REQUEST FOR A SPECIAL PROJECT 2018–2020

MEMBER STATE: The Netherlands

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Bert van Ulft and Erik van Meijgaard (KNMI, The Netherlands)

Project Title: Present-day and future climate of Antarctica and Greenland modelled with RACMO2.

If this is a continuation of an existing project, please state the computer project account assigned previously.	**SPNLBERG**	
Starting year: (A project can have a duration of up to 3 years, agreed at the beginning of the project.)	2018	
Would you accept support for 1 year only, if necessary?	YES ☒	NO ☐

Computer resources required for 2018-2020: (To make changes to an existing project please submit an amended version of the original form.)		**2018**	**2019**	**2020**
High Performance Computing Facility	(SBU)	30.000.000		
Accumulated data storage (total archive volume)[2]	(GB)	125.000		

An electronic copy of this form must be sent via e-mail to: *special_projects@ecmwf.int*

Electronic copy of the form sent on (please specify date):

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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 an annual progress report of the project's activities, etc.

[2] 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.

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Extended abstract

Summary

For all low-lying coastal zones across the globe, sea level rise due to significant mass loss from the Antarctic Ice Sheet (AIS) and the Greenland Ice Sheet (GrIS) is the largest threat associated with projected climate change. In the project proposed here, the regional climate model RACMO2 will be used to simulate the AIS and GrIS surface mass balance. Firstly, updated estimates of the recent contribution of surface mass loss from the AIS and GrIS are provided using RACMO2 driven by ERA5 reanalysis. Furthermore, a detailed future climate run (1980-2100) for the Antarctic Peninsula will be carried out. Finally, a novel snow albedo scheme will be implemented and tested. The proposed runs will provide new insights in the driving aspects of the surface mass balance of the AIS and GrIS and the stability of the Antarctic ice shelves in the coming century.

Motivation

The AIS and GrIS are the two largest fresh water bodies on Earth and store a water volume equivalent to 56 and 7.3 m of global sea level rise, respectively. In the last decades, both ice sheets increasingly contributed to global sea level rise, which was of 3.2 mm a^{-1} for 1993-2010 (IPCC 2013). Their combined contribution to global sea level rise has increased from about 0.28 mm a^{-1} for the period 1992-2000 to about 0.95 mm a^{-1} for 2005-2010 and finally about 1.4 mm a^{-1} for 2010-2015 (Shepherd and others 2012; Van den Broeke and others, 2016; Gardner and others, 2017). For the 21st century and beyond, even larger contributions are projected (e.g. Van Angelen and others, 2013; DeConto and Pollard, 2016), however with great uncertainty. For many low laying countries and regions like The Netherlands or London, future sea level rise is a larger threat that climate warming, so accurate global sea level rise projections are essential.

For the GrIS, enhanced snow and ice melt is the primary cause for the recent enhanced mass loss (e.g. Van den Broeke and others, 2016). For the AIS, the recent mass loss is primarily due to enhanced ice discharge driven by ocean-ice sheet processes. However, ice discharge into the ocean is restrained by ice shelves that provide buttressing. The stability of many Antarctic ice shelves is at risk in a warmer future climate with significant snowmelt (Kuipers Munneke and others, 2014; Lenaerts and others, 2016), potentially leading to an even larger contribution of the AIS to future global sea level rise. Concluding, understanding of the processes that currently govern melt and projections of future climate and snow and ice melt for the AIS and GrIS are indispensable for future sea level rise projections, and, eventually, for sustained flood security of several hundred million people.

Mass losses by enhanced melt water runoff from glaciers and ice caps are firstly determined by the mean climate, in which a warmer and dryer climate leads to more melt and melt water runoff. Secondly, melt and subsequent runoff are largely determined by the surface albedo of snow and ice, as the downwelling short wave radiation flux is the largest energy source. The broadband albedo (reflectivity) of pure snow depends mainly on grain size. Fresh, fine-grained snow has a high (~0.85) albedo, limiting melt, whereas older or melting course grained snow has a lower (~0.7) albedo, doubling absorption of shortwave radiation and greatly enhancing melt water production. Glacier ice, which surfaces once all snow has melted away, has an even lower albedo of 0.3 to 0.5, depending on the impurity content. The powerful positive melt-albedo feedback (melt reduces albedo, which further enhances melt) underlines the necessity to model snow and ice albedo correctly, as small errors in modelled albedo will amplify by erroneous evolution of the snow/firn pack through the summer. Thirdly and finally, subsurface refreezing and retention of melt water in deeper firn layers mitigate surface mass loss as it buffers part of the surface melt water. For the GrIS, retention and refreezing currently prevents more than 40% of the melt water to run off, while for the AIS this is > 99%. Even for the milder Antarctic Peninsula, only about 10% of the melt water production is simulated to flow into the ocean (Van Wessem and others, 2014; 2016).

On top of these surface processes that determine melt water runoff and thus the SMB, changes in melt water production and melt water refreezing will alter the thickness and air content of the firn layer. Increasing melt leads to a thinner firn layer, and once snowmelt approximates snowfall, the firn layer disappears in summer, subsequently allowing melt water ponding. The recent ice shelf collapses of the Larsen A and B and Wilkins Ice Shelves showed that melt water ponding is a trigger for their disintegration. In a warmer future climate, enhanced melt will threaten the much larger Larsen C ice shelf in the Antarctic Peninsuls, as well as the various ice shelves around East and West Antarctica or even the large Filchner-Ronne and Ross Ice Shelves.

Main research questions

We aim to answer the following research questions with the model simulations proposed below.

1) How have the climate and SMB of the AIS and GrIS changed during the 1979-2017 period?

2) Are the remaining ice shelves of the Antarctic Peninsula stable in warmer future climate?

3) What is the impact of radiation penetration and cloud-albedo effects on the SMB of the GrIS?

Methods: polar RACMO2

As the current generation of global climate models (GCMs) still show serious deficiencies in the representation of ice sheet surface – atmosphere interactions, and hence in estimating snow and ice melt, regional climate models (RCMs) are commonly used to model the surface mass balance (SMB) of the AIS and GrIS. We plan to use the latest version of the Regional Atmospheric Climate Model RACMO2, which has been adapted to model the climate over ice sheets and has been used and evaluated extensively before.

The polar version RACMO2 is one of the leading RCMs in this research field, and has been used for numerous studies of the SMB and climate of the AIS and GrIS and its peripheral glaciers, as well as other glaciated areas like the Canadian Arctic and Patagonia (e.g. Noël and others, 2015; 2017; submitted, Van Wessem and others, 2014; Lenaerts and others, 2013). RACMO2 is developed by the Royal Netherlands Meteorological Institute (KNMI) and consists of the dynamics of HIRLAM (version 5.0.6) and ECMWF IFS physics (currently version CY33R1). In order to represent the surface processes of glaciated areas, the polar version of RACMO2, hereafter simply referred to as RACMO2, is extended with an interactive multi-layer snow model which includes heat conduction, firn densification, drifting snow processes, melt water percolation, retention and refreezing and an albedo parameterization using the snow grain evolution. In 2017, we improved the performance of RACMO2 by retuning snow albedo, snowdrift, firn densification and precipitation and cloud-precipitation conversion processes (Noël and others, in preparation; Van Wessem, in preparation).

Like HIRLAM, RACMO2 is a fully parallel model with separated I/O and along with RACMO2 there is a suite of batch pre- and postprocessing scripts. RACMO2 is typically run on 300 to 700 cores (SMT) at ECMWF.

Runs to be performed

1) A present-day (1979-2017) run for Greenland will be performed at 5.5 km resolution. This run is forced by ERA5 and will be run as continuation of the existing run covering 1958-1978, driven by ERA-40. This RACMO2 run at 5.5 km resolution over Greenland costs approximately 19 kSBU per month, so the full run requires 8.7 MSBU and 36 TB storage space.
2) A present-day (1979-2017) run of whole Antarctica will be carried out at 18 km resolution. This run will also be driven by ERA5 boundaries. This run will not be preceded with an ERA-40-driven run as reanalysis data prior 1979 have shown to be of insufficient quality for Antarctica and the Southern Ocean. The computing costs of this run are 9 kSBU per month, thus 4.2 MSBU and 26 TB of data for the whole run. These first two runs are used to answer research question 1.

3) A future climate (1980-2100) run for the Antarctic Peninsula will be carried out at 5.5 km resolution using the RCP8.5 scenario. This simulation will be driven by CESM data directly or the 1980-2100 RACMO2 run driven by CESM data, which will be completed in 2017. Figure 1 demonstrates that runs on 5.5 km resolution allows to resolve the melt patterns over the Antarctic Peninsula in full detail, in contrast to runs on 18/27 km resolution. Estimated costs are 10 kSBU per individual month thus 15 MSBU and 52 TB storage space for the full run.

4) Various test runs required for the implementation, testing and evaluation of TARTES in RACMO2. TARTES is a narrowband shortwave radiation model for the reflection and penetration of shortwave radiation in snow (Libois and others, 2013; 2015). Estimated costs are about 1 to 2 MSBU (20 years Greenland on 11 km resolution) and 10 TB of data.

Applications:

- As ERA5 is expected to be an improvement compared to ERA-Interim, it is expected that the ERA5 driven runs for Greenland and Antarctica will lead to an improved representation of the surface climate and subsequently the SMB of the GrIS and the AIS. For the GrIS, 5.5 km model simulation is required because recent research has shown that 11 km resolution, which we have used so far, is insufficient to model the large SMB gradients in the narrow ablation zones of the GrIS or the SMB of the numerous smaller glaciers on Greenland (Noël and others, 2016; 2017). The results for Greenland will be further refined using statistical downscaling to a 1 km product.
- The output of the 1958-2017 GrIS and the 1979-2017 AIS simulations will be used to drive two firn densifications models (Steger and others, 2016) in order to investigate the long-term evolution of the firn layer in response to increasing temperatures and surface melt. These additional simulations will also provide precise estimates of the changes in the thickness of the firn column, which are required to relate satellite altimetry data to ice sheet mass changes.

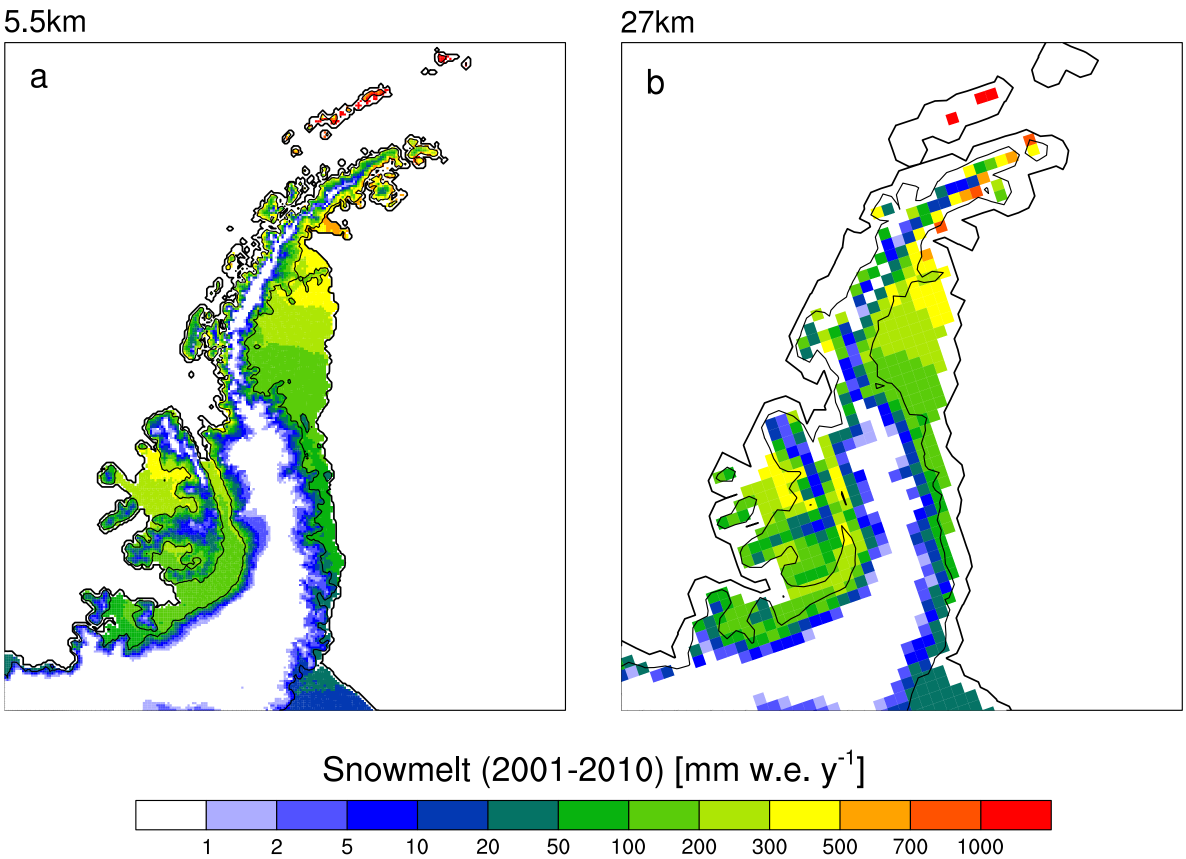

Figure 1: *Modelled snowmelt by RACMO2.3 on the Antarctic Peninsula (Van Wessem and others, 2016).*

- The high-resolution future climate run for the Antarctic Peninsula will be used to assess the projected increase of melt and the subsequent impact on ice shelf stability. When and where might we expect more ice shelves in the Antarctic Peninsula to disintegrate? Furthermore, the run will be analysed for the current and future presence of firn aquifers on the Antarctic Peninsula (research question 3).
- The implementation of TARTES, a spectral radiation model for reflection and penetration of shortwave radiation in snow and ice, aims to further improve the representation the albedo over glaciated surfaces in RACMO2. As the albedo of snow highly spectrally dependent – virtually 1 for most of the visual wavelengths but almost 0 for the near-infra red – a narrowband radiation scheme for snow now allows to explicitly model the effects of clouds, impurities and snow metamorphism on the net shortwave absorption. Furthermore, as subsurface heating by insolation is also highly wavelength dependent, including TARTES allows physically correct estimates of subsurface heating and subsequent melting. It is expected that this code extension will improve the modelled surface energy balance, melt rates and subsurface temperatures. Furthermore, it is expected that the coupler, which limits the computing costs of TARTES without loss of quality, currently under development, is also suitable for SURFEX, which is, for example, used within HARMONIE-AROME.
- Besides the applications listed above, the data will be used for numerous other applications and model output will be shared with the international research community.

Embedding

The proposed model runs will be of vital importance for several on-going and fully funded PhD and Postdoc projects at IMAU, Utrecht University. These PhDs and Postdocs will carry out the majority of the model simulations and the subsequent data analysis. The PI will manage the computing resources and will provide local support on RACMO2.

Total computational requirements

In total, we estimate to need 30 MSBU high performance computing facilities. In this request, 5% overhead is included for additional tests. As we are used to archive model output in detail, the data storage request is significant with 125 TB. This storage, however, is needed to allow detailed analysis of the model output in a later stage of the research.

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