# SPECIAL PROJECT PROGRESS REPORT

Progress Reports should be 2 to 10 pages in length, depending on importance of the project. All the following mandatory information needs to be provided.

| | |
|---|---|
| **Reporting year** | 2017 |
| **Project Title:** | Present and future climate of Antarctica and Greenland modelled with RACMO2. |
| **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) | ………………………………………………………………<br>……………………………………………………………… |
| **Start date of the project:** | 1-1-2017 |
| **Expected end date:** | 31-12-2017 |

**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) | | | 40 mSBU | 8.65 mSBU |
| **Data storage capacity** | (Gbytes) | | | 210 TB | 67 TB |

## Summary of project objectives

*(10 lines max)*

In this project we use the regional climate model RACMO2 for simulations over the ice sheets of Antarctica and Greenland, and other smaller ice caps including Svalbard and the Canadian Arctic. The project is a continuation of a research line previously carried out using KNMI budgets.
For 2017 we planned to perform the following simulations:

1) 1958-2016 for Greenland on 5.5 km resolution, driven by ERA-40 and ERA-Interim.
2) 2x 1980-2100 for Greenland, 11 km, driven by CESM 2.0 simulations with RCP2.6 and RCP8.5.
3) 1980-2016 for Antarctica on 18 km resolution, driven by ERA-Interim
4) 1980-2015 for the Amundsen Sea Sector, Antarctica, 5.5 km, driven by ERA-Interim
5) 2x 1980-2100 for Antarctica, 27 km, driven by CESM 2.0 simulations with RCP2.6 and RCP8.5.

## Summary of problems encountered (if any)

The release of CESM 2.0 by the CESM consortium has been significantly delayed. Prior to the planned RACMO simulations, we will carry out our own CESM2.0 simulations (atmosphere only, 1800-2100). These simulations will be carried out on SARA (The Netherlands). For our CESM simulations, initialisation fields are required, e.g. SSTs. In the initial CESM2.0 planning, these initialization fields should have been made available by the end of 2016. The current planning is a delivery of these fields by the end of July 2017. If this deadline is met, we most likely can complete simulations 2) and 5) within 2017. If the release of CESM2.0 and initialization fields is further delayed, the possibility exists that this part of the project cannot be completed in 2017.

## Summary of results of the current year (from July of previous year to June of current year)

*This section should comprise 1 to 8 pages and can be replaced by a short summary plus an existing scientific report on the project*

**1) Completed numerical tasks (1-1-2017 to date)**

Within the nlspberg project, we have currently completed the following tasks

1) A present-day climate run for Greenland, the Canadian Arctic and Svalbard for 1958-2016 at 11 km resolution and driven by ERA-40 and ERA-Interim. The modelled daily surface mass balance fields are also statistically downscaled to 1 km resolution.
2) A present-day climate run for Antarctica for 1979-2016 on 27 km resolution, driven by ERA-Interim.
3) A present-day climate run for the Antarctic Peninsula for 1979-2016 on 5.5 km resolution, driven by ERA-Interim.

The climate simulation for the Amundsen Sea Sector, Antarctica, as listed in the project proposal was already completed in 2016 using the nlcko budget.

**2) Scientific results with RACMO using ECMWF computational resources (1-7-2016 to date)**

These scientific results are derived using RACMO simulations carried out between 2015 and now on the ECMWF system. Prior to 2017, these calculations were performed using the nlcko budget; the nlspberg special project budget has been used since January 2017.
Below the scientific results and papers written by UU/IMAU scientists working with RACMO2 are discussed. We share our data with many colleagues and groups internationally, but the numerous papers that use these data are not listed here.

**2.1) Published results for Greenland**

- Using RACMO2 simulations carried out in 2015 and statistically downscaled to 1 km, B.P.Y. Noël and others published in Nature Communications the paper "A tipping point in refreezing accelerates mass loss of Greenland's glaciers and ice caps". In this paper we prove that the majority of the peripheral glaciers surrounding the Greenland Ice Sheet will disappear in a warming climate as they have already lost their accumulation areas due to the warming that has occurred since 1997.
- These RACMO2 simulations were also the core of the paper "A daily, 1 km resolution data set of downscaled Greenland ice sheet surface mass balance (1958–2015)" by B.P.Y. Noël in The Cryosphere. This paper demonstrates the improved performance and added value of statistical downscaling compared to the original 11 km resolution RACMO2 simulations. For example, the strong gradients in the ablation zone, where narrow outlet glaciers are found, are much better resolved; leading to a significantly better agreement with in situ observations.
- RACMO2 results were also used in the paper "On the recent contribution of the Greenland ice sheet to sea level change" by M.R. van den Broeke in The Cryosphere. This paper provides an update of the contribution of the Greenland Ice Sheet to global sea level rise. Enhanced runoff of meltwater, estimated from RACMO2 runs, dominates the mass budget of the Greenland Ice Sheet. As a result, the GrIS is now a major (~25%) source of global sea level rise.

**2.2) Published results for Antarctica**

- A dedicated present-day (1979-2015) RACMO2 run for Dronning Maud Land, Antarctica, at 5.5 km resolution was used to highlight the potential threat of snow sublimation and surface melt for the stability of East Antarctic ice shelves, as appeared in Nature Climate Change paper "Meltwater produced by wind–albedo interaction stored in an East Antarctic ice shelf" by J.T.M. Lenaerts and others (2016).
- A dedicated present-day (1979-2015) RACMO2 run for the Antarctic Peninsula, Antarctica at 5.5 km resolution provides the first detailed estimate of the SMB of this region of Antarctica, published in the paper "The modelled surface mass balance of the Antarctic Peninsula at 5.5km horizontal resolution" by Van Wessem and others (2016).
- This high-resolution Antarctic Peninsula run was also used to provide improved estimates of meteoric fresh water fluxes towards the oceans surrounding the Antarctic Peninsula, presented in the paper "Characteristics of the modelled meteoric freshwater budget of the western Antarctic Peninsula" by Van Wessem and others (2017).

**2.3) Publications in preparation/submitted of runs completed in 2016 or before**

- Using the model run for Greenland performed in 2015 and already mentioned above, the downscaling technique is here applied to refine the SMB estimates for the Canadian Arctic. These results reinforce the conclusions of earlier papers that the glaciers and ice caps in Canadian Arctic, and especially those in the southern archipelago, are increasingly losing mass. The accumulation areas of the larger glaciers and ice caps in the Northern Canadian Arctic can still efficiently buffer meltwater through refreezing, while the Southern Canadian Arctic smaller ice bodies have lost this refreezing capacity, which indicatinges that their disappearance in the near future is inevitable. These results have been submitted to the Journal of Geophysical Research Earth Surface.
- Dedicated 11 and 3.5 km resolution simulations were carried out for Svalbard in 2015 and 2016. These simulations highlight the sensitivity of the glaciers and ice caps on Svalbard to climate change and the long-term importance of the firn layer for the surface mass balance. Firn has in two ways a positive effect on the surface mass balance: melt water can refreeze in firn, reducing the runoff, and, as the firn prevents darker glacial ice to surface, it limits the decrease in albedo through the melt season, lowering melt fluxes. As it takes up to more than a decade to accumulate or melt away a firn layer, a firn layer buffers enhanced melt for

years. Hence, the initialisation of the firn layer, which is difficult in absence of sufficient in situ data, influences the modelled surface mass balance for several years. A paper on these results is currently in drafting phase.

- In 2016, we also completed a present-day (1979-2016) simulation for the Amundsen Sea Sector, Antarctica at 5.5 km resolution. Compared to the RACMO2 simulation of whole Antarctica, this run resolves the SMB over the ice shelves and ice sheet margins in much greater detail, better resolving the observed sharp gradients in SMB. A publication is currently in preparation, but the model results are already used to drive ocean models with a focus on the ocean-ice shelf interaction in this sector of Antarctica.

**2.4) Publications in preparation using model results completed in 2017**

In 2017, we completed development work on RACMO, leading to improved version RACMO2.3p2. With this model version, we completed the three model simulations as listed in 1). This version leads to significantly improved results in terms of modelled climate and SMB over both the ice sheets of Greenland and Antarctica. In figures 1 to 4, we highlight three improvements in this new model version.

One aim of the model development is to improve the precipitation fields over Greenland and Antarctica, which is achieved by increasing the critical cloud content for efficient precipitation formation. Figure 1 and 2 indicate that this retuning leads to an improvement of modelled SMB in the accumulation zone for both ice sheets.

A second aim was to improve the albedo in the wet snow zone – the zone that experiences significant snow melt, but never become snow-free. Figure 3 shows an example for Southeast Greenland, which clearly indicates that with the new model version, the seasonal evolution of snow albedo is now more in line with in situ observations.

Thirdly, we reduced the suspended snow particle concentration during drifting snow events, as we observed that the modelled drifting snow fluxes exceeded values obtained from the very few observations. This adjustment does not change the frequency of snowdrift events as this was already well modelled by RACMO2. As a result, the sublimation, which is partly from sublimation of drifting snow, and snowdrift erosion/deposition by horizontal transport is reduced, as is visualized in Figure 4. As drifting snow sublimation is most active in the marginal zones of Antarctica (0-1500 m), this retuning also contributed to the improvement of modelled SMB over Antarctica (Figure 2). The results of these runs will be published in two separate papers that are currently in draft.

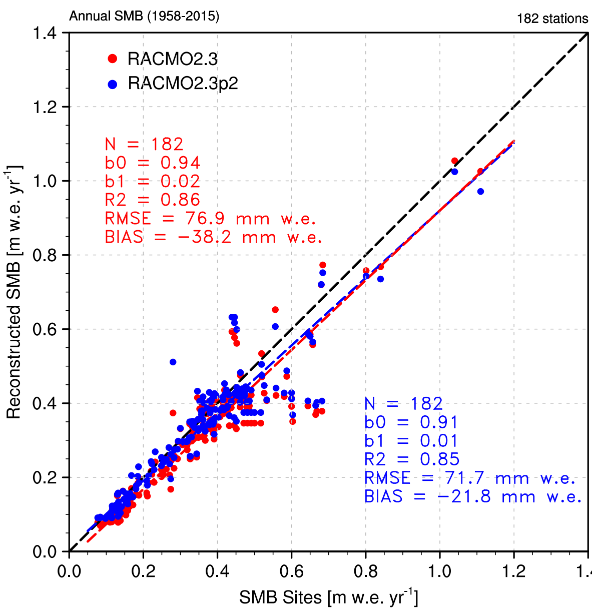


***Figure 1**: Comparison of modelled and observed SMB in the accumulation zone of the Greenland Ice Sheet (Noël and others, in prep.)*

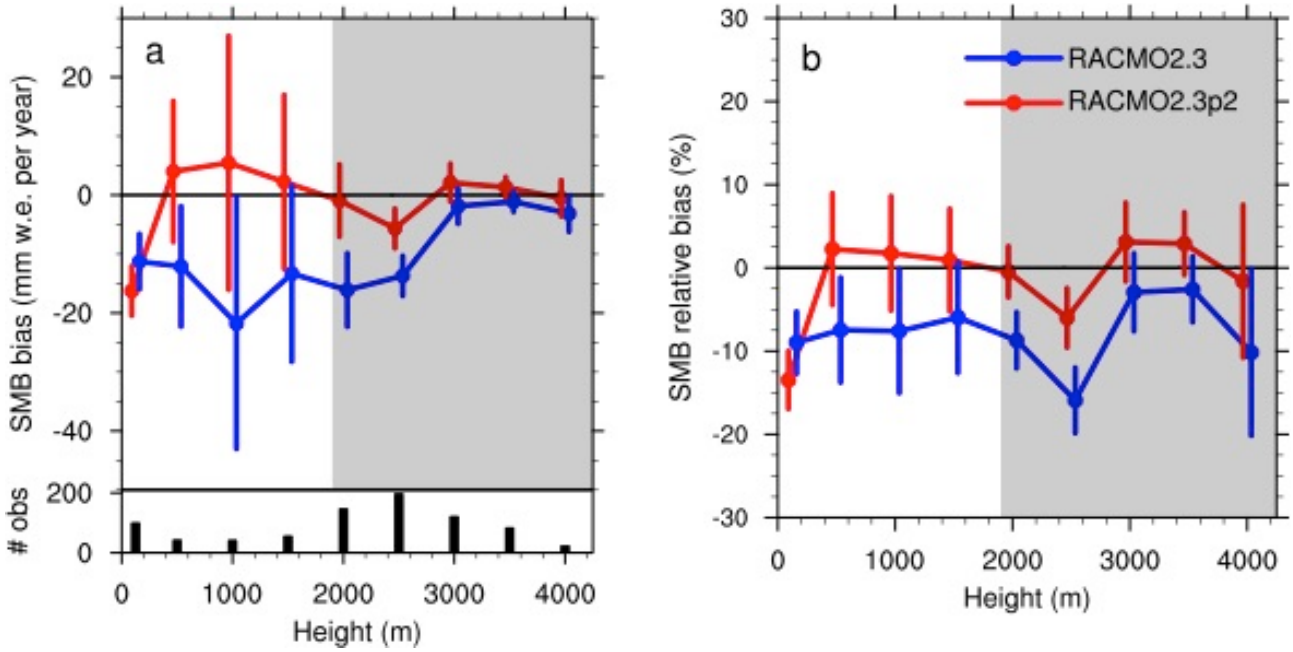


***Figure 2:*** *(a) Absolute bias and (b) relative bias ((model – observation)/model x 100%) in modeled SMB by RACMO2.3p2 (red) and RACMO2.3 (blue). The data are binned in 500 m surface elevation intervals (0–250, 250–750, etc.). Error bars denote the combined uncertainty of the model and observations within each height bin, based on Van de Berg et al. (2006); Van Wessem et al. (2014a). Elevations above 2000 m (shaded grey) represent East Antarctica exclusively. The bar chart in (a) denotes the amount of weighted observations in each bin. To separate blue and red lines, x-axis locations of each bin are displaced by 75 m.*

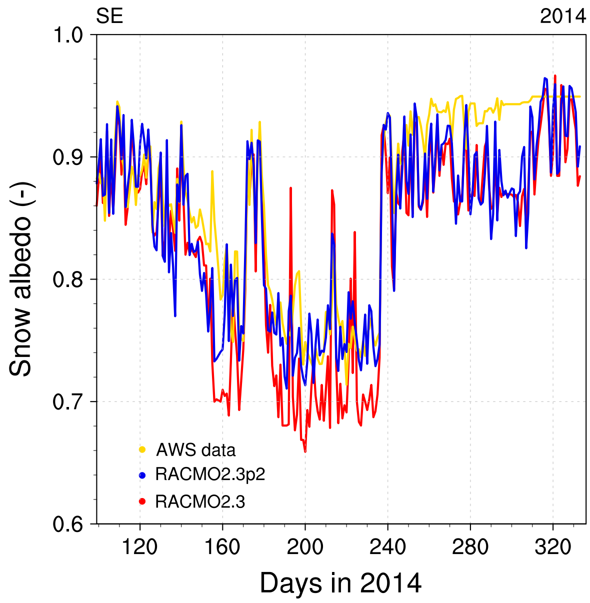


***Figure 3:*** *Time series of daily snow albedo modeled by RACMO2.3p2 (blue lines), RACMO2.3 (red lines) and measured (yellow lines) at the southeast AWS (66_N; 33_W; 1563 m a.s.l.) during summer 2014.*

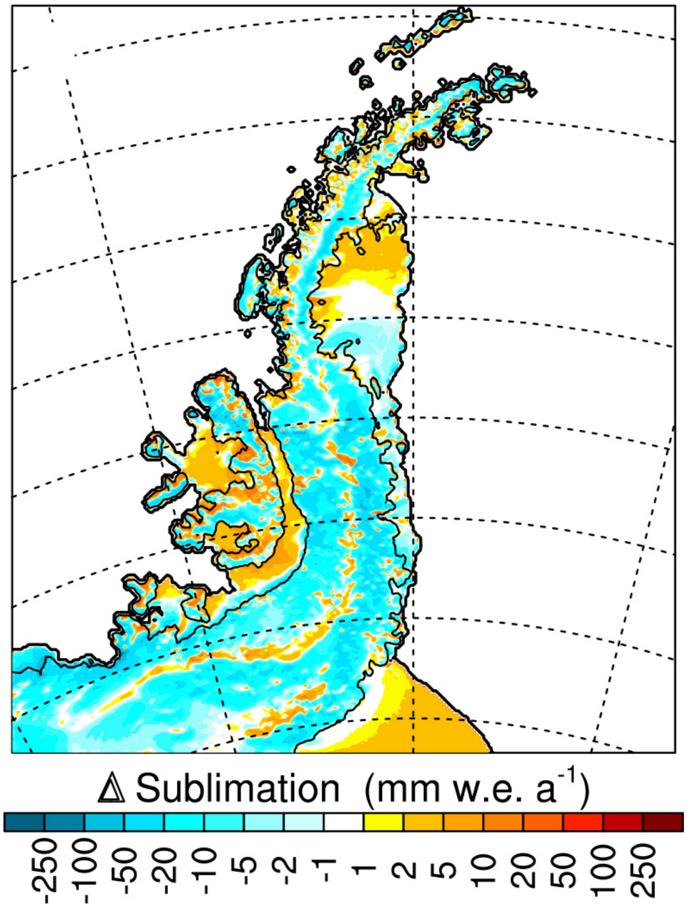


***Figure 4**: Difference in modelled sublimation, including drifting snow, between the old and new RACMO2 version. A negative value indicates a decrease of sublimation.*

## List of publications/reports from the project with complete references

*Only published or accepted papers are listed here.*


Lenaerts, J.T.M., S. Lhermitte, R. Drews, S.R.M. Ligtenberg, S. Berger, V. Helm, C.J.P.P. Smeets, M.R. van den Broeke, W.J. van de Berg, E. van Meijgaard, M. Eijkelboom, O. Eisen and F. Pattyn, 2016: Meltwater produced by wind-albedo interaction stored in an East Antarctic ice shelf, *Nature Climate Change 7*, 58-62, doi: 10.1038/nclimate3180.

Noël, B.P.Y., W. J. van de Berg, H. Machguth, S. Lhermitte, I. Howat, X. Fettweis and M. R. van den Broeke, 2016: A daily, 1 km resolution data set of downscaled Greenland ice sheet surface mass balance (1958–2015), *The Cryosphere* **10**, 2361-2377, doi:10.5194/tc-10-2361-2016.

Noël, B.P.Y., W.J. van de Berg, S. Lhermitte, B. Wouters, H. Machguth, I. Howat, M. Citterio, G. Moholdt, J.T.M. Lenaerts and M.R. van den Broeke, 2017: A tipping point in refreezing accelerates mass loss of Greenland's glaciers and ice caps, *Nature Communications* **8**, doi: 10.1038/ncomms14730.

Van den Broeke, M.R., E.M. Enderlin, I.M. Howat, P. Kuipers Munneke, B.P.Y. Noël, W.J. van de Berg, E. van Meijgaard and B. Wouters, 2016: On the recent contribution of the Greenland ice sheet to sea level change, *The Cryosphere* **10**, 1933-1946, doi:10.5194/tc-10-1933-2016.

Van Wessem, J.M., S.R.M. Ligtenberg, C.H. Reijmer, W.J., van de Berg**,** M.R. van den Broeke, N.E. Barrand, E.R. Thomas, J. Turner, J. Wuite, T.A. Scambos and E. van Meijgaard, 2016: The modelled surface mass balance of the Antarctic Peninsula at 5.5 km horizontal resolution, *The Cryosphere* **10**, 271-285, doi:10.5194/tc-10-271-2016.

Van Wessem, J.M., M.P. Meredith, C.H. Reijmer, M.R. van den Broeke and A.J. Cook, 2017: Characteristics of the modelled meteoric freshwater budget of the western Antarctic Peninsula, *Deep Sea Research Part II: Topical Studies in Oceanography*, **139**, 31-39.

## Summary of plans for the continuation of the project

*(10 lines max)*

This fall, we plan to execute a 5.5 km present-day climate run (1958-2016) for Greenland, as requested in the project proposal (simulation #1). This simulation cannot be carried out earlier as the PhD student responsible for this simulation is currently busy with completing his thesis, the planned run will be part of his Postdoc work. The four future climate runs (simulations #2 and #5) are also planned for this fall. If any further delay would occur, we will contact ECMWF representatives as soon as possible to discuss implications on the 2017 budget usage.
For 2018, we plan to use ERA5 to update our present-day climate estimate of the climate of Greenland and Antarctica. Furthermore, one high-resolution future climate simulation (1980-2100) for the Antarctic Peninsula will be carried out. This simulation will be driven by CESM RCP8.5 data. Finally, we will proceed in implementing a narrowband snow albedo scheme into RACMO2.