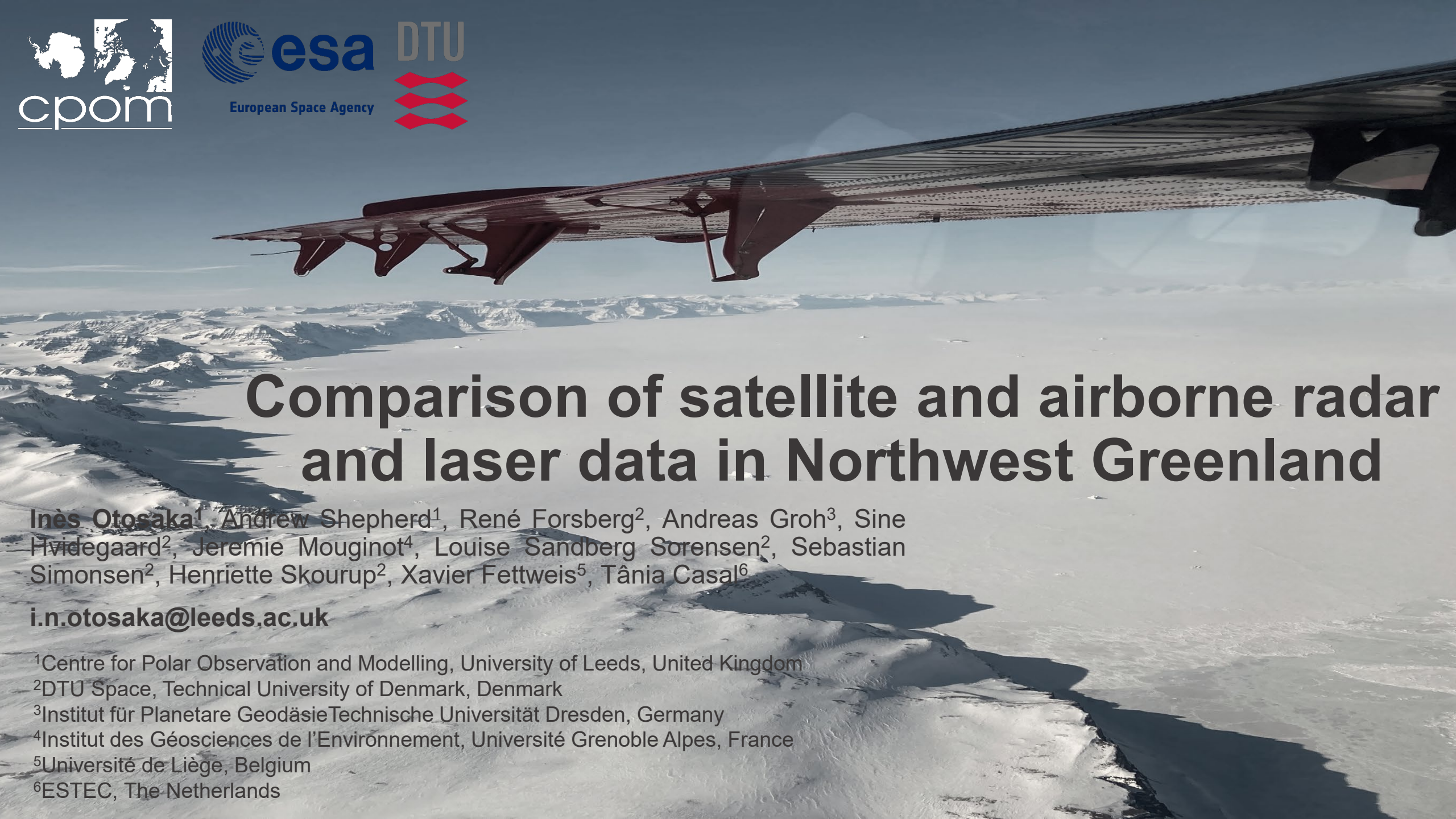

Comparison of satellite and airborne radar and laser data in Northwest Greenland

Inès Otosaka[1], Andrew Shepherd[1], René Forsberg[2], Andreas Groh[3], Sine Hvidegaard[2], Jeremie Mouginot[4], Louise Sandberg Sorensen[2], Sebastian Simonsen[2], Henriette Skourup[2], Xavier Fettweis[5], Tânia Casal[6]

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[2]DTU Space, Technical University of Denmark, Denmark
[3]Institut für Planetare GeodäsieTechnische Universität Dresden, Germany
[4]Institut des Géosciences de l'Environnement, Université Grenoble Alpes, France
[5]Université de Liège, Belgium
[6]ESTEC, The Netherlands

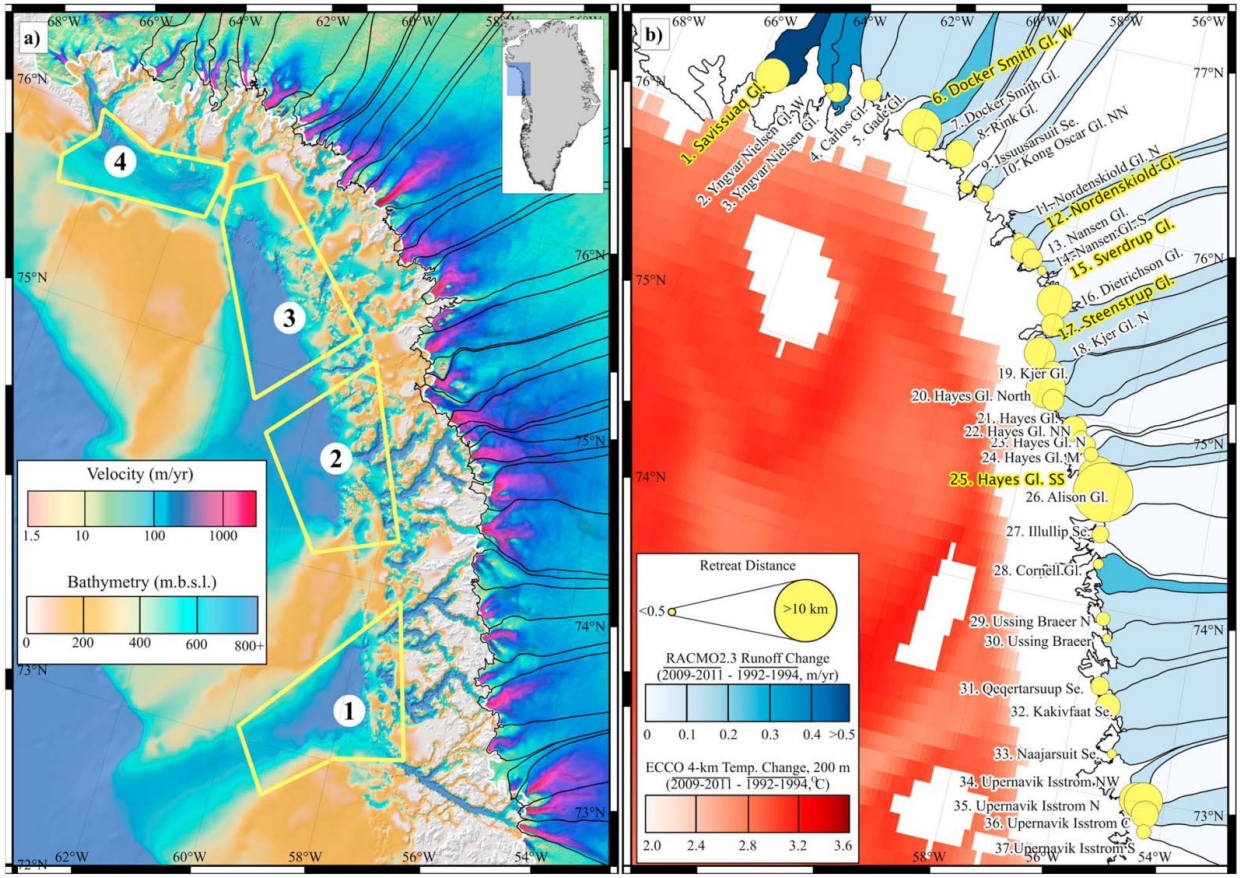
Northwest Greenland

- Greenland contributed 13.6 mm to GMSL since 1992 (IMBIE)

~1/3 of Greenland's mass loss comes from the Northwest sector

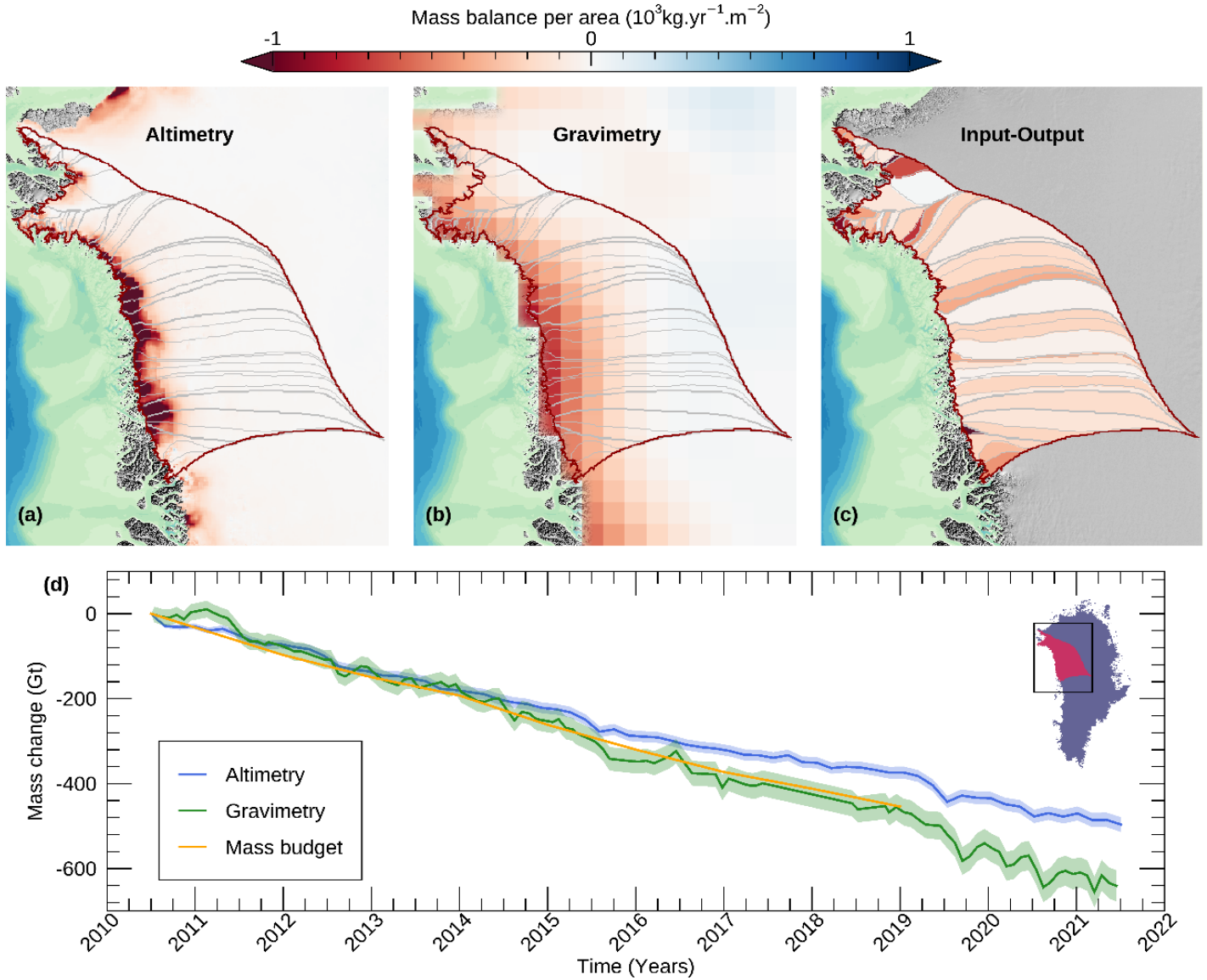
- Northwest Greenland counts a large number of marine-terminating glaciers which have experienced sustained retreat triggered by ocean-induced melting

- 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



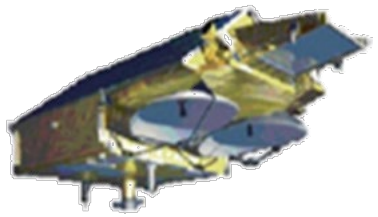
Wood *et al.* 2018

Measuring Northwest Greenland mass balance from space

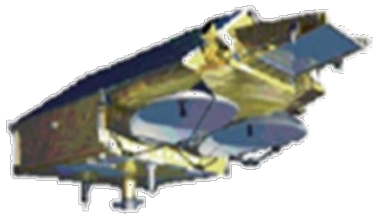
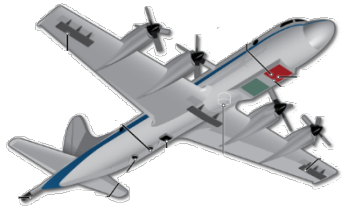


- Altimetry measures surface elevation changes at high spatial and temporal resolutions
- But there are uncertainties related to changes in the radar scattering horizon
- Airborne campaigns are key to validate surface elevation changes measured from space and improve mass balance measurements from altimetry

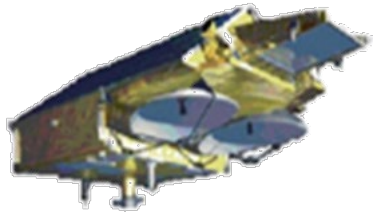
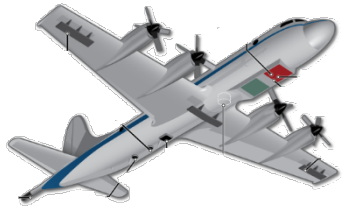
A decade of CryoSat-2 observations

	June 2010 to June 2021 24.4 million observations	Ku-band SAR/Inteferometic Radar Altimeter (SIRAL)

A decade of CryoSat-2 observations + airborne campaigns

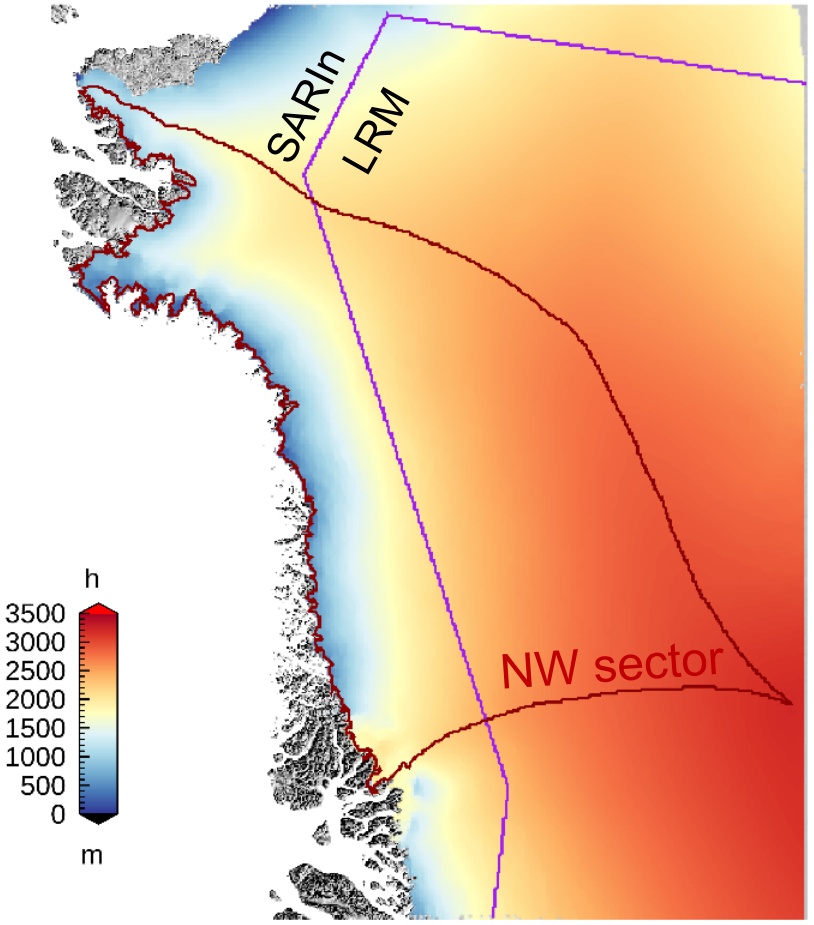
	June 2010 to June 2021 24.4 million observations	Ku-band SAR/Inteferometic Radar Altimeter (SIRAL)
	Annual campaigns from 2010 to 2019	Scanning laser altimeter: ATM

A decade of CryoSat-2 observations + airborne campaigns

	June 2010 to June 2021 24.4 million observations	Ku-band SAR/Inteferometic Radar Altimeter (SIRAL)
	Annual campaigns from 2010 to 2019	Scanning laser altimeter: ATM
	2017 & 2019-Spring campaigns	Ku-band radar: ASIRAS Ka-band radar: KAREN Scanning laser altimeter: ALS

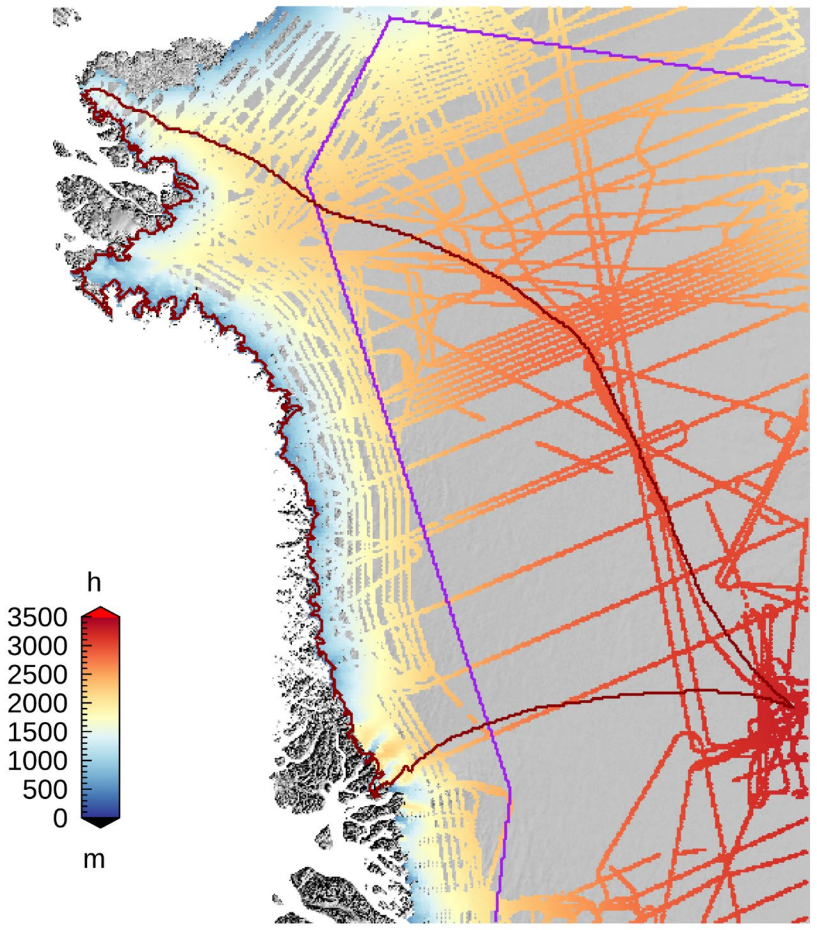
Comparison of surface elevation measurements

CryoSat-2



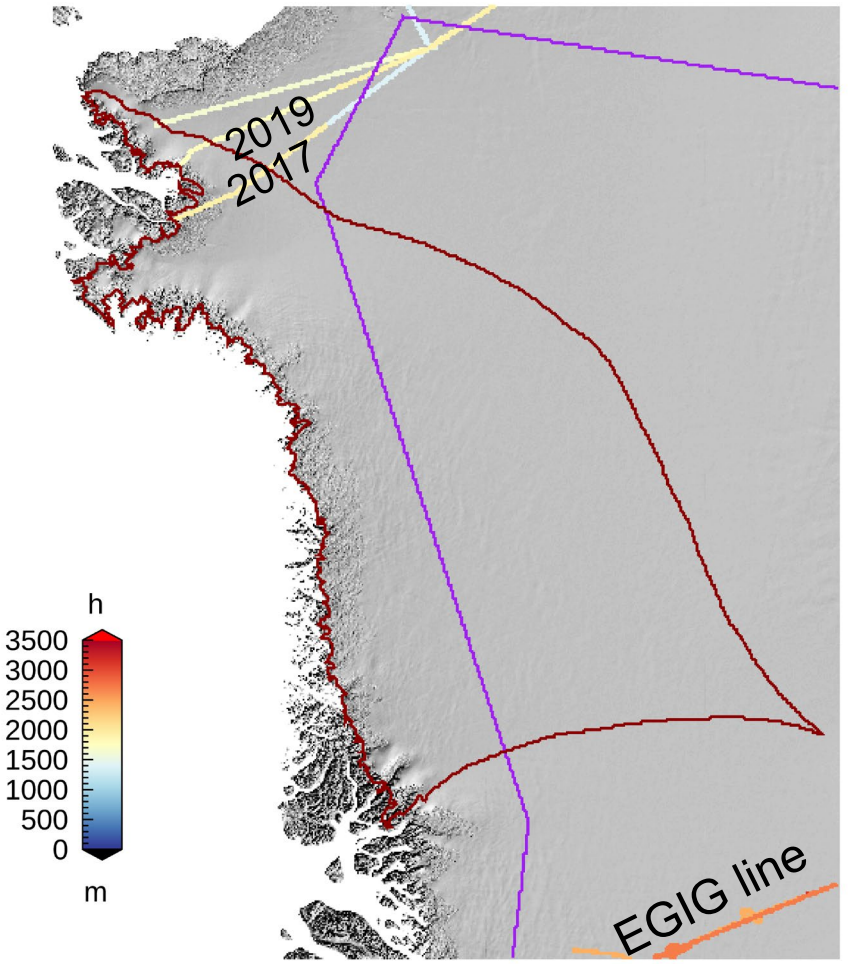
Coverage: 99.0%

Operation IceBridge



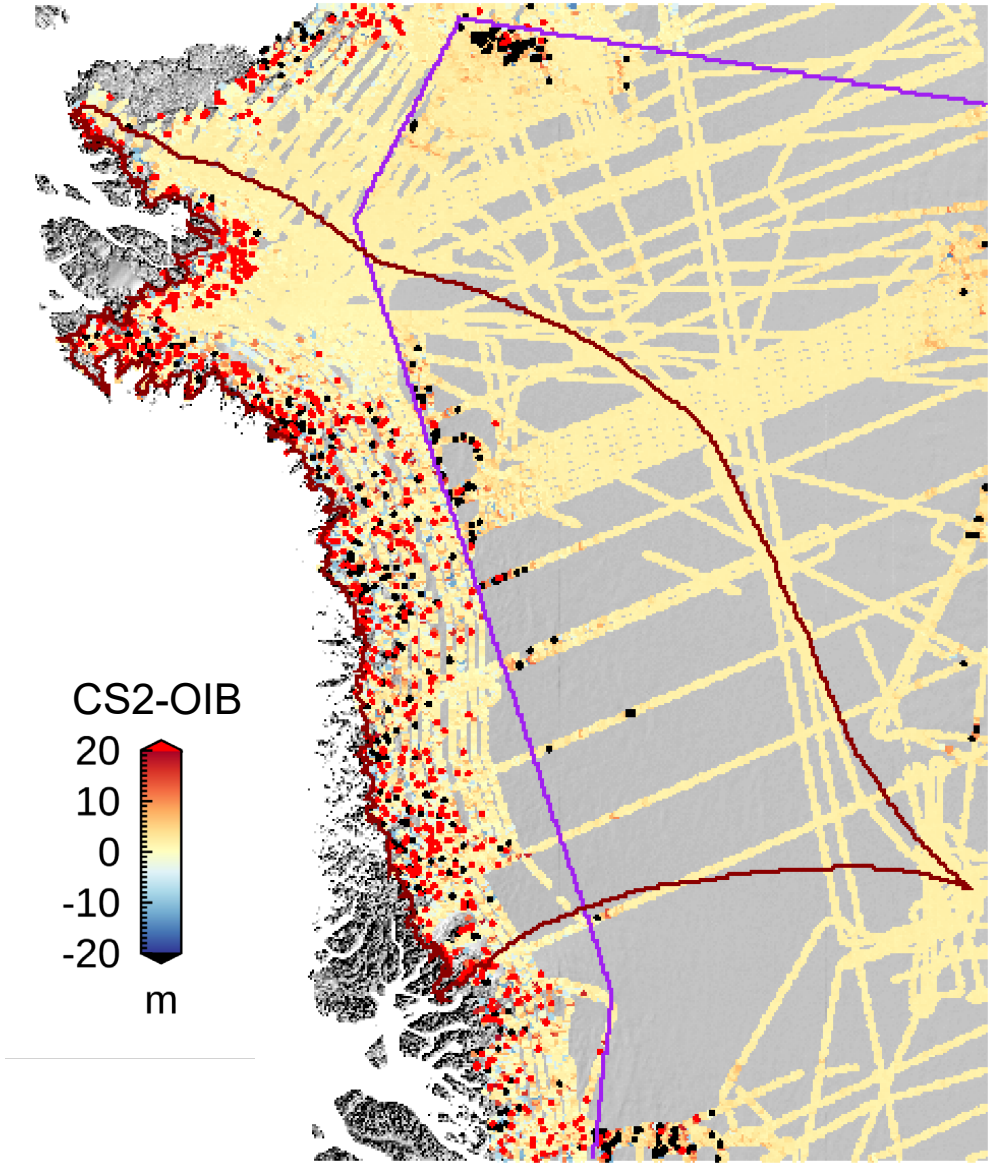
34.4%

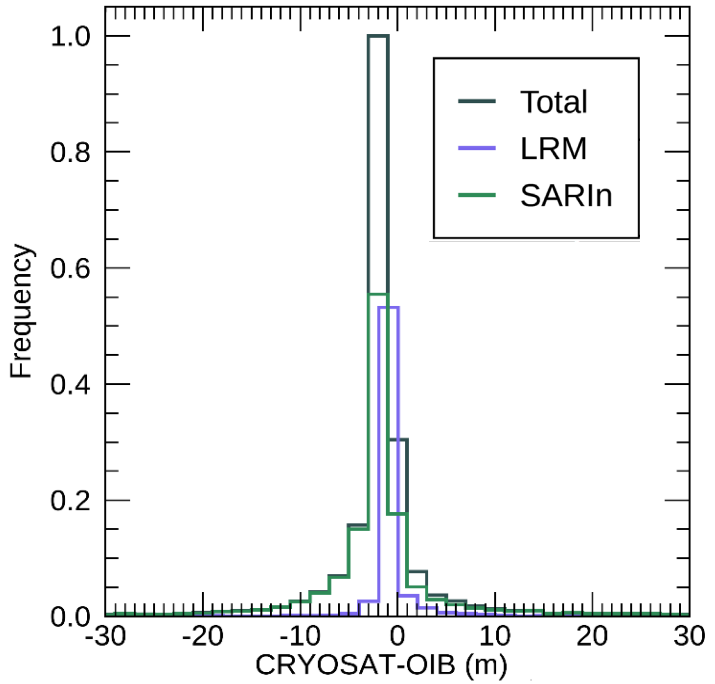
CryoVEx



0.02%

CryoSat-2 VS OIB

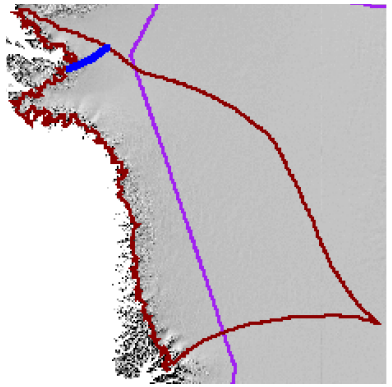


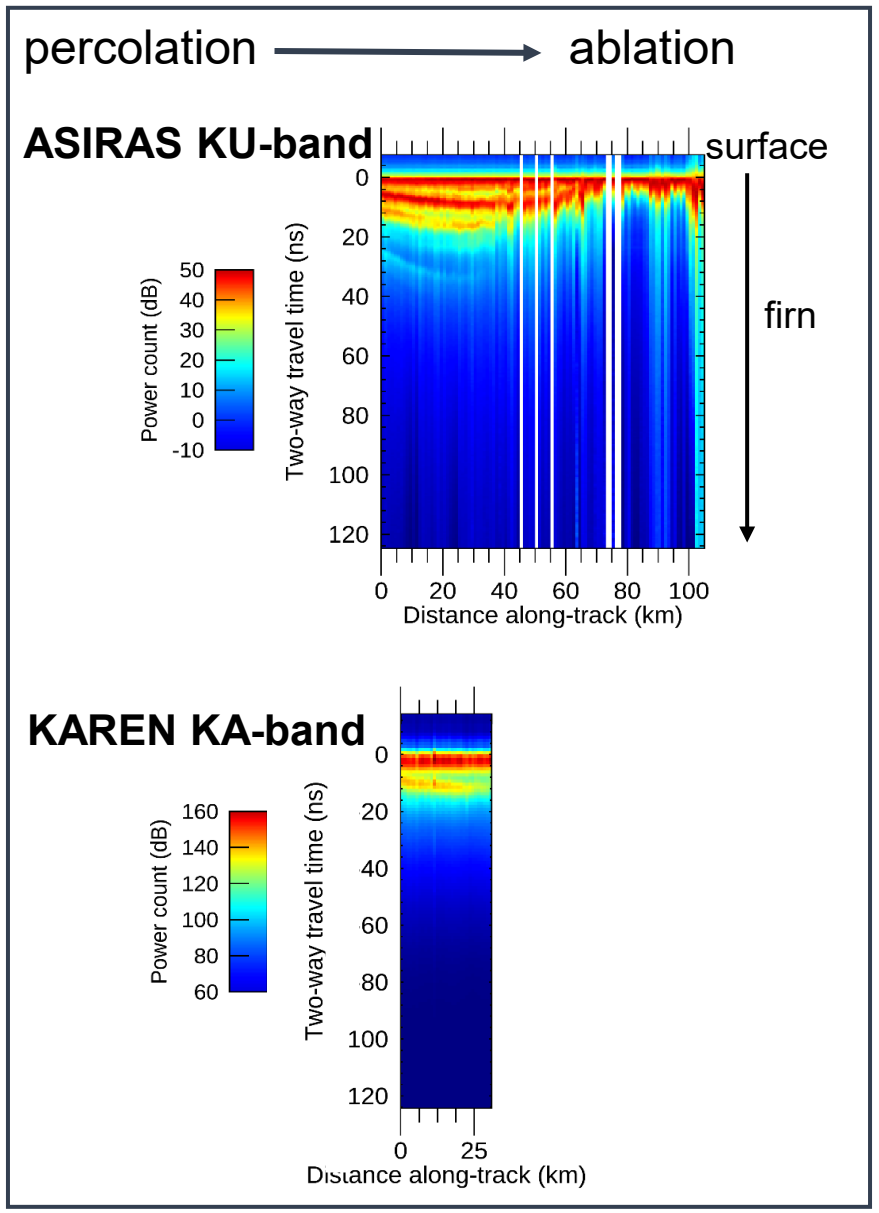


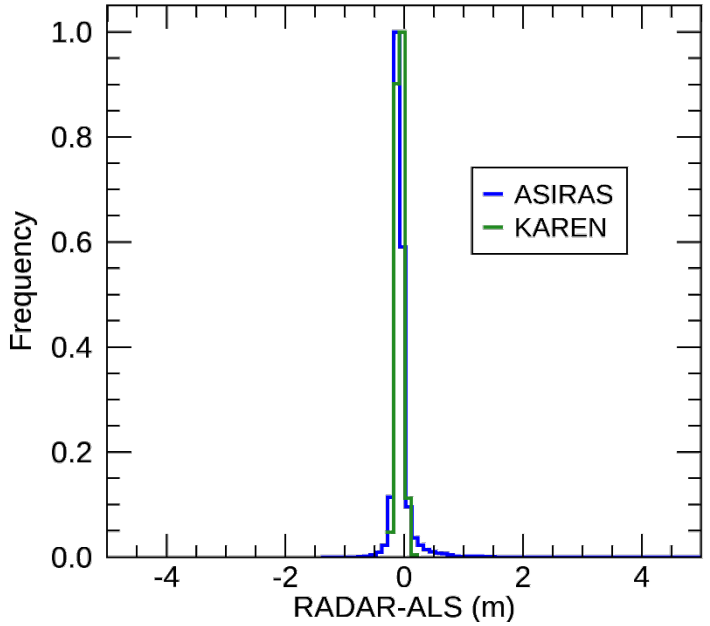
	NW sector	LRM	SARIn
Mean (m)	0.60	-0.18	1.1
Median (m)	-0.33	-0.32	0.68
STD (m)	12.4	5.1	14.6
#	12,492	4,090	8,402

CryoVEx 2017

28th March 2017





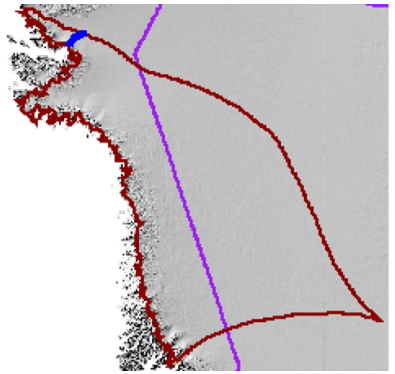


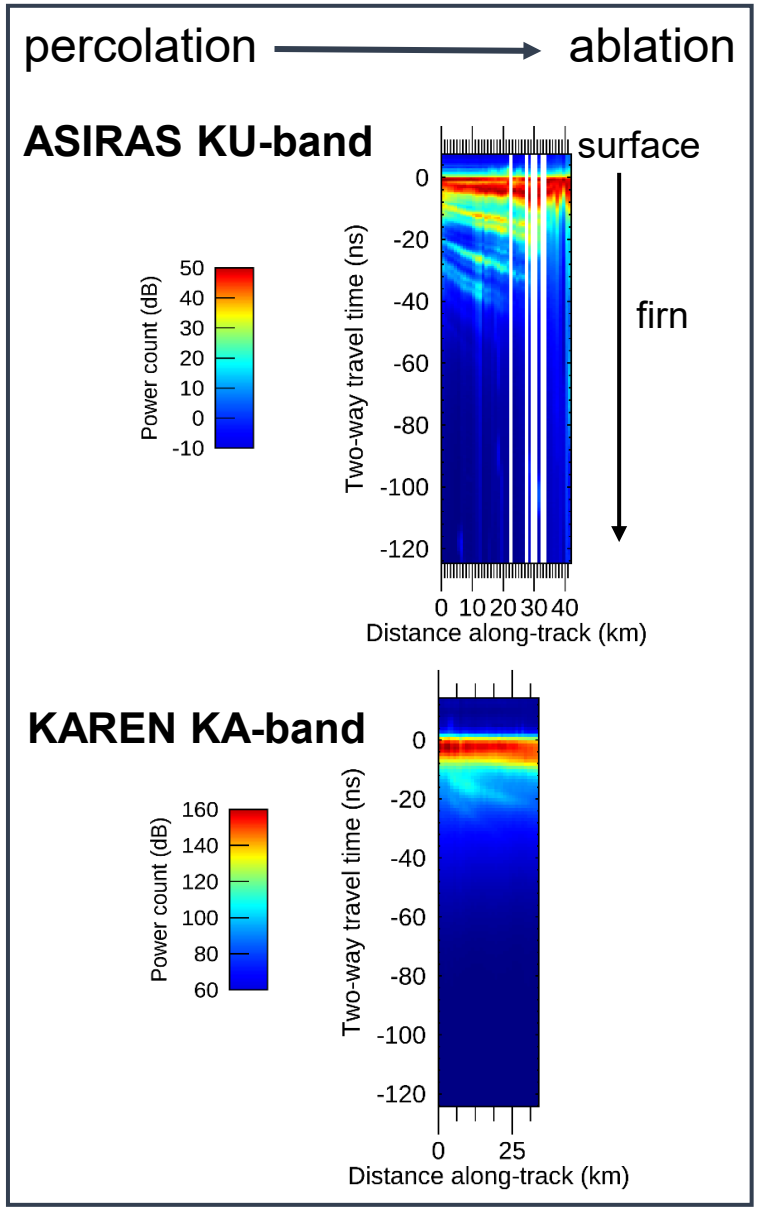
	KU-ALS	KA-ALS
Mean (m)	0.04	-0.03
Median (m)	-0.04	-0.03
STD (m)	2.4	0.06

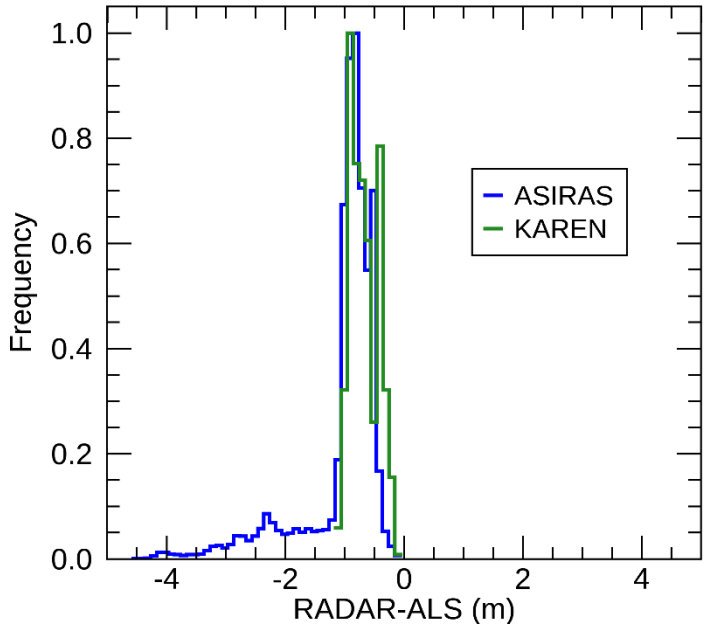
Runway calibration offset (TCOG)
ASIRAS: 3.57 m
KAREN: -0.07 m

CryoVEx 2019

30th March 2019



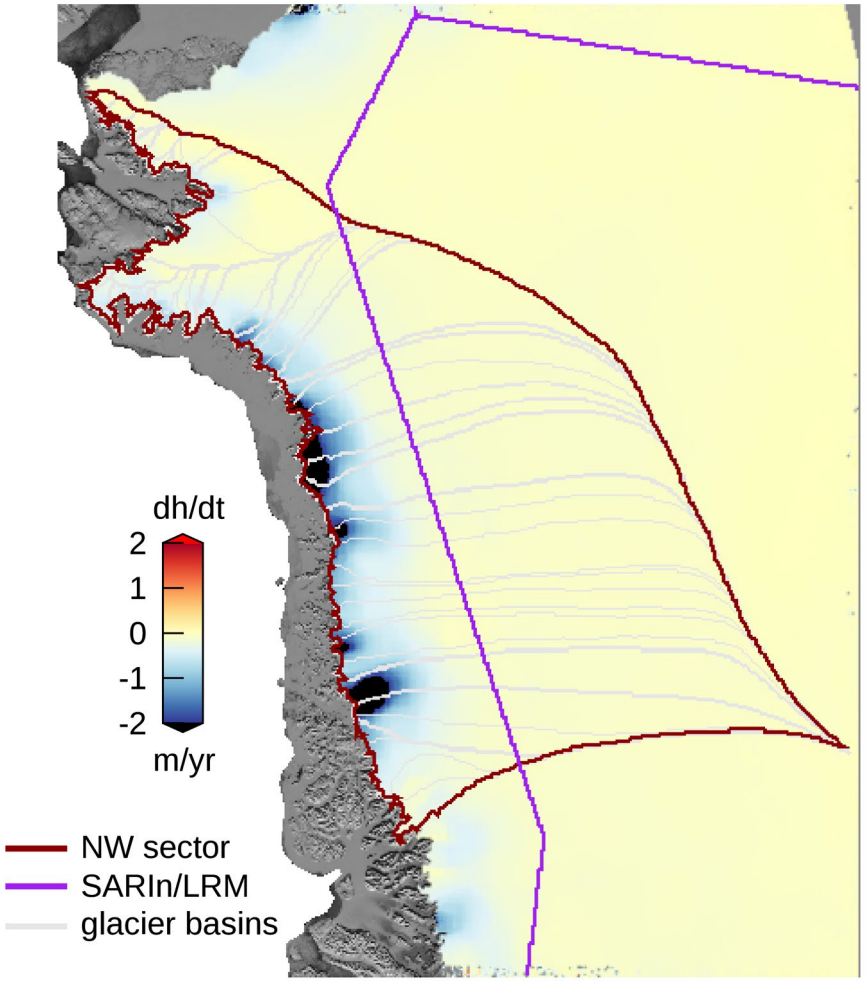


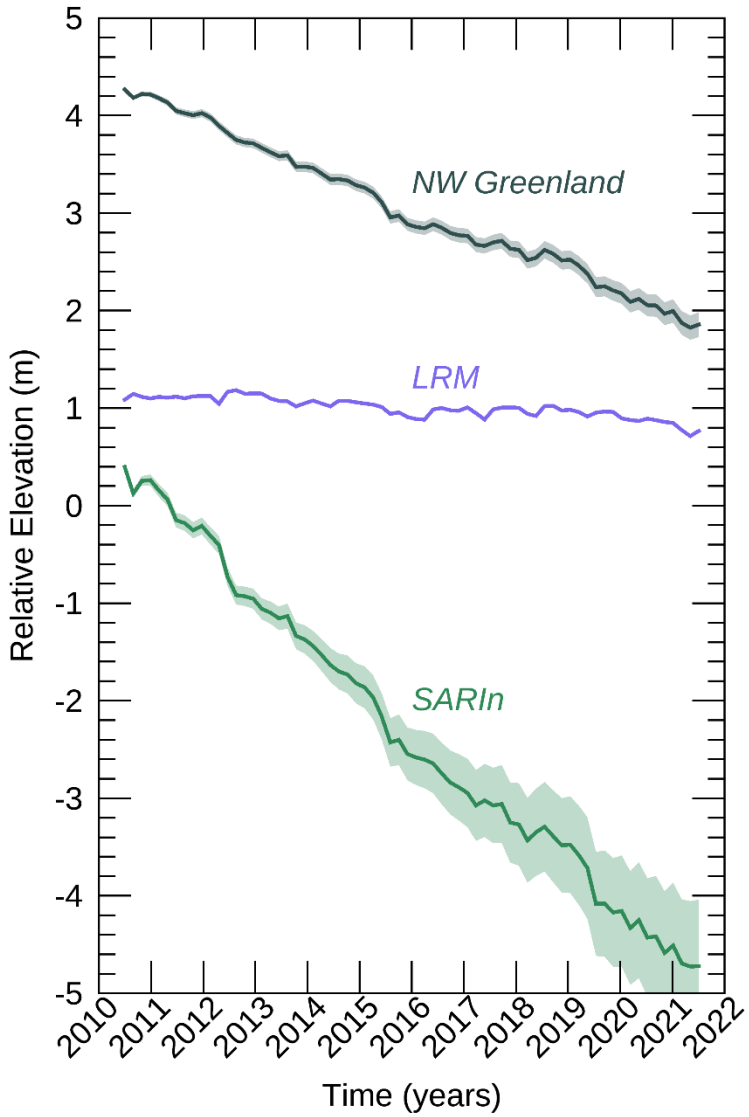


	KU-ALS	KA-ALS
Mean (m)	-1.0	-0.62
Median (m)	-0.80	-0.64
STD (m)	0.67	0.23

Runway calibration offset (TCOG)
ASIRAS: 3.23 m
KAREN: -0.35 m

CryoSat-2 surface elevation change

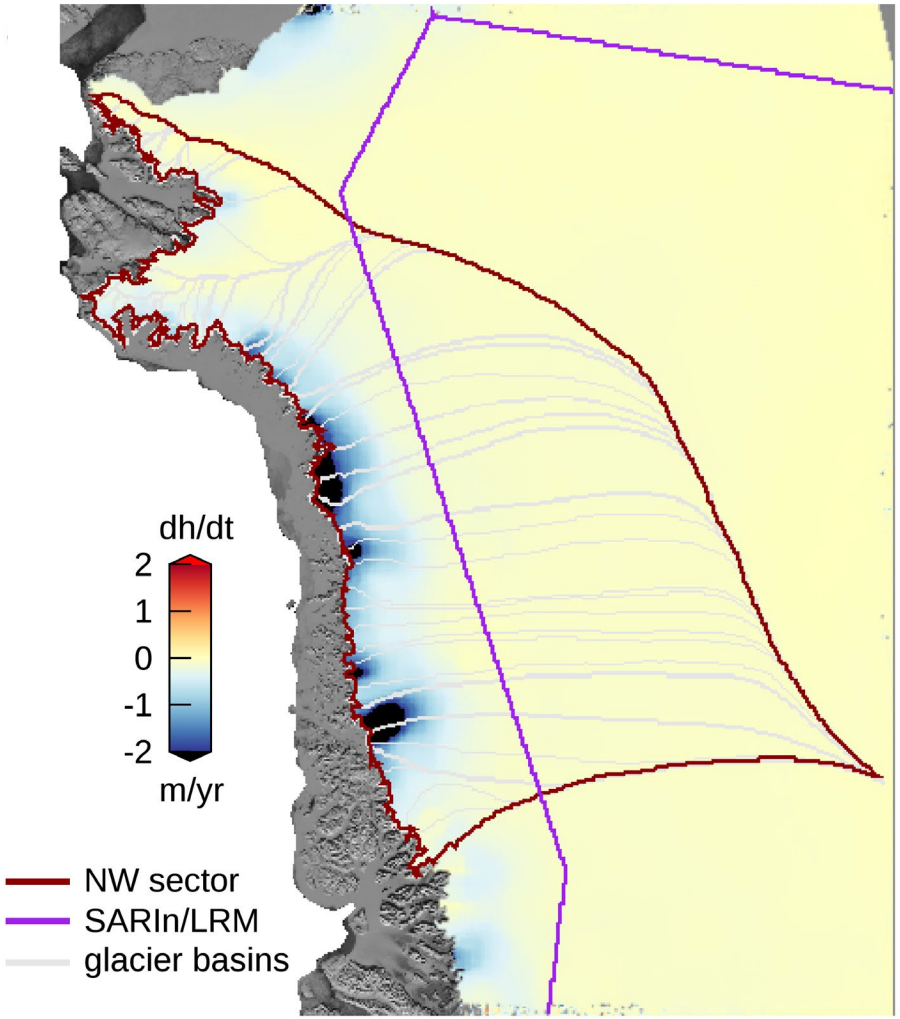




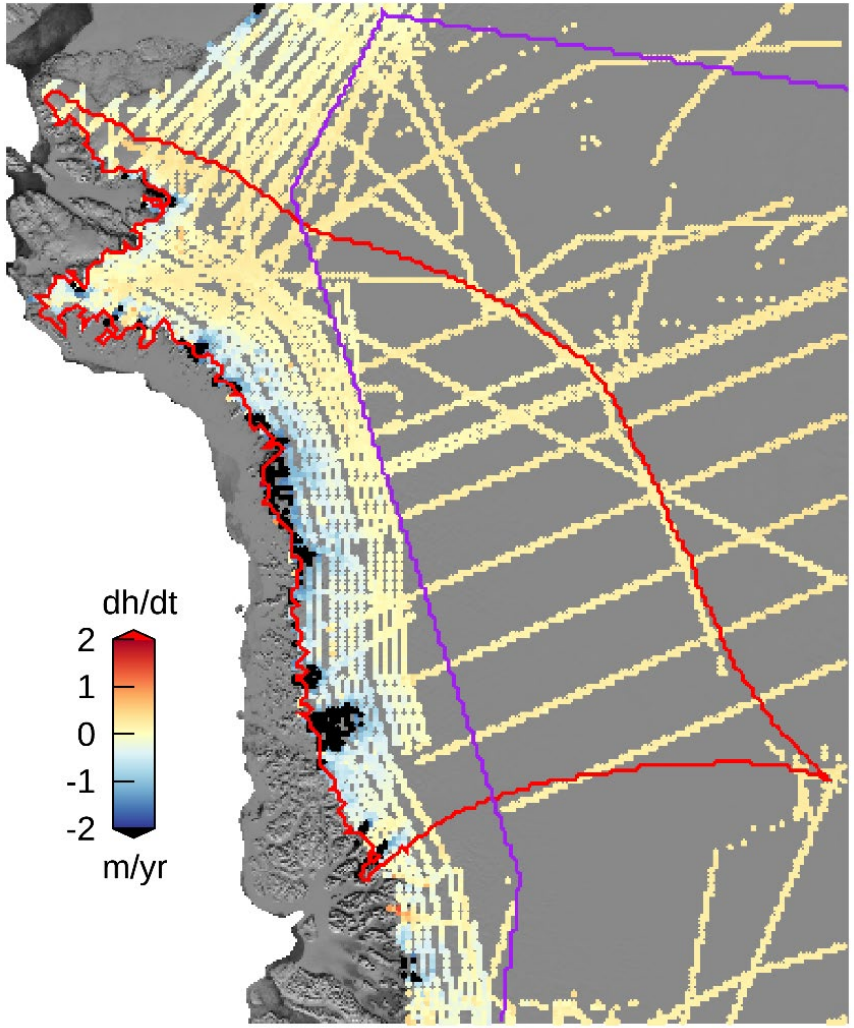
Region	dh/dt (cm/yr)
Northwest sector	-21.9 ± 1.1
SARIn	-46.9 ± 5.9
LRM	-2.7 ± 0.2

Comparison of surface elevation change rates

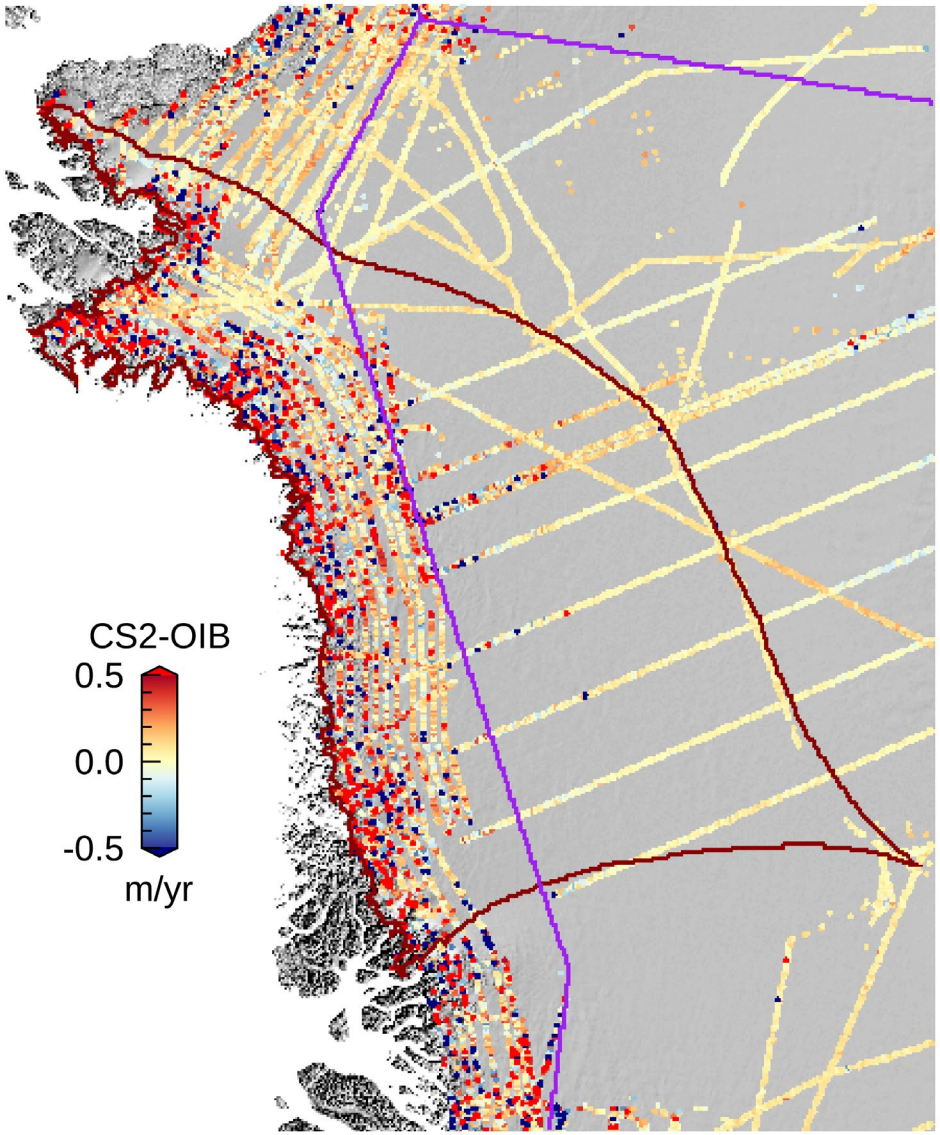
CryoSat-2

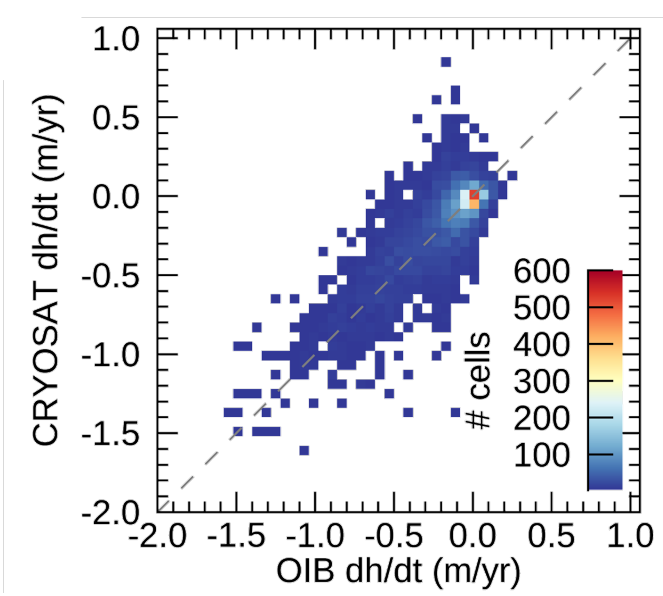


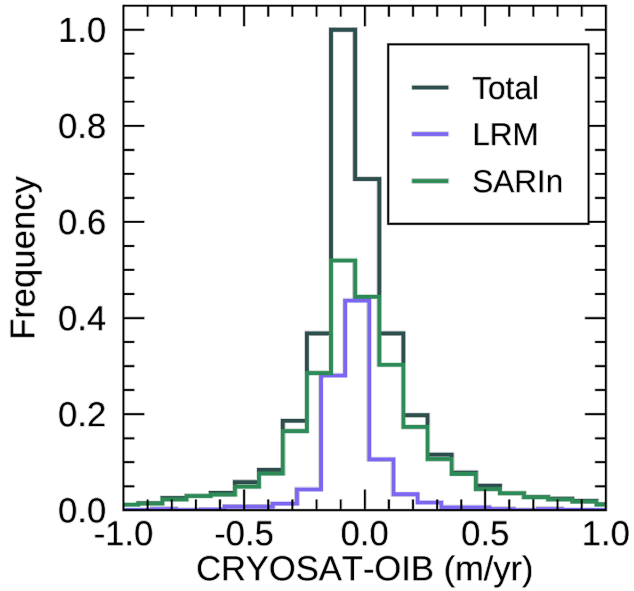
Operation IceBridge



CryoSat-2 VS OIB







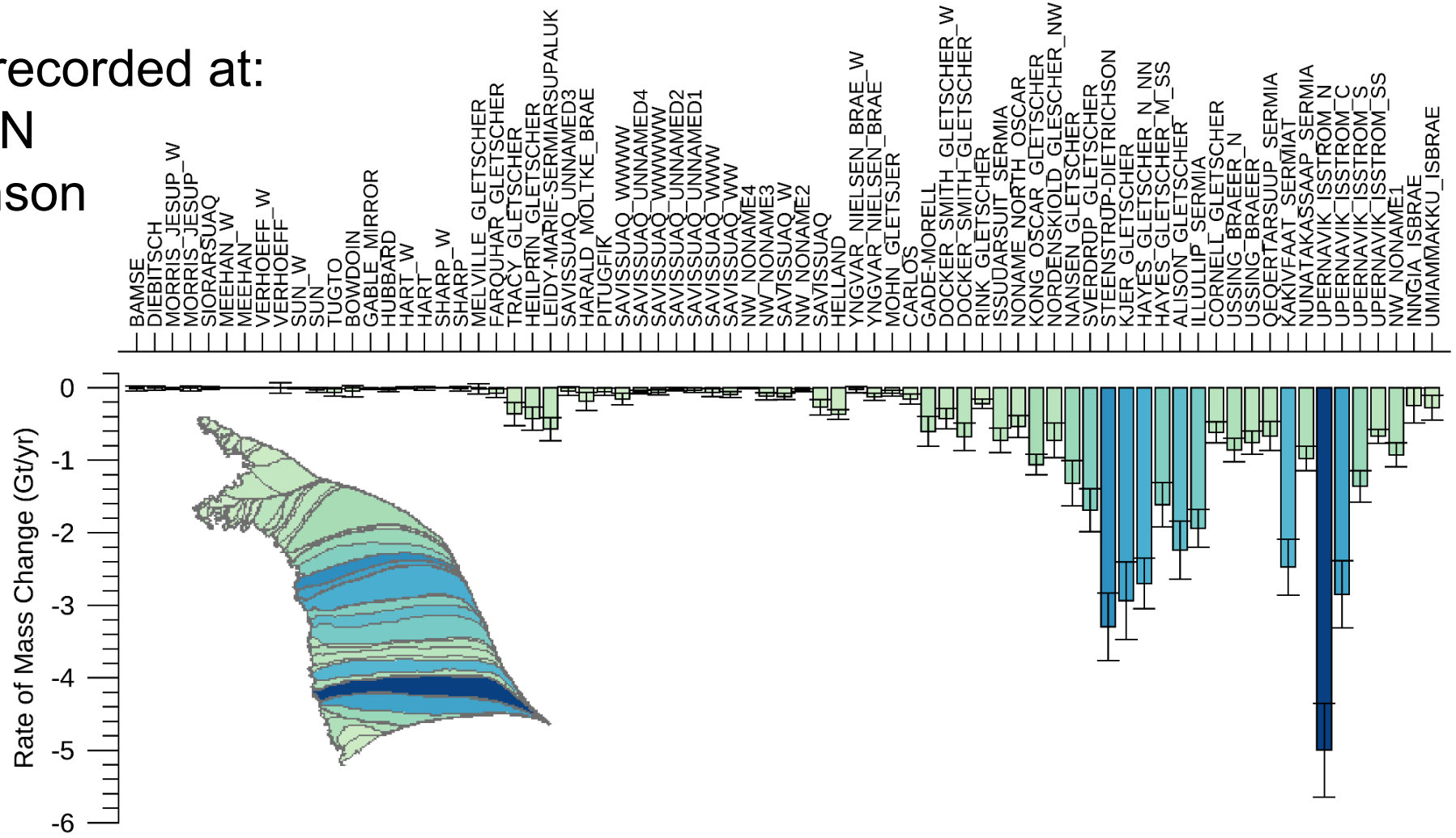
	NW sector	LRM	SARIn
Mean (cm/yr)	6.7	-0.7	9.5
Median (cm/yr)	0.4	-1.1	2.1
STD (cm/yr)	72.9	37.0	82.1
#	6,951	1,878	5,073

Mass balance of the Northwest sector from CryoSat-2

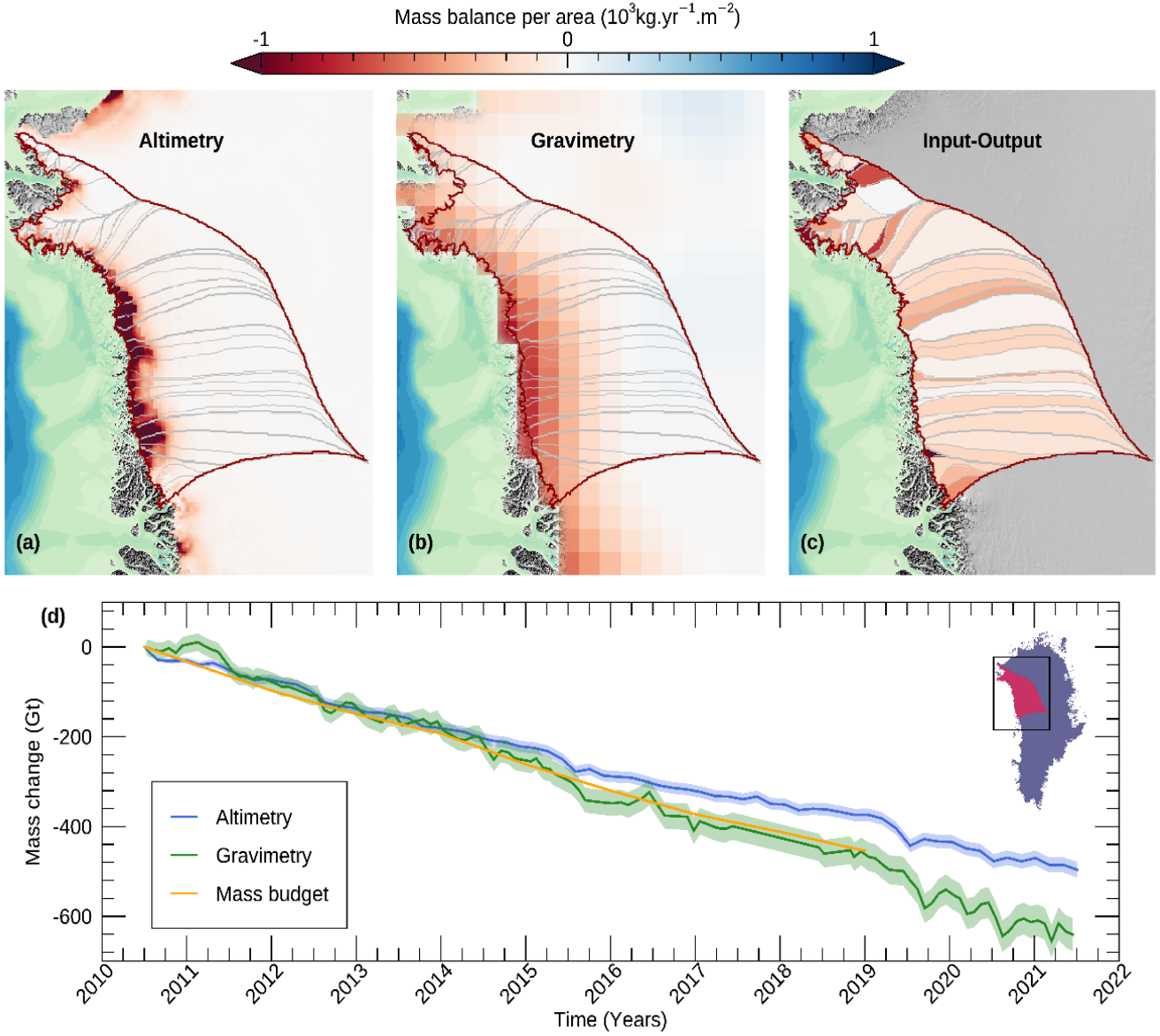
- We estimate mass change in 73 individual glacier basins of the sector

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

- 456 Gt of ice lost

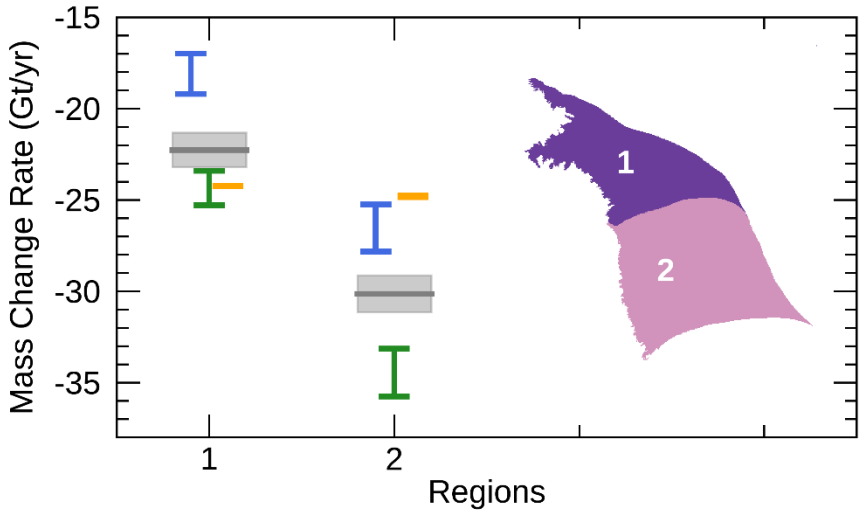


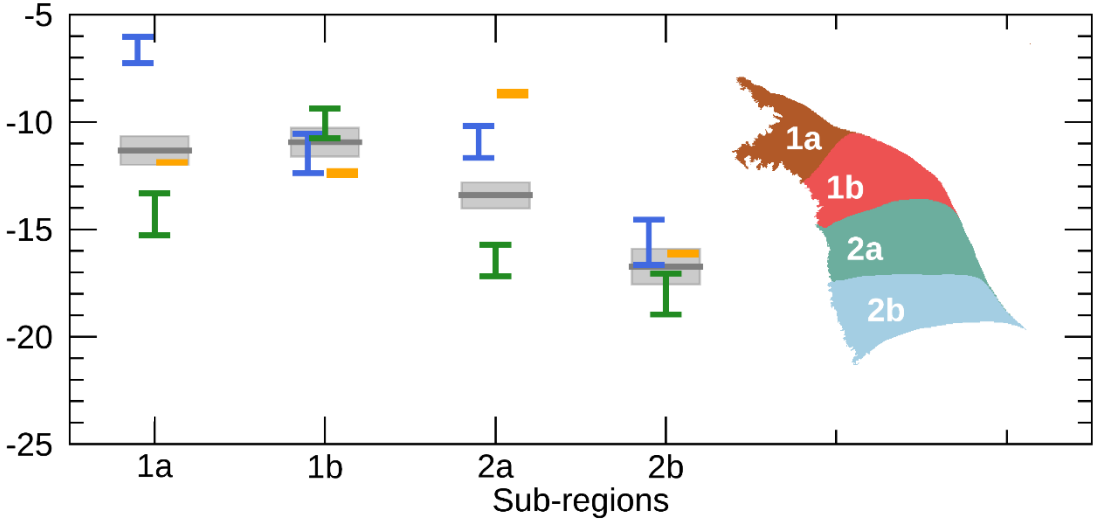
Comparison to gravimetry and the input-output method



Technique	dM/dt (Gt/yr)
Altimetry	-52.0 ± 1.9
Gravimetry (Groh & Horwath)	-57.2 ± 2.2
Input-Output (Mouginot et al., 2019, updated)	-53.4 ± 0.2

Difference in mass balance in sub-regions of the sector





Close agreement between gravimetry and the input-output estimates

Close agreement between altimetry and the input-output estimates

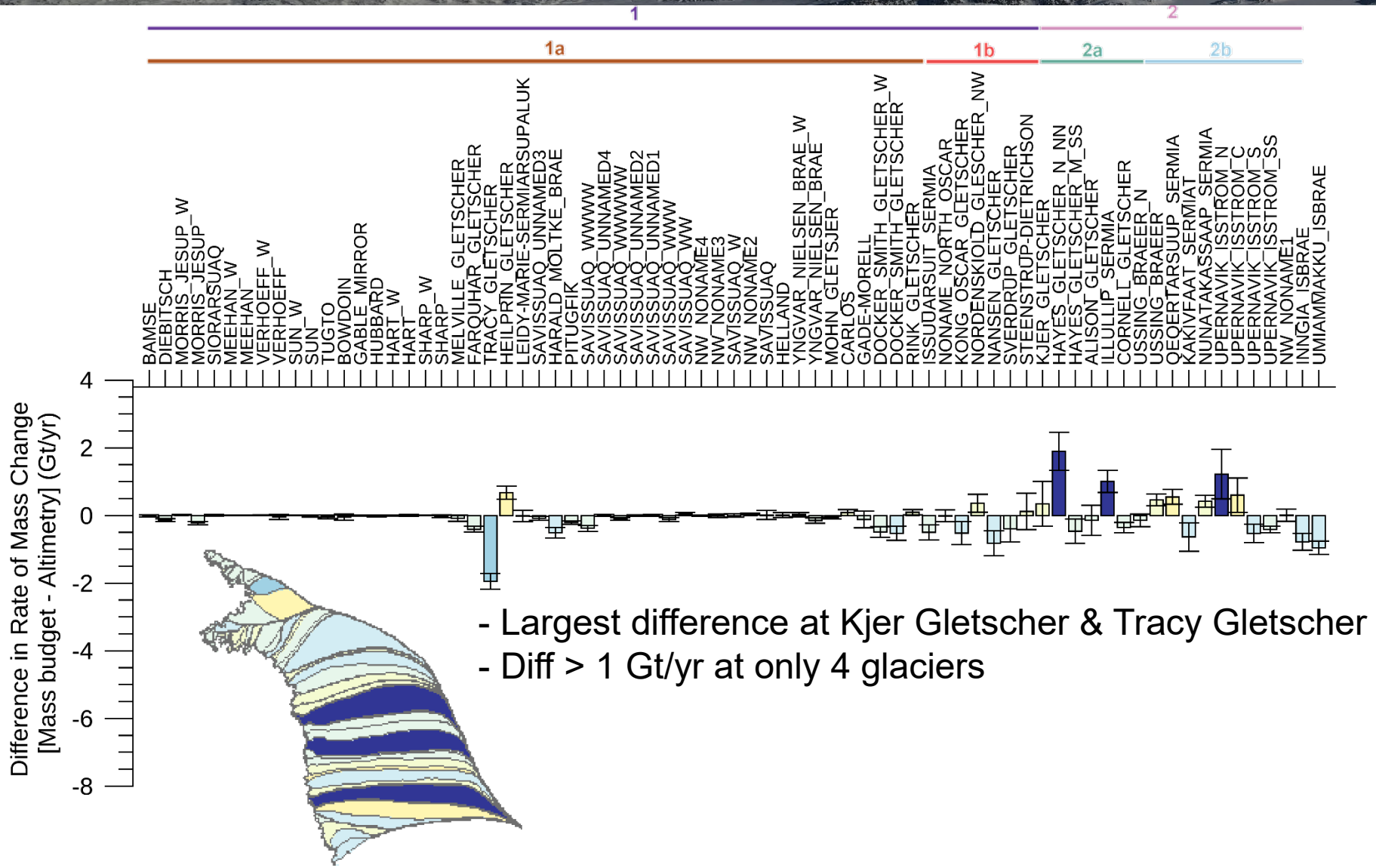
Large spread of all three estimates

All techniques are in good agreement

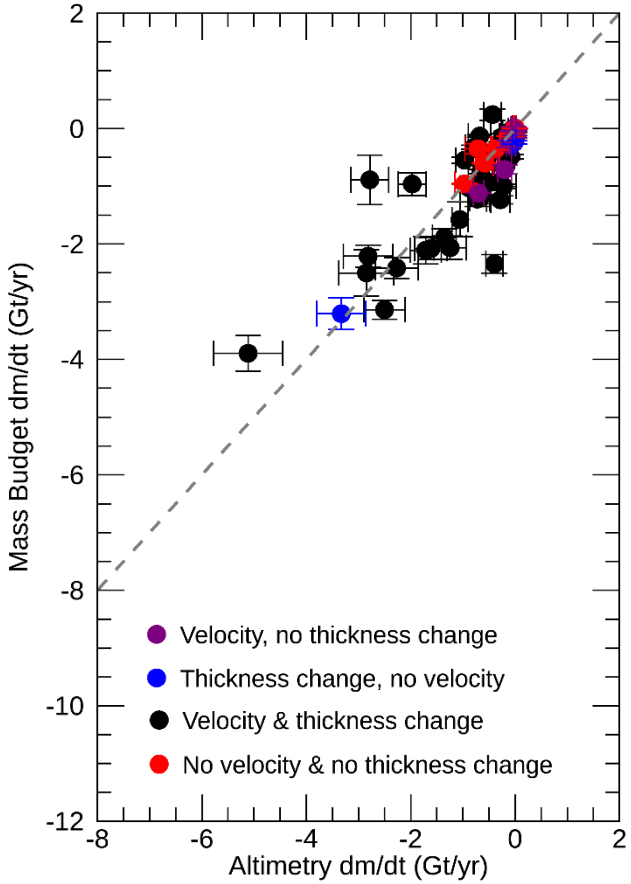
Large spread of all three estimates

All techniques are in good agreement

Comparison of altimetry and input-output in glacier basins



- Largest difference at Kjer Gletscher & Tracy Gletscher
- Diff > 1 Gt/yr at only 4 glaciers



Conclusions

- Overall there is a good agreement between CryoSat-2 and airborne laser data in elevation (0.6 m) and elevation change (6.7 cm/yr)
- The Northwest sector lost ice at a rate of 54.2 Gt/yr between 2010 and 2019
- Agreement between altimetry, gravimetry and the input-output method is variable regionally

- Now that Operation IceBridge has ended, we need to think about how to calibrate and validate CryoSat-2 and ICESat-2
- There is still more to learn on Ku/Ka radar penetration, especially in preparation for CRISTAL
- More CryoVEx tracks with Ku/Ka/Laser in Greenland and Antarctica would be useful for CRISTAL

ESA CryoVEx 2022 EGIG line campaign