

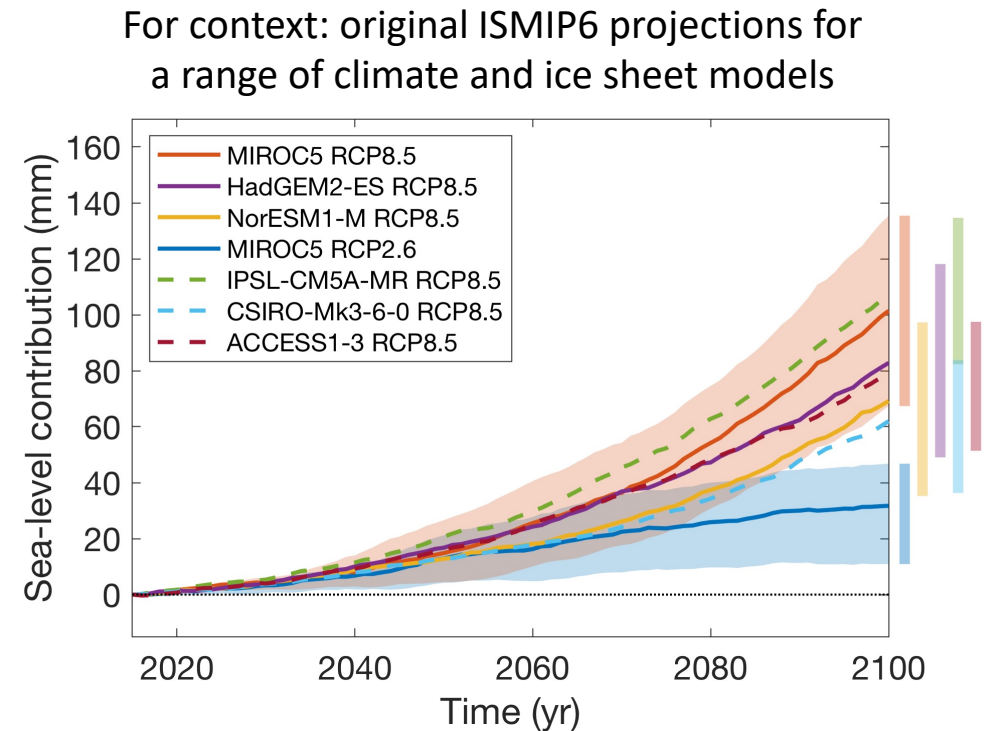
Relative importance of surface mass balance and outlet glacier forcing in ISMIP6 Greenland ice sheet sea-level projections

Heiko Goelzer and the The ISMIP6 team

vEGU 2021

ISMIP6 Greenland ice sheet sea-level projections

- The context of the presented results are model experiments performed within the framework of the Ice sheet model intercomparison project for CMIP6 (ISMIP6, Nowicki et al., 2020)
- The projections are run from 2015 to 2100 with forcing derived from CMIP5 GCMs (Goelzer et al., 2020).
 - For the surface boundary condition we prescribe surface mass balance (SMB) anomalies relative to the period 1960-1989, including parameterised SMB-height feedback (MAR, Fettweis et al., 2013, 2017).
 - For the ocean forcing we apply an empirically derived retreat parameterisation for tide-water glaciers (Slater et al., 2019, 2020) with three different sensitivities (medium, high, low).
 - Results are given relative to a control experiment to remove unwanted model drift.



ISMIP6 Greenland ice sheet sea-level projections

Experimental setup

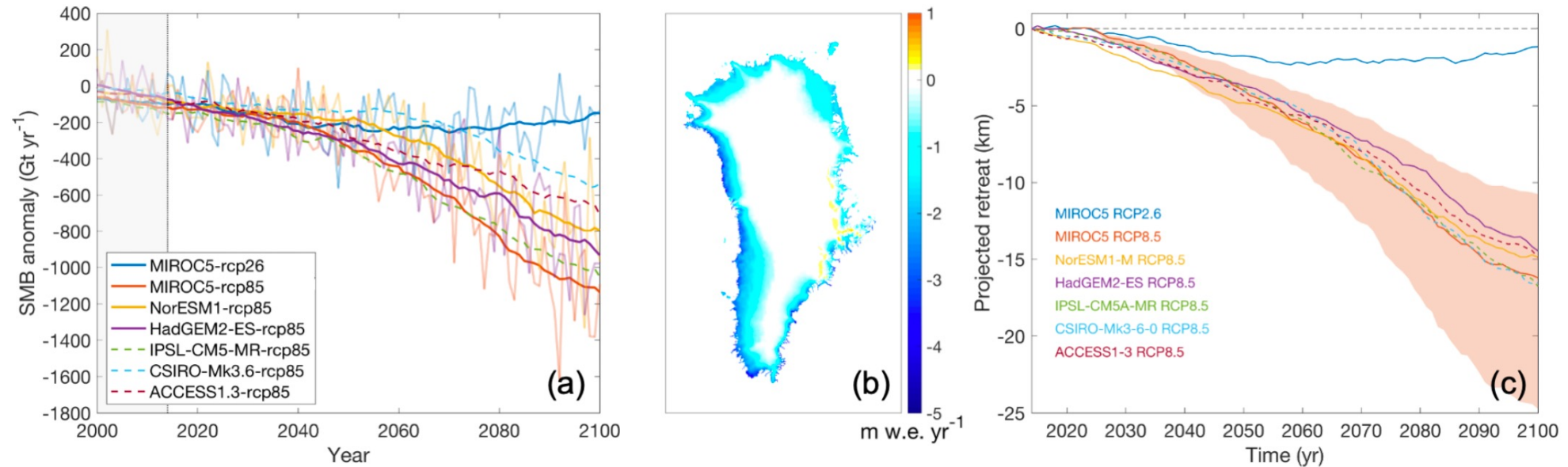


Figure 1. Illustration of atmospheric and oceanic forcing. **(a)** Greenland-wide SMB anomaly for projections starting at 2015. Strong lines are 10-year running mean values for the core experiments (solid) and extended CMIP5 experiments (dashed), plotted over the full time series in the background (omitted for the extended experiments for clarity). **(b)** spatial pattern of the average MIROC5-RCP8.5 SMB anomaly for the period 2091–2100. **(c)** Greenland-wide average of prescribed tidewater glacier retreat (Slater et al., 2019, 2020). The shading gives the range of ocean sensitivity sampled with two more experiments in MIROC5-RCP8.5-high and MIROC5-RCP8.5-low.

Relative importance of surface mass balance and outlet glacier forcing

There are two different ways of looking into the relative importance of the two forcing processes

1. Separation of mass changes due to SMB and discharge
(can be diagnosed in standard model experiments,
has been done to some extent in Goelzer et al., 2020)
2. **Compare sea-level projections with either of the forcings turned off to the full experiment. This is what is done here!**

full: apply SMB anomalies and retreat mask forcing

atm: apply SMB anomalies, but no retreat mask forcing

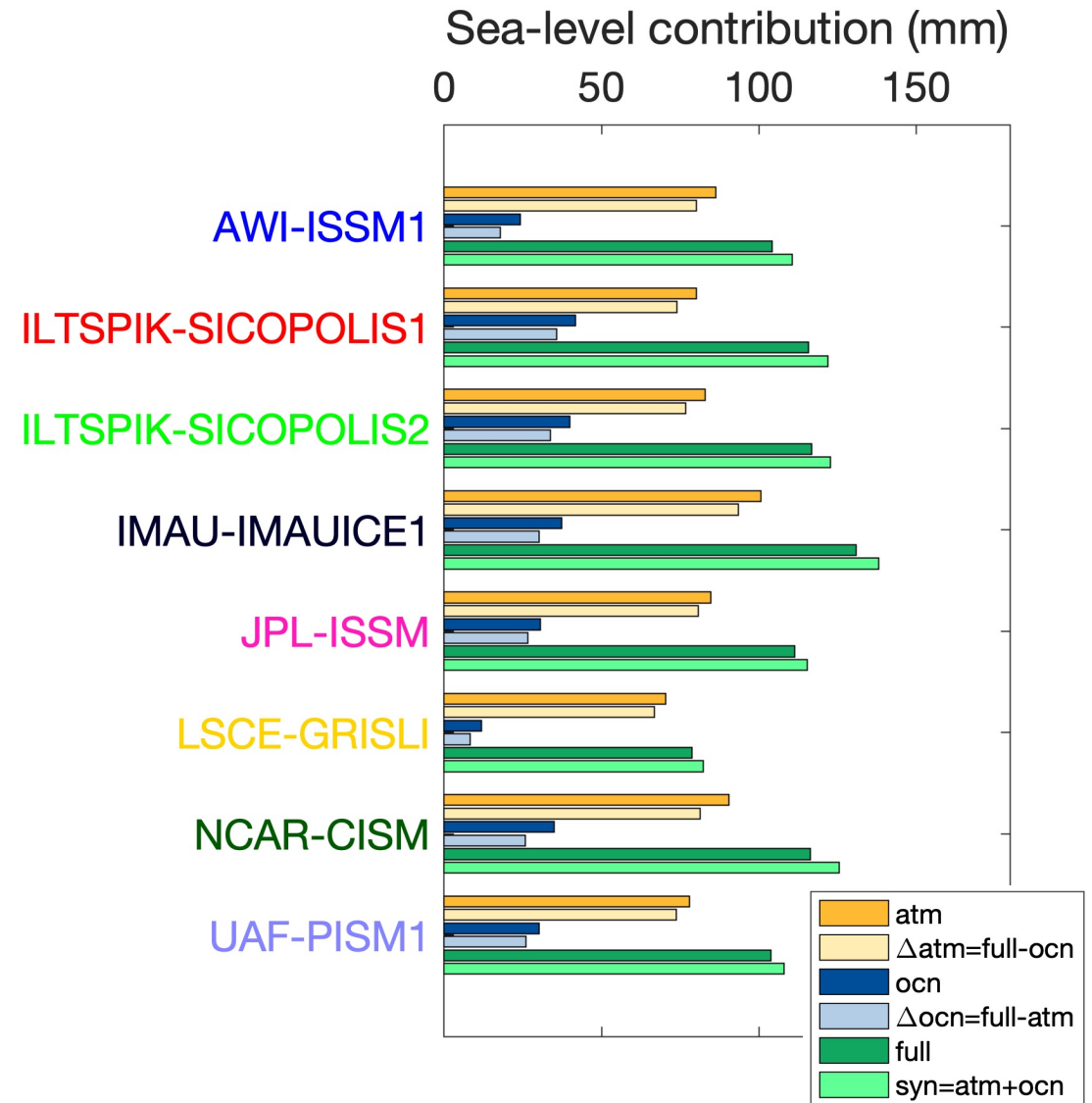
ocn: evolve retreat mask forcing, but set SMB anomalies to zero

syn = *atm* + *ocn* ≠ *full*

Results 1

Results for the climate model/scenario MIROC5-RCP8.5 and a medium sensitivity of the retreat parameterisation

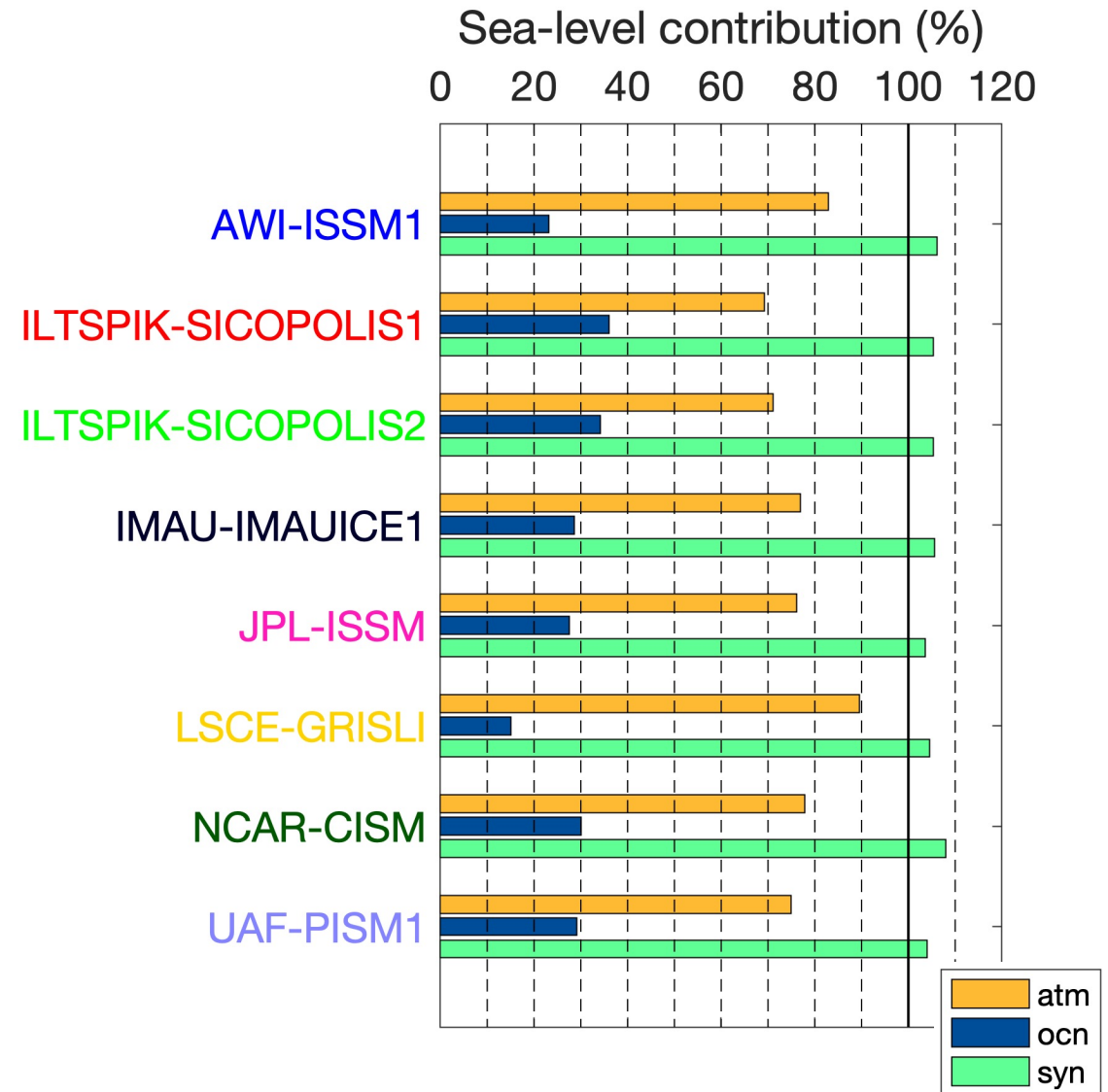
- The figure shows sea-level contributions for the single forcing experiments (**atm**, **ocn**) compared to the full experiment (**full**) and differences.
- The largest contribution to total sea-level is in all cases due to the SMB forcing.
- The sum of **atm** and **ocn** (**syn**) gives larger contributions compared to the **full** experiment.
- The reason for this discrepancy is the effect of negative SMB anomalies removing mass before it can reach the marine margin, and the retreat of outlet glaciers, reducing the area over which negative SMB anomalies can be applied.



Results 2

Results for the climate model/scenario MIROC5-RCP8.5 and a medium sensitivity of the retreat parameterisation

- The different ice sheet models agree fairly well on the relative importance of the two components.
- The relative importance of **atm** is more than two times larger than **ocn** with relative contributions of $77 \pm 13 \%$ * and $28 \pm 13 \%$ * of the SMB-only and outlet glacier-only experiments compared to the **full** experiment.
- Adding results of **atm** and **ocn** would result in a larger sea-level contribution compared to the **full** experiment. The compensating effect of combining both forcings in the **full** experiment amounts to $5.3 \pm 2.7 \%$ * of the total sea-level contribution.

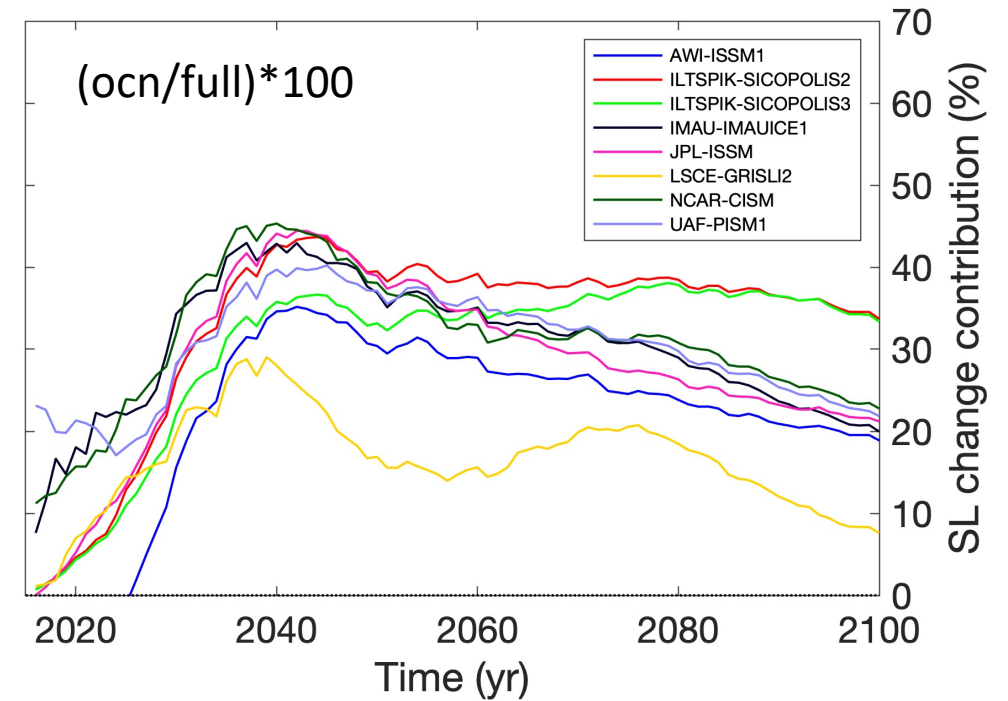


* Numbers are reported as ensemble mean ± 2 x standard deviation in percent compared to the full experiment

Results 3

Results for the climate model/scenario MIROC5-RCP8.5 and a medium sensitivity of the retreat parameterisation

- The figure shows the sea-level change ratio of **ocn** to **full** evolving over time.
- The relative importance of the retreat forcing (**ocn**) changes over the course of the experiment, with a steep increase until ~2040 and a subsequent varied decrease in most models.
- Towards the end of the experiment, some of the smaller tide-water glaciers retreat on land.
- Averaging over the length of the experiment returns the 28 ± 13 % contribution of the outlet glacier-only experiments compared to the full experiment specified on the last slide.



Results 4

- The relative importance of the two forcing processes depends on climate model and scenario.
- The importance of the SMB forcing is in all cases larger, but with decreasing importance from MIROC5 (77 %) to NorESM (66 %) and CSIRO (57 %).
- For the one RCP2.6 scenario we have tested, the importance of the retreat forcing accounts for only 17 %. But this is for MIROC5, which appears to show relatively low importance of the ocean forcing among the three climate models.
- The uncertainty in the retreat parameterisation translates to a range in the relative importance of the outlet glacier forcing between 20 % and 37 % for MIROC5 RCP8.5.
- The interaction between the two forcing processes on average accounts to between 1.4 % (RCP2.6) and 6.4 % (RCP8.5, high sensitivity ocean).

Comparison of different climate models, scenarios and sensitivities of the retreat parametersation

Climate forcing	Retreat sensitivity	SMB only (<i>atm</i>) %	OGR only (<i>ocn</i>) %	Compensation %
MIROC5 RCP8.5	Medium	77 ± 13	28 ± 13	5.3 ± 2.7
NorESM RCP8.5	Medium	66 ± 19	39 ± 18	5.4 ± 2.7
CSIRO-Mk3.6 RCP8.5	Medium	57 ± 22	47 ± 21	4.4 ± 3.1
MIROC5 RCP2.6	Medium	85 ± 15	17 ± 15	1.4 ± 2.7
MIROC5 RCP8.5	High	69 ± 16	37 ± 17	6.4 ± 3.0
MIROC5 RCP8.5	Low	84 ± 11	20 ± 10	4.3 ± 2.8

References

- Fettweis, X., Box, J. E., Agosta, C., Amory, C., Kittel, C., Lang, C., van As, D., Machguth, H., and Gallée, H.: Reconstructions of the 1900–2015 Greenland ice sheet surface mass balance using the regional climate MAR model, *The Cryosphere*, 11, 1015–1033, <https://doi.org/10.5194/tc-11-1015-2017>, 2017.
- Fettweis, X., Franco, B., Tedesco, M., van Angelen, J. H., Lenaerts, J. T. M., van den Broeke, M. R., and Gallée, H.: Estimating the Greenland ice sheet surface mass balance contribution to future sea level rise using the regional atmospheric climate model MAR, *The Cryosphere*, 7, 469–489, <https://doi.org/10.5194/tc-7-469-2013>, 2013.
- Goelzer, H., Nowicki, S., Abe-Ouchi, A., Aschwanden, A., Barthel, A. M., Calov, R., Choi, Y., Cornford, S., Cuzzone, J. K., Dumas, C., Edwards, T., Felikson, D., Fettweis, X., Gillet-Chaulet, F., Golledge, N. R., Gregory, J., Greve, R., Humbert, A., Huybrechts, P., Kennedy, J. H., Larour, E., Lipscomb, W. H., Little, C., Le clec'h, S., Lee, V., Leguy, G., Lowry, D., Martin, D., Morlighem, M., Nias, I., Pattyn, F., Payne, A. J., Quiquet, A., Rückamp, M., Schlegel, N., Seroussi, H., Shepherd, A., Simon, E., Slater, D., Straneo, F., Sun, S., Tarasov, L., and van de Wal, R.: The future sea-level contribution of the Greenland ice sheet: a multi-model ensemble study of ISMIP6, *Cryosphere*, 14, 3071–3096, <https://doi.org/10.5194/tc-14-3071-2020>, 2020.
- Nowicki, S., Goelzer, H., Seroussi, H., Payne, A. J., Lipscomb, W. H., Abe-Ouchi, A., Agosta, C., Alexander, P., Asay-Davis, X. S., Barthel, A., Bracegirdle, T. J., Cullather, R., Felikson, D., Fettweis, X., Gregory, J. M., Hattermann, T., Jourdain, N. C., Kuipers Munneke, P., Larour, E., Little, C. M., Morlighem, M., Nias, I., Shepherd, A., Simon, E., Slater, D., Smith, R. S., Straneo, F., Trusel, L. D., van den Broeke, M. R., and van de Wal, R.: Experimental protocol for sea level projections from ISMIP6 stand-alone ice sheet models, *The Cryosphere*, 14, 2331–2368, <https://doi.org/10.5194/tc-14-2331-2020>, 2020.
- Slater, D. A., Straneo, F., Felikson, D., Little, C. M., Goelzer, H., Fettweis, X., and Holte, J.: Estimating Greenland tidewater glacier retreat driven by submarine melting, *Cryosphere*, 13, 2489–2509, <https://doi.org/10.5194/tc-13-2489-2019>, 2019.
- Slater, D. A., Felikson, D., Straneo, F., Goelzer, H., Little, C. M., Morlighem, M., Fettweis, X., and Nowicki, S.: Twenty-first century ocean forcing of the Greenland ice sheet for modelling of sea level contribution, *Cryosphere*, 14, 985–1008, <https://doi.org/10.5194/tc-14-985-2020>, 2020.