SPECIAL PROJECT FINAL REPORT

All the following mandatory information needs to be provided.

Project Title:	The contemporary and projected climate of Greenland and Antarctica
Computer Project Account:	SPNLBERG
Start Year - End Year :	2021 - 2021
Principal Investigator(s)	Dr. Willem Jan van de Berg
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Other Researchers (Name/Affiliation):	Dr. Brice Noël Dr. Melchior van Wessem Dr. Carleen Reijmer Dr. Peter Kuipers Munneke Dr. Christiaan van Dalum Maurice van Tiggelen Sanne van Veldhuijsen Max Brils (UU/IMAU) Dr. Erik van Meijgaard (KNMI)

The following should cover the entire project duration.

Summary of project objectives

(10 lines max)

In 2021, the research as proposed for the 2021 SPNLBERG special project had four objectives:
1) To keep up to date our operational estimates of the climate and surface mass balance of the Antarctic and Greenland Ice Sheets using the regional atmospheric climate model RACMO.
2) To provide projections of the climate and surface mass balance of the Antarctic and Greenland Ice Sheets till 2100 for two scenarios using RACMO;
3) Carry out a total upgrade of the physical descriptions within RACMO.
4) Refine the representation of the firn layer in these projections of 2) using the Firn Densification Model IMAU-FDM.

Summary of problems encountered

(If you encountered any problems of a more technical nature, please describe them here.)

In 2021, by times the access from the interactive nodes to the $PERM and $SCRACH disk was slow, leading to very slow compilation of code. This was in particularly inconvenient while developing the updated RACMO version.

Experience with the Special Project framework

(Please let us know about your experience with administrative aspects like the application procedure, progress reporting etc.)

The application and reporting procedures are smoothly.

Summary of results

(This section should comprise up to 10 pages, reflecting the complexity and duration of the project, and can be replaced by a short summary plus an existing scientific report on the project.)

We discuss the research facilitated by the SPNLBERG project in 2021 along the lines of the aims listed above.

Motivation for dynamical downscaling

To get the best possible description of the surface climate and surface mass balance (SMB) of glaciated regions, we use the polar adapted regional atmospheric climate model RACMO. Our primary focus in 2021 lay on Antarctica and Greenland, for which we ran RACMO on a resolution of 27 and 5.5 km, respectively. For Greenland, this dynamical downscaling induces a clear increase of spatial resolution compared to ERA5 or operational analyses from the ECMWF. For Antarctica, it is no clear spatial improvement compared to ERA5 and it is even coarser than the operational analyses. Still, using RACMO improves the representation of the surface climate and SMB as the polar version of RACMO includes an improved representation of the stable near-surface boundary layer and much more detailed description of the evolution of snow, firn or ice surface of glaciers, ice caps and ice sheets. Beside this, the polar version of RACMO also parameterizes ice sheet specific processes like snow drift erosion, transport, and snow sublimation and in much greater physical detail the evolution of the albedo. As a result, RACMO based estimates of the SMB and surface climate of Antarctica and Greenland are widely used in the cryospheric community and beyond.

Objective 1: operational RACMO simulation

In 2018, we released our current operational version of RACMO, version 2.3p2 (RACMO2.3p2), using ERA-Interim as input at the lateral boundaries (Noël et al, 2018, Van Wessem et al, 2018). We renewed our operational RACMO products in 2020 by starting using ERA5 instead of ERA-Interim. In 2021, these operational estimates (RACMO2.3p2-ERA5) were updated a few times, using ERA5, and ERA5T when needed (see for example Fig. 1a and 1b). As these simulations only cover a year each, they consumed relatively little from the 2021 HPCF budget.

Objective 2: Projections with RACMO

Besides estimates of the recent past climate and SMB, we dynamically downscale projections with RACMO for both ice sheets. Realisations of the Earth System Model CESM2 were used for these projections denoted as RACMO2.3p2-CESM2. In 2020, we carried out, for both ice sheets, the simulations for the historical period (1950-2014) and for the business-as-usual scenario SSP5-8.5 (2015-2100). In the first half of 2021, we added to these simulations RACMO2.3p2-CESM2 runs for the SSP1-2.6 scenario for both ice sheets, as discussed in the 2021 progress report. In the second half of 2021, we added RACMO2.3p2-CESM2 simulations (2015-2100) for the SSP2-4.5 scenario. For all these simulations, CESM2 data with 100 km resolution was used, and RACMO was run at 27 km resolution for Antarctica, and at 11 km resolution for Greenland.

For the Greenland Ice Sheet, the RACMO projections were subsequently statistically downscaled to 1 km spatial resolution. An example is shown in Figure 1c. The historic, low-end (SSP1-2.6) and high-end (SSP5-8.5) emission scenarios RACMO simulations are published in Noël et al. (2020) and Noël et al. (2021). Therefore, we do not plan a separate publication based on the latest added simulation for SSP2-4.5.

However, to sample other warming trajectories in the 21st century and beyond, we statistically downscaled all available 100 km CESM2 climate reconstructions (1850-2014) and future projections (2015-2300; including SSP1-2.6 to SSP5-8.5) to a 1 km grid. This data set consists of 47 runs that span 450 years. Among these runs, one accounts for glacier dynamics (i.e., glacier thinning/retreat and elevation feedbacks). These new data sets are used in a paper currently in review for a high-impact journal (Noël et al., in review). We expect that, once published, these data sets will be extensively used by international collaborators investigating projected mass loss, sea level rise contribution, glacier dynamics and thinning of the Greenland Ice Sheet. We will also use these data in forthcoming publications and projects.

For the Antarctic ice sheet, the analysis of the projections focussed on the increase of melt and subsequent implications on ice shelve stability. For this, the five RACMO simulations for Antarctica are used: RACMO2.3p2-ERA5 and four RACMO2.3p2-CESM2 simulations, namely the historical run and 3 different SSPs. We fit the output of these five simulations to calculate a threshold temperature (T_T) which defines the onset of melt-pond formation on Antarctic ice shelves. Figure 1 shows T_T (Fig. 2a) and the temperature increase needed to reach T_T (ΔT) with respect to the base climate of RACMO-ERA5 (1979-2021). Locations that have already reached the threshold compare extremely well with 2015-2022 melt pond volume Sentinel 2 satellite observations. These results are also in review for a high-impact journal (Van Wessem et al., in review).

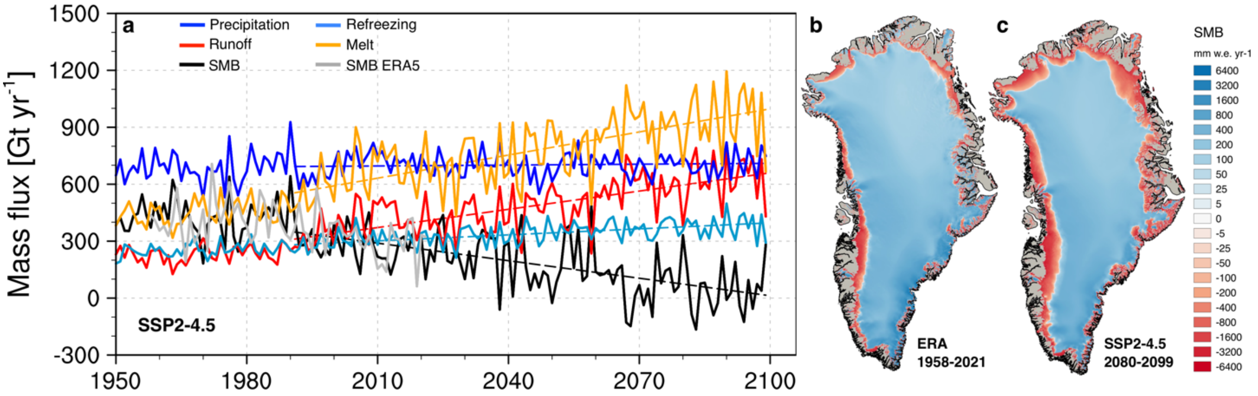

Figure 1:* *a) *Time series of SMB components from RACMO2.3p2-CESM2 at 11 km resolution, statistically downscaled to 1 km, under a moderate warming scenario (SSP2-4.5) until 2100. Variables include total precipitation (blue), total melt (orange), runoff (red), refreezing and retention in firn (cyan), and SMB (black). The grey line shows the benchmark RACMO2.3p2-ERA at 5.5 km, statistically downscaled to 1 km, forced by ERA-40 (1958-1978), ERA-Interim (1979-1989) and the latest ERA5 (1990-2021). SMB maps from* ***b)*** *RACMO2.3p2-ERA at 1 km averaged for 1958-2021,* ***c)*** *RACMO2.3p2-CESM2 under SSP2-4.5 averaged for 2080-2099.*

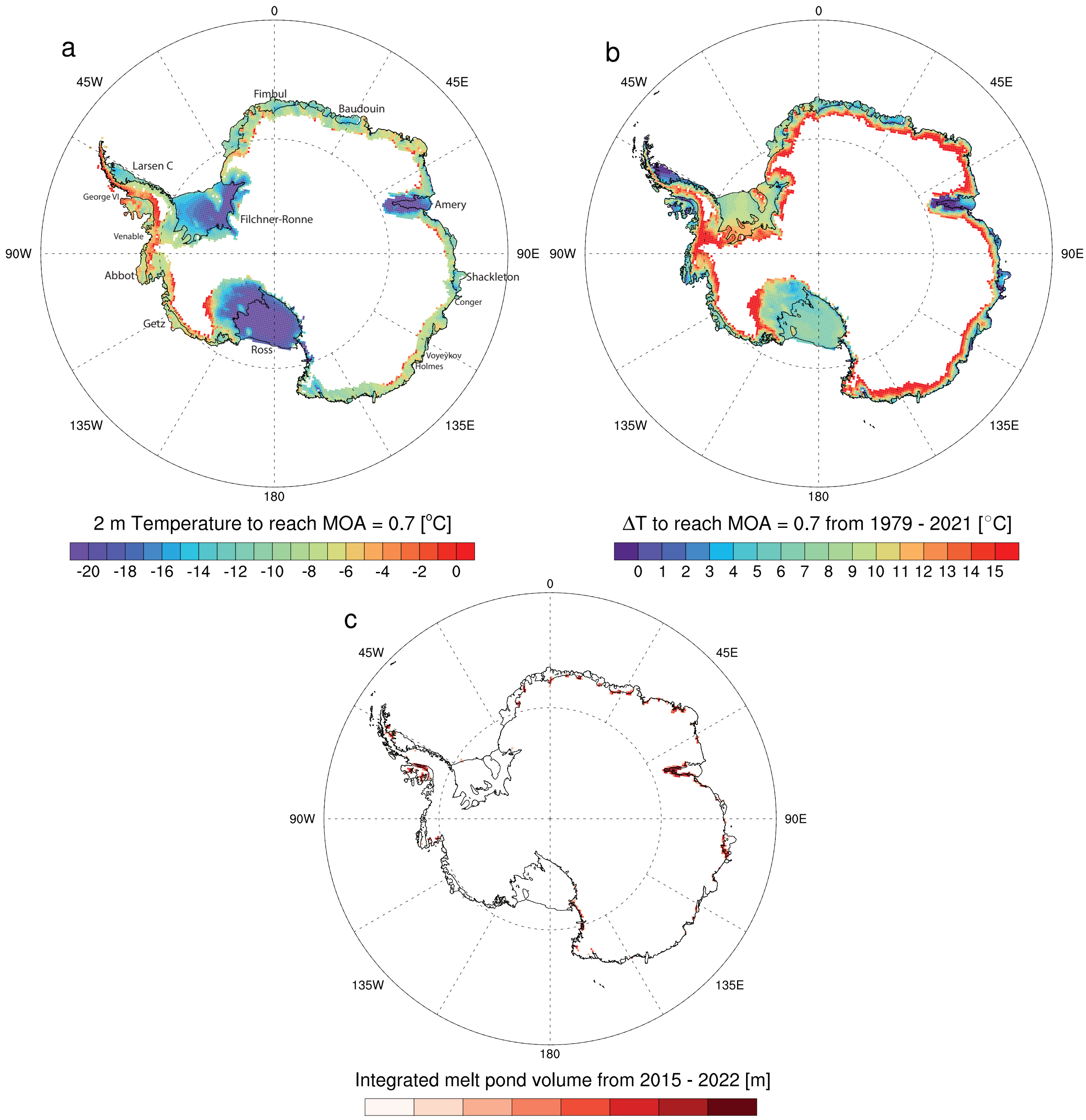

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***Figure 2**: **a)** Intersect values of the T_{2m} for which the MOA=0.7 threshold is reached (T_T). **b)** The T_{2m} increase ΔT needed to reach the MOA=0.7 threshold with respect to the base climate (1979-2021) from RACMO-ERA5. Where ΔT<0 (dark purple), T_T is already reached. **c)** Integrated 2015-2022 austral summer melt pond volume (m) from Sentinel 2*

Objective 3: Model development of RACMO

Early 2021, we started, in cooperation with KNMI, with the upgrade of RACMO to version 2.4. RACMO consists of the dynamical core of the limited area model HIRLAM and the parameterizations of physical processes as in ECMWF IFS physics packages, complemented with in-house developed code to represent glaciated surfaces better. The core of this general update is updating the physics package from the ECMWF IFS Cy33r1 to Cy47r1. Between the two IFS code versions, major improvements have been made by the ECMWF in the cloud, turbulence, radiation, surface, and convection schemes.

Prior commencing this update, it was expected that in the second half of 2021, the first test simulations with RACMO2.4 would be possible. However, as IFS has introduced numerous user defined types to structure model, parameter, state, and output data, it took longer than expected to write new coupling code for RACMO and to verify the code. As a result, no simulations were carried out in 2021. Obviously, this update project is continued in 2022.

Objective 4: Representing the firn layer evolution of ice sheets

The firn (multi-year snow) layer of ice sheets and glaciers is the surface layer in which accumulated snow get compressed to ice. The firn layer can be up to 100 m thick in the cold interior of Antarctica. It covers over 99% of the Antarctic Ice Sheet, and about 90% of the Greenland Ice Sheet. As a result, the firn layer contains a significant amount of air, up to 30 m^3 per m, and hence melt water refreezing capacity. With the dedicated firn densification model IMAU-FDM (Brils et al., in review; Veldhuijsen et al., in review), we model the evolution of the firn layers of the AIS and GrIS. Detailed information of the firn layer is needed as estimates of the evolution of firn air content are needed to convert radar altimetry data from satellites into mass changes or the assess the future stability of ice shelves. For this aim, we use the firn densification model IMAU-FDM.

IMAU-FDM is a point model running on a single core. As the ECMWF HPCF is in principle not optimized for this kind of task, namely many single core jobs, scripts have been developed to run IMAU-FDM efficiently parallelly in nf and np jobs. As IMAU-FDM is a subsurface model only, it takes surface mass fluxes from RACMO2. Hence, the spatial resolution of IMAU-FDM simulations is set by the spatial resolution of the surface data from RACMO2.

Although proposed for 2021, the planned simulations to projections of the evolution of firn layers of the AIS and GrIS till 2100 for various emission pathways are being carried out in 2022 and are discussed in the progress report of SPNLBERG for 2022. In 2021, the model update of IMAU-FDM to versions 1.2G and 1.2A, and subsequent model evaluation has been completed, as being discussed below in more detail.

Greenland

The update of IMAU-FDM is tested and evaluated for the Greenland Ice Sheet first. The model update to version 1.2G includes improved representation of heat diffusion in snow and ice, snow densification and lastly, and improved parameterization of the density of new, wind settled snow. In IMAU-FDM, the near surface temperature of the firn is now represented better, as well as its densification rate and snow surface density. These results have been compared extensively to observations from, e.g., firn cores and the description of the model update and the model evaluation will be published in Brils et al. (in review).

With IMAU-FDM 1.2G, a historic run has been performed for the Greenland ice sheet. This run provided insight into the changes of the firn characteristics from 1957 up to and including 2020. The simulation results show a clear warming trend in the South of Greenland. We investigated the impact of extreme melt years on the firn. Our results show that the GrIS responded differently to the warm summer of 2012 than to the warm summer of 2019. Using the model data, the location and formation of ice slabs into the firn layer has been investigated. Pronounced inland extension of the regions with sub-surface ice lenses would imply that the melt water buffering capacity of the GrIS to increasing melt is less than previously thought.

Antarctica

It appeared that IMAU-FDM optimized for Greenland (version 1.2G), did not perform similarly well for the Antarctic Ice Sheet. Therefore, nine sets of point-scale simulations with the IMAU-FDM for 140 locations with firn profile observations across in Antarctic were run. Using these simulations IMAU-FDM was tuned to version 1.2A. These simulations and the evaluation of version 1.2A are discussed in more detail in the progress report for 2021.

Next, an Antarctic wide simulation with the improved IMAU-FDM for the period 1979-2020 was carried out, which amounts to about 18,000 locations. The surface forcing these simulations is the RACMO2.3p2-ERA5 simulation, which has a 27 km resolution. This IMAU-FDM simulation provides time series of, e.g., firn density and liquid water content profiles and time series of the surface elevation change. With this data we can study the spatial and temporal patterns of the Antarctic firn layer (Fig. 3). Figure 3a shows that there is a large firn thickness variation across Antarctica, and that IMAU-FDM agrees well with observations. Furthermore, the surface elevation of Antarctica exhibits a large-scale pattern on decadal time scales due to decadal variation is accumulation and atmospheric temperature. These elevation changes represent only partly a mass change, as enhanced accumulation – thus mass gain – goes hand in hand with a thicker firn layer, and thus more firn air content. This modelled elevation changes allow separate in the altimetry signal the surface mass balance and firn air content contribution, both modelled by IMAU-FDM, from the ice dynamical elevation changes. The model development to version 1.2A, its evaluation and interpretation of outcomes will be published in Veldhuijsen et al. (in review).

Finally, an Antarctic Peninsula wide simulation with the improved IMAU-FDM for the period 1979-2020, which amounts to about 18,000 locations was carried out. This simulation uses an ERA5 driven RACMO simulation at 5.5 km resolution as surface forcing. This IMAU-FDM simulation is for example used in a study as a comparison to remote sensing (Sentinel-1) observed firn aquifers (Buth et al., in review).

List of publications/reports from the project with complete references

Current and past team members are highlighted in bold.

Papers directly linked to simulations carried out in 2021.

Brils, M., **P. Kuipers Munneke, W. J. van de Berg,** and **M. R. van den Broeke**, Improved representation of the contemporary Greenland ice sheet firn layer by IMAU-FDM v1.2G, Geosci. Model Dev. Discuss. [preprint], https://doi.org/10.5194/gmd-2021-303, in review, 2021.

Buth, L., B. Wouters, **S. B. M. Veldhuijsen**, S. Lhermitte, **P. Kuipers Munneke**, and **M. R. van den Broeke**: Sentinel-1 detection of seasonal and perennial firn aquifers in the Antarctic Peninsula, The Cryosphere Discuss. [preprint], in review, 2021.

Noël, B., J. T. M. Lenaerts, W. H. Lipscomb, K. Thayer-Calder, and **M. R. van den Broeke**, Peak refreezing in the Greenland firn layer under future warming scenarios. In review, 2022.

Van Wessem, J. M., **M. R. van den Broeke**, and S. Lhermitte, Snow accumulation controls atmospheric warming thresholds for Antarctic ice shelf viability. In review, 2022.

Veldhuijsen, S. B. M., W. J. van de Berg, M. Brils, P. Kuipers Munneke, and **M. R. van den Broeke**, Characteristics of the contemporary Antarctic firn layer simulated with IMAU-FDM v1.2A (1979-2020). In review, 2022.

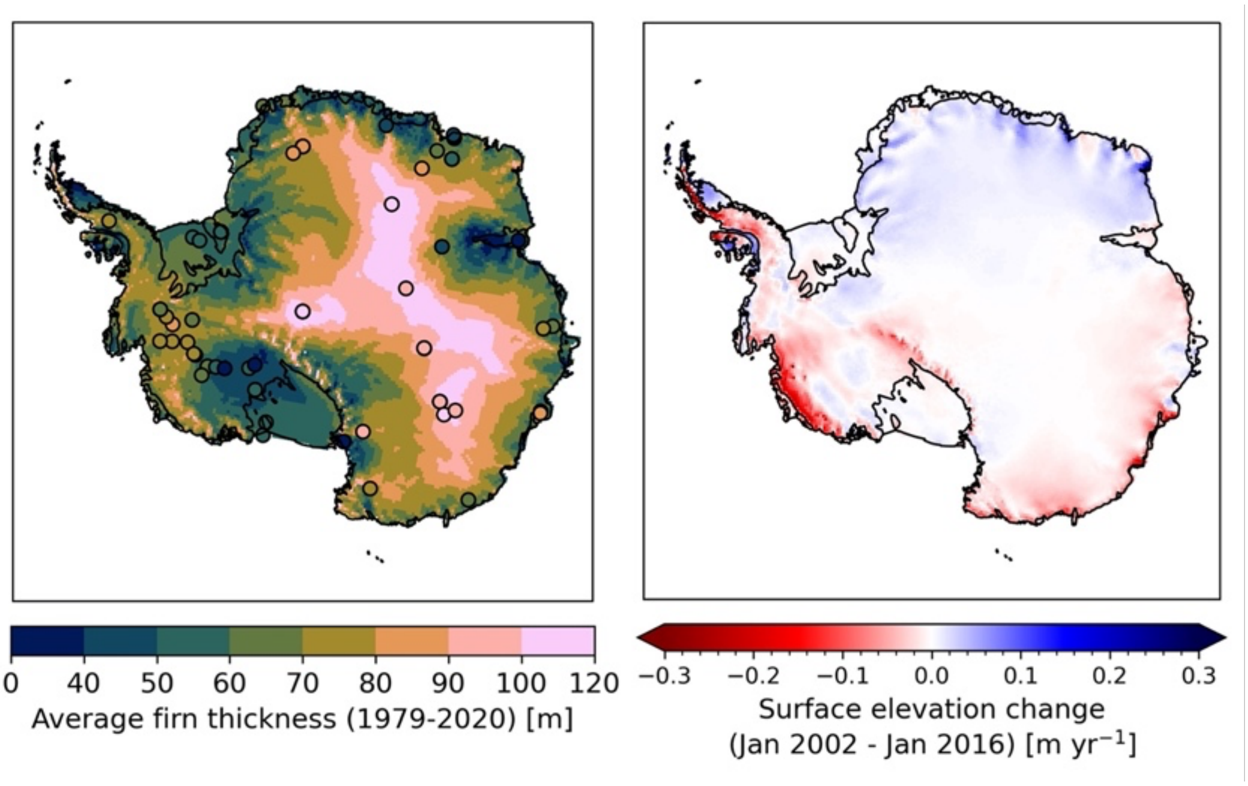

Figure 3: *a, left) Map of simulated average firn thickness (1979-2020). Circles mark the firn air thickness observations. b, right) map of simulated surface elevation change over the period 2002-2016.*

References to the cited papers using data from preceding special projects

Noël, B., W. J. van de Berg, J. M. van Wessem, E. van Meijgaard, D. van As, J. T. M. Lenaerts, S. Lhermitte, **P. Kuipers Munneke**, C. J. P. P. Smeets, **L. H. van Ulft**, R. S. W. van de Wal, and **M. R. van den Broeke**, Modelling the climate and surface mass balance of polar ice sheets using RACMO2 – Part 1: Greenland (1958–2016), The Cryosphere, 12, 811–831, 2018. doi: 10.5194/tc-12-811-2018.

B. Noël, L. van Kampenhout, **W. J. van de Berg**, J. T. M. Lenaerts, B. Wouters and **M. R. van den Broeke**. Brief communication: CESM2 climate forcing (1950-2014) yields realistic Greenland ice sheet surface mass balance, The Cryosphere, 14(4): 1425-1435, 2020. doi: 10.5194/tc-14-1425-2020.

B. Noël, L. van Kampenhout, J. T. M. Lenaerts, **W. J. van de Berg** and **M. R. van den Broeke**. A 21st century warming threshold for irreversible Greenland ice sheet mass loss, Geophysical Research Letters, 48(5): e2020GL090471, 2021. doi: 10.1029/2020GL90471.

Van Wessem, J.M., W.J. van de Berg, B.P.Y. Noël, E. van Meijgaard, C. Amory, G. Birnbaum, **C.L. Jakobs**, K. Krüger, J.T.M. Lenaerts, S. Lhermitte, **S.R.M. Ligtenberg**, B. Medley, **C.H. Reijmer**, K. van Tright, L.D. Trusel, **L.H. van Ulft**, B. Wouters, J. Wuite and **M.R. van den Broeke**, Modelling the climate and surface mass balance of polar ice sheets using RACMO2 – Part 2: Antarctica (1979-2016), *The Cryosphere*, **12**, 1479-1498, 2018.

References of papers published since January 2021 using RACMO or IMAU-FDM and with a (co-)author from the SPNLBERG research team.

It is not possible to keep track of all papers using our data.

1. Felikson, D., Catania, G. A., Bartholomaus, T. C., Morlighem, M., and **Noël, B. P. Y.** Steep glacier bed knickpoints mitigate inland thinning in Greenland. Geophysical Research Letters, 48, e2020GL090112, 2021. Doi: https://doi.org/10.1029/2020GL090112.
2. Hansen, K., Truffer, M., Aschwanden, A., Mankoff, K., Bevis, M., Humbert, A., **van den Broeke, M.**, **Noël, B.,** et al. Estimating ice discharge at Greenland's three largest outlet glaciers using local bedrock uplift. Geophysical Research Letters, 48, e2021GL094252, 2021. Doi: https://doi.org/10.1029/2021GL094252.
3. Hansen, N., Simonsen, S. B., Boberg, F., Kittel, C., Orr, A., Souverijns, N., **Van Wessem, J. M.**, and Mottram, R. (2022). Brief communication: Impact of common ice mask in surface mass balance estimates over the Antarctic ice sheet. Cryosphere, 16(2), 711–718. 10.5194/tc-16-711-2022.
4. **Jakobs, C. L., Reijmer, C. H., van den Broeke, M. R., van de Berg, W. J., and van Wessem, J. M.** (2021). Spatial Variability of the Snowmelt-Albedo Feedback in Antarctica. Journal of Geophysical Research: Earth Surface, 126(2). 10.1029/2020JF005696. estimates. The Cryosphere (Vol. 15). 10.5194/tc-15-3751-2021.
5. Khan, S. A., Bamber, J. L., Rignot, E., Helm, V., Aschwanden, A., Holland, D. M., **van den Broeke, M. R.**, King., M., **Noël, B.** et al. (2022). Greenland mass trends from airborne and satellite altimetry during 2011–2020. Journal of Geophysical Research: Earth Surface, 127, e2021JF006505. Doi: https://doi.org/10.1029/2021JF006505.
6. Laffin, M. K., Zender, C. S., Singh, S., **Van Wessem, J. M.**, Smeets, C. J. P. P., **Reijmer, C. H.** (2021). Climatologyand evolution of the Antarctic Peninsula föhn wind–induced melt regime from 1979–2018. Journal of Geophysical Research: Atmospheres, 126, e2020JD033682. 10.1029/2020JD033682
7. Laffin, M. K., Zender, C. S., **Van Wessem, J.M.**, and Marinsek, S. (2022). The role of föhn winds in eastern Antarctic Peninsula rapid ice shelf collapse. Cryosphere, 16(4), 1369–1381. 10.5194/tc-16-1369-2022.
8. Mankoff, K. D., Fettweis, X., Langen, P. L., Stendel, M., Kjeldsen, K. K., Karlsson, N. B., **Noël, B., van den Broeke, M. R.**, Solgaard, A., Colgan, W., Box, J. E., Simonsen, S. B., King, M. D., Ahlstrøm, A. P., Andersen, S. B., and Fausto, R. S.: Greenland ice sheet mass balance from 1840 through next week, Earth Syst. Sci. Data, 13, 5001–5025, 2021. Doi: https://doi.org/10.5194/essd-13-5001-2021.
9. Meredith, M. P., Stammerjohn, S. E., Ducklow, H. W., Leng, M. J., Arrowsmith, C., Brearley, J. A., Venables, H. J., Barham, M., **van Wessem, J. M.**, Schofield, O., and Waite, N. (2021). Local- and Large-Scale Drivers of Variability in the Coastal Freshwater Budget of the Western Antarctic Peninsula. Journal of Geophysical Research: Oceans, 126(6), 1–22. 10.1029/2021JC017172.
10. Mottram, R., Hansen, N., Kittel, C., **van Wessem, J. M.**, Agosta, C., Amory, C., Boberg, F., **van de Berg, W. J.**, Fettweis, X., Gossart, A., van Lipzig, N. P. M., **van Meijgaard, E.**, Orr, A., Phillips, T., Webster, S., Simonsen, S. B., and Souverijns, N. (2021). What is the surface mass balance of Antarctica? An intercomparison of regional climate model estimates. The Cryosphere (Vol. 15). 10.5194/tc-15-3751-2021.
11. **Noël, B.,** Aðalgeirsdóttir, G., Pálsson, F., Wouters, B., Lhermitte, S., Haacker, J. M., & v**an den Broeke, M. R.** (2022). North Atlantic cooling is slowing down mass loss of Icelandic glaciers. Geophysical Research Letters, 49, e2021GL095697. Doi: https://doi.org/10.1029/2021GL095697.
12. Recinos, B., Maussion, F., **Noël, B.,** Möller, M., & Marzeion, B. Calibration of a frontal ablation parameterisation applied to Greenland's peripheral calving glaciers. Journal of Glaciology, 67(266), 1177-1189, 2021. Doi: https://doi.org/10.1017/jog.2021.63.
13. Sasgen, I., Salles, A., Wegmann, M., Wouters, B., Fettweis, X., **Noël, B.P.Y.,** and Beck, C. Arctic glaciers record wavier circumpolar winds. Nat. Clim. Chang. 12, 249–255 (2022). Doi: https://doi.org/10.1038/s41558-021-01275-4.

14. Silva, T., Abermann, J., **Noël, B.,** Shahi, S., **van de Berg, W. J.,** and Schöner, W.: The impact of climate oscillations on the surface energy budget over the Greenland Ice Sheet in a changing climate, The Cryosphere Discuss., 2022 (in review). Doi: https://doi.org/10.5194/tc-2021-388.
15. Slater, T., Shepherd, A., McMillan, M., Leeson, A., Gilbert, L., Muir, A., **Kuipers Munneke, P.**, **Noël, B.,** Fettweis, X., **van den Broeke, M.**, and Briggs, K. Increased variability in Greenland Ice Sheet runoff from satellite observations. NatComms 12, 6069 (2021). Doi: https://doi.org/10.1038/s41467-021-26229-4.
16. Spergel, J. J., Kingslake, J., Creyts, T., **Van Wessem, M.J.**, and Fricker, H. A. (2021). Surface meltwater drainage and ponding on Amery Ice Shelf, East Antarctica, 1973-2019. Journal of Glaciology, 67(266), 985–998. 10.1017/jog.2021.46.
17. Tuckett, P., Ely, J., Sole, A., Lea, J., Livingstone, S., Jones, J., and **van Wessem, J. M.** (2021). Automated mapping of the seasonal evolution of surface meltwater and its links to climate on the Amery Ice Shelf, Antarctica. The Cryosphere, 1–35. 10.5194/tc-2021-177.
18. **Van Dalum, C. T., Van de Berg, W. J.,** and **Van den Broeke, M. R.**: Sensitivity of Antarctic surface climate to a new spectral snow albedo and radiative transfer scheme in RACMO2.3p3, The Cryosphere, 16, 1071–1089, https://doi.org/10.5194/tc-16-1071-2022, 2022.
19. Verjans, V., Leeson, A. A., McMillan, M., Stevens, C. M., **van Wessem, J. M., van de Berg, W. J., van den Broeke, M.** R.,Kittel, C., Amory, C., Fettweis, X., Hansen, N., Boberg, F., and Mottram, R. (2021). Uncertainty in East Antarctic Firn Thickness Constrained Using a Model Ensemble Approach. Geophysical Research Letters, 48(7), 1–11. 10.1029/2020GL092060.
20. Vijay, S., King, M., Howat, I., Solgaard, A., Khan, S., and **Noël, B.** Greenland ice-sheet wide glacier classification based on two distinct seasonal ice velocity behaviors. Journal of Glaciology, 67(266), 1241-1248, (2021). Doi: https://doi.org/10.1017/jog.2021.89.
21. Wei, T., **Noël, B.,** Ding, M., and Yan, Q. Spatiotemporal variations of extreme events in surface mass balance over Greenland during 1958–2019, International Journal of Climatology, 2022. Doi: https://doi.org/10.1002/joc.7689.
22. Willen, M. O., Broerse, T., Groh, A., Wouters, B., **Kuipers Munneke, P.**, Horwath, M., ... & Schröder, L. (2021). Separating Long-Term and Short-Term Mass Changes of Antarctic Ice Drainage Basins: A Coupled State Space Analysis of Satellite Observations and Model Products. *Journal of Geophysical Research: Earth Surface*, *126*(6), e2020JF005966.
23. Wood, M., E. Rignot, L. An, A. Bjørk, M. van den Broeke, C. Cai, I. Fenty, E. Kane, D. Menemenlis, R. Millan, M. Morlighem, J. Mouginot, **B. Noël**, B. Scheuchl, I. Velicogna, J. Willis and H. Zhang. Ocean forcing drives glacier retreat in Greenland, Science Advances, 7(1) : eaba728, 2021. Doi : https://doi.org/10.1126/sciadv.aba7282.

Future plans

(Please let us know of any imminent plans regarding a continuation of this research activity, in particular if they are linked to another/new Special Project.)

Our plans for the remainder of 2022 can be found in the progress report of 2022. Plans for 2023 are described in the special project proposal for 2023.