PROMICE

Programme for Monitoring of the Greenland Ice Sheet

# Greenland ice sheet solid ice discharge

**Authors:** Ken Mankoff and Robert S. Fausto

The Programme for Monitoring of the Greenland Ice Sheet (PROMICE) is now capable of estimating the solid ice discharge for the Greenland ice sheet on a routine basis (Mankoff et al. 2019). We combine ice thickness estimates, with updated flux gates, and ice velocity products based on Sentinel-1 satellite data (Solgaard et al. 2018), yielding a PROMICE solid ice discharge product integrated over Greenland with high temporal resolution.

The discharge gates are generated using only surface speed and an ice mask and our algorithm only generates flux gates for fast-flowing ice (greater than 100 m yr-1) close to the ice sheet terminus determined by the baseline-period data. We apply a 2D inclusive mask to the baseline data for all ice flowing faster than 100 m yr-1. We then select the mask edge where it is near the BedMachine v3 (Morlighem et al., 2017) (ice mask not including ice shelves), which effectively provides grounding line termini. We buffer the termini 5000 m in all directions creating ovals around the termini and once again down select to fast-flowing ice pixels. This procedure results in gates 5000 m upstream from the baseline terminus that bisect the baseline fast flowing ice. We manually mask some land- or lake-terminating glaciers initially selected by the algorithm due to fast flow and mask issues. For ice thickness estimates, we use surface elevation from the Greenland ice sheet mapping project (GIMP, Howat et al., (2017)), adjusted through time with surface elevation change from Khan et al. (2016) and bed elevations from BedMachine replaced by Millan et al. (2018) where available. Ice sector and region delineation is from Mouginot and Rignot (2019) (see Fig. 1).

The main PROMICE product is thus a velocity mosaic with spatial resolution of 500x500 m for the entire Greenland margin. The products span 24 days (two cycles) with a frequency of either 6 or 12 days based on SAR data from Sentinel-1A and -1B. Due to the higher frequency of the maps compared to the temporal coverage, some pairs in one map are also included in the following map. Figure 2 provides examples of the ice velocity product for each month in 2017.

Our ice discharge dataset (Fig. 2) reports a total discharge of 438 ± 43 Gt in 1986, has a minimum of 421 ± 42 Gt in 1995, increases to 452 ± 45 in 2000, further to 504 ± 49 Gt yr-1 in 2005, after which annual discharge remains approximately steady at 484 to 503 ± ~50 Gt yr-1 during the 2005 to 2019 period.

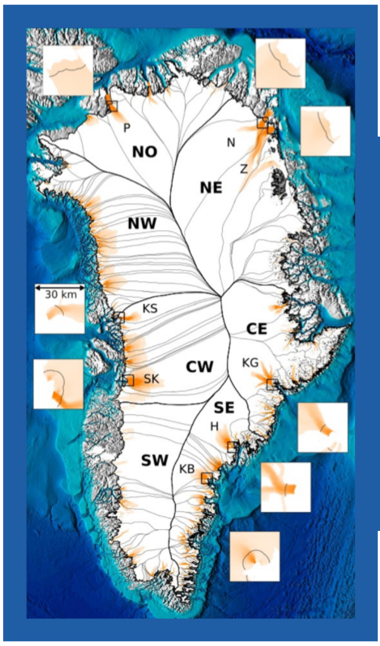


**Figure 1:** Overview showing fast-flowing ice (orange, greater than 100 m yr-1) and the gates for the top eight discharging glaciers. Gates are shown as black lines in inset images. Each inset is 30 x 30 km and all have the same color scaling, but different than the main map. Insets pair with nearest label and box. On the main map, regions from Mouginot and Rignot (2019) are designated by thicker black lines and large bold labels. Sectors (same source) are delineated with thinner gray lines, and the top discharging glaciers are labeled with smaller font. H = Helheim Gletsjer, KB = (Køge Bugt), KG = Kangerlussuaq Gletsjer, KS = Kangilliup Sermia (Rink Isbræ), N = (Nioghalvfjerdsbræ), P = Petermann Gletsjer, SK = Sermeq Kujalleq (Jakobshavn Isbræ), and Z = Zachariae Isstrøm. Basemap terrain (gray), ocean bathymetry (blues), and ice mask (white) come from BedMachine.

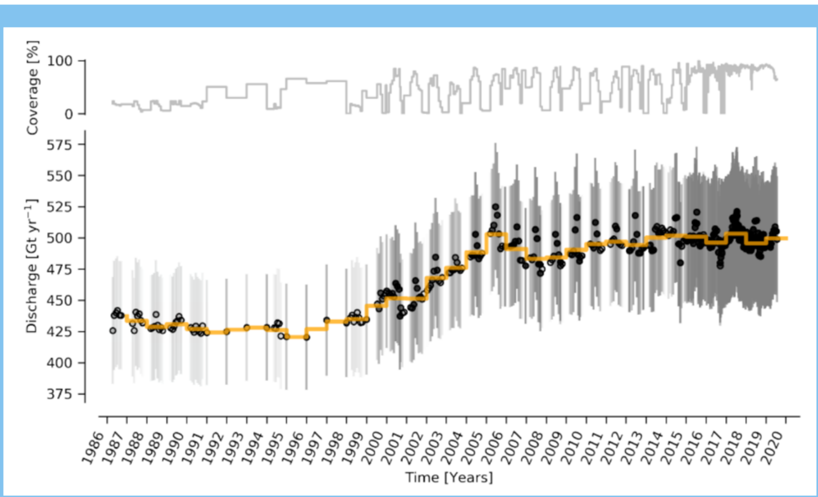


**Figure 2:** Top panel: Coverage is given as a percentage of total discharge observed at any given time. Bottom panel: Time series of ice discharge from the Greenland ice sheet. Dots represent when observations occurred. Orange stepped line is annual average.

At the region scale, the SE glaciers (see Fig. 1 for regions) are responsible for 139 to 167 (± 11 %) Gt yr-1 of discharge (30 to 34 % of ice-sheet wide discharge) over the 1986 to 2019 period. By comparison, the predominantly land-terminating NO, NE and SW together were also responsible for 131 to 168 of discharge (~31 % of ice-sheet wide discharge) during this time (Fig. 3). The discharge from most regions has been approximately steady or declining for the past decade. The NW is the only region exhibiting a persistent increase in discharge – From ~89 to 113 Gt yr-1 (21 % increase) over the 1998 through 2018 period (+ ~1 Gt yr-1 or + ~1 % yr-1). This persistent increase in NW discharge offsets declining discharge from other regions. The largest contributing region, SE, contributed a high of 166 ± 19 Gt in 2005, but dropped to a local minimum of 146 ± 18 Gt in 2016. However, it has increased its contributions in the last couple of years and ended on 157 ± 18 Gt in 2019 (Fig. 3).

Focusing on the top eight contributors (mean of last year) at the individual sector or glacier scale (Fig. 3), Sermeq Kujalleq (Jakobshavn Isbræ) has slowed down from an annual average high of ~52 Gt yr-1 in 2012 to ~45 Gt yr-1 in 2016 and ~38 Gt yr-1 in 2017, likely due to ocean cooling (Khazendar et al., 2019). The 2013 to 2016 slowdown of Sermeq Kujalleq (Fig. 3) is compensated by the many glaciers that make up the NW region (Fig. 2). The large 2017 and 2018 reduction in discharge at Sermeq Kujalleq in region CW is partially offset by a large increase in the 2nd largest contributor, Helheim Gletsjer in region SE (Fig. 3).

PROMICE continues to improve and automate the production chain associated with the generation of the solid ice velocity discharge, so that products can be used on routine basis for e.g. research or educational purposes.

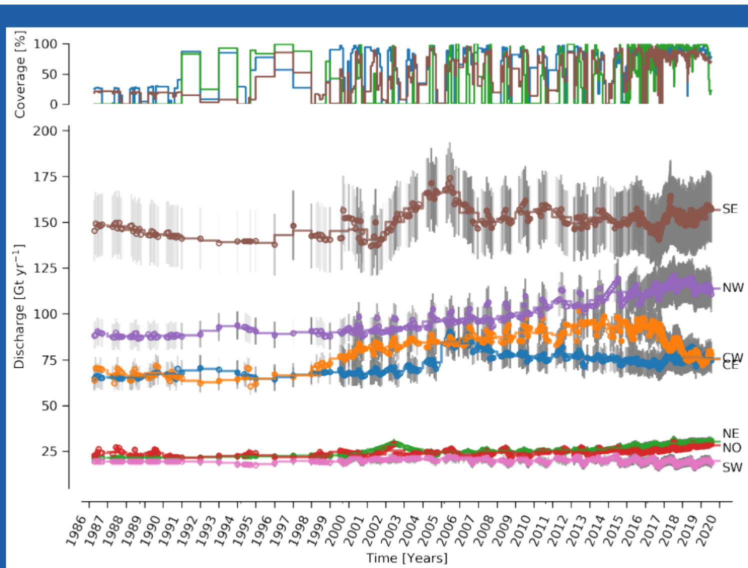


**Figure 3:** Bottom panel: Time series of ice discharge by region. Same graphical properties as Fig. 2. Top panel: The region with highest coverage (CE), lowest coverage (NE), and coverage for the region with highest discharge (SE) are shown. Coverage for other regions not shown to reduce clutter.

# References:

**All PROMICE data is freely available from promice.org.**

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**PROMICE**
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• The purpose of PROMICE is to monitor the mass loss of the Greenland ice sheet, both the melting on the surface and the volume of icebergs discharged into the sea

• PROMICE is headed in Denmark by GEUS in cooperation with DTU Space and Asiaq in Greenland. Furthermore the programme collaborates with the Danish Meteorological Institute and foreign universities and authorities.

• Read more about PROMICE on promice.org, where you can find photos and videos, get direct access to measuring data from the ice sheet and the PROMICE outreach material. On the website you can also subscribe to our newsletter.

• Information can also be found on porlarportal.org a new website where Danish research institutions display the results of their monitoring of the Greenland ice sheet and the sea ice in the Arctic.

**Further Information**

http://www.promice.dk

http://www.undergroundchannel.dk

**Author:**
Ken Mankoff and Robert S. Fausto

**Layout**
Ane Damgaard Asmussen, GEUS.

Geological Survey of Denmark and Greenland
Technical University of Denmark
Asiaq
Ministry of Energy, Utilities and Climate
Danish Energy Agency