Changes in Northwest Greenland Ice Sheet Elevation and Mass

Inès N. Otosaka[1], Andrew Shepherd[1], Andreas Groh[2]
eeino@leeds.ac.uk

[1]Centre for Polar Observation and Modelling, School of Earth and Environment, University of Leeds, Leeds, UK.

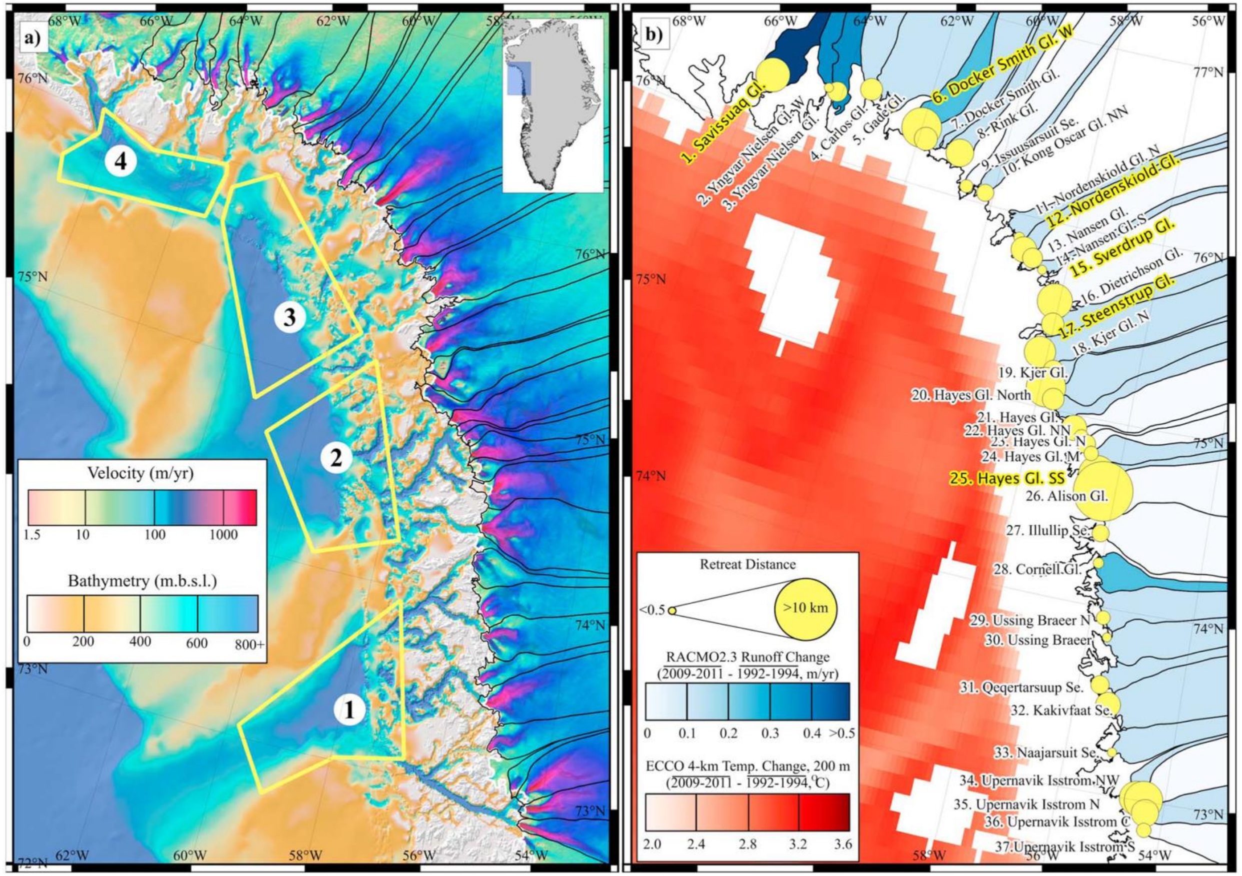
[2]Technische Universität Dresden, Dresden, Germany

Centre for Polar Observation and Modelling
cpom
Natural Environment Research Council
esa
European Space Agency
UNIVERSITY OF LEEDS

The Northwest sector is the largest contributor to Greenland’s ice losses

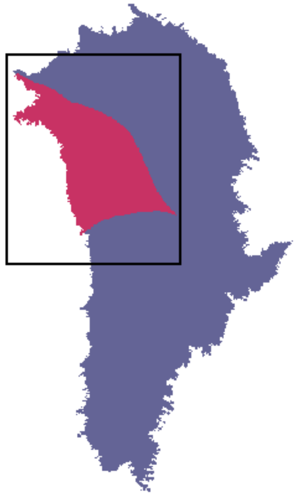
- Greenland has contributed about 20% to the global mean sea level rise since 1993
- About a third of Greenland’s total ice losses come from the Northwest sector

- Northwest Greenland counts a large number of marine-terminating glaciers which have experienced sustained retreat triggered by ocean-induced melting
- The pattern of retreat and thinning is complex and suggests that their response to oceanic forcing is modulated by their bed topography and fjord geometry



Wood et al., 2018

We use a decade of CryoSat-2 data to study ice sheet imbalance in Northwest Greenland between 2010 and 2020



CS2 processing chain

- CryoSat-2 Level 2 data
- Elevation change
- Volume change
- Mass change

External datasets

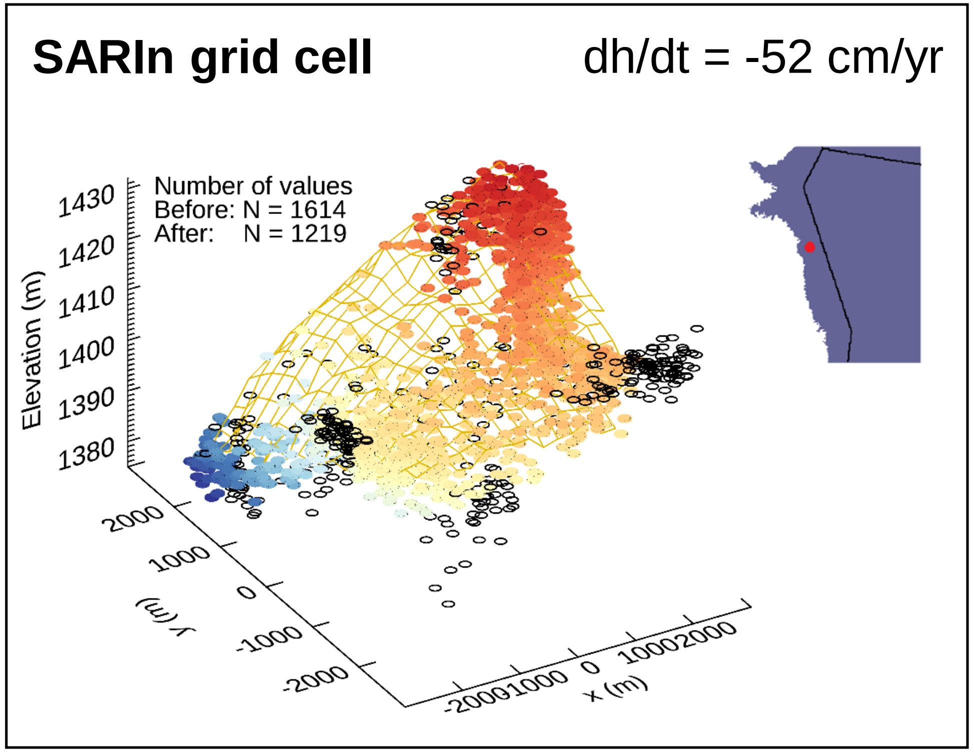
- GIA and elastic uplift corrections
- Firn density

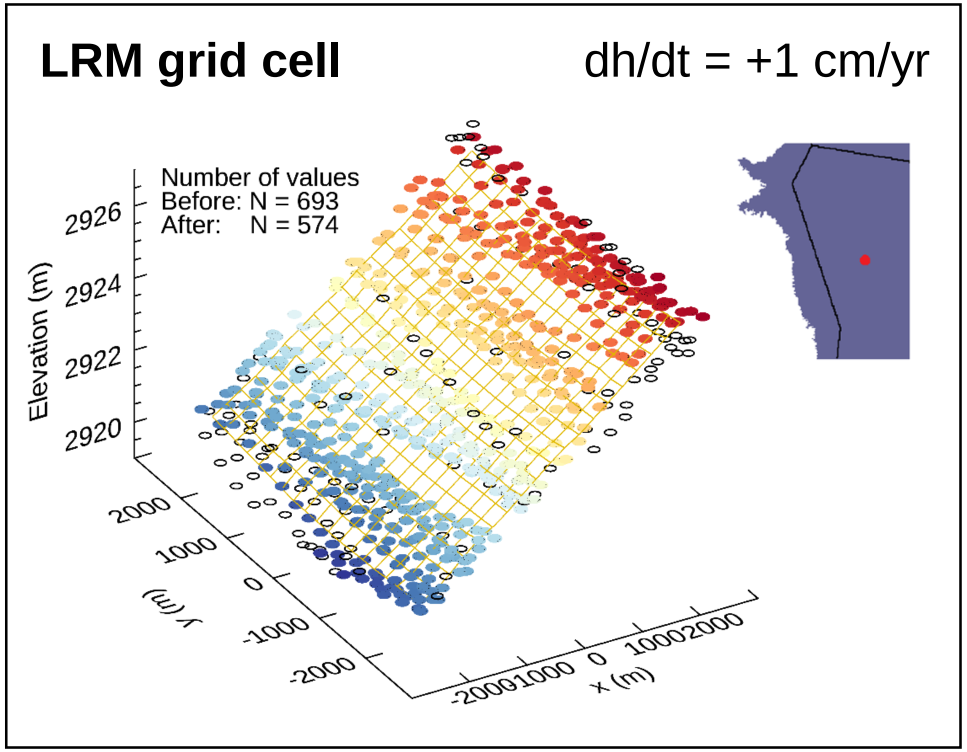
Validation/Comparison datasets

- Airborne laser altimetry
- Gravimetry and mass budget estimates

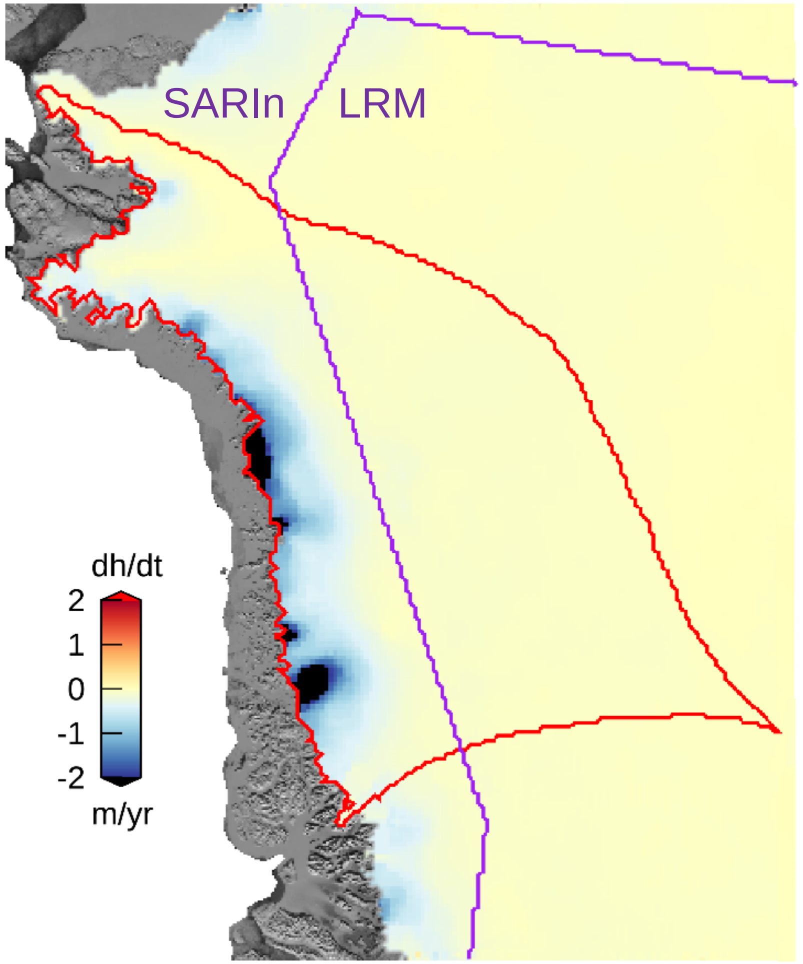
To derive surface elevation change we use a multi-model parameter fit in square grid cells of 2.5 km

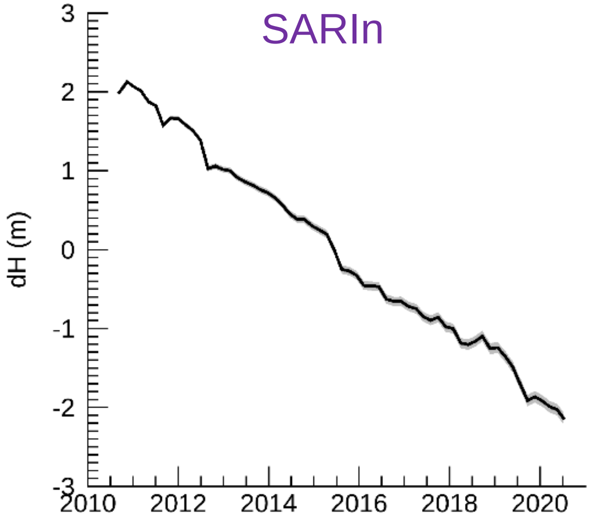
- We use 24.4 million observations from CryoSat-2
- We fit a multi-parameter least-square model fit to observed surface elevation
- We correct for the vertical displacement caused by GIA (-1 mm/yr) and elastic response to present-day ice mass changes (+2.4 mm/yr)

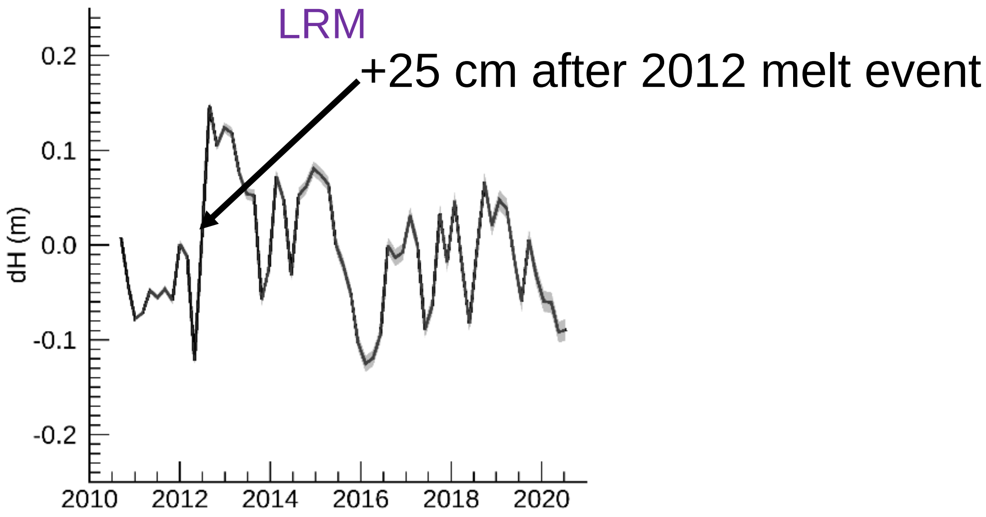




Thinning is localised in the margins of the ice sheets, where the surface is lowering at a rate of 42.7 cm/yr



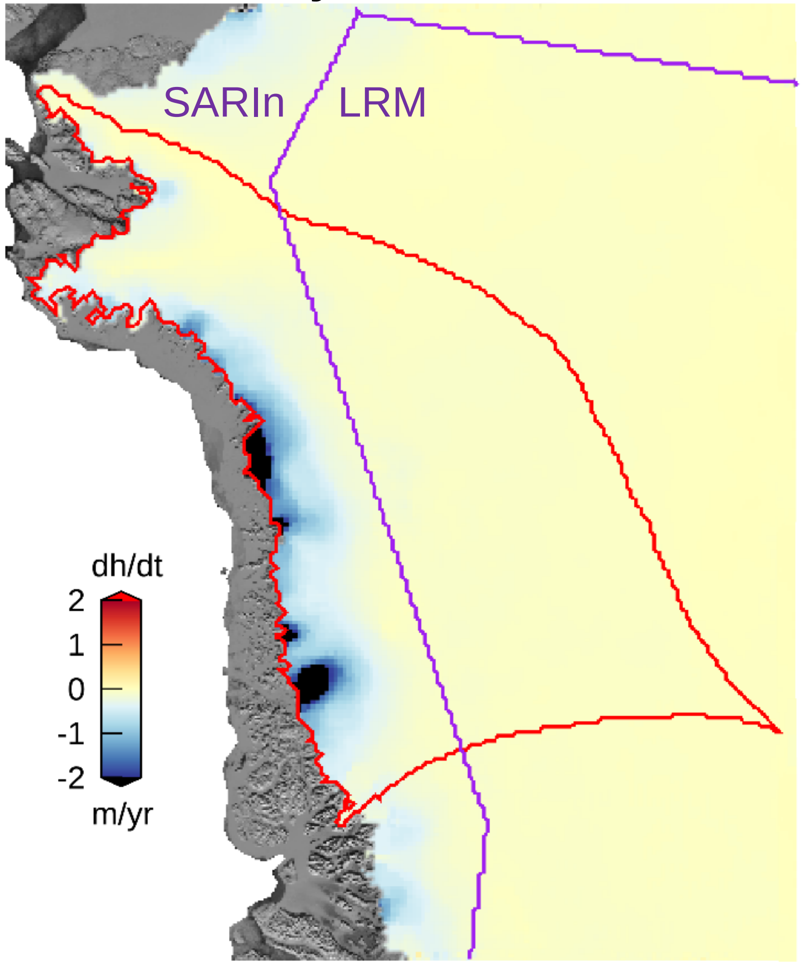




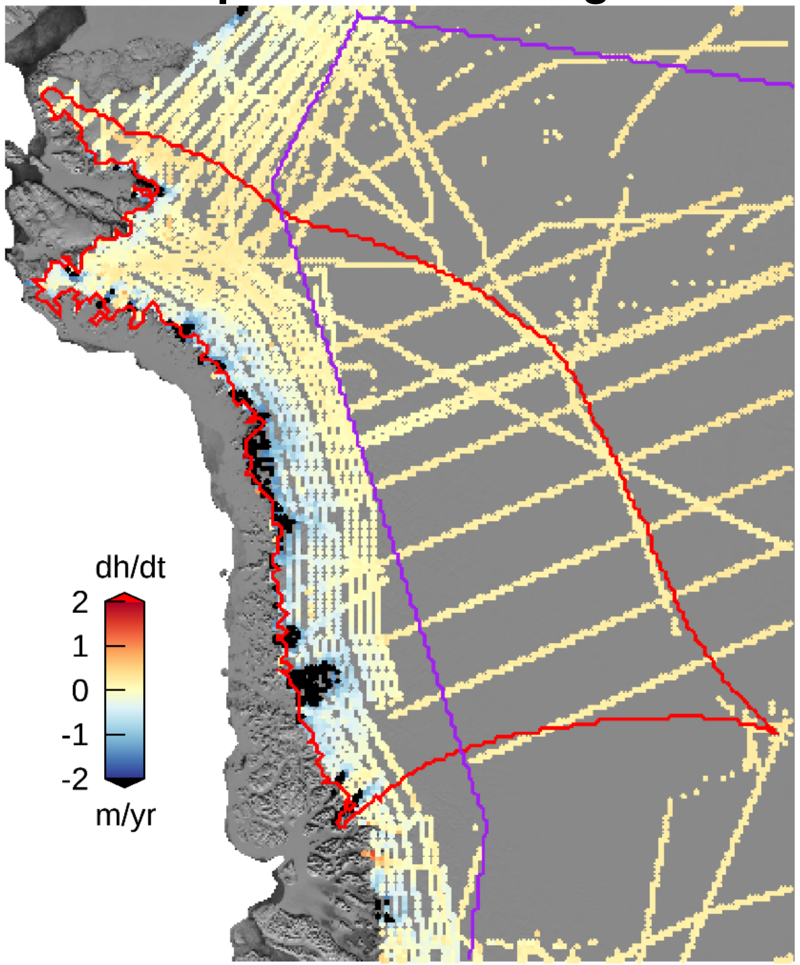
Region	dh/dt (cm/yr)
Northwest sector	-18.7 ± 0.4
SARIn	-42.7 ± 0.9
LRM	-0.3 ± 0.3

We validate the rates of elevation change with data from Operation IceBridge

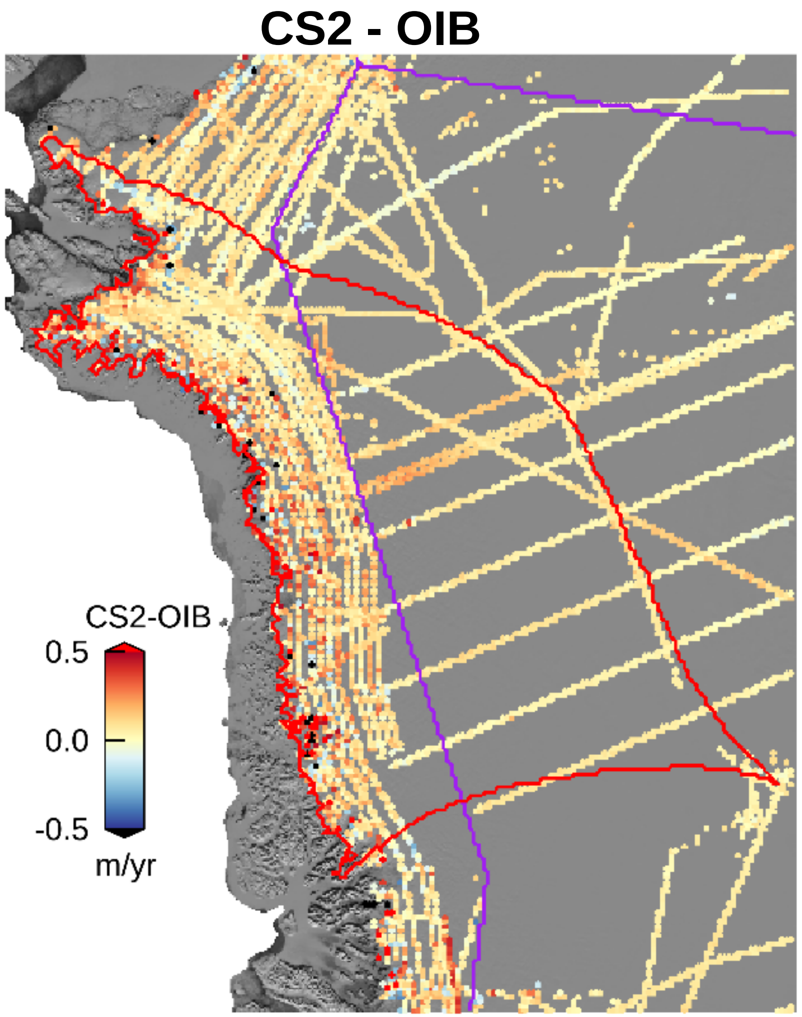
CryoSat-2

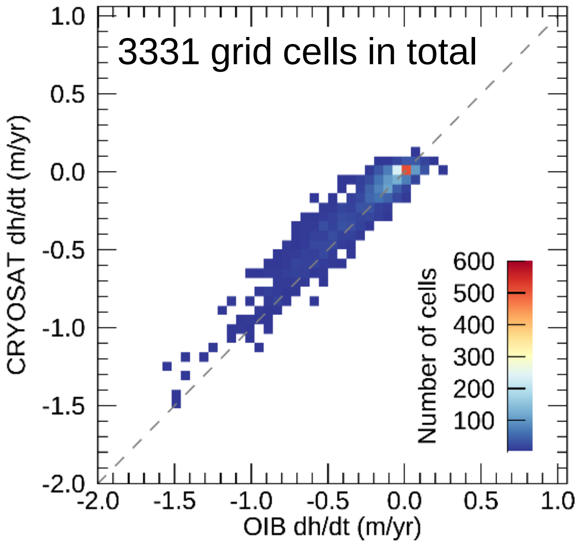


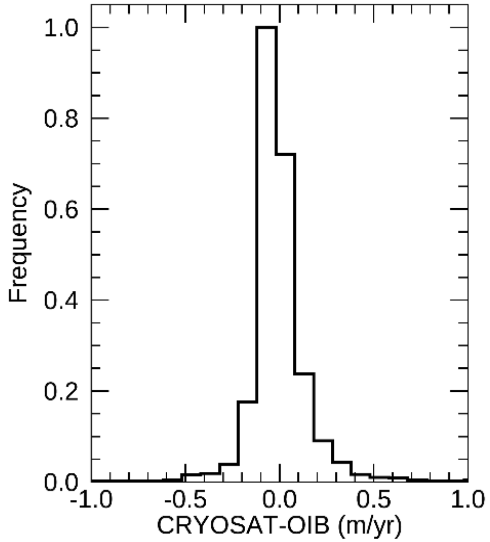
Operation IceBridge



There is an overall good agreement with a mean difference between satellite radar and airborne laser of 6.5 cm/yr





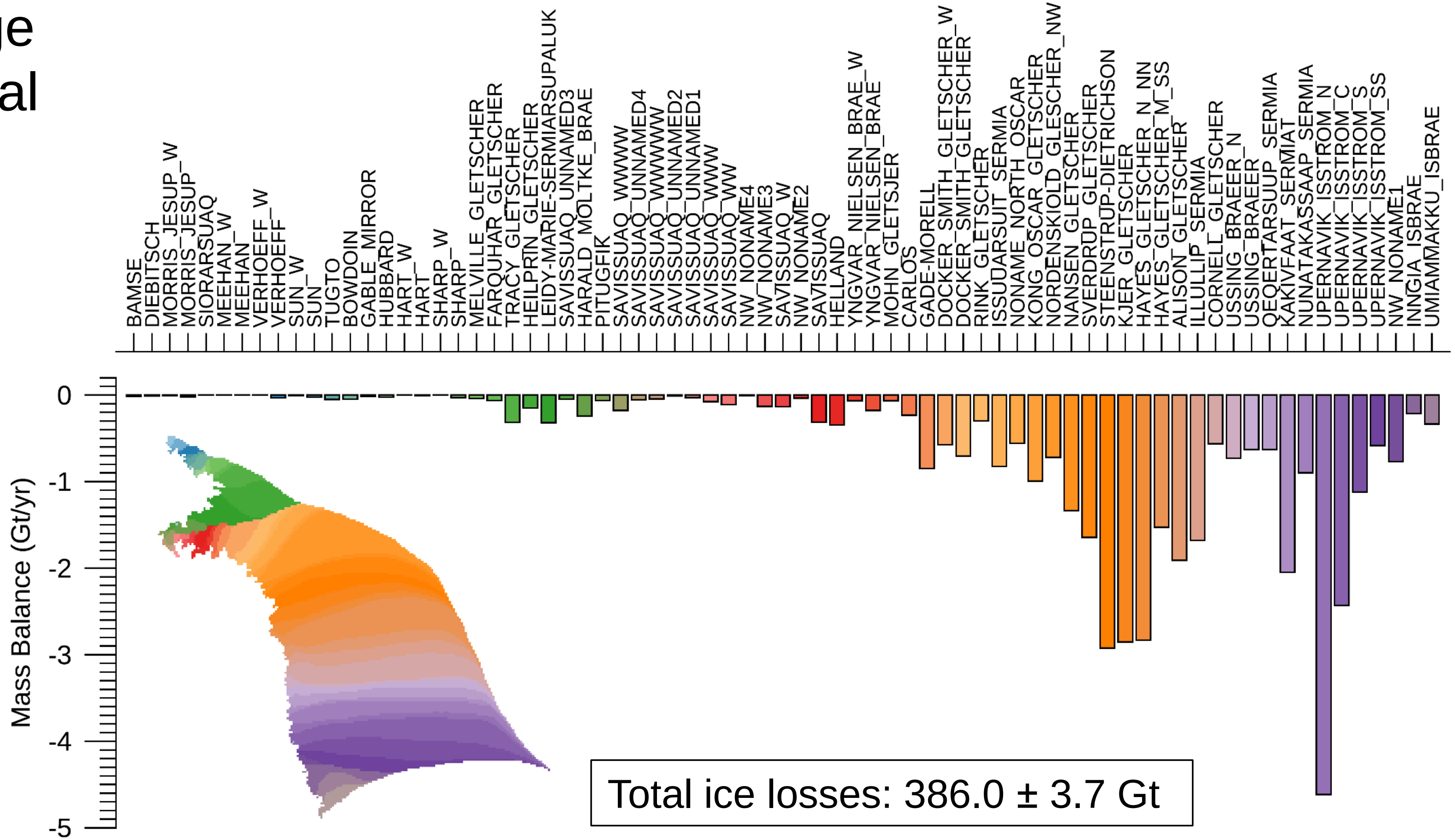


Region	dh/dt difference (cm/yr)
Northwest sector	6.5 ± 0.5
SARIn	7.8 ± 0.7
LRM	3.1 ± 0.2

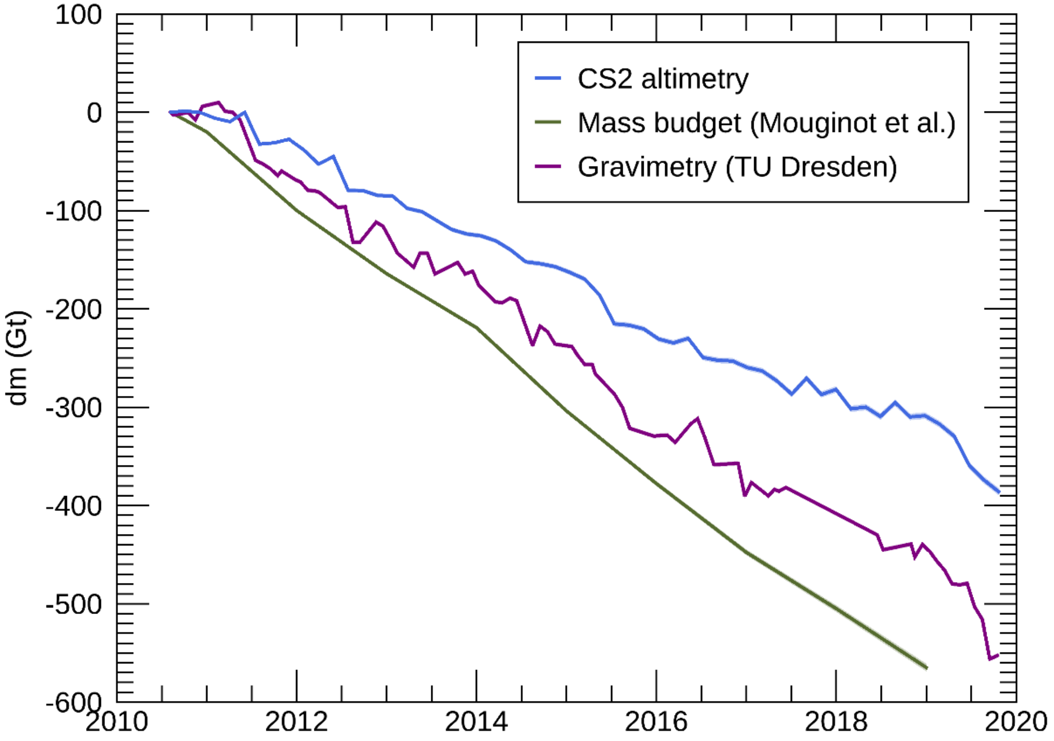
The Northwest sector lost a total of 386 Gt of ice between July 2010 and July 2019

- We estimate mass change in each of the 74 individual glacier basins of the sector

- Largest losses are recorded at:
- Upernavik-Isstrom-N
- Steenstrup-Dietrichson
- Kjer Gletscher



We assess our altimetry-based solution by comparing it to estimates from gravimetry and the mass budget method



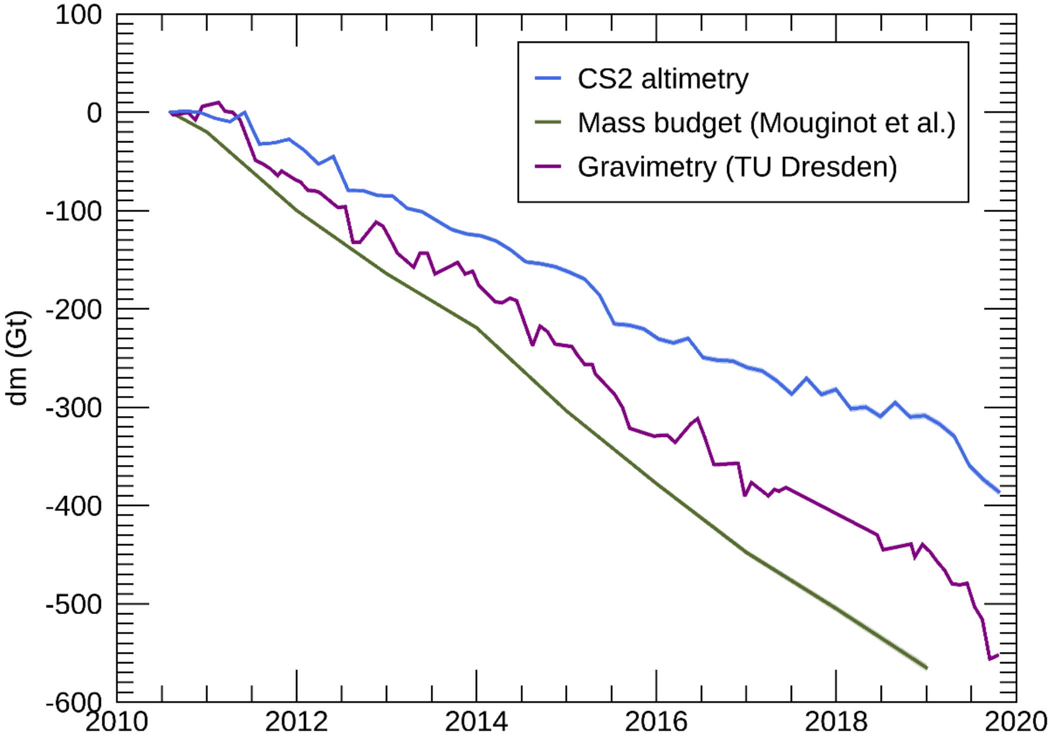
To compare our CS2 estimate we use:

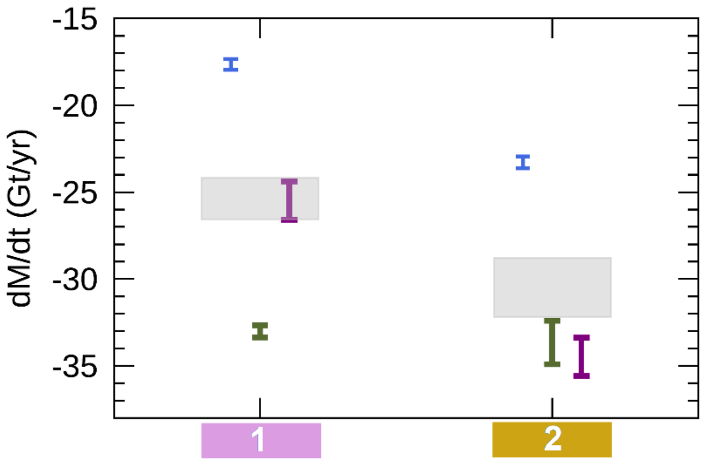
- Gravimetry estimate from Groh & Horwath (2016)
- Mass budget estimate from Mouginot et al. (2019)

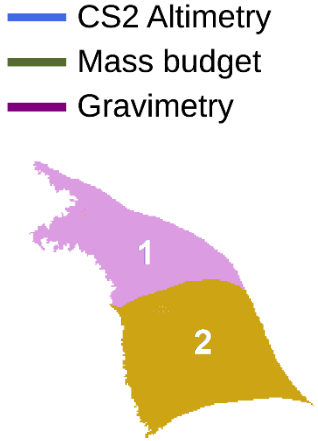
Technique	dM/dt (Gt/yr)
CS2 altimetry*	-41.7 ± 0.2
Mass budget	-66.7 ± 1.0
Gravimetry	-57.2 ± 2.2

*Here, we added the mass balance from the ice caps and peripheral glaciers to our CS2 estimate: -1.3 ± 0.1 Gt/yr from Mouginot et al. (2019)

We compared these estimates across two regional sub-divisions of the sector



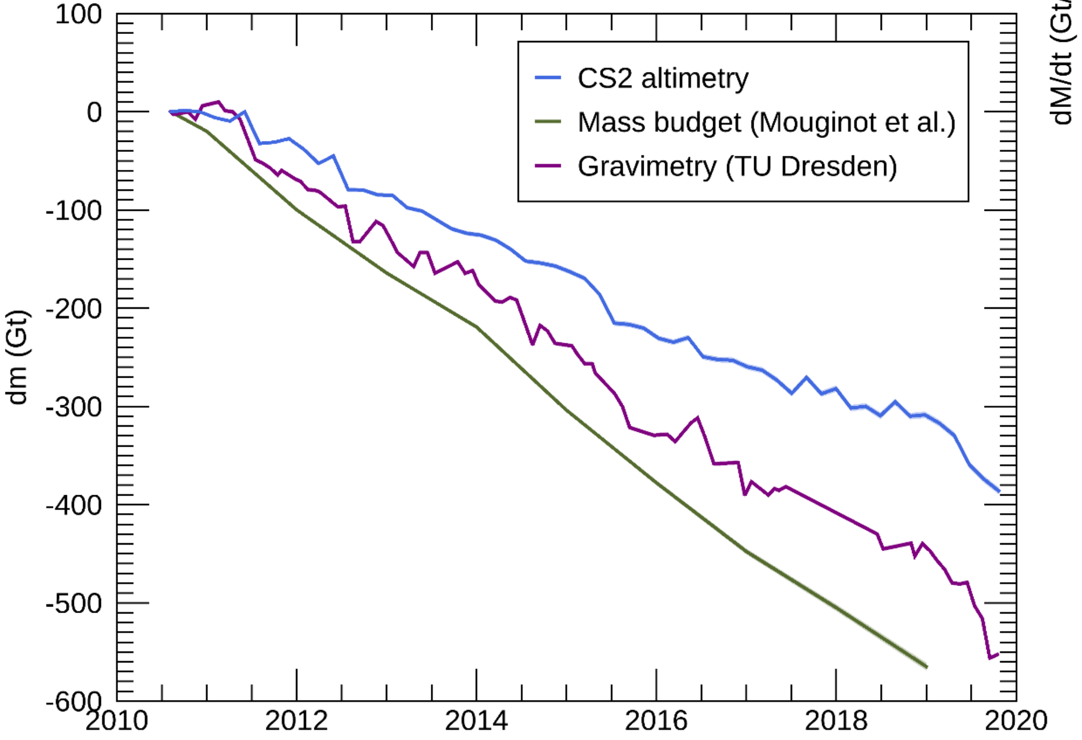


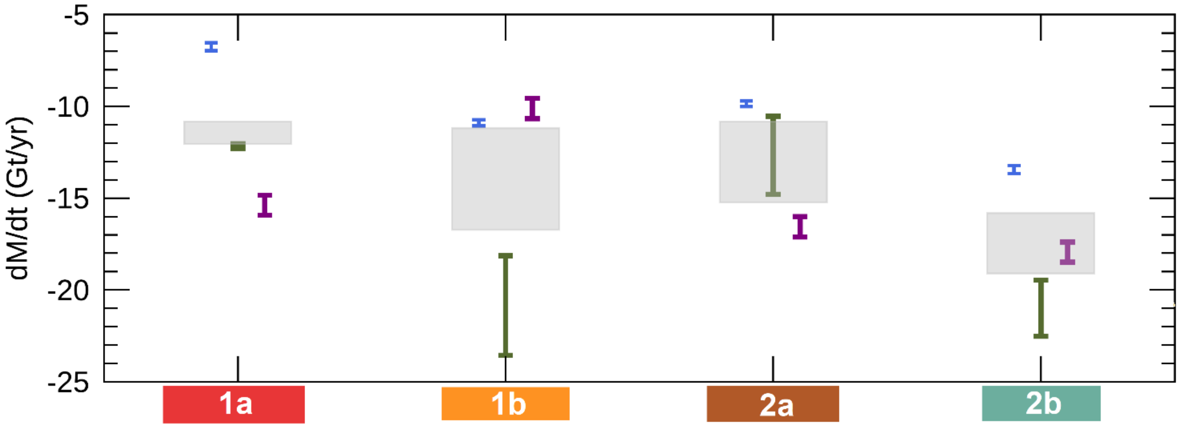


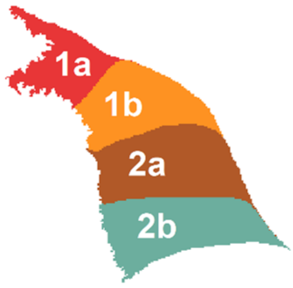
Large differences between all three estimates

Close agreement between gravimetry and the mass budget estimates

We further divided these regions into four sub-divisions of the sector, showing that differences are highly variable spatially







Gravimetry is the most negative, likely due to the inclusion of the northern ice cap

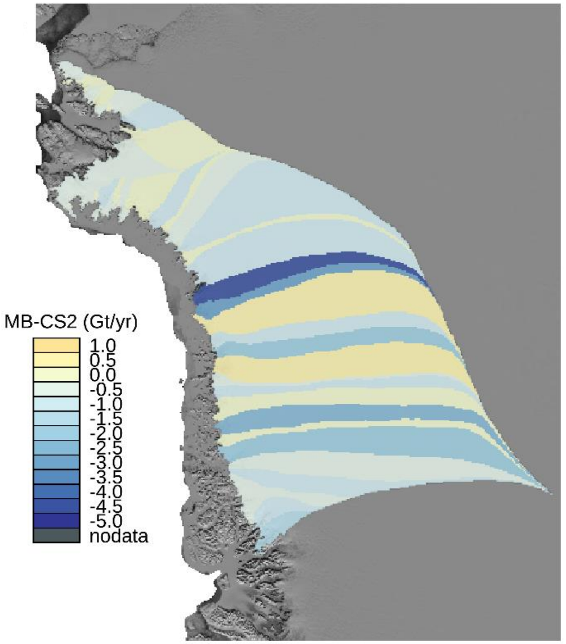
CryoSat-2 and gravimetry are in good agreement, but mass budget is twice as large

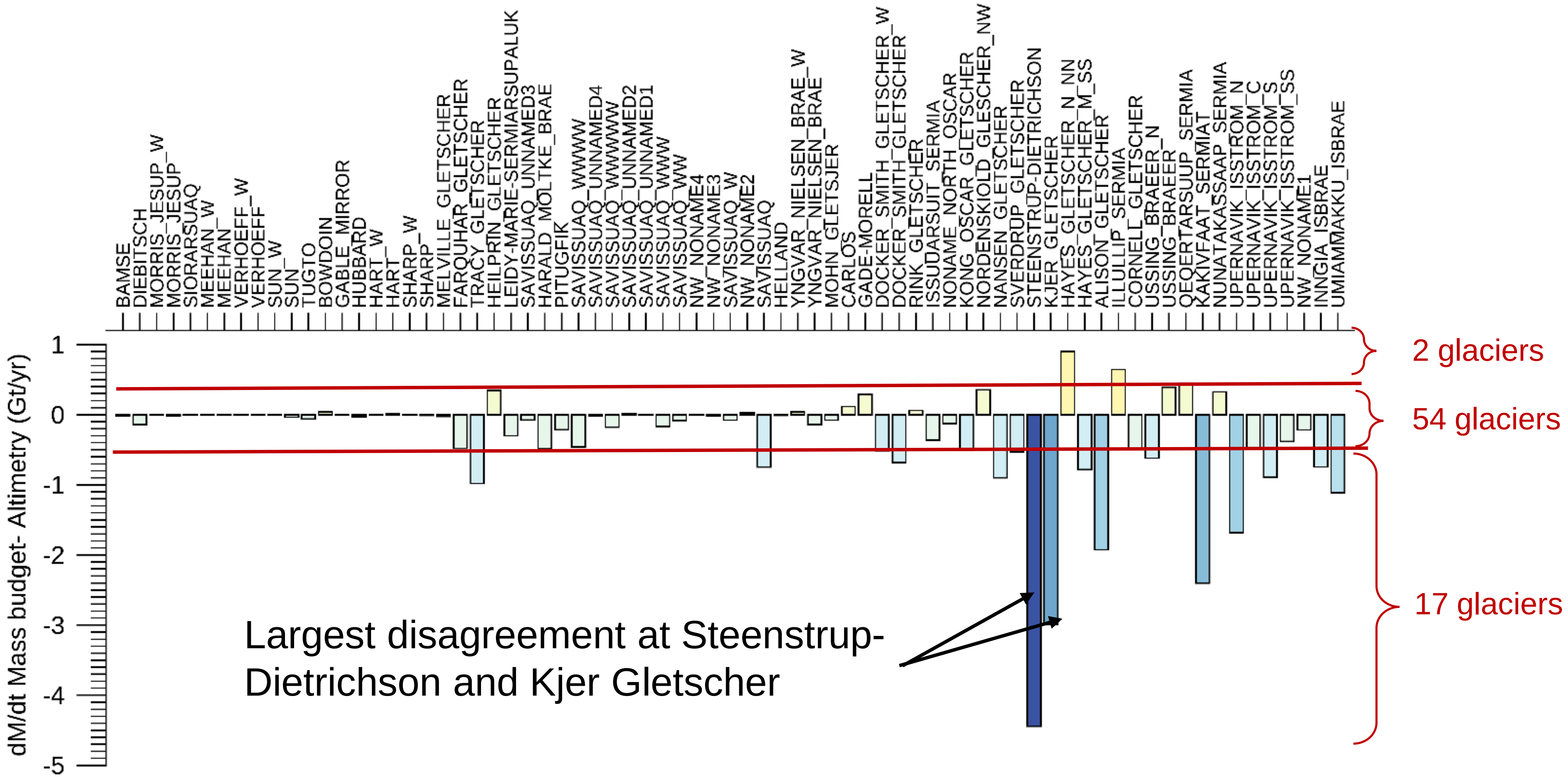
All estimates are in good agreement

CryoSat-2 largely underestimates mass loss compared to both estimates

Next, we compare mass balance estimates from CryoSat-2 and the mass budget method in individual glacier basins

Thanks to the higher spatial resolution of our CS2 estimate and of the mass budget estimate, we examine differences at the scale of individual basins:



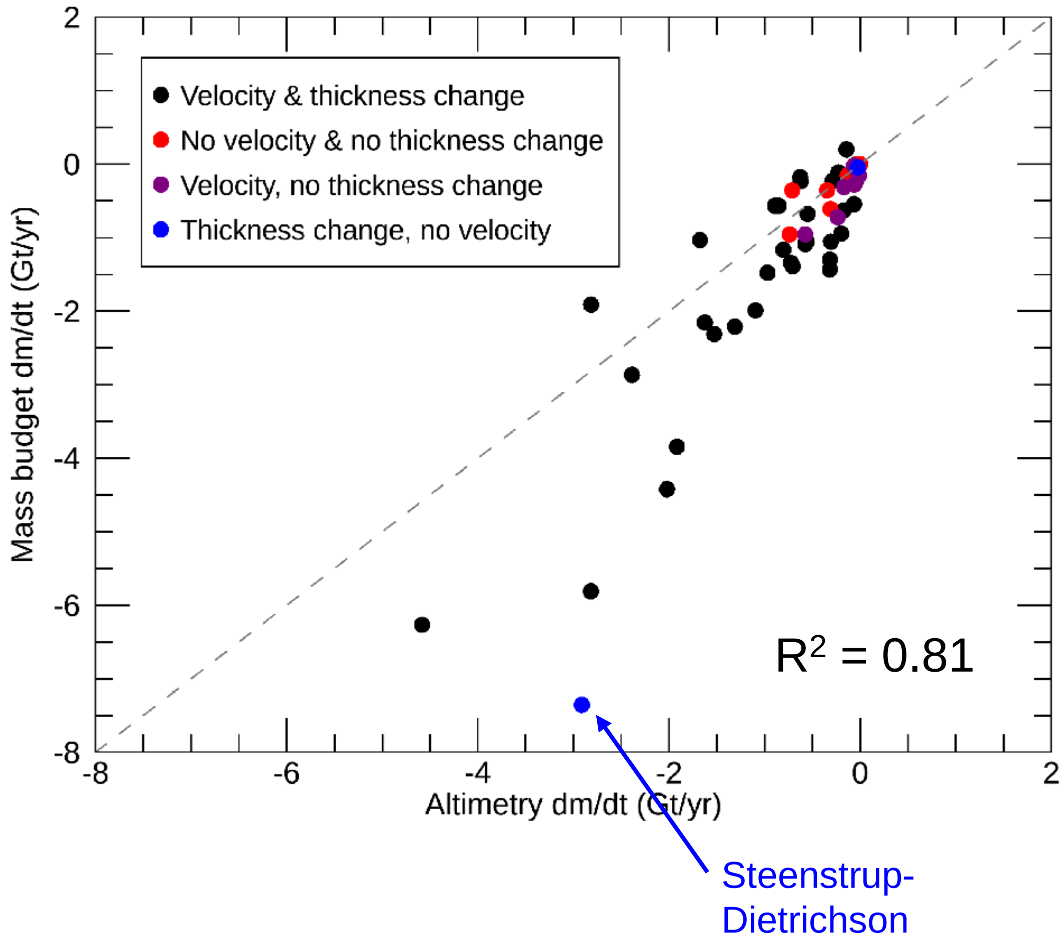


We investigate the origins of the differences, by examining the datasets used in the compilation of the mass budget estimate

- There is a high correlation between CS2 and the mass budget estimate

- We examined the availability of ice velocity and thickness change data in the estimation of the discharge component:
  - 26 basins have no velocity and no thickness change
  - 9 have velocity but no thickness change data
  - 2 have thickness change but no velocity

- The largest difference is recorded in Steenstrup-Dietrichson basin where no velocity data were used, which could explain the bias between CS2 and mass budget at this particular glacier

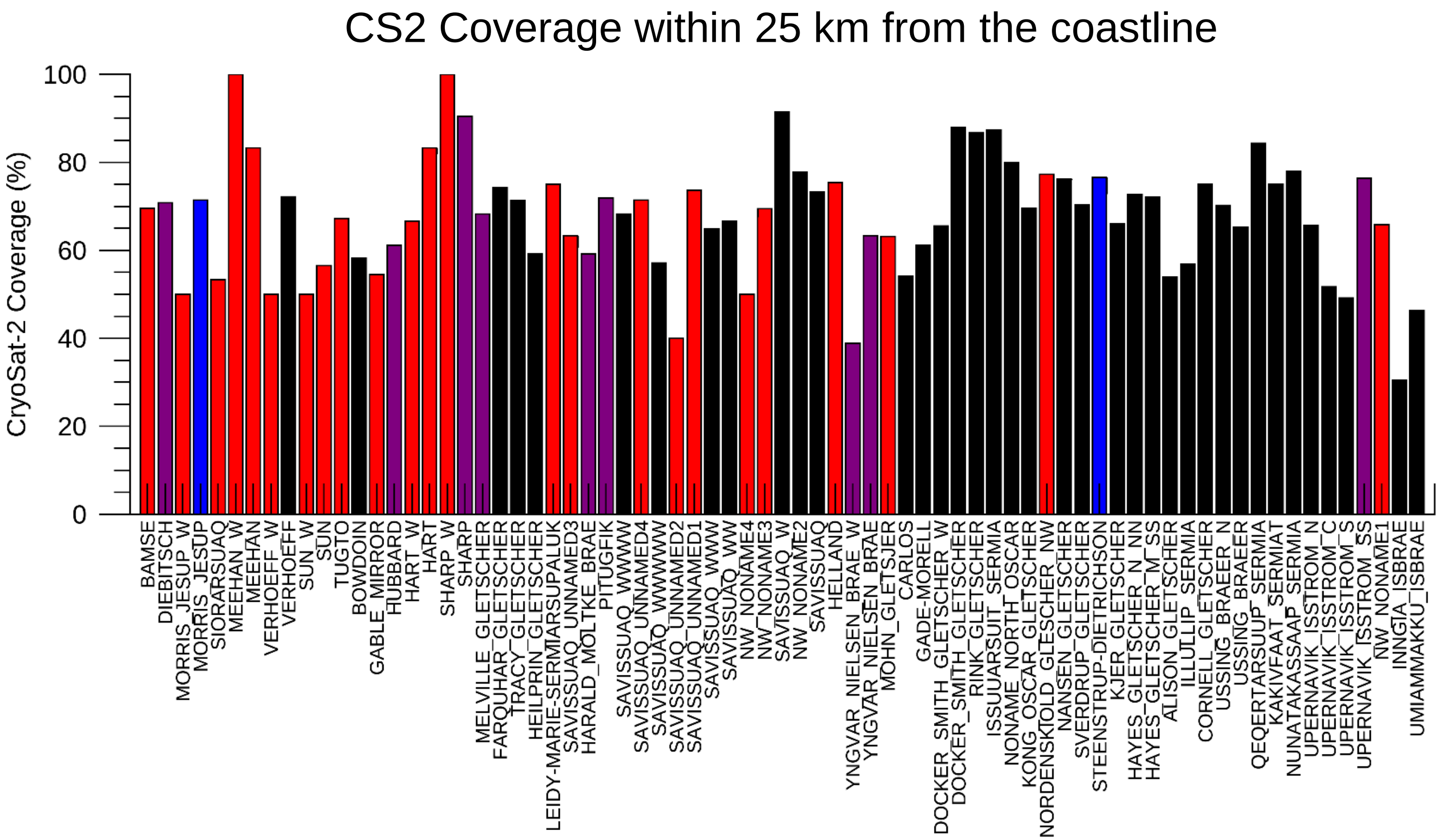


We further investigate whether a lack of CryoSat-2 coverage could contribute to the differences in mass balance estimates

- We investigate whether differences could arise from a lack of CS2 observations close to the grounding line

- Within 25 km from the coastline:
- At least 30% of the coastal region is sampled by CS2 in all basins
- Over 50% of this region is sampled at 68 basins

- This indicates that there are no significant gaps or variations in the spatial coverage of CS2



Summary and Conclusion

- **All glacier basins have lost ice**, with an overall rate of mass loss of 41.3 Gt/yr

- **CryoSat-2 underestimates** mass loss compared to gravimetry (57.2 Gt/yr) and mass budget (66.7 Gt/yr)

- However, the disagreement between techniques is **variable regionally**

- Potential **sources of bias** include:

- Difference between satellite radar and airborne laser altimetry rates of elevation change: overall good agreement (difference of 6.5 cm/yr) *but* important disagreements remain in the margins of the ice sheet, which could result in an additional mass loss of up to 11.8 Gt/yr
- No adjustment of elevation changes for firn compaction were made
- Prescription of surface density
- Omission of peripheral glaciers and ice caps in our altimetry estimate

References

- Groh, A., & Horwath, M. 2016. The method of tailored sensitivity kernels for GRACE mass change estimates. Geophysical Research Abstracts, 18, EGU2016-12065.
- Mouginot, J., E. Rignot, A. A. Bjørk, M. van den Broeke, R. Millan, M. Morlighem, B. Noël, B. Scheuchl and M. Wood. 2019. Forty-six years of Greenland Ice Sheet mass balance from 1972 to 2018. *Proceedings of the National Academy of Sciences,* **116**(19), pp.9239-9244.
- Wood, M., E. Rignot, I. Fenty, D. Menemenlis, R. Millan, M. Morlighem, J. Mouginot and H. Seroussi. 2018. Ocean-Induced Melt Triggers Glacier Retreat in Northwest Greenland. *Geophysical Research Letters,* **45**(16), pp.8334-8342.