REQUEST FOR A SPECIAL PROJECT 2024–2026

MEMBER STATE: Ireland

Principal Investigator[1]: Dr. Tido Semmler

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Project Title: Freshwater influence on the Atlantic Meridional Overturning Circulation

To make changes to an existing project please submit an amended version of the original form.)

If this is a continuation of an existing project, please state the computer project account assigned previously.	spiesemm	
Starting year: (A project can have a duration of up to 3 years, agreed at the beginning of the project.)	2024	
Would you accept support for 1 year only, if necessary?	YES X☐	NO ☐

Computer resources required for project year:		**2024**	**2025**	**2026**
High Performance Computing Facility	[SBU]	100 million	100 million	240 million
Accumulated data storage (total archive volume)[2]	[GB]	240,000	480,000	480,000

EWC resources required for project year:		**2024**	**2025**	**2026**
Number of vCPUs	[#]			
Total memory	[GB]			
Storage	[GB]			

[1] The Principal Investigator will act as contact person for this Special Project and, in particular, will be asked to register the project, provide annual progress reports of the project's activities, etc.

[2] These figures refer to data archived in ECFS and MARS. If e.g. you archive x GB in year one and y GB in year two and don't delete anything you need to request x + y GB for the second project year etc.

[3] The number of vGPU is referred to the equivalent number of virtualized vGPUs with 8GB memory.

Number of vGPUs[3]	[#]			

Continue overleaf.

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Extended abstract

All Special Project requests should provide an abstract/project description including a scientific plan, a justification of the computer resources requested and the technical characteristics of the code to be used. The completed form should be submitted/uploaded at https://www.ecmwf.int/en/research/special-projects/special-project-application/special-project-request-submission.

Following submission by the relevant Member State the Special Project requests will be published on the ECMWF website and evaluated by ECMWF and its Scientific Advisory Committee. The requests are evaluated based on their scientific and technical quality, and the justification of the resources requested. Previous Special Project reports and the use of ECMWF software and data infrastructure will also be considered in the evaluation process.

Requests exceeding 5,000,000 SBU should be more detailed (3-5 pages).

For north-western Europe the fate of the AMOC is extremely important. The AMOC does not only ameliorate the climate of north-western Europe transporting warm and salty water masses towards north-western Europe, but also keeps the sea level low. In other words, without the AMOC the sea level would be 30 cm higher along the north-western European coastlines (Couldrey et al., 2023).

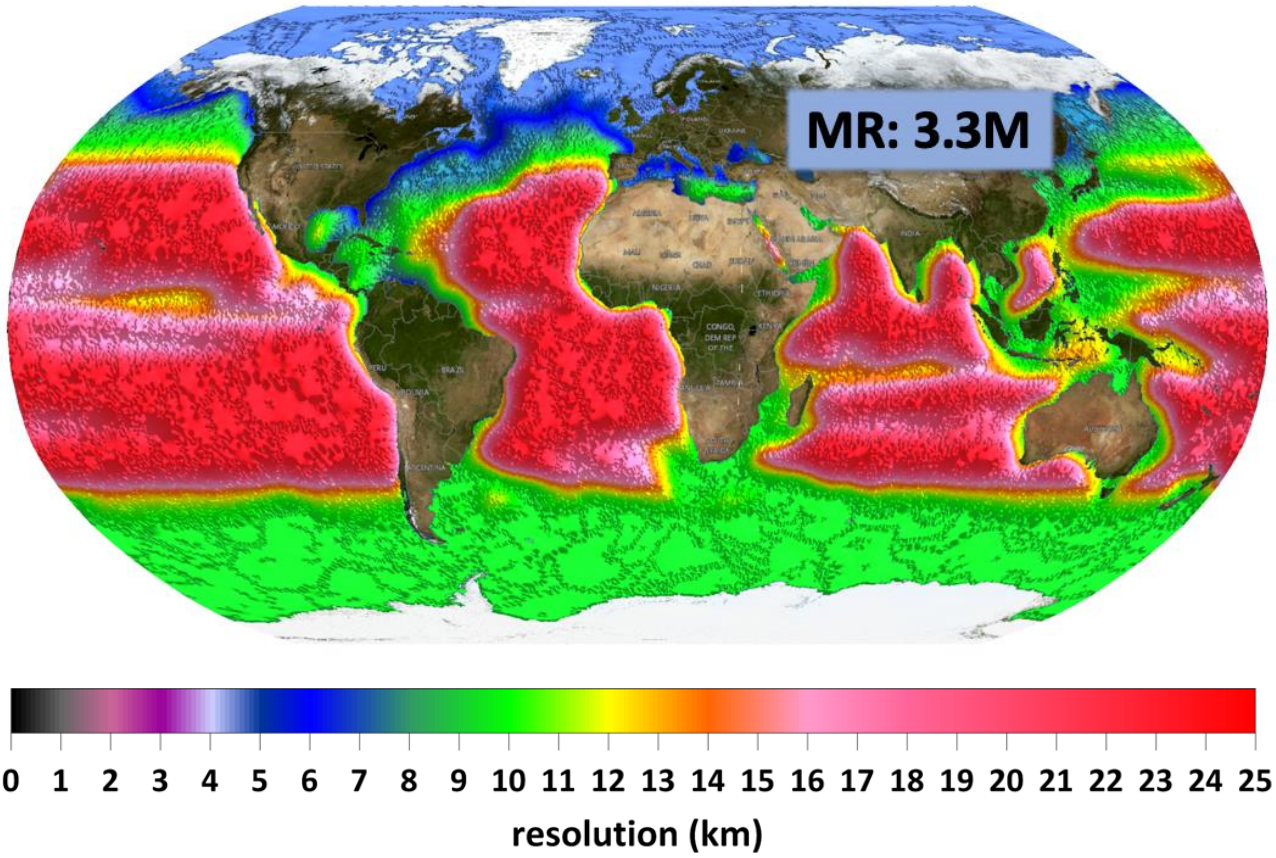
Various studies indicate that the AMOC has been weakening over the last decades and climate models from the last generations of the Coupled Model Intercomparison Project (CMIP) indicate that a weakening of the AMOC is to be expected as a response to greenhouse gas concentration increases. Caesar et al. (2020) even indicate that the AMOC is at its weakest since at least a millennium. According to the IPCC-AR6 report (IPCC, 2021), a total shutdown of the AMOC is very unlikely but should still be considered as a low-likelihood, high-risk event.

However, state-of-the-art climate models do not explicitly consider Greenland and Antarctic ice sheet melting and the corresponding freshwater input. A recent study by Sinet et al., (2023) indicates that there is a tug-of-war between Greenland and Antarctic ice sheet melting. Additional freshwater input from Greenland ice sheet melting on top of Arctic sea ice melting and increase of precipitation could lead to further weakening of the AMOC while additional freshwater input from Antarctic ice sheet melting would strengthen the AMOC. However, their study has been conducted with a conceptual model.

To make a step change towards the next Coupled Model Intercomparison Project (CMIP7) to inform the next IPCC assessment report, for this computing time proposal the idea is to consider realistic freshwater input from (a) only Greenland ice sheet melting, (b) only Antarctic ice sheet melting, and (c) both Greenland and Antarctic ice sheet melting using a sophisticated rather than a conceptual coupled climate model as in Couldrey et al. (2023). It has been shown that the resolution in the boundary currents is crucial for the realistic simulation of the subpolar gyres and therefore the overturning circulation. If the resolution is too coarse, the mixing of the freshwater from the boundary current into the subpolar gyre is not well represented so that the extra freshwater may not enter the subpolar gyre and not affect the AMOC (Swingedouw et al., 2022).

For this reason, our tool for the proposed simulations is the AWI-CM 3.0 consisting of OpenIFS cycle 43r3 (ECMWF, 2017) in TCO319 resolution (32 km globally) coupled to the Finite Element Sea ice Ocean Model 2.0 (FESOM2) (Danilov et al., 2017; Danilov et al., 2015).

The FESOM model features an unstructured mesh which makes it possible to resolve the areas of interest in a high resolution and leave other less dynamically active regions such as the subtropics at a relatively coarse resolution. The ocean model setup to be applied features a 6 km resolution over the North Atlantic current and even 4-5 km resolution over the Irminger Current and in the Labrador Sea. Also, around the north-western European coasts the resolution is between 4 and 6 km, and over the Southern Ocean around 10 km (Fig. 1).



Baseline simulations according to an extended HighResMIP protocol (100 years spin-up simulation with constant 1950 greenhouse gas and aerosol forcing, 150 years of 1950-control simulation, 65 years of 1950-historical simulation with increasing greenhouse gas and changing aerosol concentrations for 1950-2014, and 85 years of SSP5-8.5 scenario simulation) but without any consideration of additional Greenland or Antarctic meltwater input already exist. It has been shown that comparing the root mean square error of the AWI-CM3 historical simulation for various atmospheric and oceanic parameters (measured against state-of-the-art observations) with the one averaged over all CMIP6 simulations, an error reduction of about 20% could be achieved averaged over the different parameters and different regions of the globe. It has also been shown that the AMOC streamfunction is realistically simulated; a weakening of the AMOC by about 40% until the end of the century along with a warming hole over the North Atlantic subpolar gyre is simulated in this baseline SSP5-8.5 simulation. The evaluation of the proposed sensitivity simulations will focus on the changes in the AMOC due to the additional freshwater input as well as the impact on the north-western European climate with a focus on Ireland. Of particular interest will be the impact of the AMOC changes on temperature, precipitation, and wind patterns.

The OpenIFS model has been extensively tested on the HPC ECMWF-atos for the obvious reason that the model is developed and maintained at ECMWF. FESOM2 has been extensively tested not only on HPC ECMWF-atos, but also on many different HPCs including the HPC levante (German

Climate Computing Centre), HPC aleph at the IBS Centre for Climate Physics in South Korea, and others. Therefore, we believe that the ECMWF-atos is the right HPC for this application and an efficient use of the resources can be made.

This application for extension of the project is due to the technical difficulties encountered when setting up the AWI-CM 3 on ecmwf-atos as indicated in the progress report for 2024. In addition, waiting for the most recent version of Greenland and Antarctic meltwater data, had led to the decision to use the available computing resources in 2024 to make an extension of the AWI-CM 3 simulation that had been carried out at DKRZ (German Climate Computing Centre) for the next century (2101-2200). The scientific question to be answered was if the AMOC would shut down completely under extreme greenhouse gas forcing in such a high-resolution model set up. The AMOC shows a gradual decline until mid of next century and does not decline any further than to 5 Sv.

Now, that the new forcing data set to be used for CMIP7 simulations without interactive ice sheet is published by Mankoff et al. (2025), and after some sanity tests with a coarser resolution version of the AWI-CM 3 model, the work on the 3 simulations (only Greenland meltwater input, only Antarctic meltwater input, Greenland and Antarctic meltwater input combined) can start.

The schedule for the work is as following:

Second half of 2025: Greenland freshwater experiment from 1950-2100: 140 million SBU

First half of 2026: Antarctic freshwater experiment from 1950-2100: 140 million SBU

Second half of 2026: Greenland and Antarctic freshwater experiment from 1950-2100: 140 million SBU

Since these cutting-edge experiments are very expensive due to the high resolution, and since Met Éireann is very keen to pursue these experiments given the high relevance for Ireland, Met Éireann is willing to perform substantial parts of these experiments from the national allocation. We have been granted 143.75 million SBU for 2024, 100 million SBU for 2025 and request 240 million SBU for the year 2026 in this special project application and would contribute the remaining 80 million SBU from the national allocation.

These experiments will feed into the project “Improving EC-Earth’s Modelling of the North Atlantic Ocean-Atmosphere system”, WP5 “Investigation of OpenIFS-FESOM in the simulation of the North Atlantic Climate” (PI: Dr. Paul Nolan) and it is therefore important that the experiments can be finished as early as possible in 2026. The project was originally funded until mid of 2026 and has been extended until end of 2026. Some months are needed for the evaluation of the last planned experiment. Furthermore, the experiments will be used for further downscaling on the km scale using the coupled regional climate model HCLIM-NEMO.

References:

Caesar, L., G. D. McCarthy, D. J. R. Thornalley, N. Cahill, and S. Rahmstorf (2020): Current Atlantic Meridional Overturning Circulation weakest in last millenium. Nature Geoscience, 14, 118-120, doi: 10.1038/s41561-021-00699-z

Couldrey, M. P., J. M. Gregory, X. Dong, O. Garuba, H. Haak, A. Hu, W. J. Hurlin, J. Jin, J. Jungclaus, A. Koehl, H. Liu, S. Ojha, O. A. Saenko, A. Savita, T. Suzuki, Z. Yu, and L. Zanna (2023): Greenhouse-gas forced changes in the Atlantic meridional overturning circulation and related worldwide sea-level change. Climate Dynamics, 60, 2003-2039, doi: 10.1007-s00382-022-06386-y

Danilov, S., D. Sidorenko, Q. Wang, and T. Jung (2017): The Finite-volumE Sea ice–Ocean Model (FESOM2), Geosci. Model Dev., 10, 765–789, https://doi.org/10.5194/gmd-10-765-2017

Danilov, S., Q. Wang, R. Timmermann, N. Iakovlev, D. Sidorenko, M. Kimmritz, T. Jung, and J. Schröter (2015): Finite-Element Sea Ice Model (FESIM), version 2, Geosci. Model Dev., 8, 1747–1761, http://www.geosci-model-dev.net/8/1747/2015/

ECMWF (2017): IFS user documentation cycle 43r3. Available online at: IFS documentation | ECMWF

IPCC (2021): *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, In press, doi:10.1017/9781009157896.

Mankoff, K., J. Nicolas, J. Marson, A. Olivé Abelló, P. Mathiot, B. Davison, and G. A. Schmidt (2025): Freshwater sources from Antarctica and Greenland. Available online: https://zenodo.org/records/15360328.

Sinet, S., A. S. von der Heydt, and H. A. Dijkstra (2023): AMOC stabilization under the interaction with tipping polar ice sheets. GRL, doi: 10.1029/2022GL100305

Swingedouw, D., M.-N. Houssais, C. Herbaut, A.-C. Blaizot, M. Devilliers, and Julie Deshayes (2022): AMOC recent and future trends: a crucial role for oceanic resolution and Greenland melting? Frontiers in Climate, doi: 10.3389/fclim.2022.838310