

Subglacial Discharge of the Greenland Ice Sheet from Basal Melt

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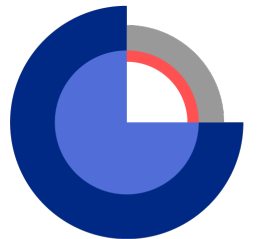
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G E U S

Introduction



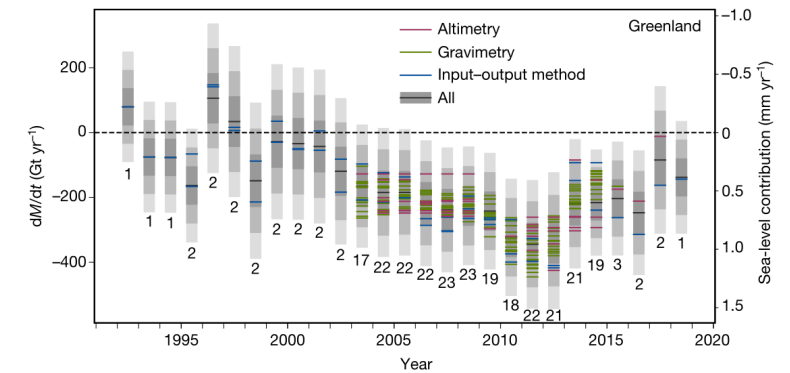
Greenland is melting from above.

But what about the basal melt?



Basal Melt: Is it important?

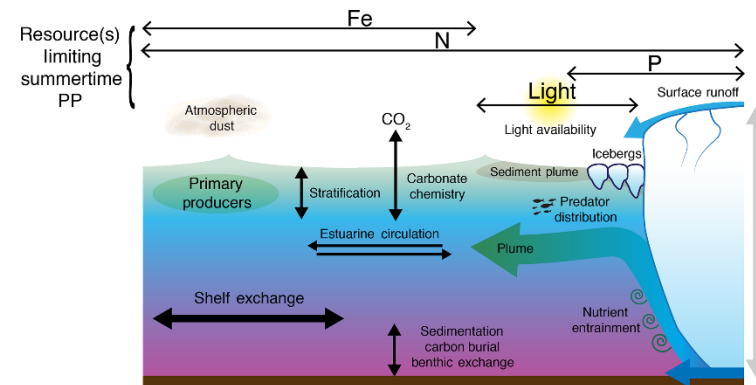
Basal melt is part of the total mass budget.



Shepherd et al., 2019.

<https://doi.org/10.1038/s41586-019-1855-2>

Subglacial discharge modifies fjord circulation and impacts eco-systems.



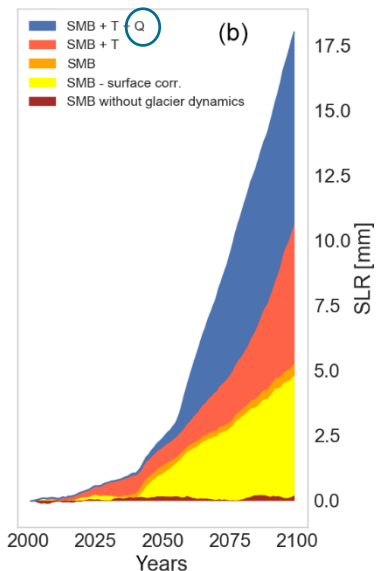
Hopwood et al., 2019: Review article: How does glacier discharge affect marine biogeochemistry and primary production in the Arctic? *The Cryosphere*.

<https://doi.org/10.5194/tc-14-1347-2020>

Tidewater calving processes are modified by subglacial water.

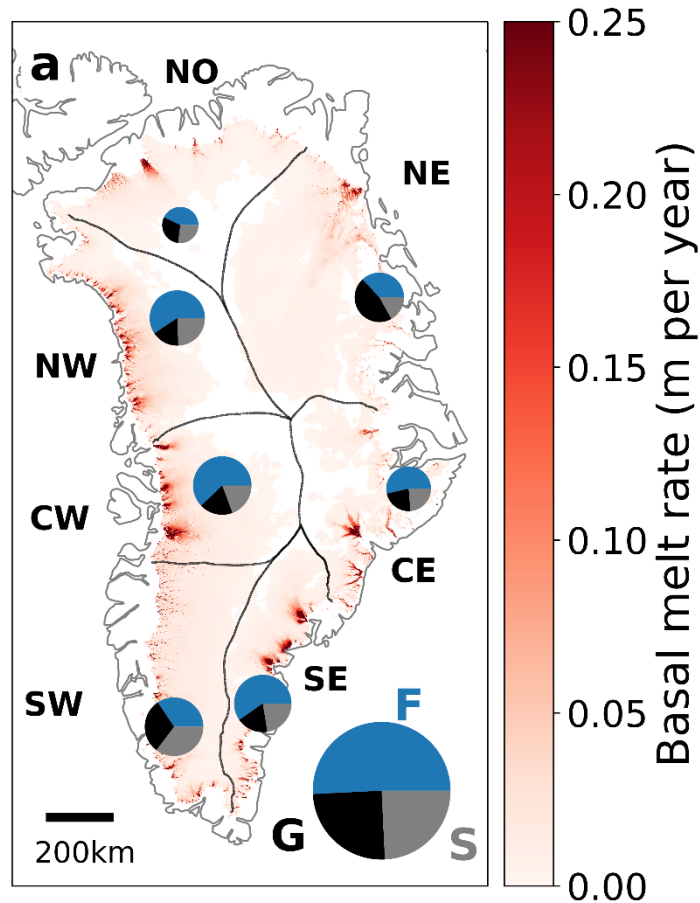
Beckmann et al., 2019.

<https://doi.org/10.5194/tc-13-2281-2019>



Subglacial system dynamics is influenced by seasonal availability of subglacial water.

Basal Melt of the Greenland Ice Sheet



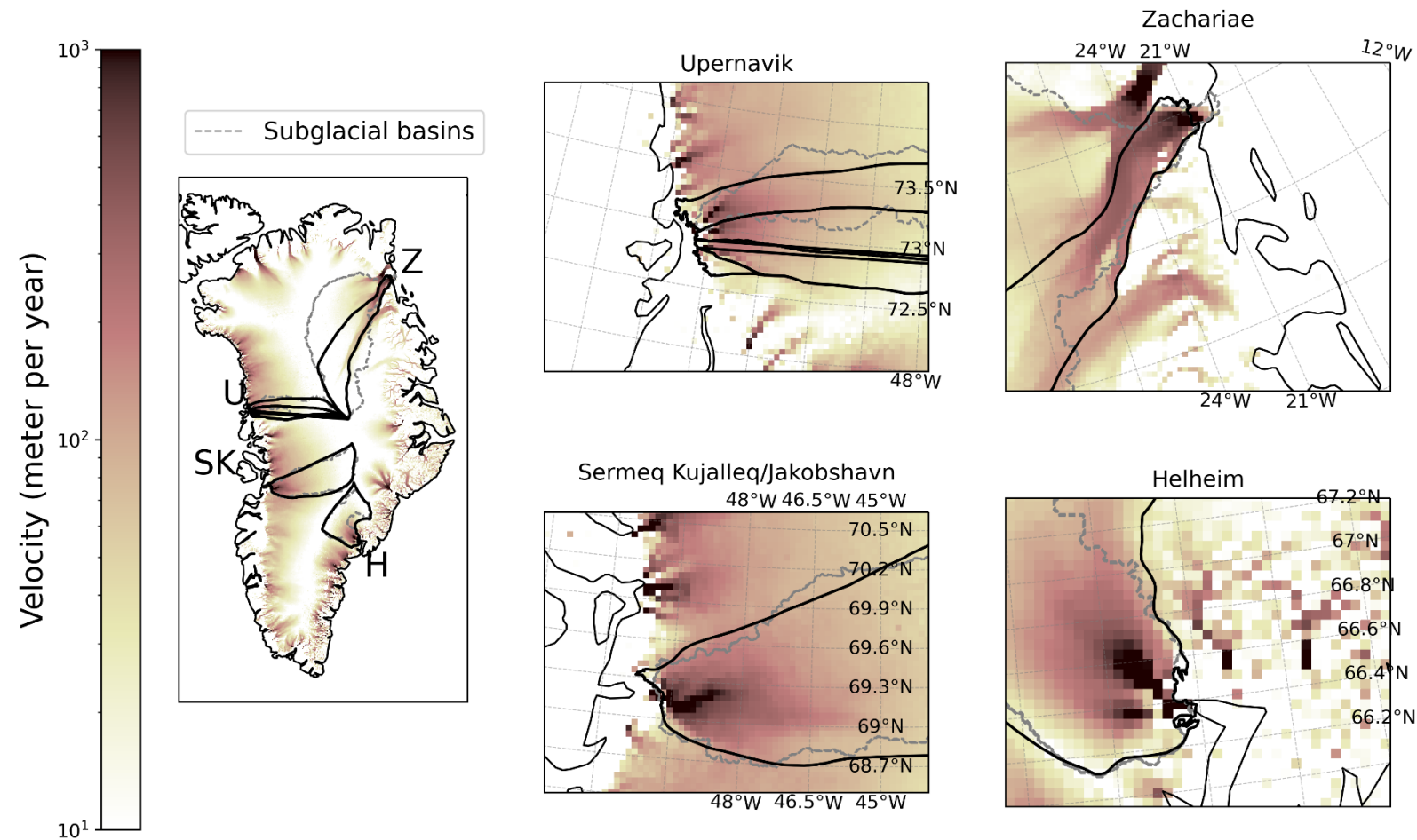
- Basal melt of $21.4 +4.4/ -4.0$ Gt per year.
 - Friction melt: 50%
 - Geothermal melt: 25%
 - Melt from surface meltwater: 25%
- Equivalent to 8% of current ice sheet imbalance.

Geothermal and friction heat are active year round -> freshwater is discharged during the winter.

(see slides on methods at the end of this presentation)

Karlsson et al., 2021, in review, Nature Comms.
Preprint: [10.31223/osf.io/rjt4v](https://doi.org/10.31223/osf.io/rjt4v)

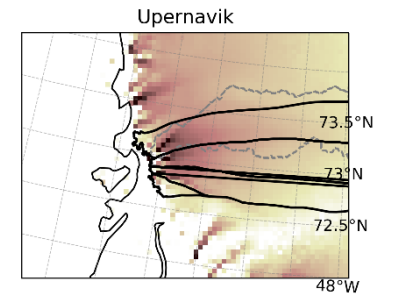
Basal Melt on a Basin Scale



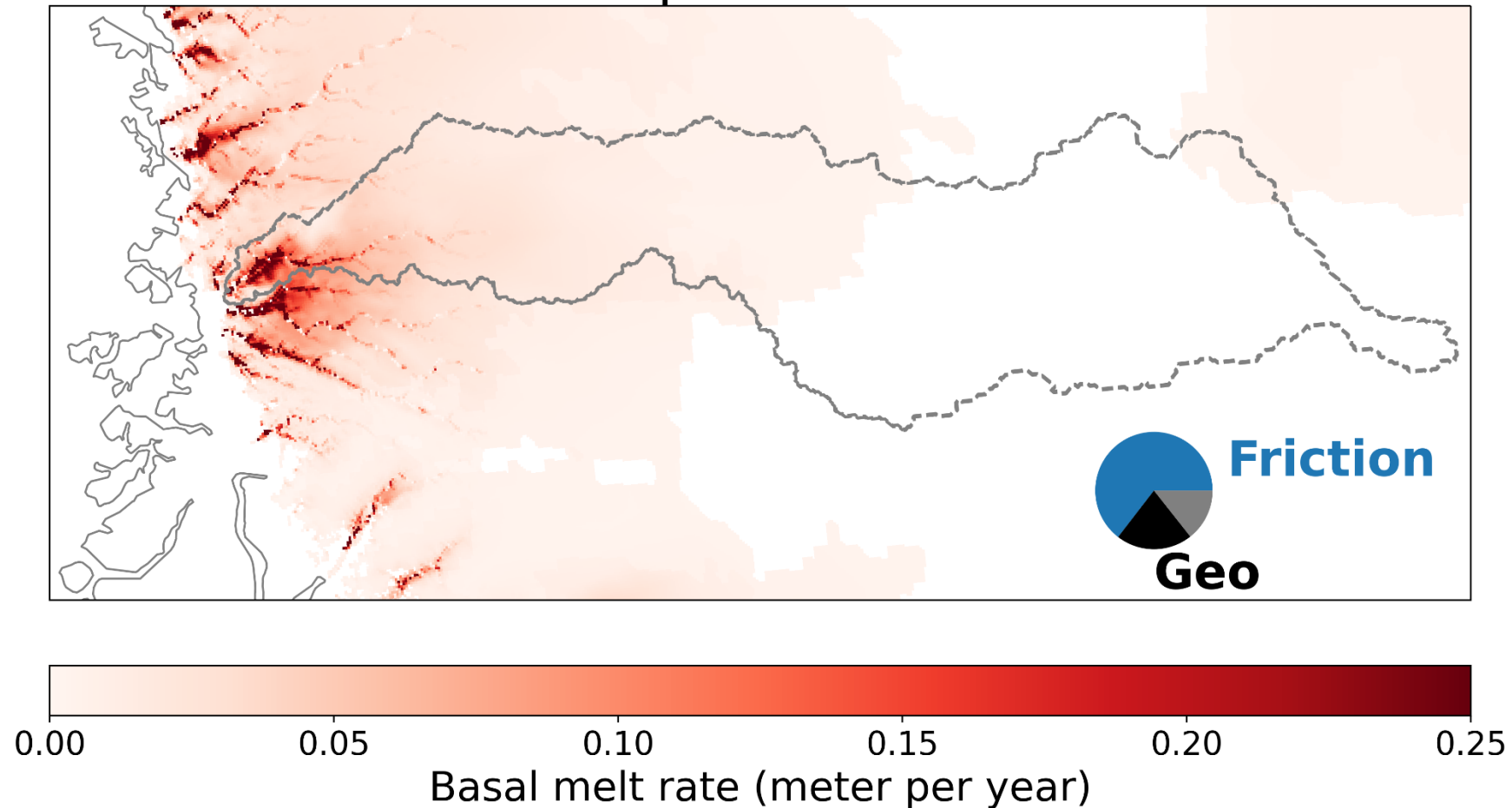
Velocities: Solgaard et al., 2021, in review, ESSD
 Preprint: [DOI: 10.5194/essd-2021-46](https://doi.org/10.5194/essd-2021-46), data:

Upernavik

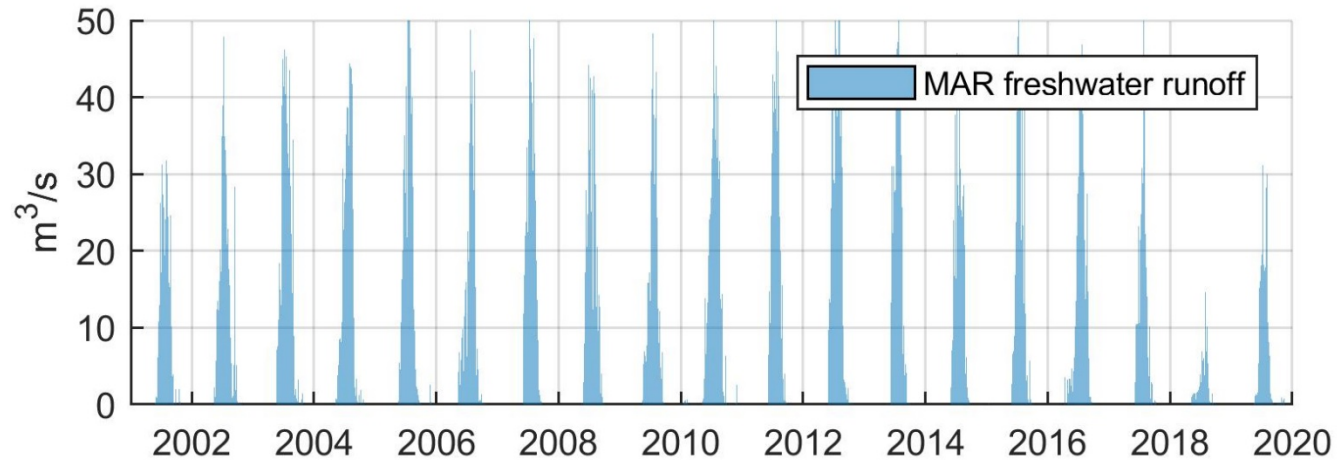
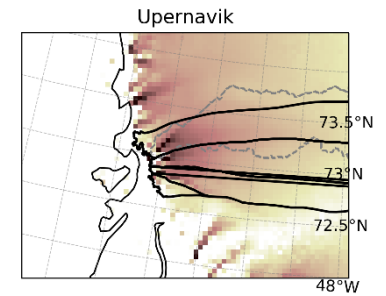
Upernavik



65% of basal melt derives from friction heat.

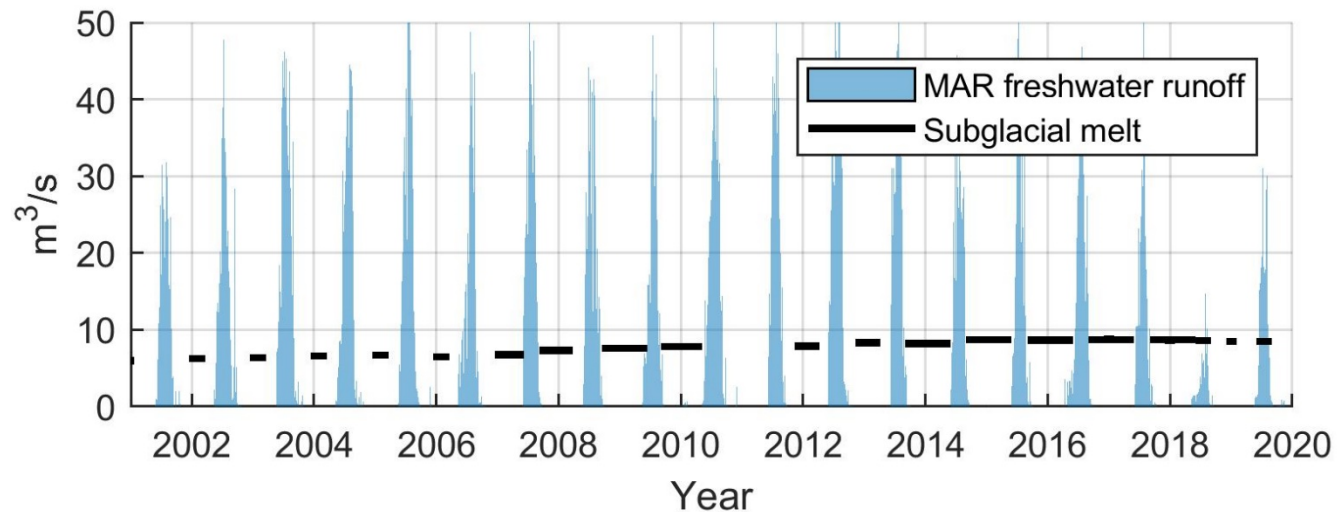


Upernavik



Surface freshwater discharge from regional climate model MAR (Fettweis et al., 2017). See Mankoff et al., 2020, DOI: [10.5194/essd-12-2811-2020](https://doi.org/10.5194/essd-12-2811-2020).

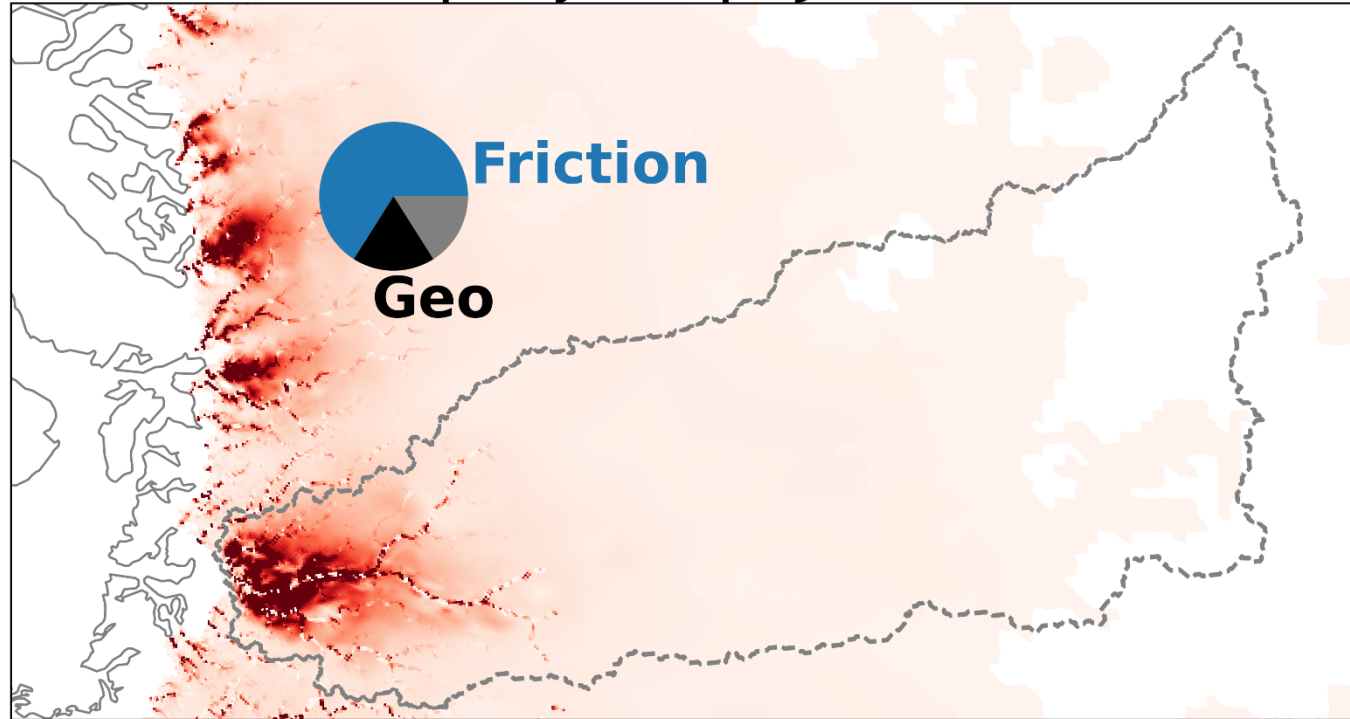
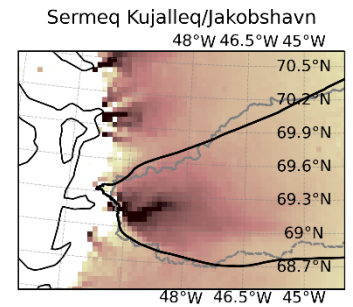
Summer peaks of approx. $50\text{m}^3/\text{s}$



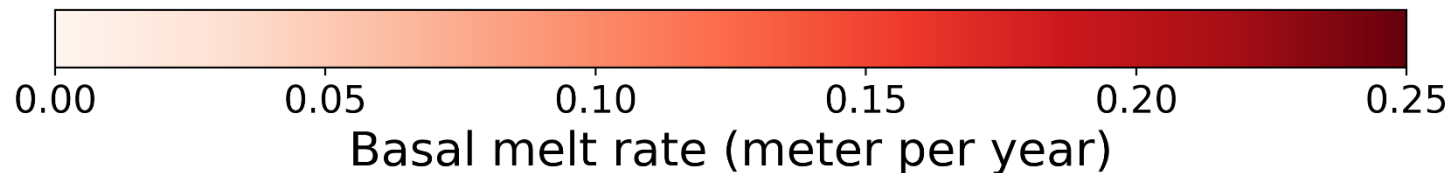
Subglacial melt is less than $10\text{m}^3/\text{s}$ but in years of low melt (2019) the subglacial melt approaches the same value as the surface melt.

Sermeq Kujalleq / Jakobshavn Isbræ

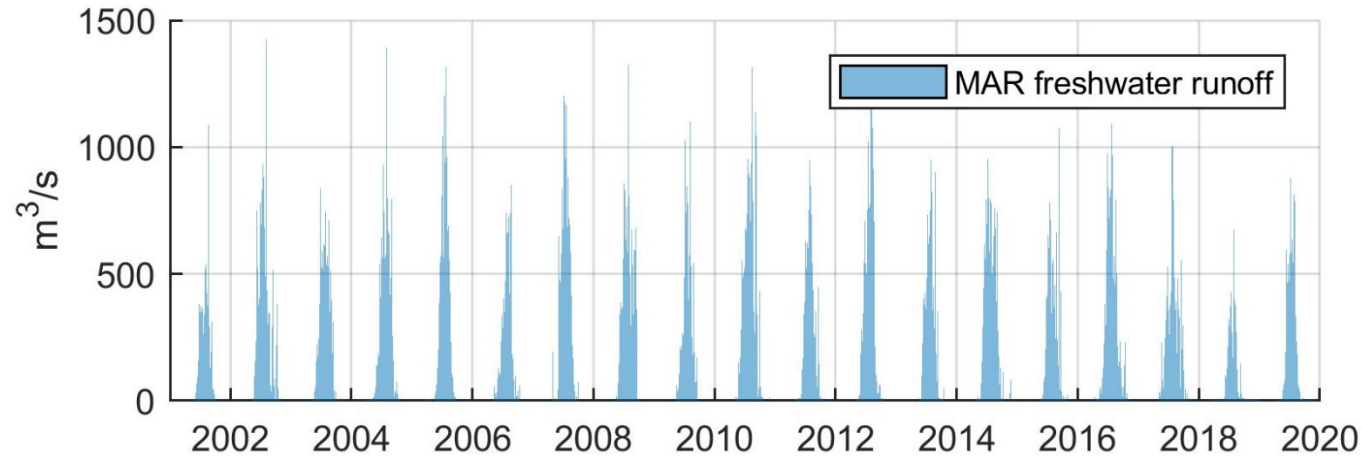
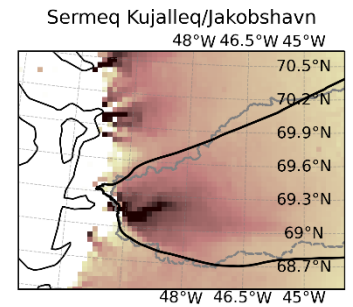
Sermeq Kujalleq / Jakobshavn



66% of basal melt derives from friction heat.

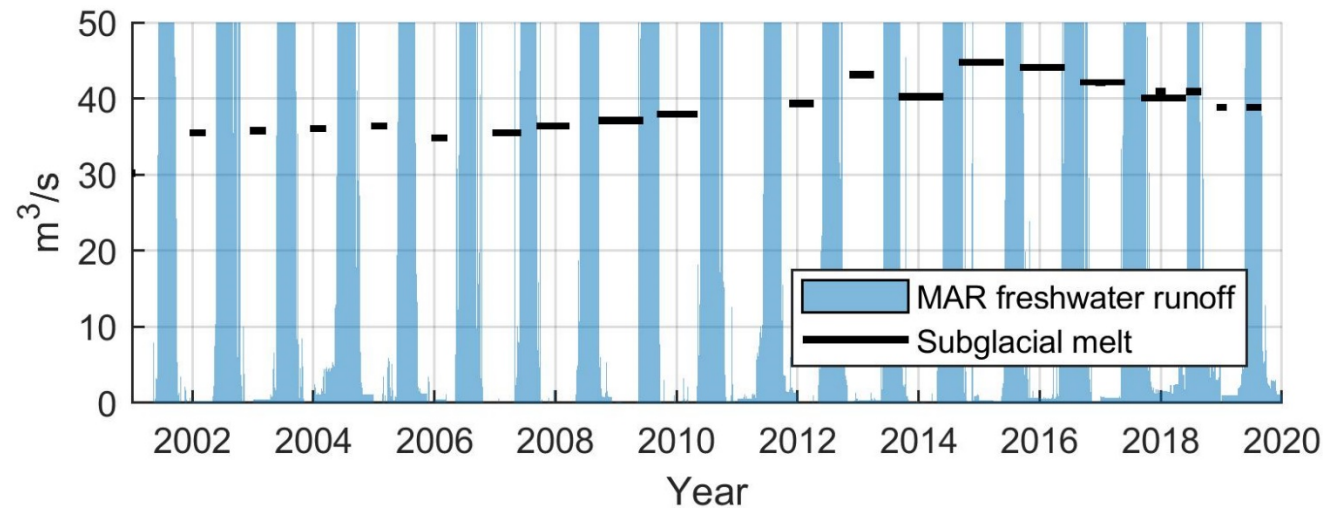


Sermeq Kujalleq / Jakobshavn Isbræ



Surface freshwater discharge from regional climate model MAR (Fettweis et al., 2017). See Mankoff et al., 2020, DOI: 10.5194/essd-12-2811-2020.

Summer peaks > 1000 m^3/s .



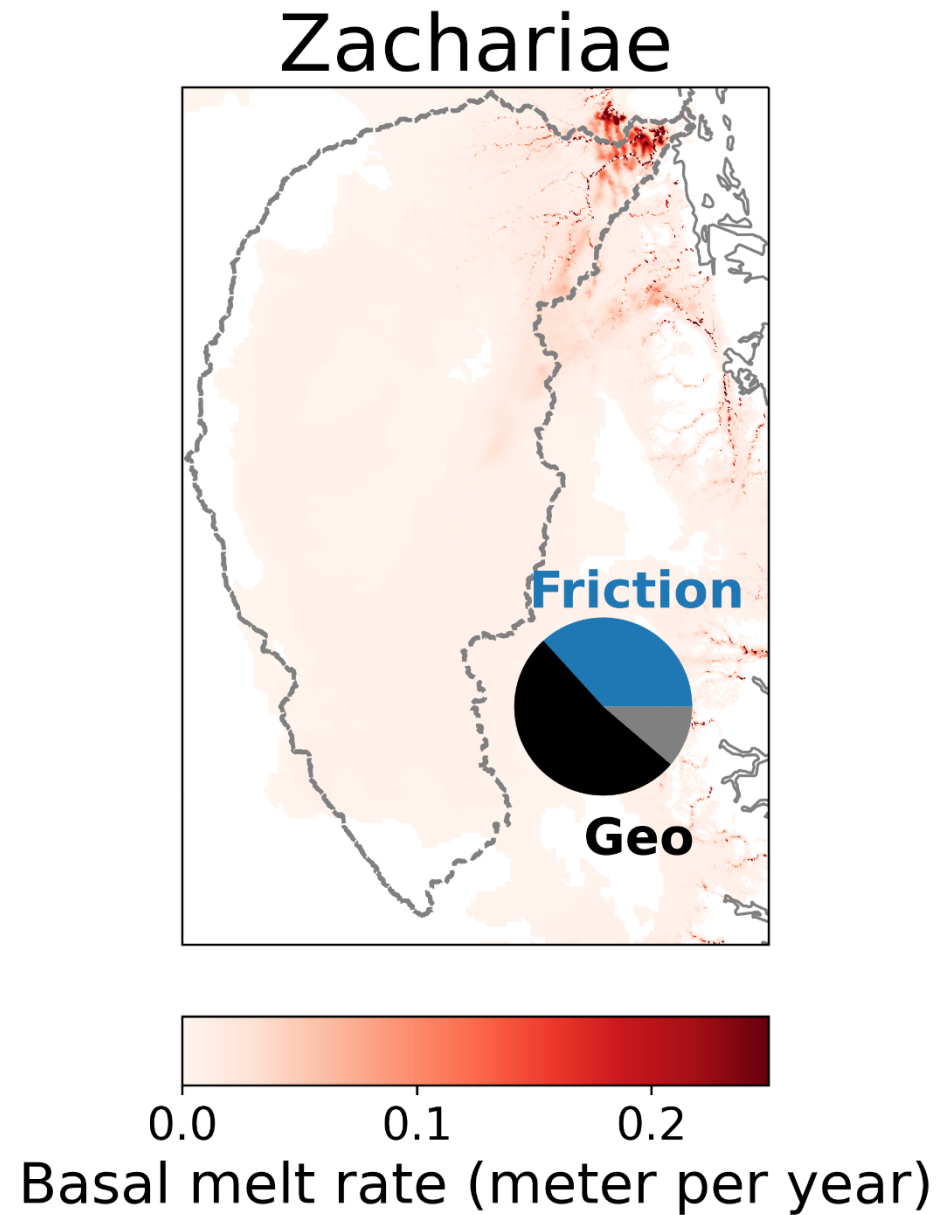
Subglacial discharge is orders of magnitude smaller, however, during the winter it exceeds surface melt water.

Basal melt is of the order of 35 – 45 m^3/s .

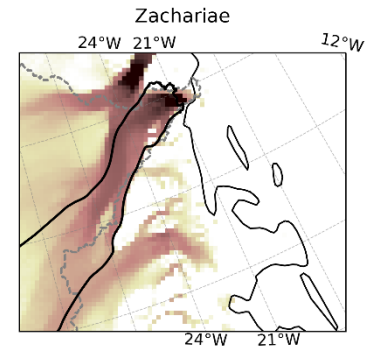
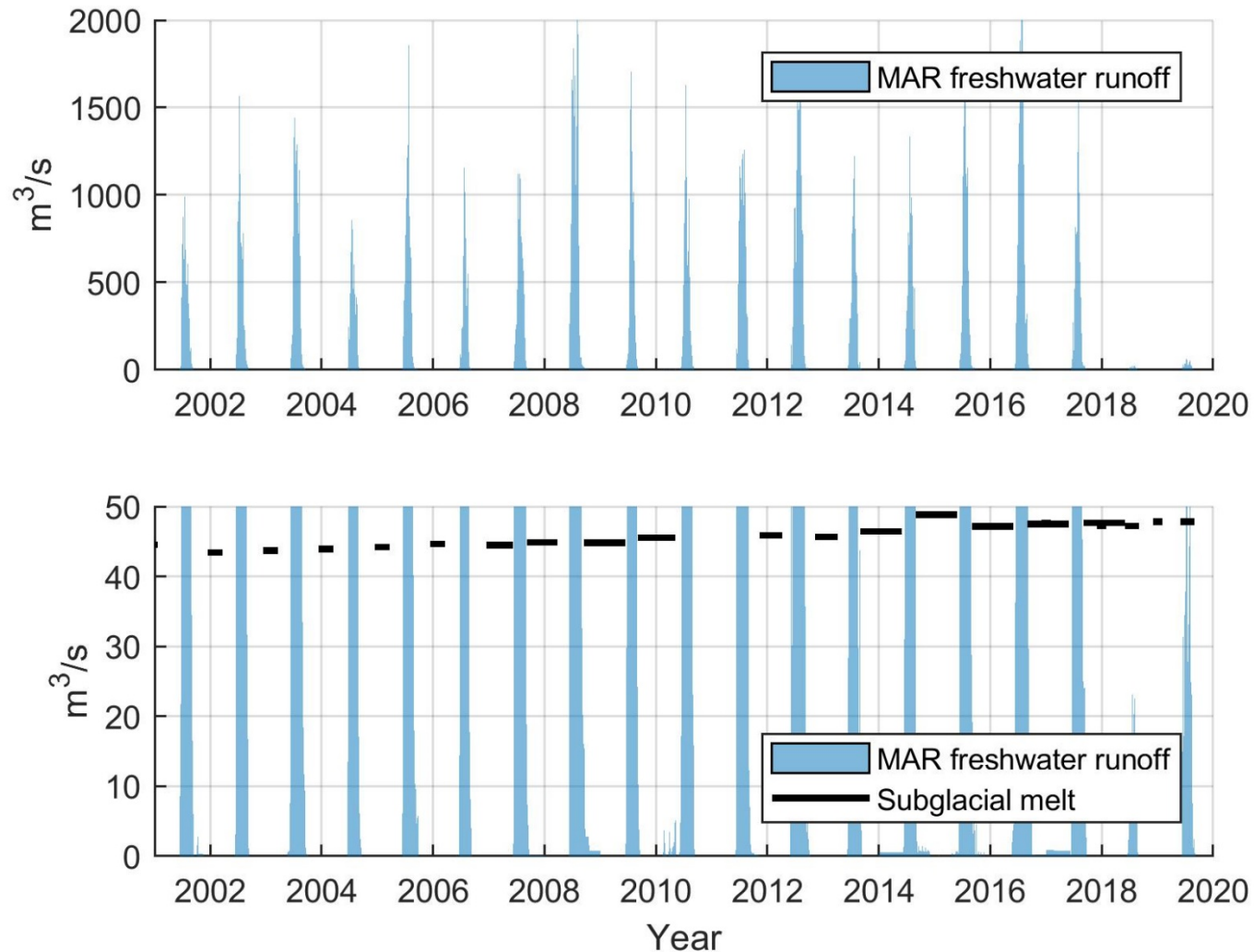
Zachariae Isstrøm

52% of basal melt derives from geothermal flux while frictional heat makes up 37%.

This is in spite of the presence of the North East Greenland Ice Stream where fast ice-flow velocities extend far inland.



Zachariae Isstrøm



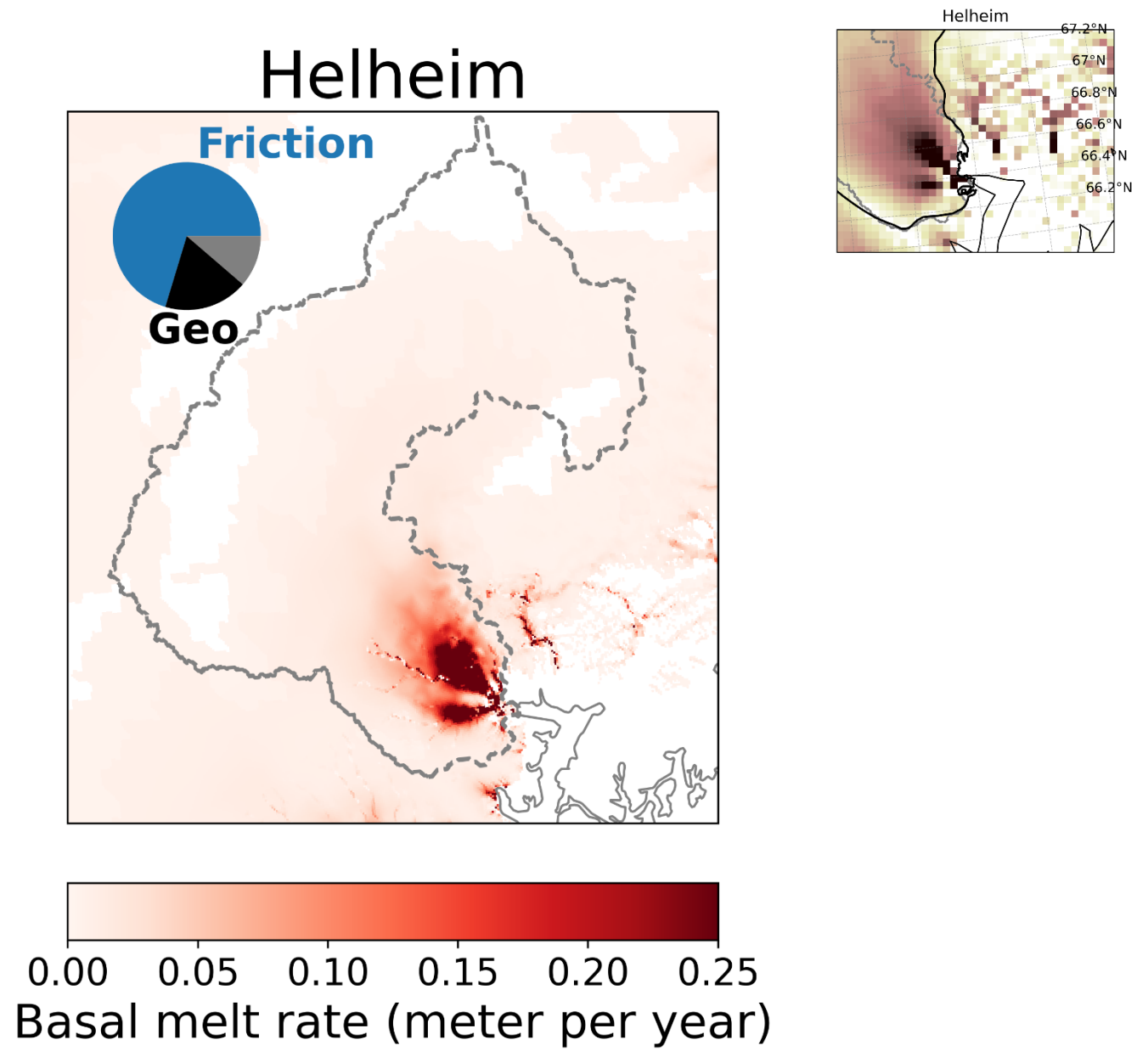
Surface freshwater discharge from regional climate model MAR (Fettweis et al., 2017). See Mankoff et al., 2020, DOI: [10.5194/essd-12-2811-2020](https://doi.org/10.5194/essd-12-2811-2020).

Summer melt reaches $2000\text{m}^3/\text{s}$ in some years

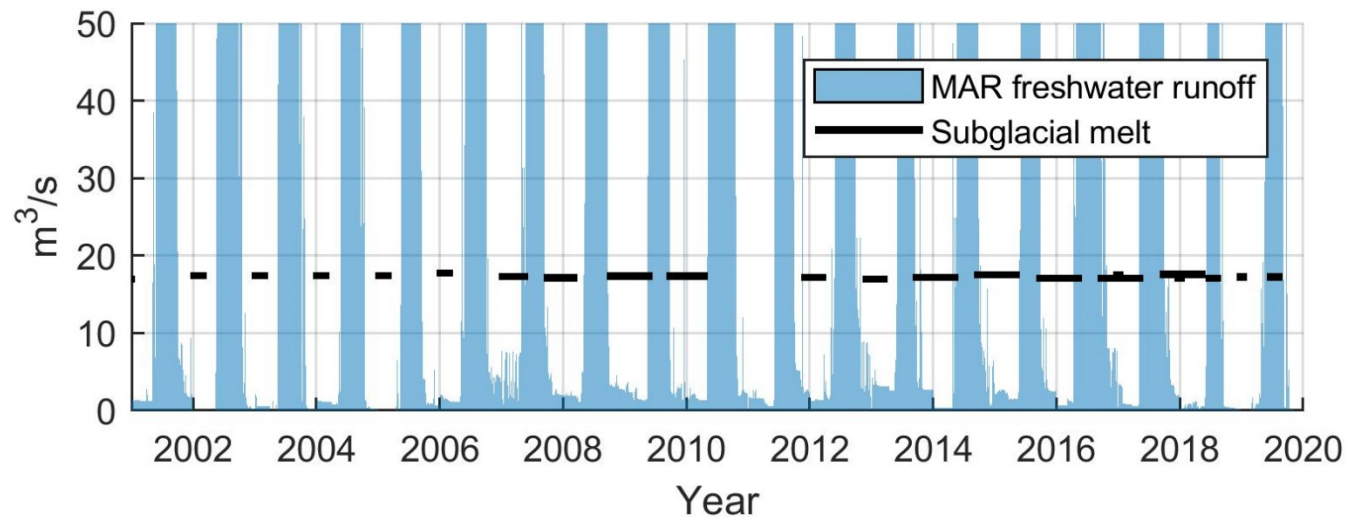
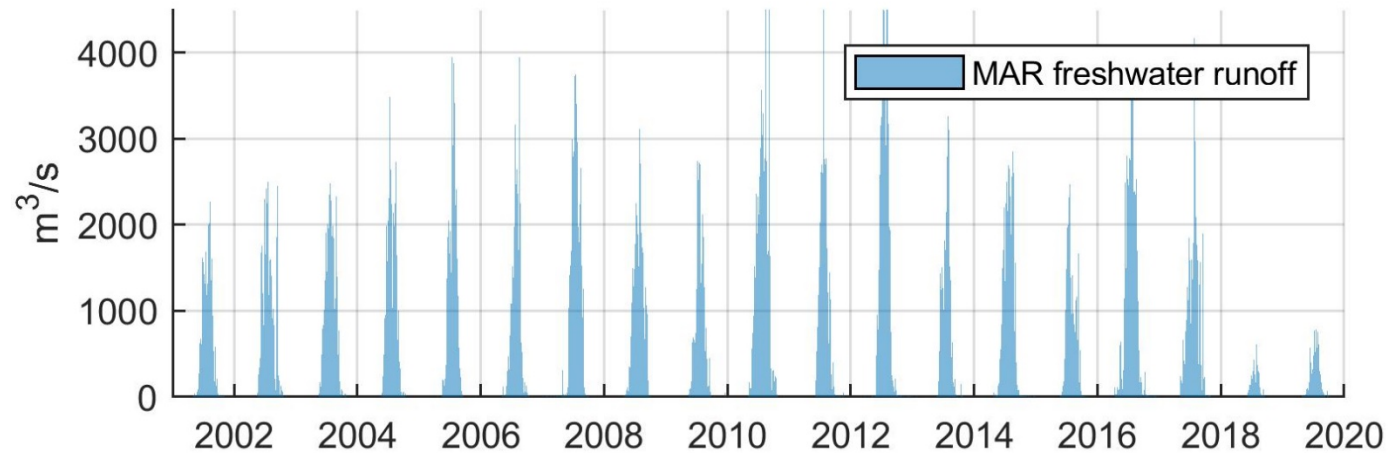
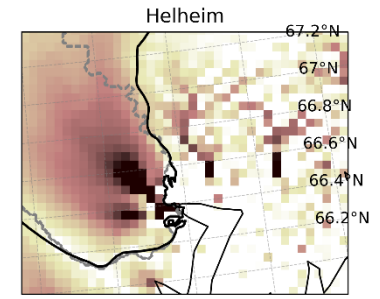
Subglacial discharge is orders of magnitude smaller at $50\text{m}^3/\text{s}$, however, during the winter it exceeds surface melt water.

Helheim Gletsjer

70% of the basal melt is caused by friction heating.



Helheim Gletsjer



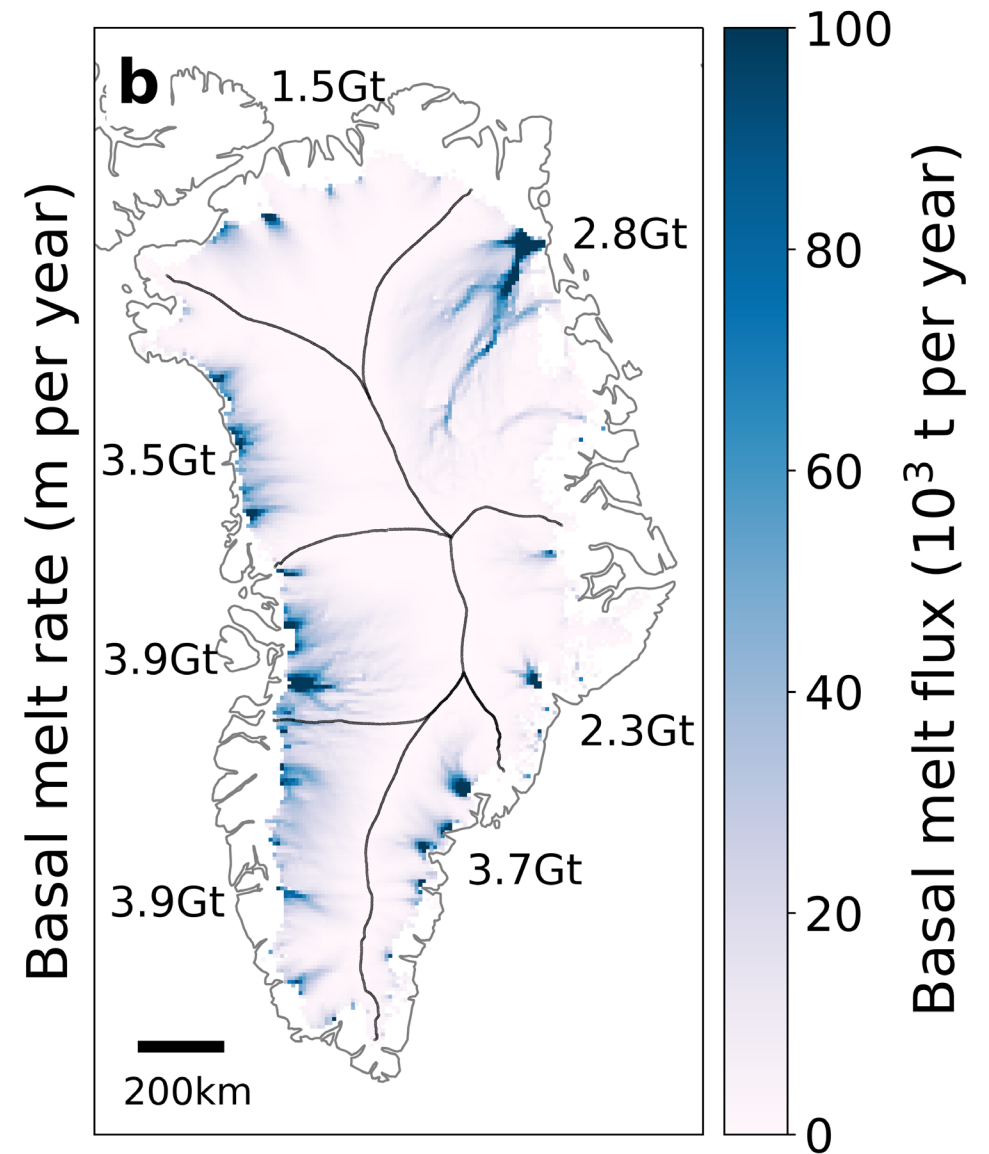
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See Mankoff et al., 2020, DOI:
[10.5194/essd-12-2811-2020](https://doi.org/10.5194/essd-12-2811-2020).

Summer melt reaches almost $4000\text{m}^3/\text{s}$ in some years

Subglacial discharge never exceeds $20\text{m}^3/\text{s}$, however, during the winter it exceeds surface melt water.

Summary

- The basal melt is a non-negligible part of the Greenland mass budget.
- Surface meltwater volumes exceed basal melt volumes for all investigated glaciers during the summer.
- During winter months, basal melt exceeds surface meltwater volumes.
- Evidence of a continuous (if small) supply of freshwater to the fjords.
- The basal melt volumes may impact glacier dynamics and fjord circulation.



Uncertainties

Total GF uncertainty could be upwards of 50% in some regions.

Multiple unknowns

1. Geothermal flux

- Not well constrained
- Melt depends on basal condition (frozen/thawed)

2. Friction melt estimates depend on

- Stress approximation
- Ice temperatures

Uncertainty between 30% and 60% depending on region.

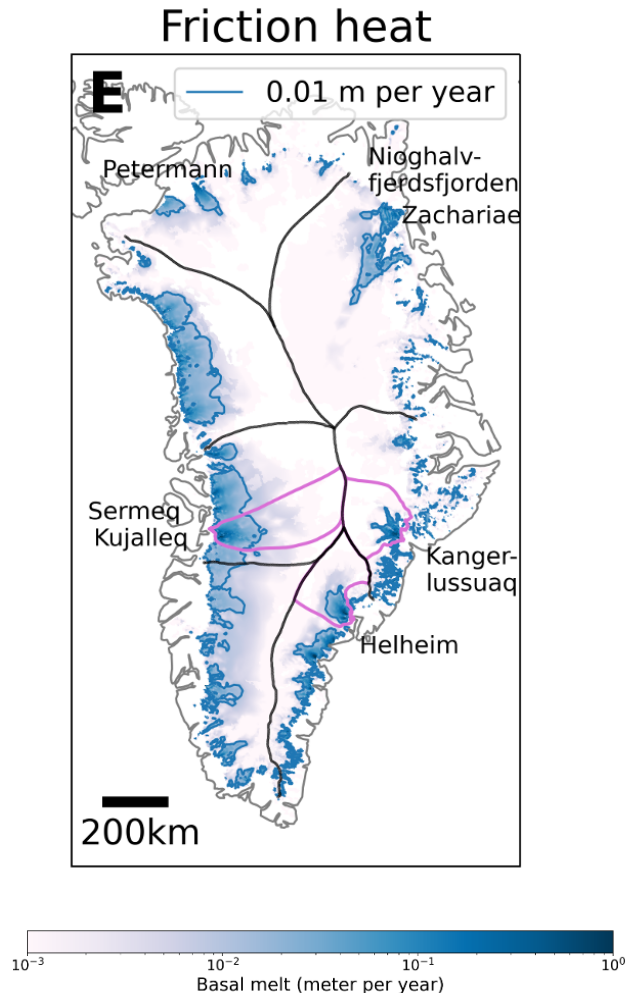
Approximately 25% uncertainty.

3. We assume instantaneous drainage of surface meltwater but englacial storage time-scales are unknown (and likely highly variable).

Late release of surface meltwater may mix with basal melt.



Methods: Friction Heat



Friction heat is derived from two sources:

- baseline value (red/white melt maps): Elmer/Ice
- Time-varying (comparison w. surface melt): Shallow ice approximation (SIA)

Equations for the SIA:

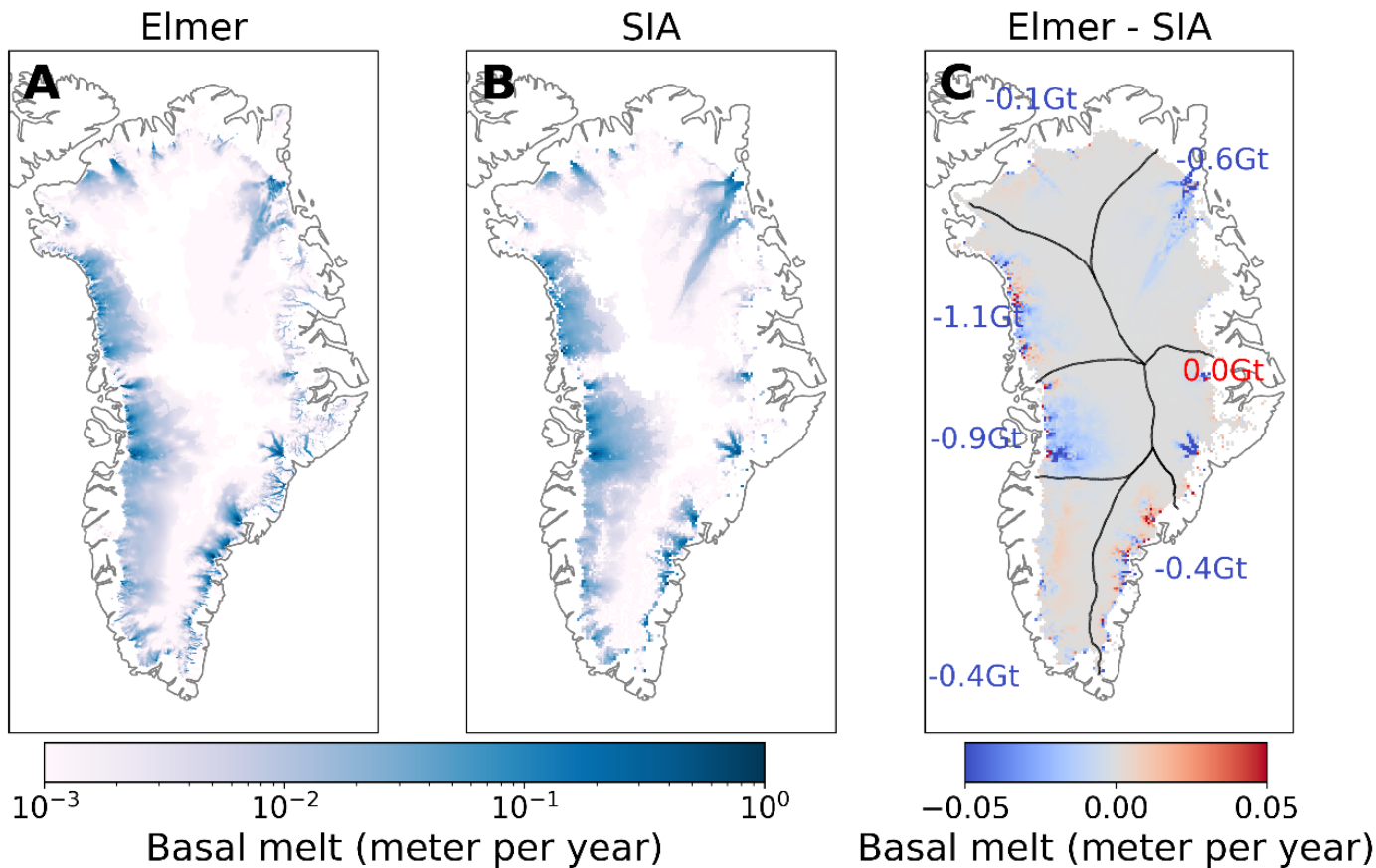
$$u_{s,def} = \frac{2A(T)}{n+1} \tau_b^n H ,$$

$$u_b = u_o - u_{s,def}$$

$$\dot{b}_m = \frac{u_b \tau_b}{\rho_i L}$$

Where b_m is basal melt, and u denotes surface velocities (deformational, observed and basal sliding). Driving stress relates directly to basal velocity (Weertman-approximation).

Methods: Friction Heat

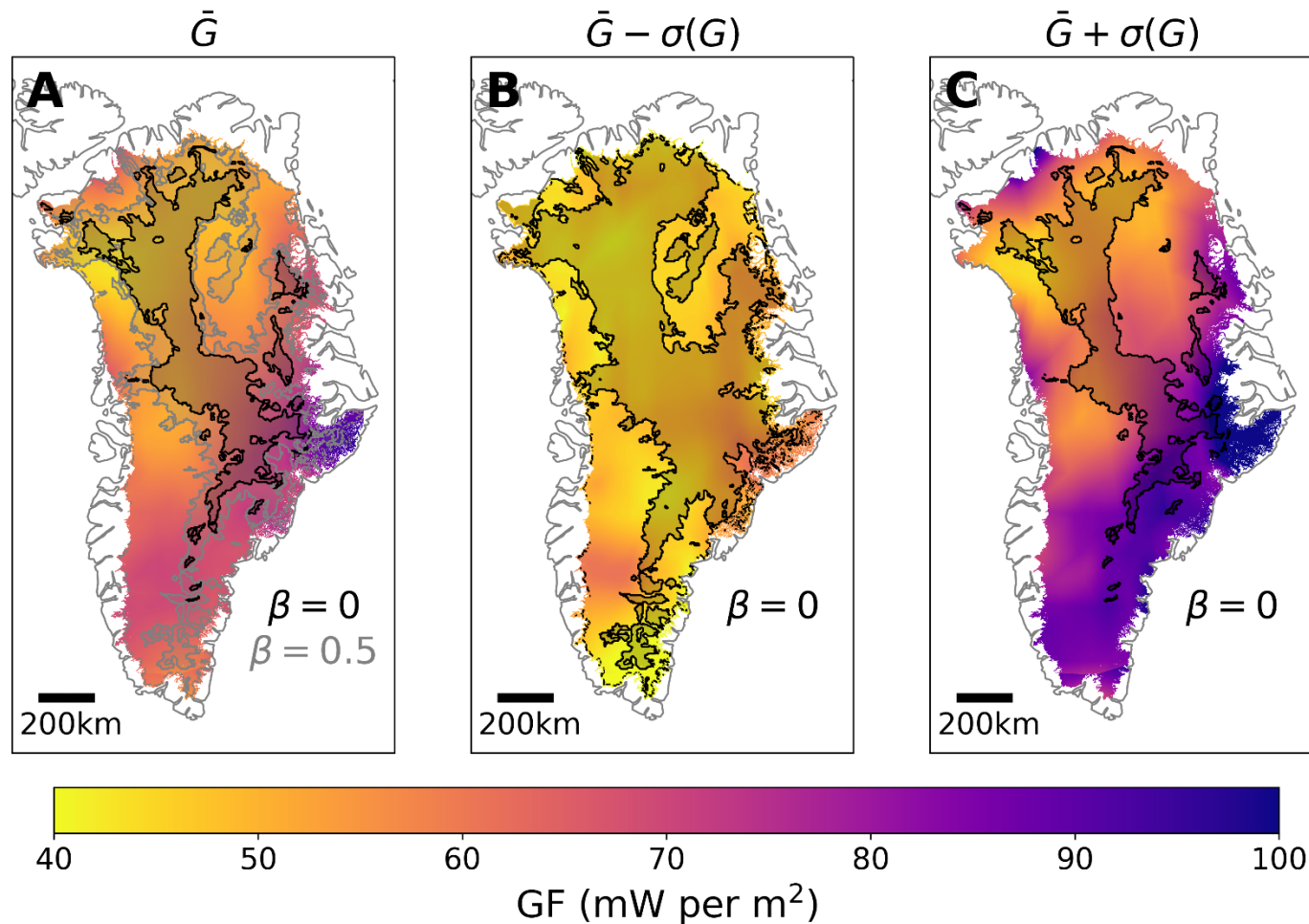


SIA introduces a lot of uncertainties relating to internal ice temperatures, resolution and stress regimes.

The SIA leads to an overestimation of basal melt rates of 31 % compared to Elmer.

Importantly, the uncertainty on the change in friction heat is a lot smaller because the individual uncertainties are (more or less) constant from year to year.

Methods: Geothermal Flux



We construct an average geothermal flux map ($\hat{G}$) using data published in Fox Maule et al. (2009), Shapiro and Ritzwoller (2004) and Martos et al. (2018).

We mask the result with a best estimate of basal conditions (β) from MacGregor et al. (2015).

We explore the range of values by constructing a “cold” and a “warm” state representing lower and upper boundary, respectively.

Methods: Geothermal Flux

This allows us to quantify the uncertainty on a sector-by-sector basis.

Sector	Geothermal (Gt per year)
Central east (CE)	0.5 +0.5/-0.3
Central west (CW)	0.7 +0.3/-0.2
Northeast (NE)	1.3 +0.6/-0.5
North (NO)	0.4 +0.3/-0.3
Northwest (NW)	0.6 +0.2/-0.2
Southeast (SE)	0.7 +0.5/-0.3
Southwest (SW)	1.2 +0.4/-0.4
Total	5.3 +2.8/ -2.2

