REQUEST FOR A SPECIAL PROJECT 2022–2024

MEMBER STATE: Netherlands

Principal Investigator[1]**:** Dr. S.S. Drijfhout…………

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Project Title: Impact of Greenland melt water on EC-Earth high resolution simulations

If this is a continuation of an existing project, please state the computer project account assigned previously.	**SP** NLDRIJ_________________	
Starting year: (A project can have a duration of up to 3 years, agreed at the beginning of the project.)	2022	
Would you accept support for 1 year only, if necessary?	YES X☐	NO ☐

Computer resources required for 2022-2024: (To make changes to an existing project please submit an amended version of the original form.)		**2022**	**2023**	**2024**
High Performance Computing Facility	(SBU)	10,000,000	10,000,000	10,000,000
Accumulated data storage (total archive volume)[2]	(GB)	240,000	240,000	240,000

Continue overleaf

[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.

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Extended abstract

The completed form should be submitted/uploaded at https://www.ecmwf.int/en/research/special-projects/special-project-application/special-project-request-submission.

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.

Following submission by the relevant Member State the Special Project requests will be published on the ECMWF website and evaluated by ECMWF as well as the Scientific Advisory Committee. The evaluation of the requests is based on the following criteria: Relevance to ECMWF's objectives, scientific and technical quality, and 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 asking for 3,000,000 SBUs or more should be more detailed (3-5 pages). Large requests asking for 10,000,000 SBUs or more might receive a detailed review by members of the Scientific Advisory Committee.

This special project is a follow-up (not a continuation) of project SPNLHAAR "EC-Earth high resolution simulations" from PI Haarsma, now Co-I. In the previous project simulations with the high-resolution version of EC-Earth_v3.2 were performed with T511/ORCA025, following the HighResMIP protocol and within the European H2020 PRIMAVERA project. In a new grant from the National Polar Programme of the Netherlands it was proposed to extend the 3 EC-Earth members that followed the SSP585 emission scenario in the CMIP6 protocol in the PRIMAVERA project till 2100 (now 2050), and rerun those from the same year 2000 initial condition following additional Greenland meltwater forcing, allowing global sea-level to change mass. This set-up targets two main objectives. First, we anticipate a response in ocean circulation, in particular the Atlantic Meridional Overturning Circulation (AMOC). At this resolution we anticipate a stronger ocean-to-atmosphere forcing, in particular an anticyclone (high-pressure field) over the British Isles that is associated with increased summer droughts in north-west Europe, as found in the unforced runs ran to 2050. This high has been demonstrated to arise as response to cold subpolar gyre temperatures associated with a declining AMOC. Extended the runs to 2100 enhances the signal-to-noise ratio of this response and the additional meltwater forcing would further enhance the feature. A second objective is to investigate in more detail the associated changes in sea-level (SSH). Circulation changes associated with AMOC-decline are the strongest signal (and uncertainty in projections) in regional sea-level change along the west-European coasts. We know that the AMOC-decline initially is associated with a signal at the US-east coast (west-side of the Atlantic), but that the signal progresses to the east coast over time causing not only a decreased east-west gradient in SSH, but also an a decreased north-south gradient implying additional rise at the European coastline. How this transient response evolves over time is not well studied and only in coarse resolution models while we know from ocean-only runs that this response is seriously affected by wave adjustment and sensitive to ocean-resolution.

This project will be carried out in collaboration with EC-Earth partner BSC (Barcelona Supercomputing Centre) and part of the runs will be performed at BSC, part at ECMWF.

Motivation

The High Resolution Model Intercomparison Project (HighResMIP) has applied, for the first time, a multimodel approach to the systematic investigation of the impact of horizontal resolution on climate-change simulations and projections. The set of HighResMIP experiments was divided into three tiers consisting of atmosphere only and coupled runs and spanning the period 1950-2050. The protocol was outlined in Haarsma et al. 2016. In the European project PRIMAVERA 7 modelling centres (MetOffice, EC-Earth, CEFACS, MPG, AWI, CMCC, ECMWF) performed these runs according to the HighResMIP protocol.

In the Dutch Polar Climate and Cryosphere Change Consortium proposal, especially Work-Package 2 focuses on the link between changes in AMOC, regional sea-level and regional climate through atmospheric circulation changes. The AMOC is one of the fundamental drivers of European climate. It is associated with deep convection in the Labrador and Irminger Sea and in the Nordic seas. This deep convection occurs at small scales. An important research question is the impact of increasing resolution on the AMOC, in particular the response of the AMOC to global warming. Because of the change from parameterised (ORCA1) to eddy permitting (ORCA025) significant changes in deep convection and the dynamics of the AMOC are expected, especially in the northern North Atlantic where the AMOC is tightly coupled to the gyre-circulation with swift and narrow boundary currents that are not well-resolved in the standard CMIP6 configuration of climate models, which are dominated by 1-degree ocean models . Changes in AMOC dynamics will have large impact on Artic processes and Europe, but also outside these regions there will be significant effects.

An example of such effect is the warming hole in the North Atlantic caused by the weakening of the AMOC. This will induce an anomalous high over the eastern North Atlantic and the United Kingdom in spring and summer (Haarsma et al. 2015). Comparison of EC-Earth SST forced simulation at T159 and T799 suggests that this anomalous high increases with resolution, thereby enhancing the possibility of summer droughts in a future climate (Van Haren et al. 2015). The impact of resolution is supported by comparison with the ERA 20C reanalysis data set suggesting that CMIP5 models underestimate the amplitude of the anomalous high (Haarsma et al. 2015). Also, preliminary analysis of the EC-Earth PRIMAVERA run simulated in SPNLHAAR shows a stronger high and increased change of extreme summer droughts.

Lacking interactive ice-sheets it is common practice for climate models to balance snowfall on the icecaps with meltwater run-off at every timestep, conserving mass/volume of both ice caps and the World Ocean. At present, however, the icecaps are losing mass and this mass loss is projected to increase in the future (Shepherd et al., 2020; Slater et al., 2020). The resulting meltwater release to the ocean is therefore no longer balancing snowfall, contributing to sea-level rise at an accelerating rate. This also affects the ocean circulation, by decreasing the salinity of the waters where the meltwater is released and affecting salinity and density further downstream through advection.

Palaeoceanographic reconstructions provide evidence for large reductions in the AMOC related to freshwater input from melting ice caps (Condron and Windsor 2012). Currently, Greenland is losing mass at an accelerated pace and at the same time there has been a 50% decrease in Labrador Sea Water formed by deep convection (Yang et al., 2016). Accounting for the associated freshwater release indicates an extra AMOC weakening under a high emission scenario ranging from 5-15% (Lenaerts et al., 2015, Golledge et al., 2019). Results depend on horizontal resolution in ocean models, and the source region of the freshwater. Therefore, we propose to use the high-resolution version of EC-Earth adding a second SSP585-scenario run with the Greenland meltwater-release scenario from Lenaerts et al. (2015), which consists of a quadratic regression of melt to T500 JJA anomalies relative to the model's 1970-2000 climatology. In addition, this experiment allows for isolating the time-dependent impact of AMOC weakening on sea-level for the West-European coast. This signal is anticipated to evolve from a maximum at the US east-coast at short timescales to more basin-wide sea-level rise in the northern North Atlantic at longer timescales, whose time-dependent adjustment is essentially modified by small scales in the ocean (Brunnabend et al. 2017).

Model configuration

The modelling systems used in this special project will be the HighResMIP high resolution version of EC-Earth, EC-Earth3P-HR with a resolution of T511ORCA0.25 (Haarsma et al. 2020). EC-Earth is a global climate model developed by a European consortium of climate research institutes (Hazeleger et al., 2010; 2011). EC-Earth3P-HR, the version of the model used in PRIMAVERA, consists of an atmospheric circulation model based on ECMWF's Integrated Forecasting System (IFS) cycle 36r4, the NEMO3.6 ocean model, which also includes the LIM3 sea ice model (Haarsma et al. 2020).

Workplan and simulations

Targeted simulations with EC-Earth3P-HR (T511/ORCA025).

In 2021 as part of the former late submission request we intend to finale the three extension of the PRIMAVERA-runs with EC-Earth to 2100 (within PRIMVERA run to 2050). As far as these runs were not performed at ECMWF initial states for (atmospheric) restarts have to be produced locally at KNMI, which in the middle of the KNMI23 scenario-project has to be carefully scheduled. In the mean time we develop a meltwater-forcing protocol for mass loss of the Antarctic and Greenland Ice Sheets (partly) based on model variables of the three runs without meltwater forcing added. This protocol will be based on downscaling/regression models developed with stand-alone ice sheet models for the surface mass balance. For ocean basal melt existing parameterisations will be used based on ocean temperature anomalies simulated by EC-Earth, for changes in calving a protocol has to be developed and tested with prescribed output from EC-Earth and compared with scenario's where it is fully prescribed. Also, possibly bias-adjustment/flux correction based on analysis of bias in the polar/subpolar climate will be investigated. After the protocol s fully developed

3 historical and RCP8.5 runs starting from initial states in 1980 as simulated by the 3 members without meltwater forcing and run to 2100 will be carried out within the project.

As experienced in SNPLHAAR, one year of coupled simulation for EC-Earth3P-HRrequires 200.000 units, with a throughput of 2.3 years per day on 1080 cores. The simulations did produce 1.2 TB/year in grib format for the T511ORCA0.25 resolution and the HighResMIP requested output tables. We will probably reduce the output by focusing on monthly-mean values and only 6-hourly output for a limited number of 2d-variables. Part of the CMORIZED data will be stored at the JASMIN server, at KNMI and at BSC, leaving a limited amount at ECMWF.

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