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	2024
Project Title:	*Storylines of changing polar climates*
Computer Project Account:	SPNLBERG
Principal Investigator(s):	Dr. Willem Jan van de Berg
Affiliation:	Utrecht University Institute for Marine and Atmospheric Research Utrecht (IMAU)
Name of ECMWF scientist(s) collaborating to the project (if applicable)	
Start date of the project:	1 January 2024
Expected end date:	31 December 2024

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)	200.000.000+ 27.700.000	220.887.112	200.000.000	41.730.300[1]
Data storage capacity	(Gbytes)	400.000	1.999.936	400.000	2.099.183[2]

[1] As for 17 June 2024.
[2] As for 10 June 2024.

Summary of project objectives (10 lines max)

This project aims to improve our understanding of the Arctic and Antarctic historical and projected climate as well as evolution of the firn layer, and subsequently the surface mass balance, of the Greenland and Antarctic Ice Sheet. A wealth of data is already provided by atmospheric reanalyses, like ERA5, and Earth System Models (ESMs), but both lack resolution, especially ESMs, and dedicated parameterizations to describe, for example, the snowpack of an ice sheet, in sufficient detail. Therefore, we use the polar adapted regional atmospheric model RACMO, as well as HCLIM with polar modifications. Furthermore, we refine the description of the surface snow layer of ice sheets with the firn densification model IMAU-FDM.

In 2024, our primary focus of the simulations is of the projected climate of the Arctic and Antarctica for different storylines using RACMO.

Summary of problems encountered (10 lines max)

The most severe problem encountered was of personal nature. The Postdoc initially tasked to carry out these RACMO projections left our group for a permanent position elsewhere. We recruited a successor; however, she went on maternity leave. As a result, the first of these longer simulations was not launched in December 2023 as planned, but in April this year. As a result, these simulations weigh heavier on the 2024 budget, and due to their later completion, less time remains to carry out further planned RACMO simulations.

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

For 2024, the plans remain in line of the proposal. We will extend operational simulations in 2024 (#1) and carry out two projections for both the Arctic and Antarctica (#3 and #4). The lower resolution climate projection till 2300 of Antarctica (#5) will be ... Due to the delays of the polar RACMO projections (simulations #3 and #4), the subsequent IMAU-FDM simulations are postponed as these simulation and subsequent analysis does no longer fit timewise in the associated PhD projects.

List of publications/reports from the project with complete references

No publications are already ready from the work carried out in the past 6 months. Nonetheless, the publications will be written using the numerical experiments carried out.

Summary of results

In the project proposal for 2024, six numerical experiments are listed. Here, we discuss the work carried out on the experiments. For clarity, we do not follow the order in the proposal, but organize the work carried out on basis of the model used.

RACMO2.4

Model development and postprocessing existing runs (5.4 million SBU)

In 2023, the main development of RACMO2.4 was completed. This version was officially baptised as RACMO2.4p1 and a publication on the first results, described in the special project report of 2023 and below, is in review (van Dalum et al., 2024). In 2024, the historical simulation for Antarctica forced with ERA5 data, discussed in the special project final report of 2023, was completed till the 1st of January 2024. A paper on the modelled climate and surface mass balance - the net mass gain (or loss) of the ice sheet surface due to atmosphere-ice surface interactions - of Antarctica is in draft. During the analysis phase of these results, we concluded some output was inconveniently exported. This required some reprocessing and testing of adjusted code.

Historical simulation of Greenland on 5.5 km (18.3 million SBU)

Next to the historical ERA5 driven simulation for Antarctica, we completed a similar simulation for Greenland, on 5.5 km resolution. This simulation covers the period 1945 to 1 January 2024. After a thorough evaluation, yet to be done, the results will be used for a publication, and data will be made publicly available by publishing on Zenodo.

The left panel in Figure 1 displays the mean modelled surface mass balance of glaciated surfaces for 1993-2022, thus the Greenland Ice Sheet as well as surrounding glaciers and ice caps. It shows the known patterns, like high accumulation on the south-eastern side of Greenland Ice Sheet and ablation zones along the western and northern edges. However, the modelled ablation zones are narrower than in preceding estimates, in part due to higher precipitation rates in RACMO2.4p1 compared to the previous operational version (2.3p2). The difference in modelled precipitation between versions 2.4p1 and 2.3p2 for the period 1993-2022 is shown in the right panel of Figure 1. Besides a considerable enhancement of precipitation along the wet Eastern coast of Greenland, precipitation is also enhanced along the western margin of the Greenland Ice Sheet. More precipitation balances summer melt water runoff, but also reduces melt, due the net summer albedo increase of more winter snowfall. Enhanced precipitation - by snowfall - increases the SMB in the ablation zone thus typically twice the enhanced amount. Further evaluation is thus needed to assess the quality of the results obtained in this simulation.

Projections within the PolarRES (7.5 million SBU)

As part of our commitment to the EU-funded H2020 project PolarRES, we run two projections till 2100 for both the Arctic as Antarctica in 2024. By the end of June, the Antarctic historical simulations preceding these projections are being run, these run for the Arctic have not yet been start up. However, a conversion error during the boundary generation process was observed in the first Antarctic historic simulations after running 20 years of the simulation. After correction, this historical simulation was restarted. Hence, some budget has been spent on this sub-project in 2024, but no results can be shown yet.

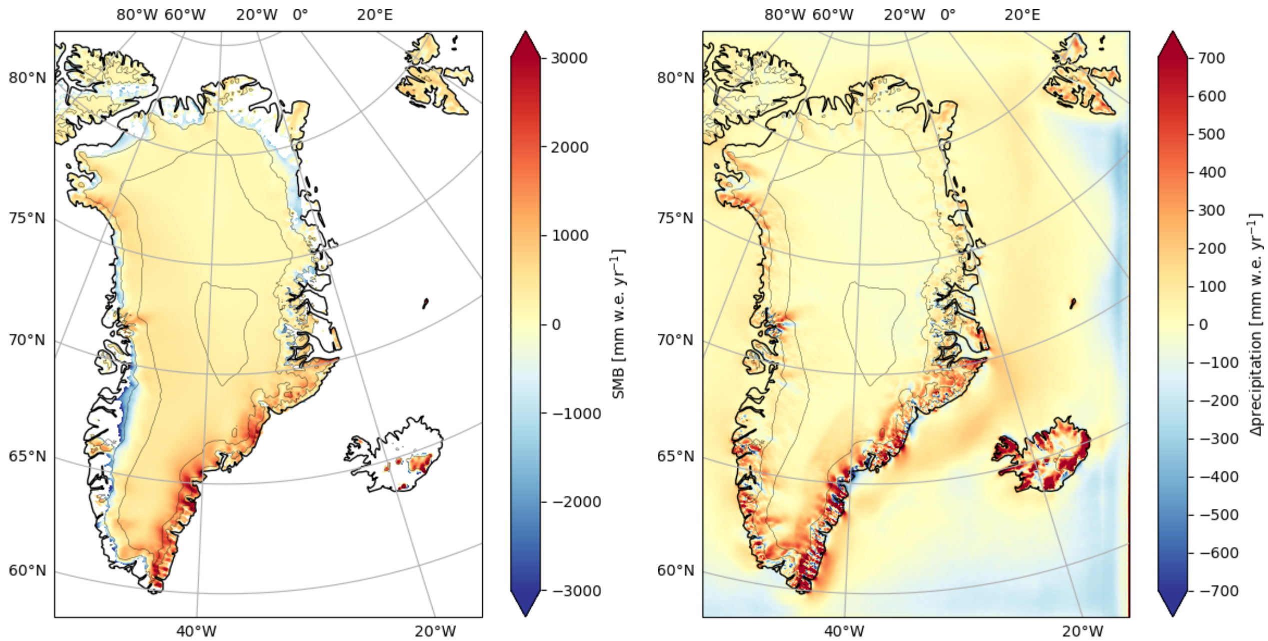

Figure 1: *(left) Mean annual modelled surface mass balance of glaciated points for 1993-2022 by RACMO2.4p1. Grid points without glaciated tile are masked out. (right) Difference in modelled precipitation by version 2.4p1 compared to 2.3p2, for 1993-2022. Values are positive when 2.4p1 exceeds 2.3p2.*

HCLIM

Model development and sea ice research (8.1 million SBU)

HCLIM-AROME was run alongside other regional atmospheric (MAR, RACMO), oceanic (MetROMS-UHel) and coupled (MAR-NEMO) models to compare the representation of the basic sea ice characteristics: sea ice albedo, snow and ice thickness, and meteorological data, during the melt periods of two Antarctic domains with very different sea ice conditions, using data of the ISPOL and Marsden field campaigns. With updated snow grain size to snow density relation, HCLIM-AROME performs well next to the other models, over large scales, such as the Weddell Sea shown in Figure 2.

However, comparisons with satellite images and in-situ measurements reveal, that the ability to reproduce 10 km-scale spatial and temporal variations, depends on the local conditions. Overall, the models did well reproducing the snow-covered sea ice during the ISPOL campaign, when the weather was mild, with the air temperature mostly above -5 ℃. But, the Marsden field campaign took place in an area of complex topography, cold conditions, and greatly varying sea ice states, where the models tend to overestimate the albedo and can not reproduce the thin, patchy snow cover over the campaign site. This work is being prepared for publication.

Furthermore, within collaboration with the British Antarctic Survey, NCAR and DMI, HCLIM-AROME, with the new set-up is being used in a comparative regional climate modelling study of extreme precipitation in West Antarctica.

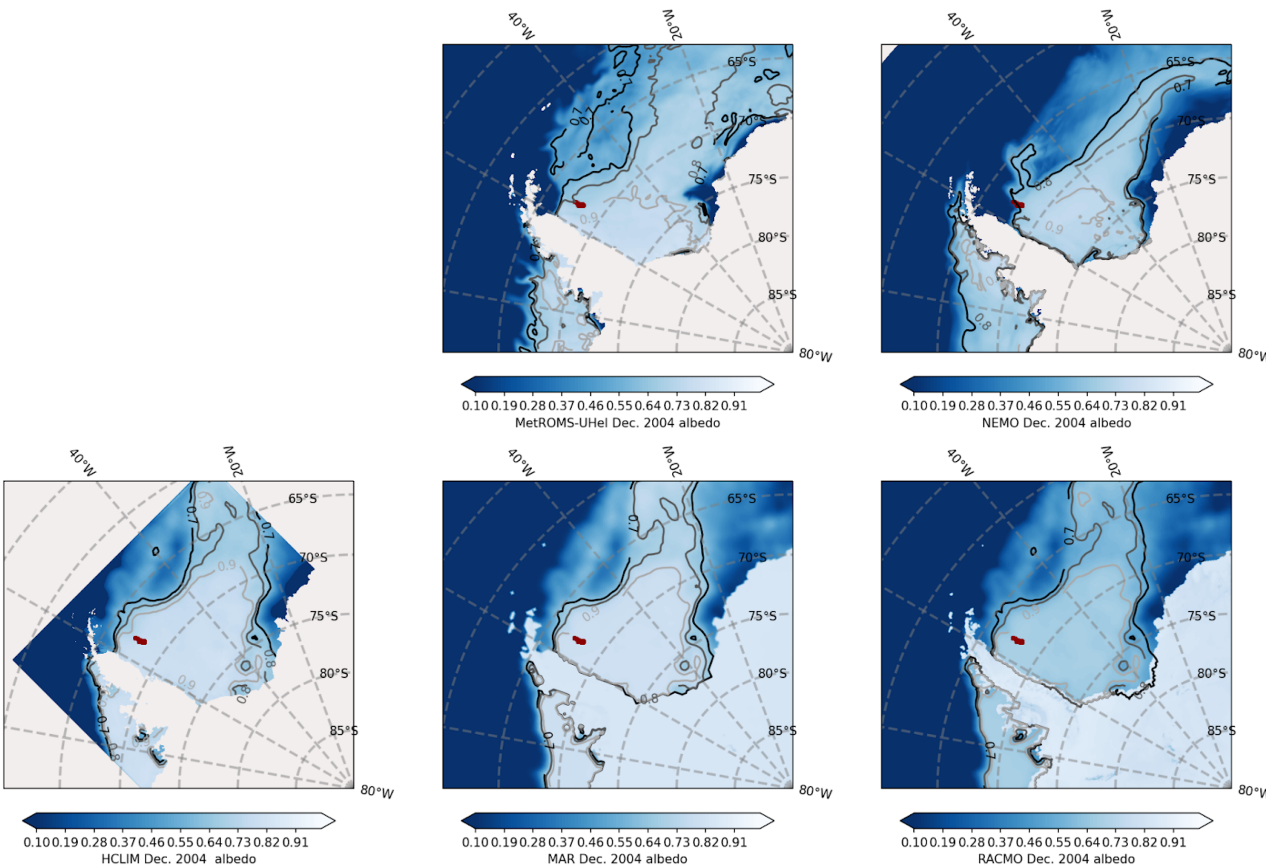

Figure 2. *Monthly mean modelled total albedos of MetROMS-UHel, NEMO, HCLIM, and MAR over the Weddell Sea domain. Sea ice concentration contours are shown on top. The red dots mark the location of the observations during the ISPOL campaign.*

IMAU-FDM

Projections for Antarctica (0.9 million SBU)

Future IMAU-FDM firn simulations over Antarctica (1950-2100) for several emission scenarios have been performed in 2023. A small bug was found in the model code, and therefore a part of the simulations had to be rerun in 2024. For details on these future simulations, we refer to the Special Project final report of spnlberg for 2023 and Veldhuijsen et al. (2024).

Operational IMAU-FDM simulations (0.2 million SBU)

Firn simulations over Antarctica for the contemporary climate (1979-2022) have been performed in 2023. The simulations are forced by output of RACMO2.3p2 at a 27 km resolution. In 2024, these operational simulations were kept up to date by extending the simulations until December 2023, predominantly to meet the demand of the altimetry community.

High resolution firn modelling Antarctica (1.2 million SBU)

High resolution IMAU-FDM simulations across four ice shelf regions in Antarctic have been performed. These simulations are forced by statistically downscaled RACMO2.3p2 output at a 2 km resolution. The statistically downscaled RACMO2.3p2 technique and results are described in Noël et al. (2023). When going from a 27 km resolution to a 2 km resolution the amount of grid points increases by a factor of 183. Therefore, as a precursor to a continental wide assessment, we performed 2 km IMAU-FDM simulations for four ice shelf regions in Antarctica. Figure 3 shows the simulated firn air content (FAC, the vertically integrated amount of pore space in the firn) for each of these regions for the 2 km resolution (a,d,j,g) and for the 27 km resolution (b,e,h,k) and the FAC difference between the 2 km and 27 km resolution (c,f,i,l). Overall, at 2-km resolution, topography is resolved better, especially in areas with complex topography and strong elevation gradients. This is mainly prevalent along the grounding lines of Larsen C and George VI ice shelves. Here, the results show higher FAC on the grounded ice and a lower FAC on the ice shelf at a 2 km resolution. The results will also be compared to in-situ firn observations and satellite observed meltwater lakes for evaluation.

references

Noël, B., van Wessem, J. M., Wouters, B., Trusel, L., Lhermitte, S., & van den Broeke, M. R. (2023). Higher Antarctic ice sheet accumulation and surface melt rates revealed at 2 km resolution. *Nature Communications*, *14*(1), 7949. https://doi.org/10.1038/s41467-023-43584-6

van Dalum, C. T., van de Berg, W. J., Gadde, S. N., van Tiggelen, M., van der Drift, T., van Meijgaard, E., van Ulft, L. H., & van den Broeke, M. R. (2024). First results of the polar regional climate model RACMO2.4. *EGUsphere*, *2024*, 1-36. https://doi.org/10.5194/egusphere-2024-895

Veldhuijsen, S. B. M., van de Berg, W. J., Kuipers Munneke, P., & van den Broeke, M. R. (2024). Firn air content changes on Antarctic ice shelves under three future warming scenarios. *The Cryosphere*, *18*(4), 1983-1999. https://doi.org/10.5194/tc-18-1983-2024

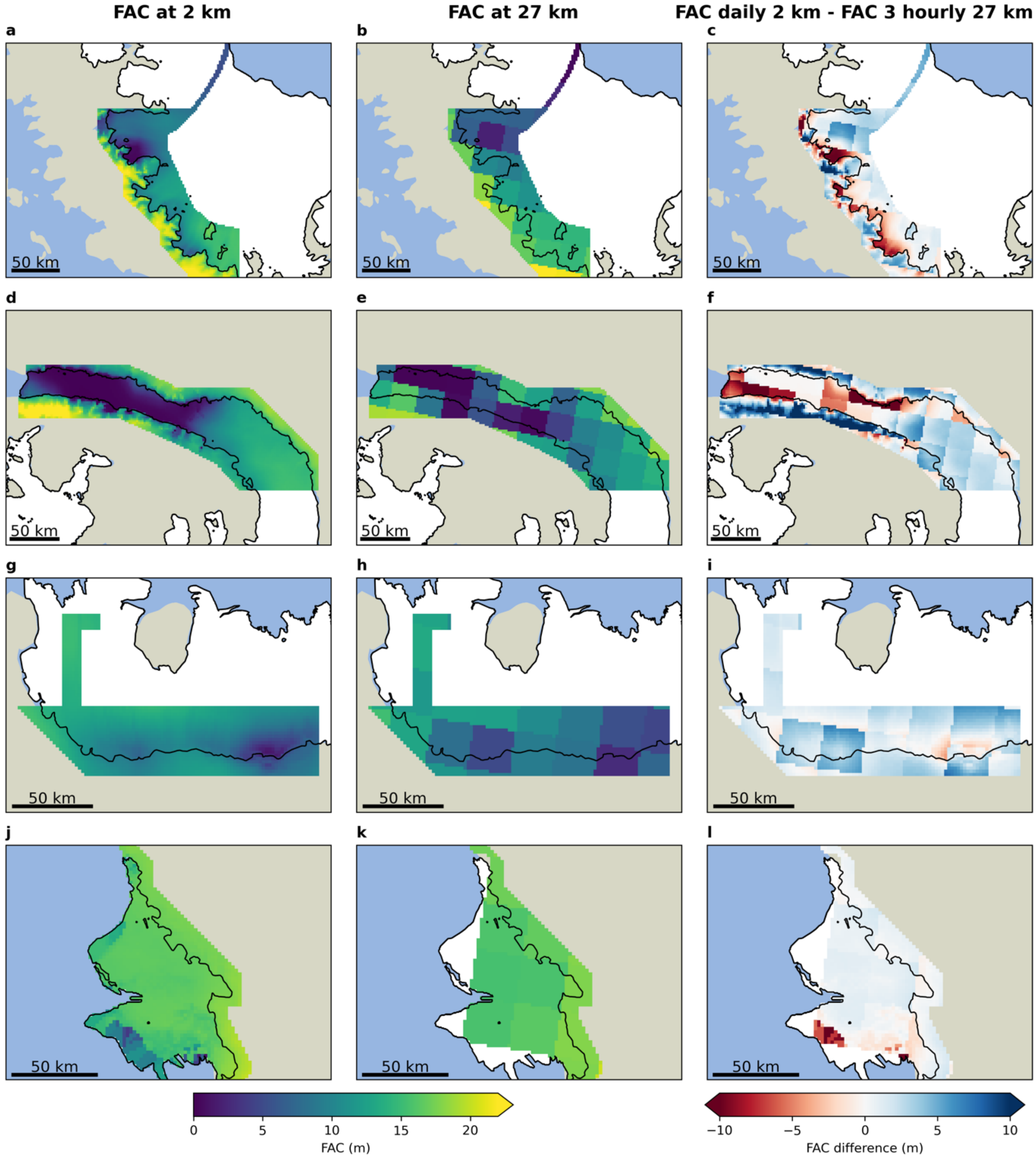

Figure 3. *Simulated firn air content (FAC, the vertically integrated amount of pore space in the firn) for Larsen C (first row), George VI (second row), Roi Baudouin (third row) and Thwaites (fourth row) for the 2 km resolution (a,d,j,g) and for the 27 km resolution (b,e,h,k) and the difference between the 2 km and 27 km resolution (c,f,i,l).*