Mapping dynamic mass loss by fully decomposing glacier elevation change

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Abstract

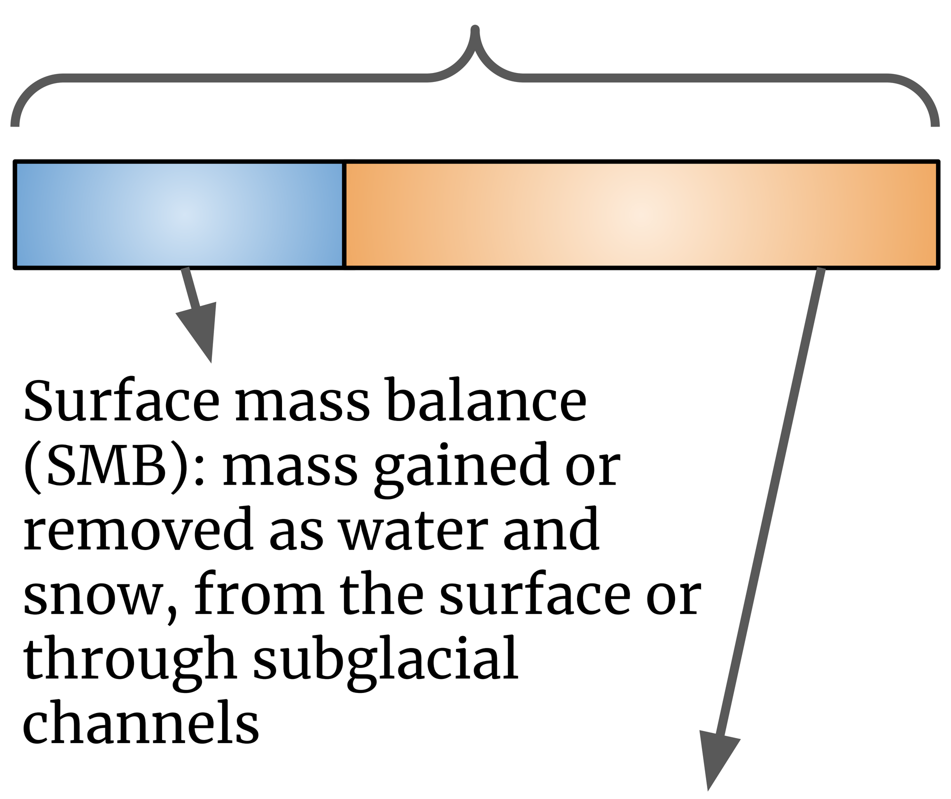
Glaciers and ice sheets lose their mass by ablation (the output term of their surface mass balance) and discharging into a water body (dynamic loss). The latter is associated with multiple physical characteristics such as bed geometry, inland thinning, terminus stability, and basal conditions. Better assessing the dynamic loss, especially its spatiotemporal variability within a drainage basin, will help improve our understanding of the underlying processes and quantify the future contribution of sea level rise. We propose a new inverse model to decompose glacier elevation change and optimize the dynamic mass loss components for each pixel of the elevation data grid. The model unmixes the observed elevation change from remote sensing data using the modeled surface mass balance and the ice flux as constraints. We use two approaches to design the ice flux term; one is based on glacier surface velocity and the conservation of mass, and the other builds on the flow law and the Shallow Ice Approximation. We test the model for selected marine-terminating glacier outlets in the Greenland ice sheet. If the surface velocity can be decomposed into short-term (seasonal) and multi-year signals, our model may be able to further resolve the dynamic loss components of different physical processes.

A new method to map glacier dynamical change, pixel by pixel

Introduction

Glacier dynamical mass change (glacier ice accumulated or removed by its flow) contributes to about the half of the mass loss in the Greenland ice sheet. [1] Despite this significance, we calculate it using indirect methods.

Here we develop a method to directly extract this dynamical change for every unit area on a glacier: a statistical model unmixing the term of glacier elevation based on the conservation of mass.



[1] IMBIE, 2020. 10.1038/s41586-019-1855-2
[2] Porter, Claire, et al., 2022. 10.7910/DVN/C98DVS
[3] Morlighem et al., 2017. 10.1002/2017GL074954
[4] Van Dalum et al., 2021. 10.5194/tc-15-1823-2021
[5] Gardner et al., 2022. 10.5067/IMR9D3PEI28U
[6] Joughin et al., 2020. 10.5194/tc-14-211-2020
[7] Zheng et al., in preparation.

Proof of concept

Data used

1. Surface elevation: ArcticDEM [2]
2. Bed elevation (for ice thickness): BedMachine v3 [3]
3. Surface mass balance: RACMO 2.3p3 [4]
4. Glacier velocity: ITS_LIVE Landsat-8 16-day scene pairs [5]

All available data from 2014-present are used. We resample and project them into a common grid prior to the statistical inversion. No smoothing.

Target area

Sermeq Kujalleq (aka Jacobshavn Glacier), Greenland's largest outlet glacier, with high seasonal and multi-year variability of glacier speeds [6].

Preliminary results

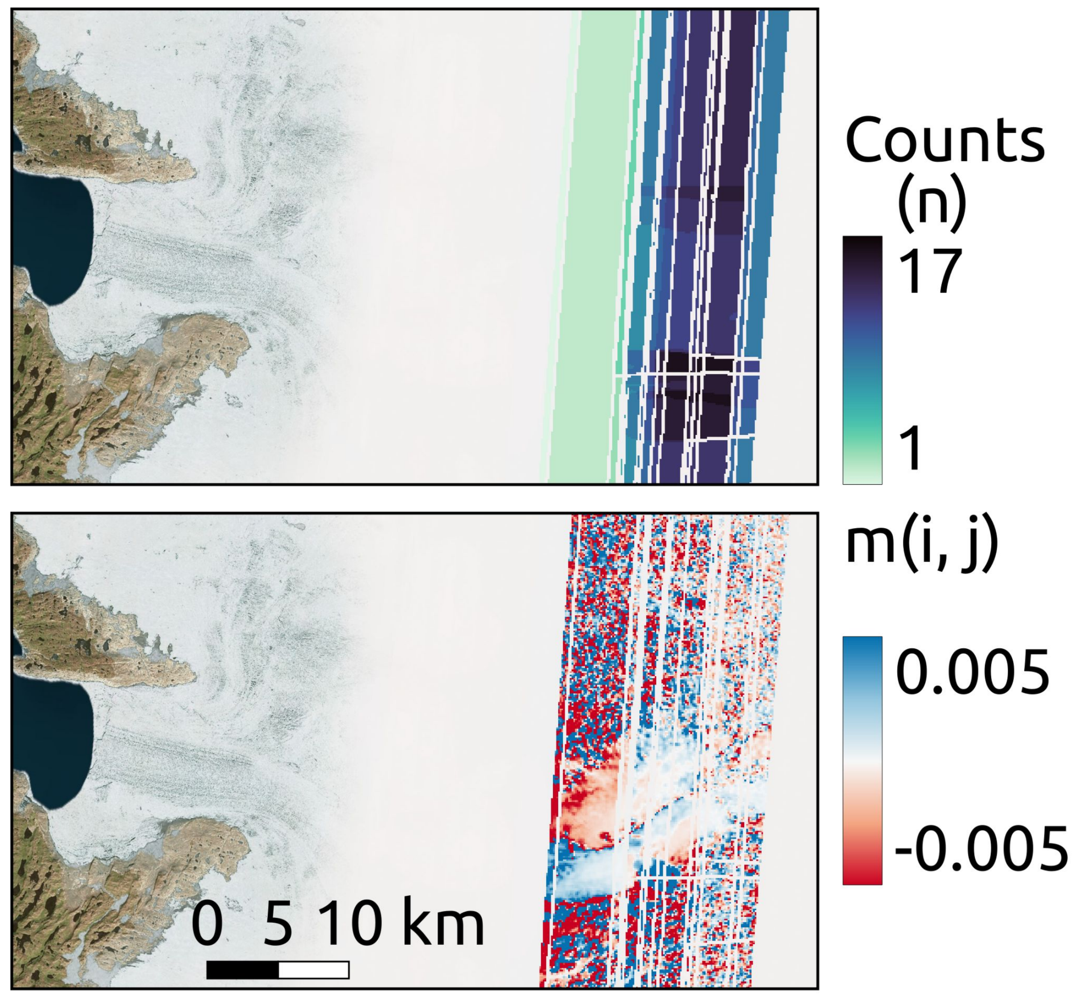


Figure 1. (Top) sample counts for the statistical model. (Bottom) Map of mixing parameter m. Sermeq Kujalleq flows to the left.

Discussion

Theoretically, m should be close to 1. Small m is likely due to the noise in the velocity maps, which creates large local velocity gradient.

Statistical model

$$\Delta h_{i,j,T} - \frac{\dot{b}_{i,j,T}}{\rho_{firn}} = m_{i,j}\, \nabla(H_{i,j,T}\; u_{i,j,T}) \quad \text{(Definitions on the right)}$$

$$= m_{i,j}\left(H\frac{\partial u_x}{\partial x} + \frac{\partial H}{\partial x}u_x + H\frac{\partial u_y}{\partial y} + \frac{\partial H}{\partial y}u_y\right)$$

Future directions

(1) Experiment different smooth level for glacier velocity. A smooth level optimized for glacier modeling may be good for this purpose. [7]

(2) Expand input data sets for additional constraints, such as altimetry data.

(3) If total dynamic change can be quantified, further decomposing this signal (e.g., seasonal change vs. long-term change) will help understand the physical mechanisms of ice flow variability.

$$\frac{\partial H}{\partial t} = \dot{b}_{volume} + \Sigma_k \dot{h}_k$$

We will have two ways to express the k-th elevation change component and do the inversion.

$$① \quad \dot{h}_k = -\frac{n+1}{\beta(n+2)}\nabla(Hu_k)$$

$$② \quad \dot{h}_k = \frac{1-\beta}{2A\tau_d^n}\frac{\partial u_k}{\partial t}$$

- h: ice elevation
- b: surface mass balance
- ρ: density (here we use firn density = 850 kg/m^3)
- H: ice thickness
- u: ice velocity
- m: mixing parameter
- Subscripted i, j, and T: The pixel at unit area location (i, j) during a period T
- n and A: flow law parameter
- β: mixing parameter
- τ_d: driving stress
- Subscripted k: The k-th component of glacier velocity

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