seas. Maximum convection in the Nordic Seas appears to be stronger than in the Labrador and Irminger Seas. Both LR simulations show stronger convection in both areas, especially the Greenland LR simulation. The HR simulations tend to be closer to the ORAS5 reanalysis data, but with only weak convection activity in the Nordic Seas. The HR Greenland simulation shows clearly stronger Labrador convection compared to the HR standard simulation which comes as a surprise. While only one ensemble member has been simulated, a possible explanation is the consideration of the latent heat of fusion in our Greenland simulations. Melting the ice bergs calving from Greenland takes energy from the ocean surface, destabilizing the upper ocean and having the opposite effect than the surface freshening arising from the freshwater input. This effect has only recently been acknowledged to be important.

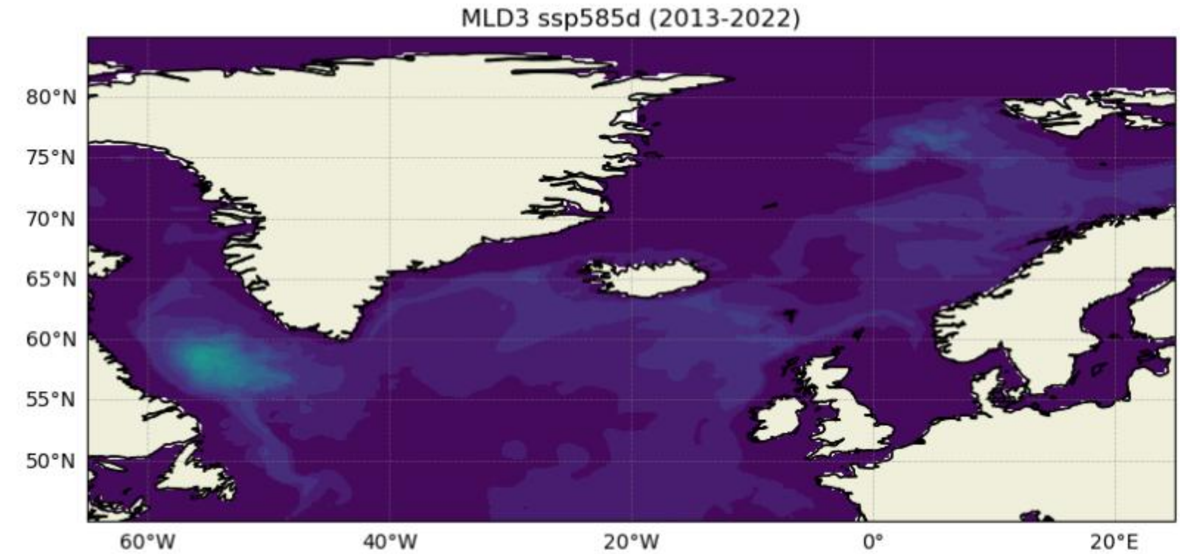
a)


MLD3 OPER (2013-2022)
80°N
75°N
70°N
65°N
60°N
55°N
50°N
60°W
40°W
20°W
0°
20°E

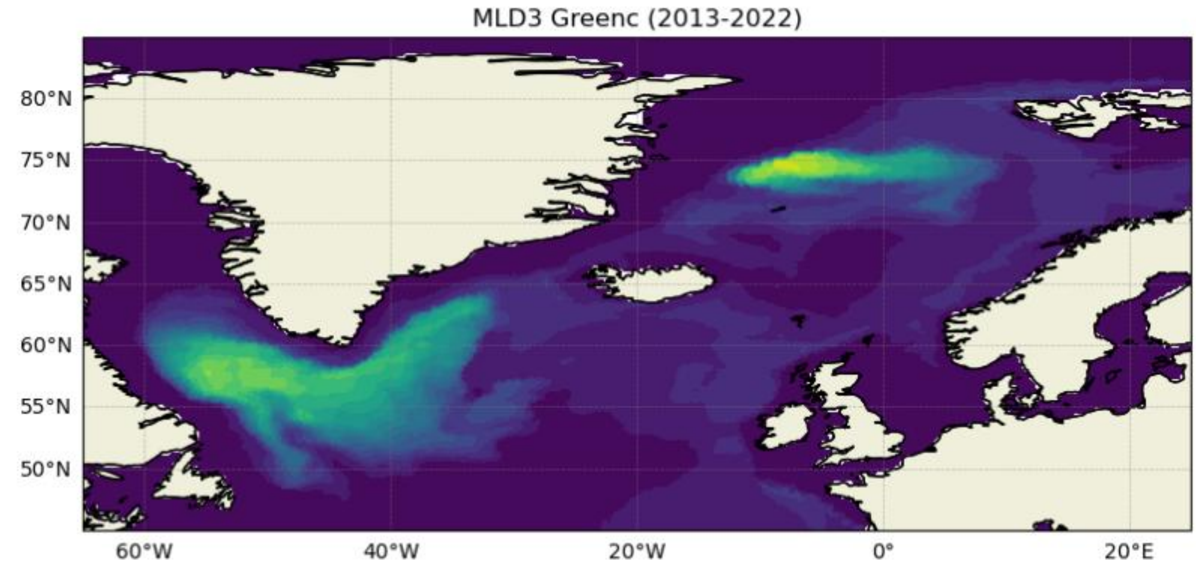
b)


MLD3 ssp585c (2013-2022)
80°N
75°N
70°N
65°N
60°N
55°N
50°N
60°W
40°W
20°W
0°
20°E

c)


MLD3 ssp585d (2013-2022)
80°N
75°N
70°N
65°N
60°N
55°N
50°N
60°W
40°W
20°W
0°
20°E

d)



e)

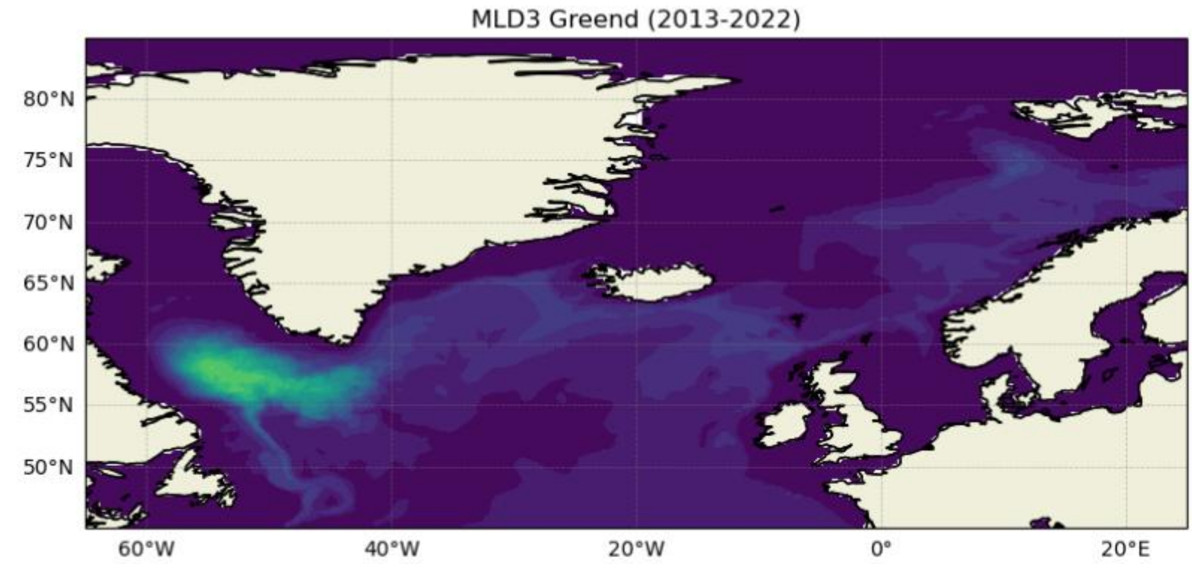


Fig. 4: Mixed layer depth in 2013-2022 from a) ORAS5 reanalysis data, b) LR standard, c) HR standard, d) LR Greenland, e) HR Greenland

It can be concluded that with these simulations various caveats of state-of-the-art CMIP6 simulations have been addressed with the aim of narrowing the uncertainty of processes contributing to a possible AMOC slowdown in the future. Two major caveats of CMIP6 simulations have been addressed: the resolution helping to resolve the narrow boundary currents and overflows over the Greenland – Iceland – Scotland ridge, and the prescription of realistic Greenland liquid water runoff and solid ice discharge estimates from Mankoff et al. (2025) which are often only very rudimentarily represented in state-of-the-art CMIP6 simulations. At least for the historical time period, the AMOC does not decline at a faster rate in the most sophisticated simulations compared to standard simulations. Surprisingly, the realistic consideration of Greenland liquid runoff and solid ice discharge even leads to a slower AMOC decline in the HR set-up compared to the rudimentary representation.

References:

Mankoff, K. D., Jourdain, N., Marson, J., Olivé Abelló, A., Mathiot, P., Davison, B., & Schmidt, G. A. (2025): Freshwater sources from Antarctica and Greenland. Data publication on zenodo. https://doi.org/10.5281/zenodo.14020895

Mouginot, J., E. Rignot, A. A. Bjork, and M. Wood (2019): Forty-six years of Greenland Ice Sheet mass balance from 1972 to 2018. Earth, Atmospheric, and Planetary Sciences 116 (19) 9239-9244, https://doi.org/10.1073/pnas.1904242116