



Calibration of a frontal ablation parameterization applied to Greenland's peripheral calving glaciers.

Material from *Recinos, et al. in review at Journal of Glaciology*.

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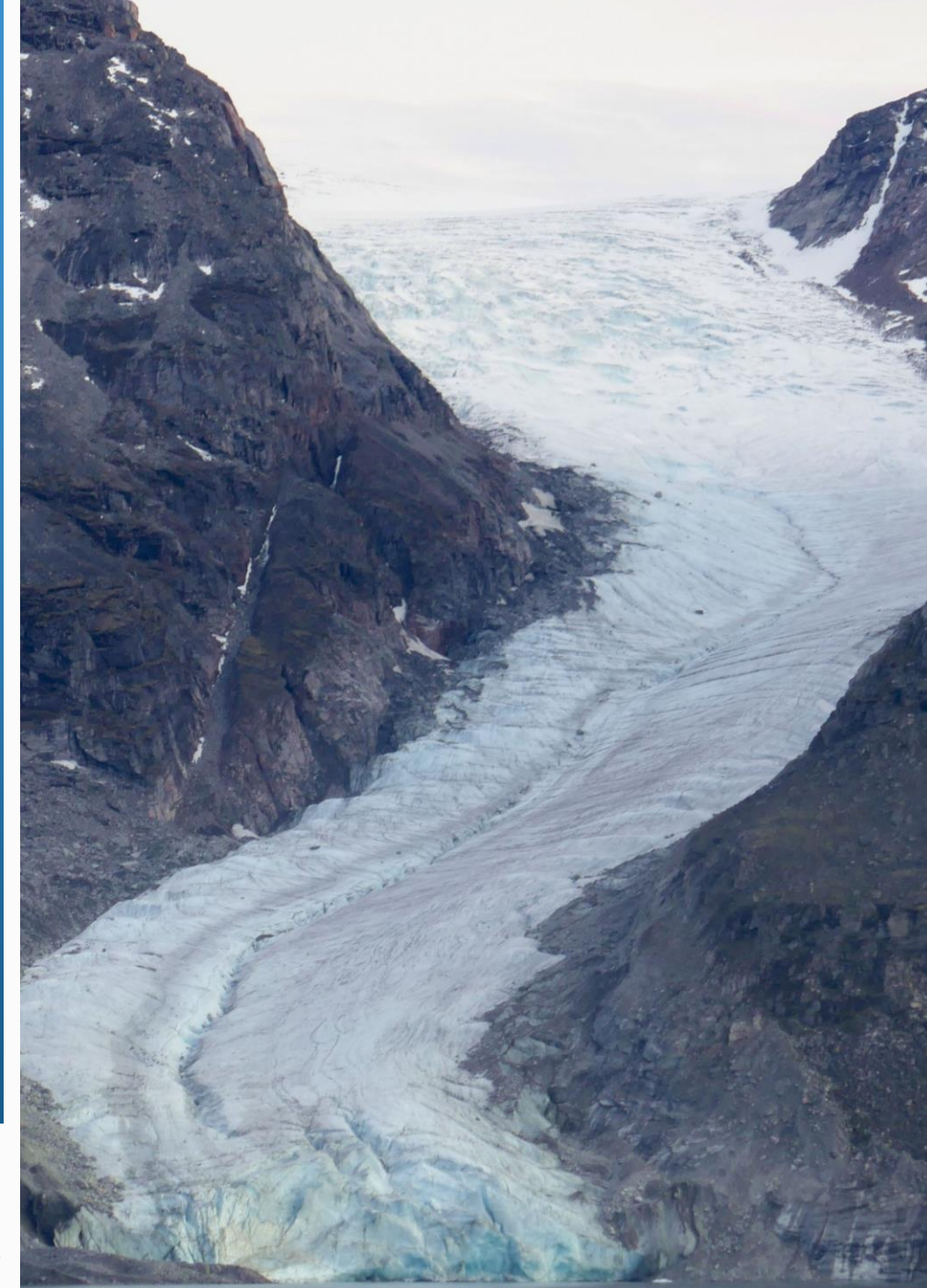
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Throughout the slides there are [links highlighted](#) that will take you to more information, for this you can also click the many OGGM logos that you will encounter.



Motivation and study area: Greenland Peripheral Glaciers (PGs)

- Most regional studies estimate ice sheet wide discharge focusing on outlet glaciers of the ice sheet.
- There are no regional estimates of frontal ablation for PGs.
- PGs have different levels of connectivity with the ice sheet.
- We only focus on glaciers that are weakly or not connected, that is connectivity levels 0 and 1 in the Randolph Glacier Inventory (RGIv6) (25% of the glaciated area outside the ice sheet)

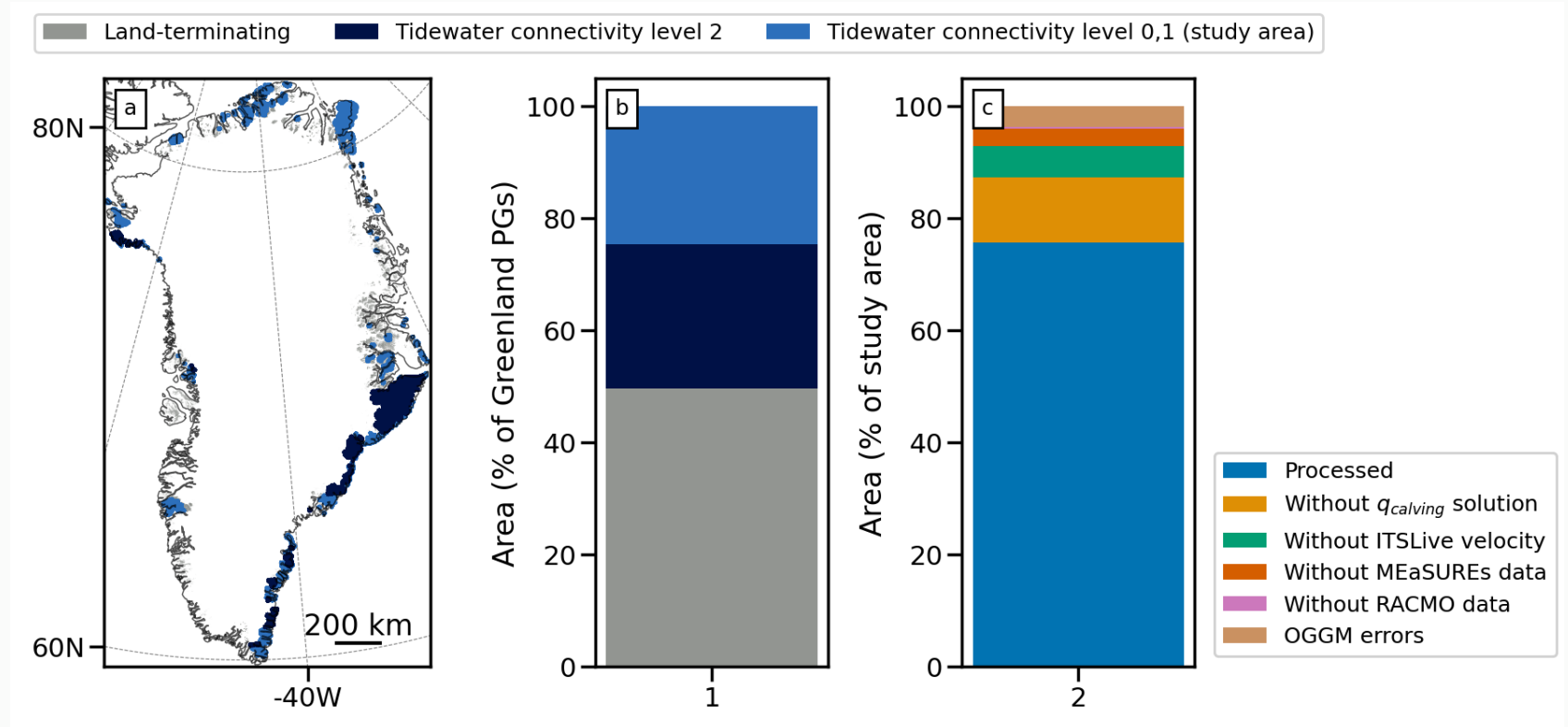


Figure 1. **a:** Map with the PG distribution. **b:** fraction of the ice sheet area covered by each glacier category in percent taken from the Randolph Glacier Inventory attributes: terminus type and connectivity levels. **c:** percentage of the study area (light blue in b.) that can and cannot be modelled by the Open Global Glacier Model due to preprocessing errors (brown), gaps in observational data (green, red and pink), or for which no calving value can be determined by the parameterization.

Data input required by



Click on the logo to read the specifics of each data input.

- Randolph Glacier Inventory (RGIv6)
Only one glacier entity was manually modified: **the Flade Isblink Ice Cap**.
The original RGI outline has been subdivided into different basins and these have been **re-classified as non-calving and calving basins** using satellite velocity data.
- Topography: ArcticDEM and GIMP
- Climate Research Unit (CRU) time series of temperature and precipitation.
- Surface mass balance (SMB) measurements from the World Glacier Monitoring Service.

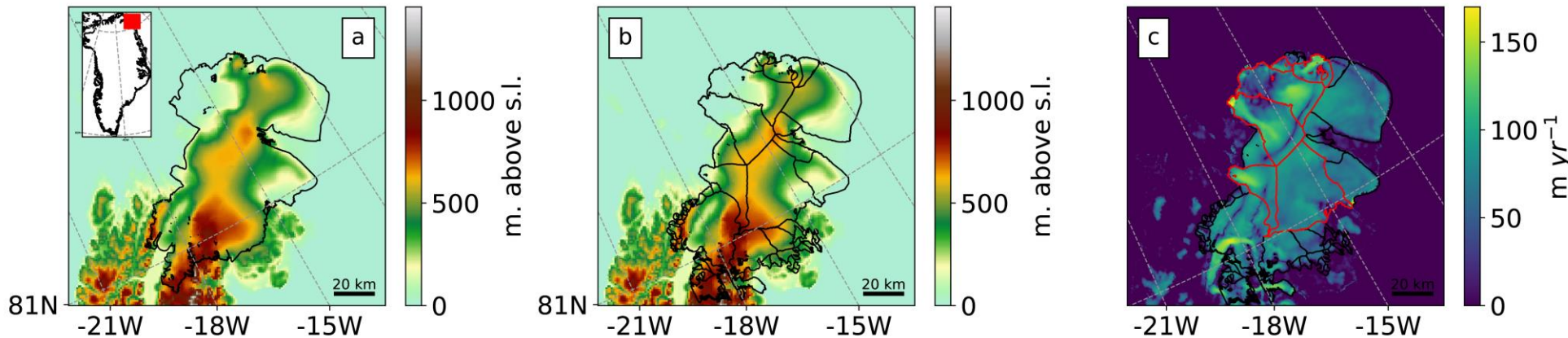


Fig. 2. Flade Isblink Ice Cap outlines (black and red lines), topography and surface velocity (color maps). **a:** original outline from the RGIv6.0. (ID RGI60-05.10315) **b:** subdivided outline processed using ArcticDEM data and velocity fields from MEASURES and ITS_LIVE. **c:** velocity fields over the ice cap. The active tidewater basin outlines are highlighted in red.

Data input used to calibrate the calving parameterization in OGGM

Velocity observations from two satellite products:

- [MEaSURES v1.0 \(a\)](#)
- [ITS LIVE \(b\)](#)

Now the ITS_LIVE data set comes with OGGM, for more information click here:

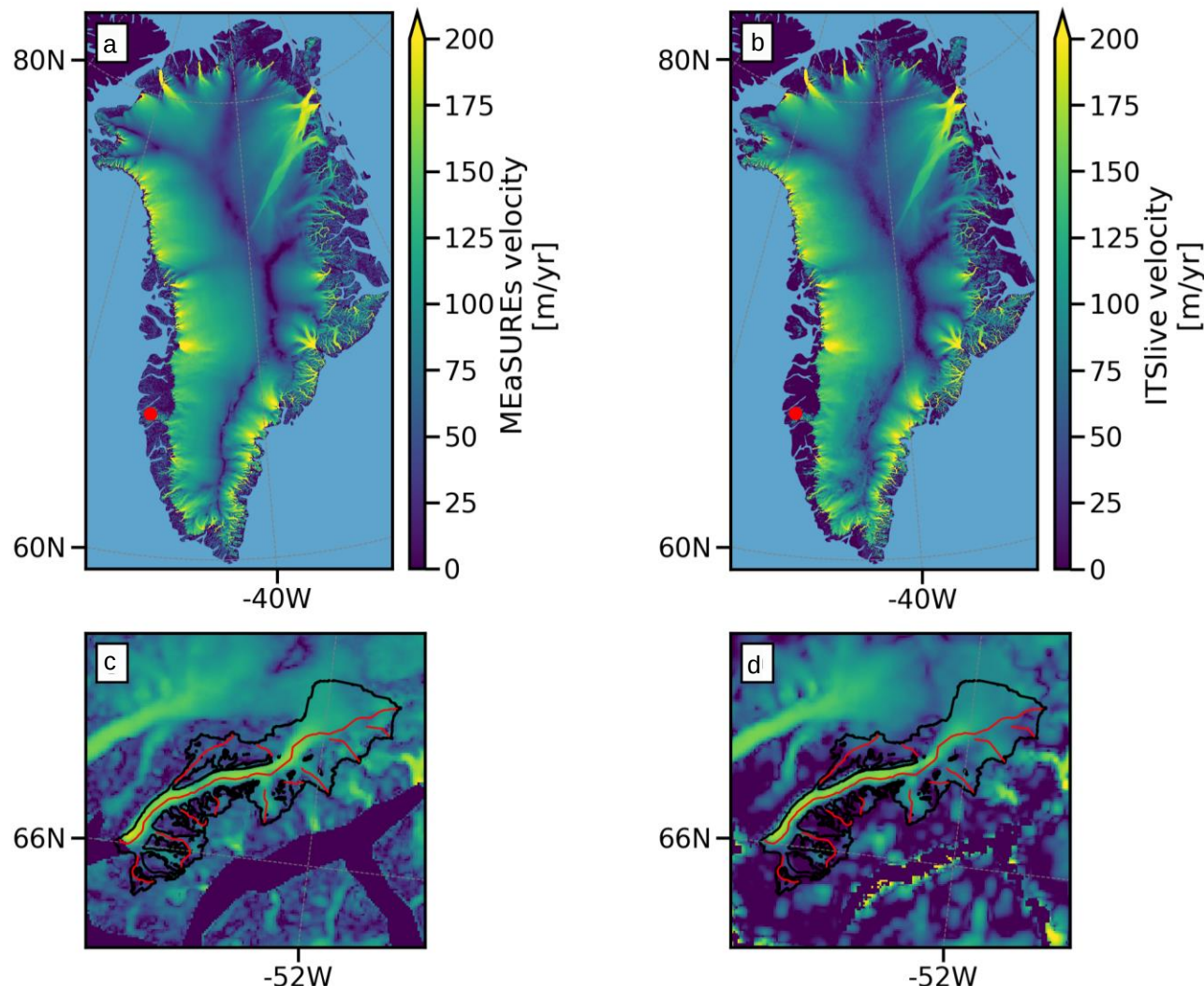
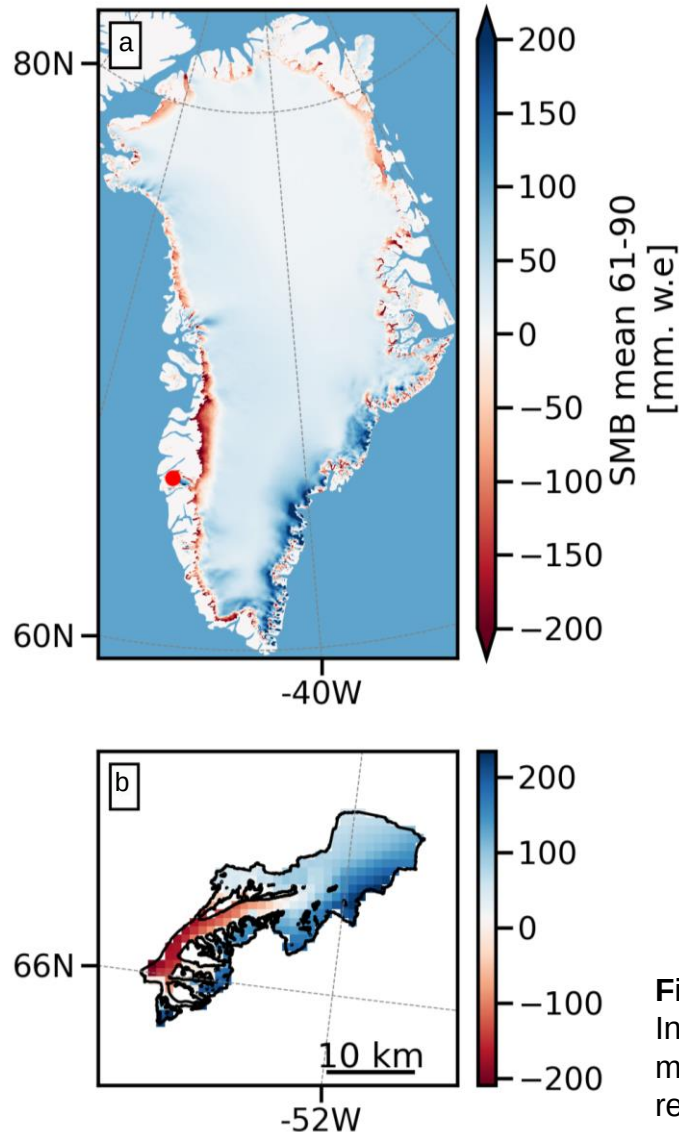


Fig. 3. Input data using the glacier with ID RGI60-05.00800 as an example (red dot in the Greenland map).
a: MEaSURES Greenland 250 m velocity mosaic.
b: ITS_LIVE Greenland 120 m velocity mosaic.
c and d: velocity data reprojected to the glacier grid.

Data input used to calibrate the calving parameterization in OGGM



- Surface Mass Balance (SMB) estimates from the monthly output of the Polar Regional Atmospheric Climate Model (RACMO2.3p2), downscaled to 1 km resolution. For details see:
 - [Noël and others, 2019.](#)
 - [Noël and others, 2016.](#)
- We average these SMB estimates over an “equilibrium reference period” (1961-1990) and use these estimates as a reference to calibrate the calving parametrization.

Fig. 4.

Input data using the glacier with ID RGI60-05.00800 as an example (red dot in the Greenland map). **a:** RACMO2.3p2 surface mass balance mean over 1960-1990. **b:** RACMO SMB average re-projected to the glacier grid.

Methods

In both calibration methods we assume equilibrium conditions for the ice dynamics:

The ice flux that passes through the terminus of the glacier in a MB year

The ice flux delivered to the terminus computed by OGGM via the physics of ice deformation and sliding.

$$q_{calving} = q_{OGGM} \quad (1)$$

$$\max(0; kd h_f) \cdot w = \left[\frac{2A}{n+2} h_f (\rho g h_f \alpha)^n + \frac{f_s (\rho g h_f \alpha)^n}{h_f} \right] h_f \cdot w \quad (2)$$

click on the logo for info regarding

q_{OGGM}



Calving law ($q_{calving}$) components:

- k : calving constant of proportionality
- d : water depth
- h_f : thickness of the calving front
- w : calving front width

q_{OGGM} components:

- A : ice creep parameter
- n : exponent of Glen's flow law
- ρ : ice density
- g : gravitational acceleration
- α : surface slope
- f_s : sliding parameter

See [this link](#) more information regarding the solving of Eq. 2. More details also in [Recinos, et.al. 2019](#).

Methods: sensitivity experiment on k

We vary the calving constant of proportionality k over a wide range of values: $0.01 - 3 \text{ yr}^{-1}$.
And estimate the following:

- Model frontal ablation fluxes $q_{calving}$ via Eq. 4.
- Model surface velocities u_s along the main flowline using Eq. 3.

$$u_s = u_b + \frac{2A}{n+1} \tau^n h \quad (3)$$

$$q_{calving} = \max(0; k dh_f) \cdot w \quad (4)$$

- u_s : surface velocity
- u_b : basal sliding velocity
- A : ice creep parameter
- n : exponent of Glen's flow law
- τ : basal shear stress
- h : ice thickness computed with a specific k value

Calibration methods: Velocity method

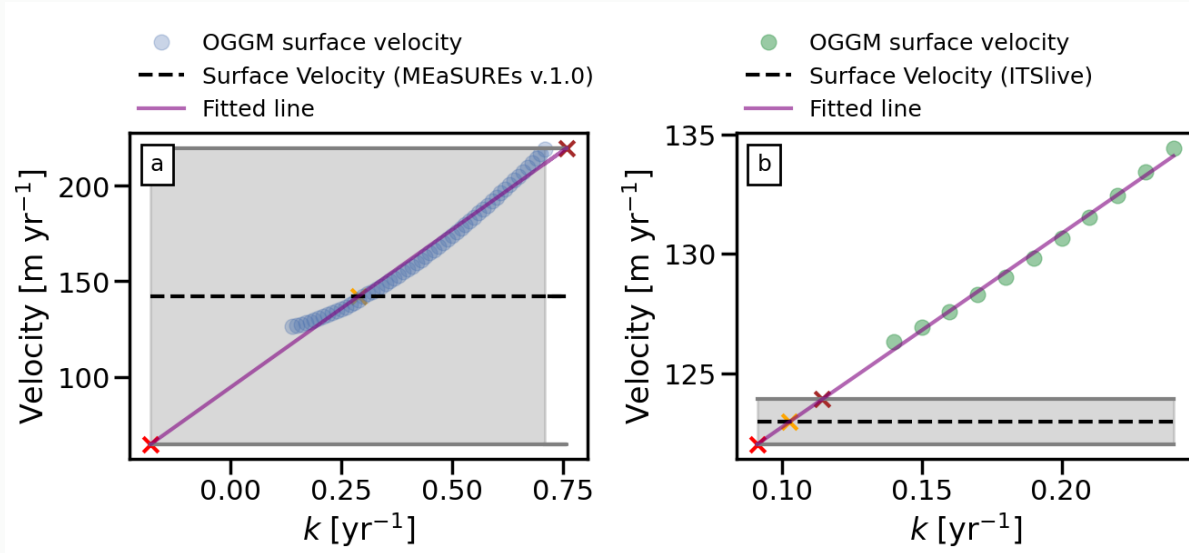


Fig. 5.

Illustration of the different ways to calibrate the calving constant of proportionality k for the glacier with ID RGI60-05.00800, shown in Fig.3 as an example. **a and b:** OGGM surface velocities computed with different k values (blue and green dots). The dashed black lines indicates surface velocity from MEaSUREsv1.0 (**a**) and from ITS_LIVE (**b**), with the light grey shading indicating the standard errors as provided on each data product. Crosses in all plots represent the intercepts to velocity observations.

- From both modelled and observed surface velocities, we extract values along the glacier main flowline and compare them, in order to calibrate the calving parametrization.
- We select k parameter values that match surface velocity observations and their uncertainty.

Calibration methods: SMB-RACMO method

- This second method uses frontal ablation fluxes derived from RACMO2.3p2 SMB means over an equilibrium reference period.
- And is based on the strong assumption that most PGs during that time have a balanced budget (i.e., did not experience any mass loss or gain).
- According to different studies in the literature like: [Fettweis and others \(2017\)](#) and [Noël and others \(2017\)](#), the period between **1961-1990** has been considered as a period when the total mass balance of the GrIS was stable ([Rignot and Kanagaratnam, 2006](#)) and near zero.
- Here we assume that **most PGs also experienced the same equilibrium conditions** and that their total mass balance should have also been near zero.

Calibration methods: SMB-RACMO method

- This second method assumes that most PGs during the reference period of 1961-1990 have an equilibrium between mass gain via SMB and mass loss via frontal ablation.
- **That is a positive SMB average over that period.**
- We can verify this by using RACMO SMB estimates from [Fig 4b](#).
- Based on this and the mass conservation principles defined in [Eq.1](#) we assume:

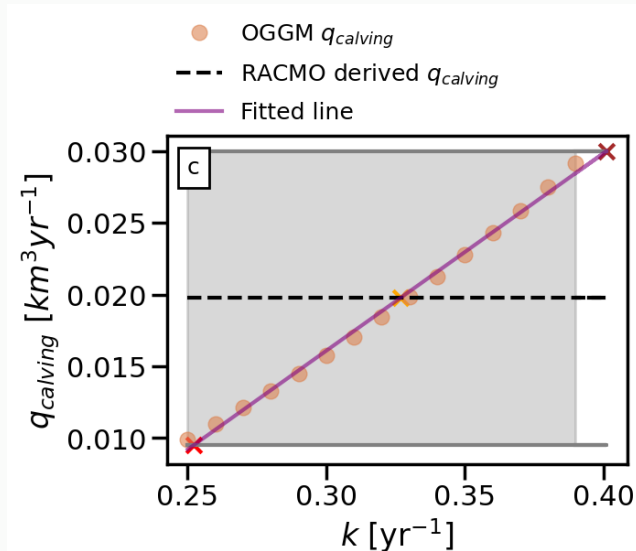


Fig. 6. Illustration of the RACMO calibration method for the glacier with ID RGI60-05.00800, shown in Fig.4 as an example. **c:** OGGM frontal ablation fluxes computed with different k values (orange dots). The dashed black line indicates the RACMO derived frontal ablation estimate and the light grey shading its uncertainty. Crosses in the plot represent the intercepts to the RACMO derived frontal ablation estimate.

$$q_{calving-RACMO} = \frac{\bar{m}_{1961-1990} \cdot A_{RGI}}{\rho} \quad (5)$$

- $q_{calving-RACMO}$: RACMO derived calving fluxes
- A_{RGI} : *RGI area*
- ρ : ice density
- $\bar{m}_{1961-1990}$: SMB mean over the reference period

We select k values that match RACMO derived calving fluxes and its uncertainty estimate.

Key points

- Assuming that **RACMO** $\bar{m}_{1961-1990}$ equals the glacier mean frontal ablation flux would be a meaningless approach if not compared with frontal ablation fluxes derived from constraining the calving parameterization with velocity observations.
- The difference between the results from both calibration methods serves as an indication of how strong the dynamic imbalance might have been for PGs during that period.
- We then compare the output of OGGM between both calibration methods (**velocity constrain** and **SMB constrain**) and all data input used for calibration, and we obtained:
 - k parameter per glacier and its uncertainty.
 - glacier thickness distribution
 - frontal ablation fluxes and calving rates
 - glacier volume and volume below sea level

Results

- For most glaciers (areas $> 15 \text{ km}^2$) the model output derived using the velocity method (blue and green) is significantly larger in magnitude than the output derived using the SMB-RACMO method (orange).

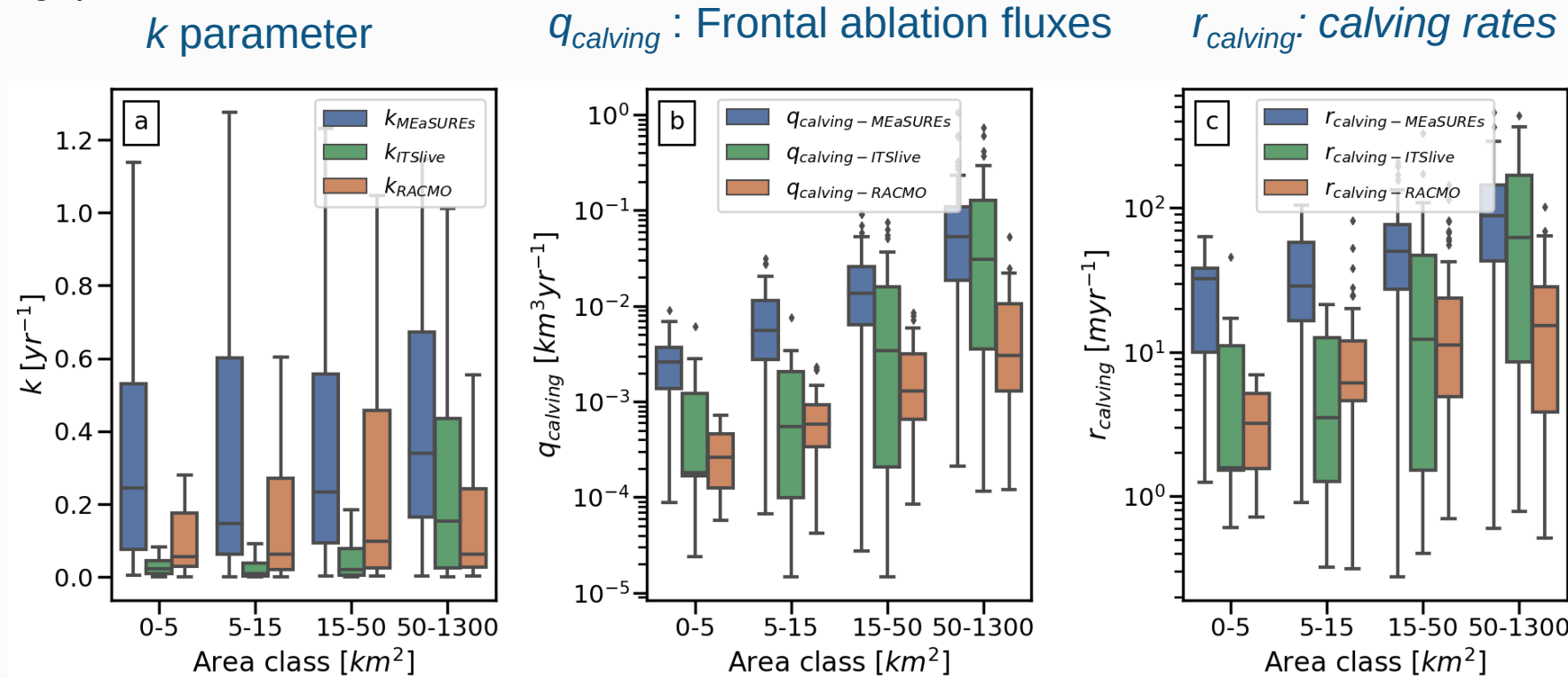
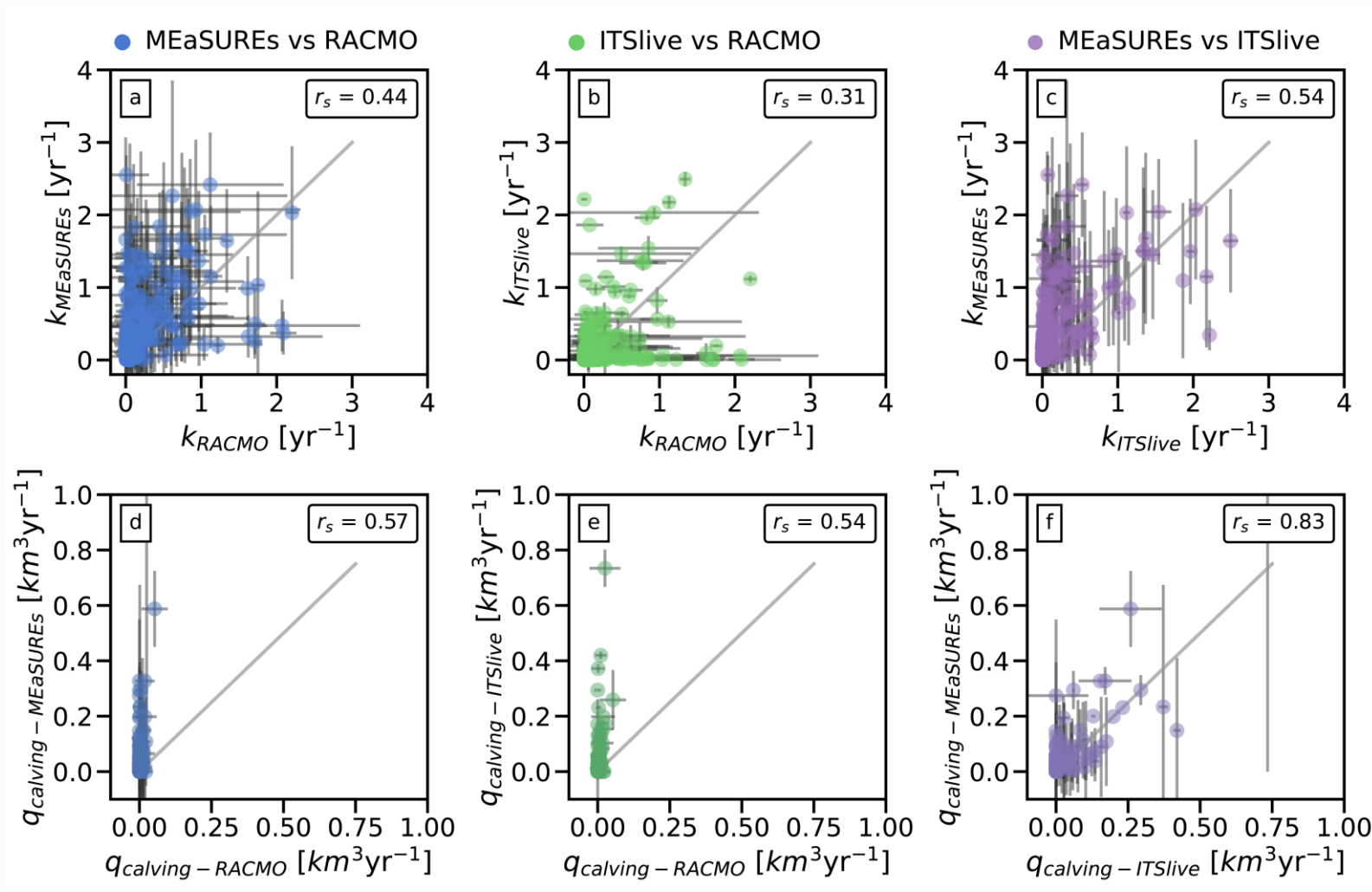


Fig. 7.

Difference between k values **(a)**, frontal ablation fluxes **(b)** and calving rates **(c)** obtained by calibrating OGGM's calving parameterization with three independent data sets: i) MEaSURES v1.0 (blue), ii) ITS_LIVE (green) and ii) RACMO (orange). The x-axis is broken into different glacier size categories. The width of the boxes represents the inter quartile range (IQR) of the data values. The line dividing the boxes represents the median. The whiskers represent the range of values for 99.3% of the data. Points outside this range only contain 0.7% of the values distribution.

Results



- No significant correlations between k parameters estimated via the different methods, but a strong correlation between **velocity-constrained $q_{calving}$ fluxes**

Fig. 8. Comparison of k values (a to c) and frontal ablation fluxes (d to f) obtained by calibrating OGGM's calving parameterization with three independent data sets: i) using MEaSUREs v1.0 surface velocities, ii) ITS_LIVE surface velocities and ii) RACMO derived frontal ablation fluxes. (a to c) scatter plot of k parameters. (d to f) scatter plot of frontal ablation fluxes. Correlation coefficient are also given, all correlations are highly significant at the $p < 1 \times 10^{-5}$ level. The grey error bars represent each parameters uncertainty.

Model limitations before calibration

- We are only able to estimate frontal ablation fluxes for ~70% of the study area.
- This is due to gaps in the input data used for calibration and/or OGGM pre-processing errors (~10% of the study area).
- Another ~10% of the study area comprises of glaciers that [do not calve](#) according to OGGM and the condition of mass conservation. The model does not produce a frontal ablation flux for these glaciers under any k value from the range $0.01 - 3 \text{ yr}^{-1}$. [Click here](#) to learn about glaciers where we can't find a solution to [Eq.2](#)

Model limitations after calibration

- Another small percentage of glaciers (~10%) also have a frontal ablation flux of zero according to the model even after calibrating the k parameter.
- Half of these glaciers shouldn't calve according to the velocity observations from ITS_LIVE.
- Velocities near the calving front for these PGs are < 5 m/yr, and probably their ice discharge is approx. zero.
- But there are big difference when we look at the MEaSUREs estimate.
- Velocity data for the other half of these glaciers indicate that they should be active calving glaciers.
- [Click here](#) to read about glaciers where the frontal ablation estimated **after calibration** is still too large to sustained by the climate.

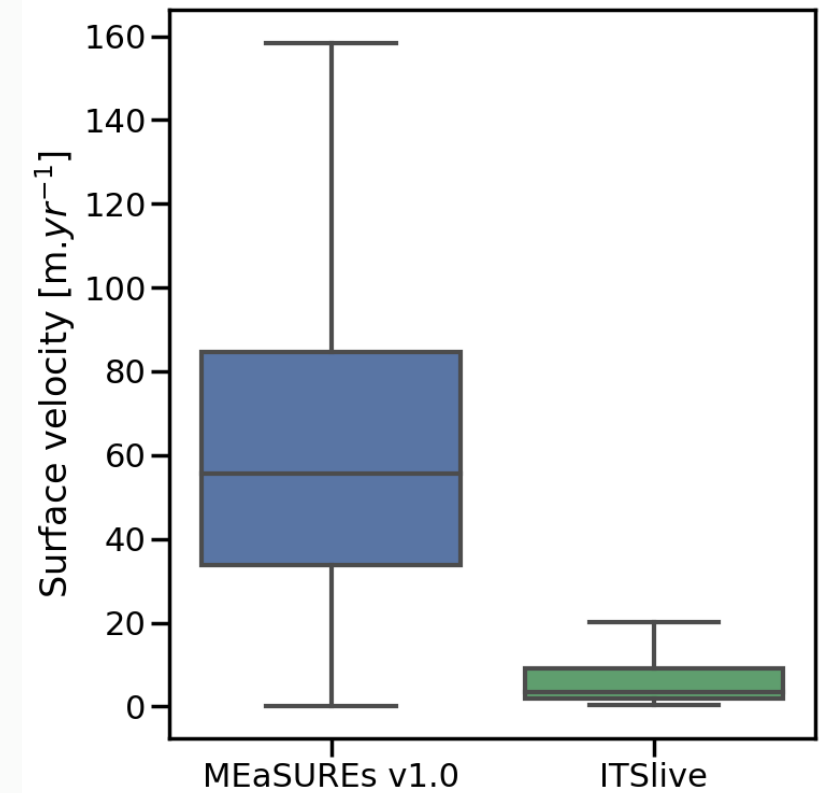


Fig. 9. Surface velocity estimates at the last one third of the glacier flowline extracted from MEaSUREs (blue box plot) and ITS_LIVE (green box plot) for glaciers which have no calving after calibration. The width of the boxes represents the inter quartile range (IQR) of the data values. The line dividing the boxes represents the median. The whiskers represent the range of values for 99.3% of the data. Points outside this range only contain 0.7% of the values distribution and are not shown in the figure.

Model performance

- We can calibrate the calving parametrization in three different ways.
- We then compare model surface velocities (**computed after calibration**) to the same velocity input data (MEaSUREs and ITS_LIVE observations).
- And find that the model is not able to predict individual tidewater glacier dynamics if it relies only on RACMO SMB estimates and the assumption of a closed budget to constrain the calving parameterization (**see orange scatter plot**) . Velocity observations are essential to constrain the model and estimate the dynamic mass loss of PGs.

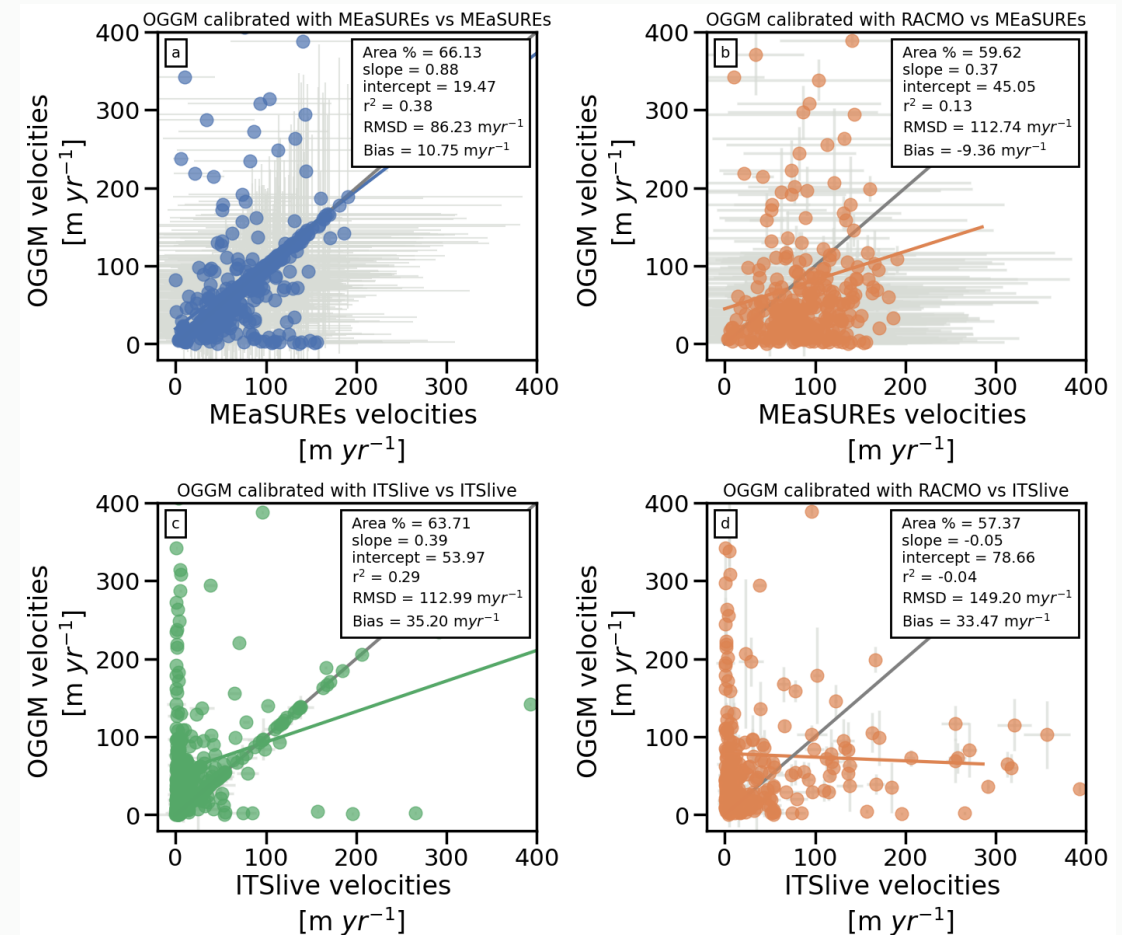


Fig. 10. Model performance. **a and c:** comparison of modelled (after calibrating k with the velocity method) and observed surface velocities from (a) MEaSUREs and (c) ITS_LIVE. **b and d:** comparison of modelled (after calibrating k with the RACMO method) and observed surface velocities from (b) MEaSUREs and (d) ITS_LIVE. Regression lines (solid lines) and statistics are shown in the upper right corner, i.e. % of study area represented in the graph, regression slope, intercept, coefficient of determination (r^2), RMSD and bias. P-values are all smaller than 0.05. Grey solid lines represent slopes equal to 1 and intercepts equal to zero and in all scatter plots uncertainty bars are plotted in light grey.

Model performance

- If we remove glaciers with a calving flux of zero after calibration.
- The performance of OGGM improves and model surface velocities are well correlated to satellite observations when the frontal ablation parameterization is calibrated via the Velocity Method (**see blue and green scatter plots**).
- This still does not improve for the SMB-RACMO method. (**orange scatter plot**)

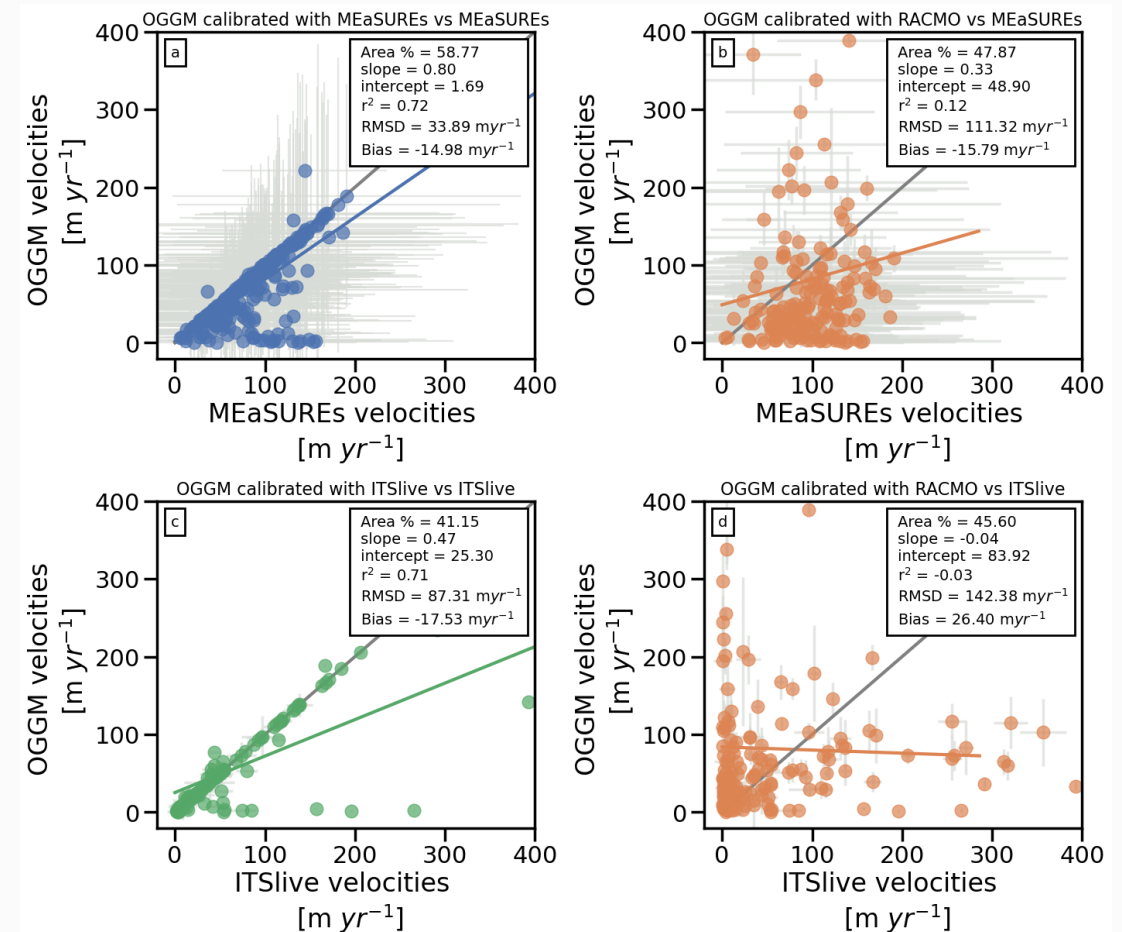


Fig. 11. Model performance. **a and c:** comparison of modelled (after calibrating k with the velocity method) and observed surface velocities from (a) MEaSUREs and (c) ITS_LIVE. **b and d:** comparison of modelled (after calibrating k with the RACMO method) and observed surface velocities from (b) MEaSUREs and (d) ITS_LIVE. Regression lines (solid lines) and statistics are shown in the upper right corner, i.e. % of study area represented in the graph, regression slope, intercept, coefficient of determination (r^2), RMSD and bias. P-values are all smaller than 0.05. Grey solid lines represent slopes equal to 1 and intercepts equal to zero and in all scatter plots uncertainty bars are plotted in light grey.

Want to see more results and conclusions

Join me at:

EGU21-2926 | vPICO presentations | [CR3.5](#)

[Calibration of a frontal ablation parameterization applied to Greenland's peripheral calving glaciers](#)

Beatriz Recinos, Fabien Maussion, Brice Noël, Marco Möller, and Ben Marzeion

We also have the following talk, where data from this study is used:

EGU21-10539 | vPICO presentations | [CR3.4/OS1.9](#) | **Highlight**

[Increase of ice discharge from Greenland's peripheral tidewater glaciers over recent decades](#)

Marco Möller, Beatriz Recinos, and Ben Marzeion

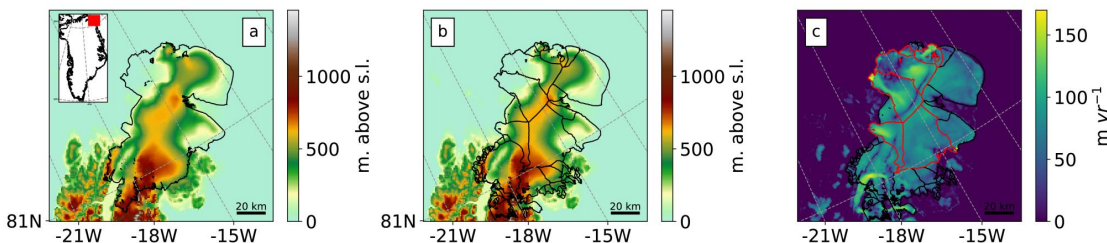
For references and to get access to the links in this slide [see additional material](#).

Results

- Regional glacier volumes (of PGs semi/detached from the Ice sheet) are underestimated by 12% **if frontal ablation is ignored (brown)** and/or if the **Open Global Glacier Model** only relies on **surface mass balance estimates (SMB, orange)** and the assumption of a closed budget to calibrate the **calving parameterization**.
- This change in volume is also reflected in the ice thickness distribution of PGs and hence the **regional volume below sea level (grey)**.
- Including frontal ablation in the model increases the sea level rise contribution for PGs when using velocity observations to constrain the frontal ablation parametrization (**blue** and **green**).

- By comparing the model output after applying both calibration methods, we find that the model is not able to predict individual tidewater glacier dynamics if the calving parameterization is SMB constrained.
- Velocity observations are essential to constrain the model and estimate the dynamic mass loss of PGs.

The Flade Isblink Ice Cap contributes to most of the regional volume (see line pattern bars)



(a) Original ice cap outline from the RGIv6 not subdivided. (ID RGI60-05.10315)

(b) Subdivided outline processed using ArticDEM topography and velocity fields from MEaSUREs v1.0 and ITS_LIVE.

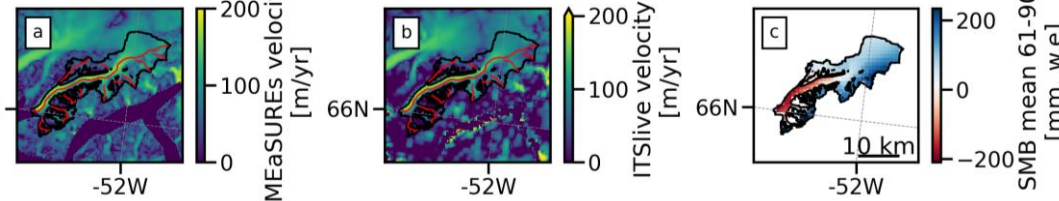
(c) Velocity fields over the ice cap used to classify the active tidewater basins highlighted in red.



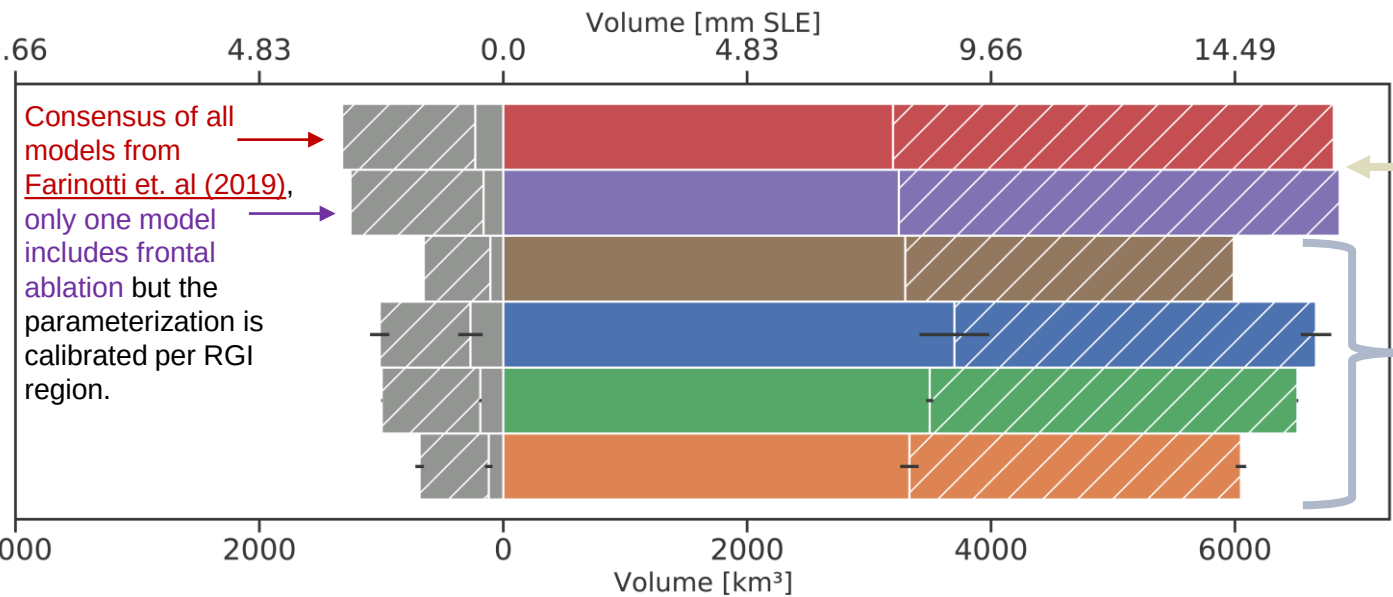
Velocity constraint
a) MEaSUREs v1.0
ITS_LIVE

b)

SMB constraint with
derived frontal ablation fluxes from
c) RACMO2.3p2 downscaled to 1 km average over an equilibrium reference period (1961-1990).



Regional volume of PGs for different model configurations



Farinotti et al. (2019)
Huss and Farinotti. (2012)
Without $q_{calving}$
Flade Isblink ice cap

With $q_{calving}$ - MEaSUREs
With $q_{calving}$ - ITS_LIVE
With $q_{calving}$ - RACMO

Methods
applied to each PGs
[More click here](#)

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