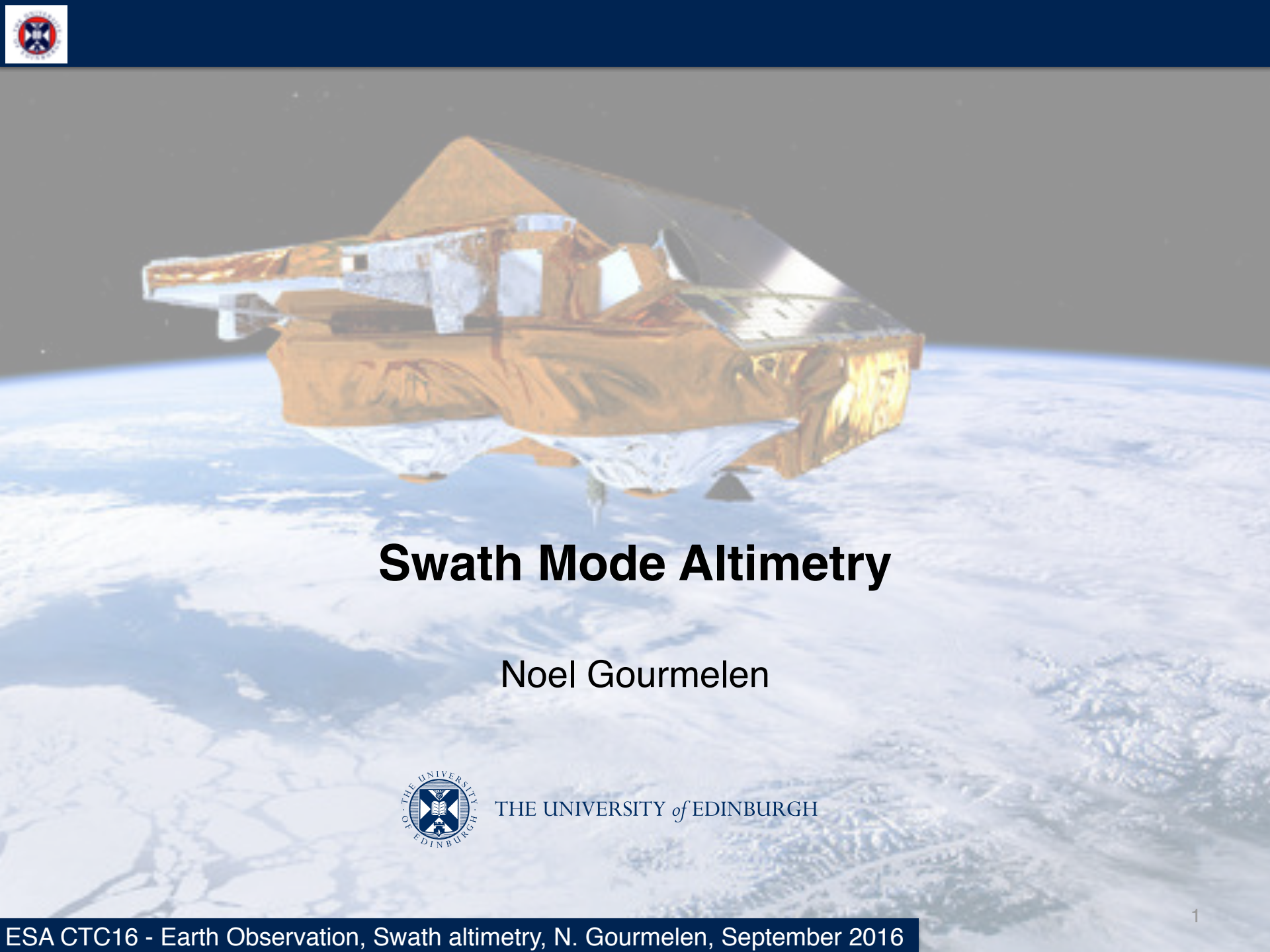


Swath Mode Altimetry

Noel Gourmelen

THE UNIVERSITY of EDINBURGH

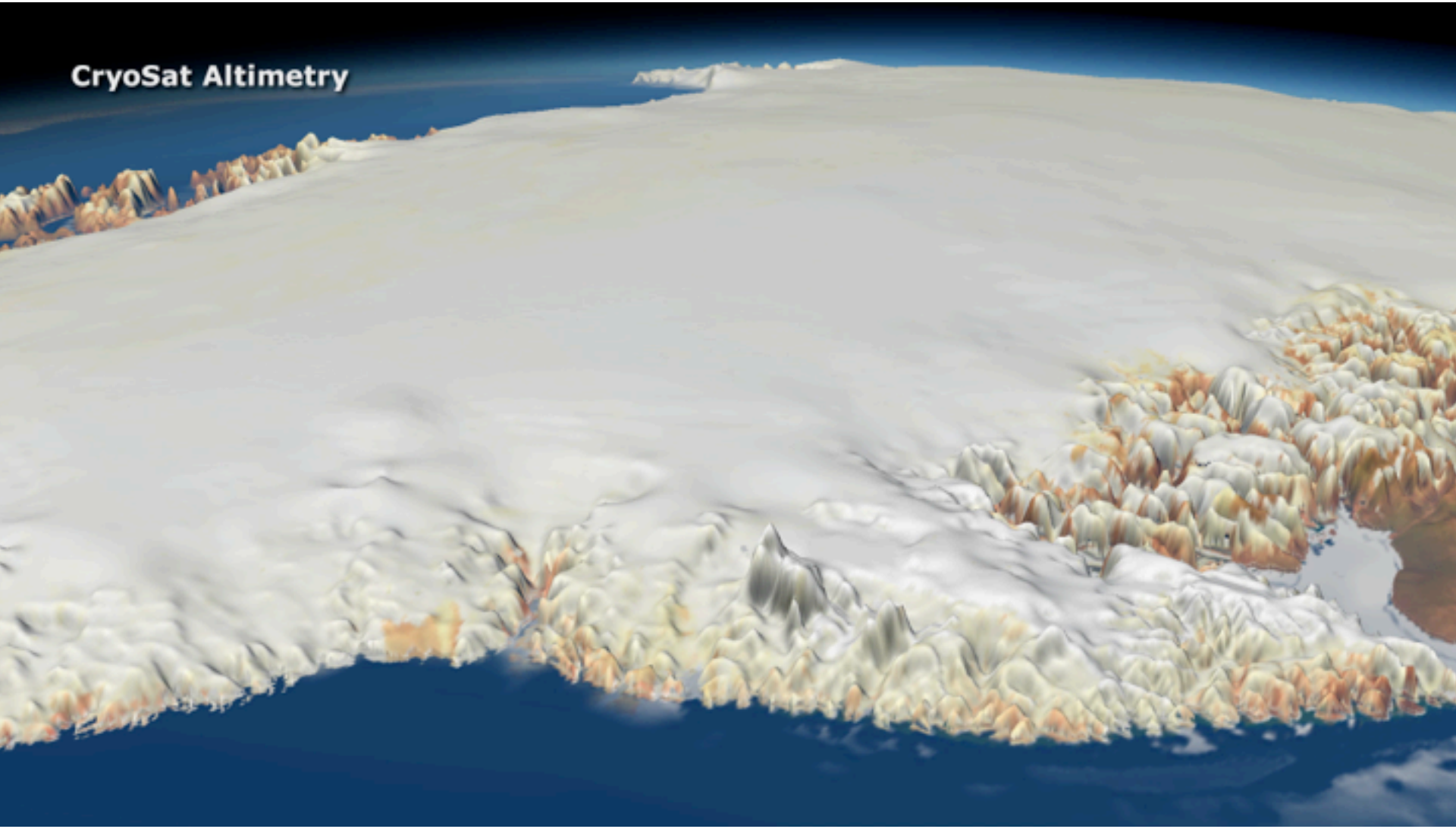
Outline

- Background
- Impact case studies:
  - Topography
  - Rates of surface elevation change

Products and applications of radar altimetry over Ice Sheet, Ice Caps, Glaciers:

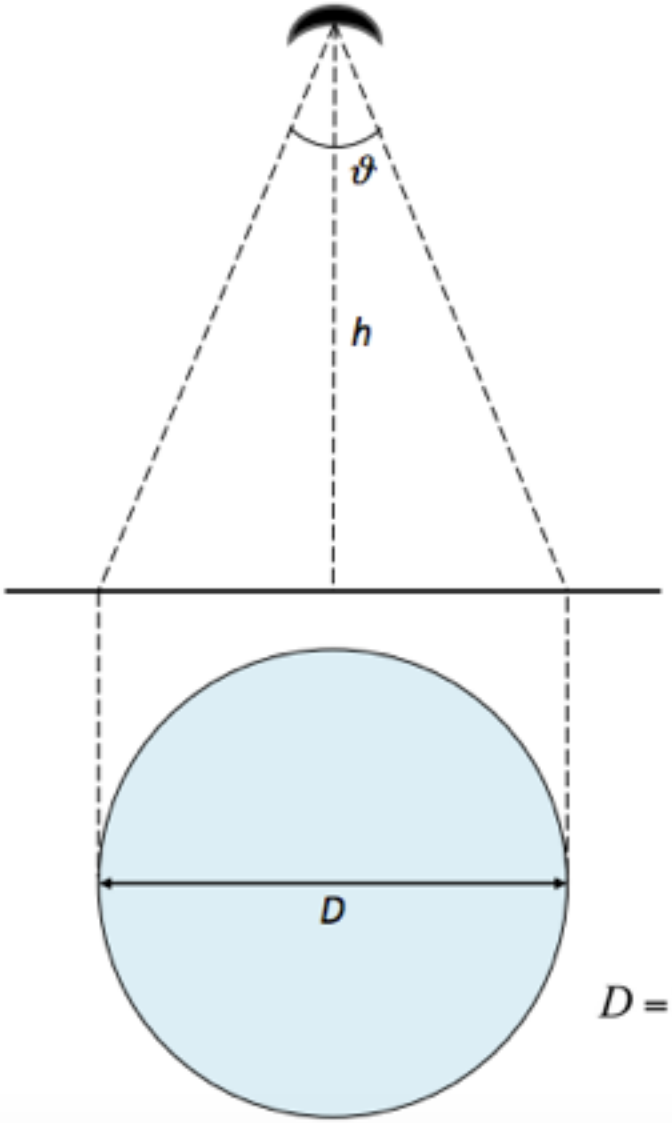
- Surface elevation
- Scattering mechanism
- Surface roughness
- Digital elevation models
- Rates of surface elevation change
- Ice Sheet mass balance
- Surface Mass Balance
- Ice dynamics (e.g. surges)
- Sub-glacial lakes detection
- Supra-glacial lakes detection
- …

POCA



POCA is only a small sample of the data acquired

Beam limited footprint



$$D = 2h \cdot \tan(\vartheta/2)$$

For CryoSat:
h ~ 730 km
ϑ =1.08° in along-track
ϑ = 1.20° in across-track

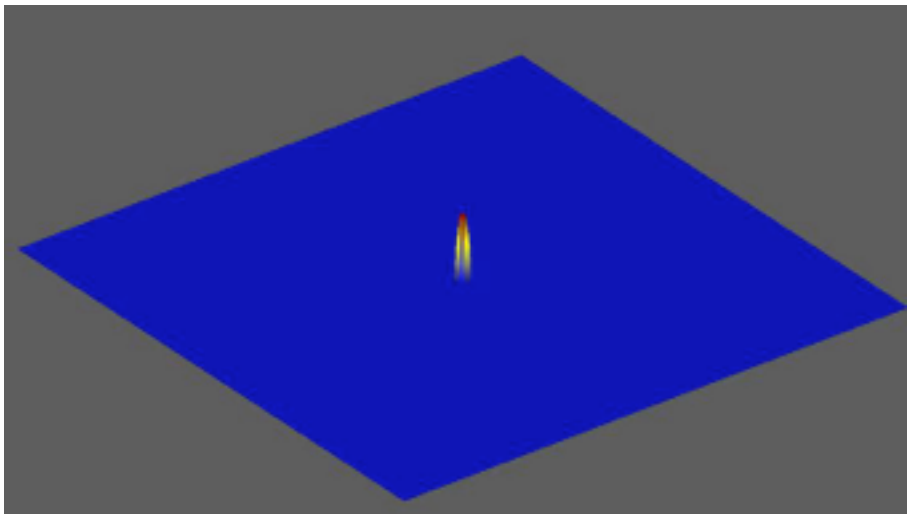
- width in along-track ~ 13.8 km
- width in across-track ~ 15.3 km

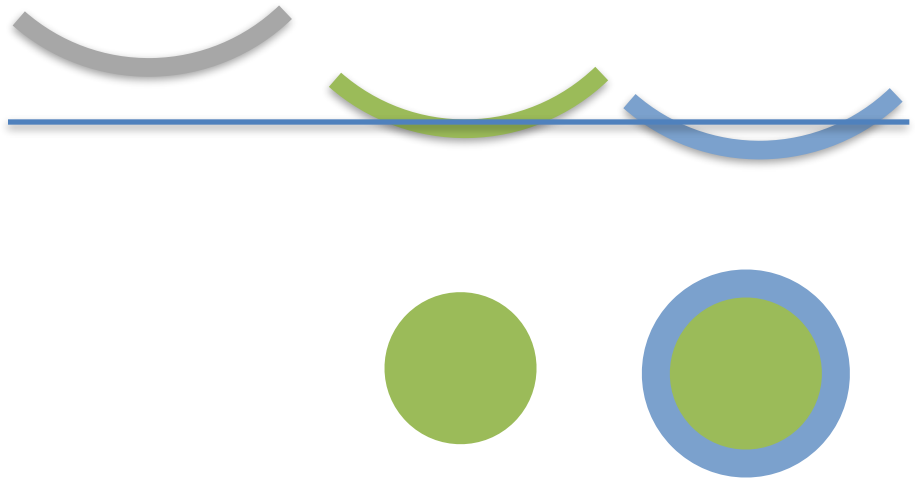
POCA is only a small sample of the data acquired

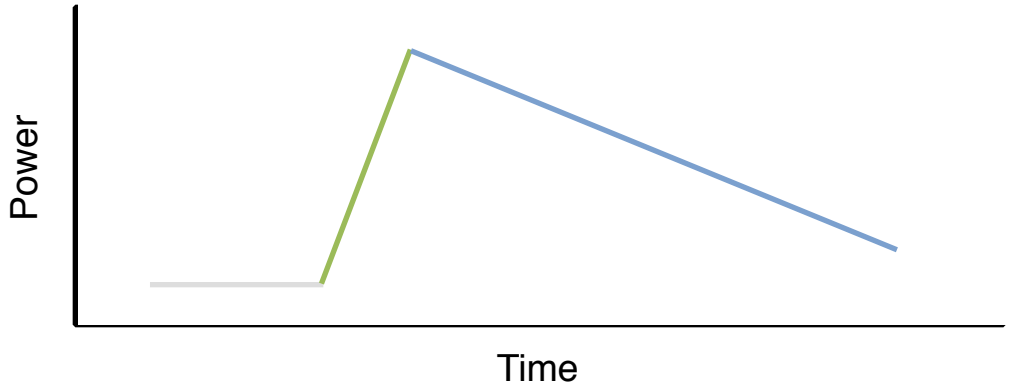
Pulse-limited footprint

$$r = \sqrt{h\frac{c}{B}}$$

For CryoSat: 2r = 1.65km

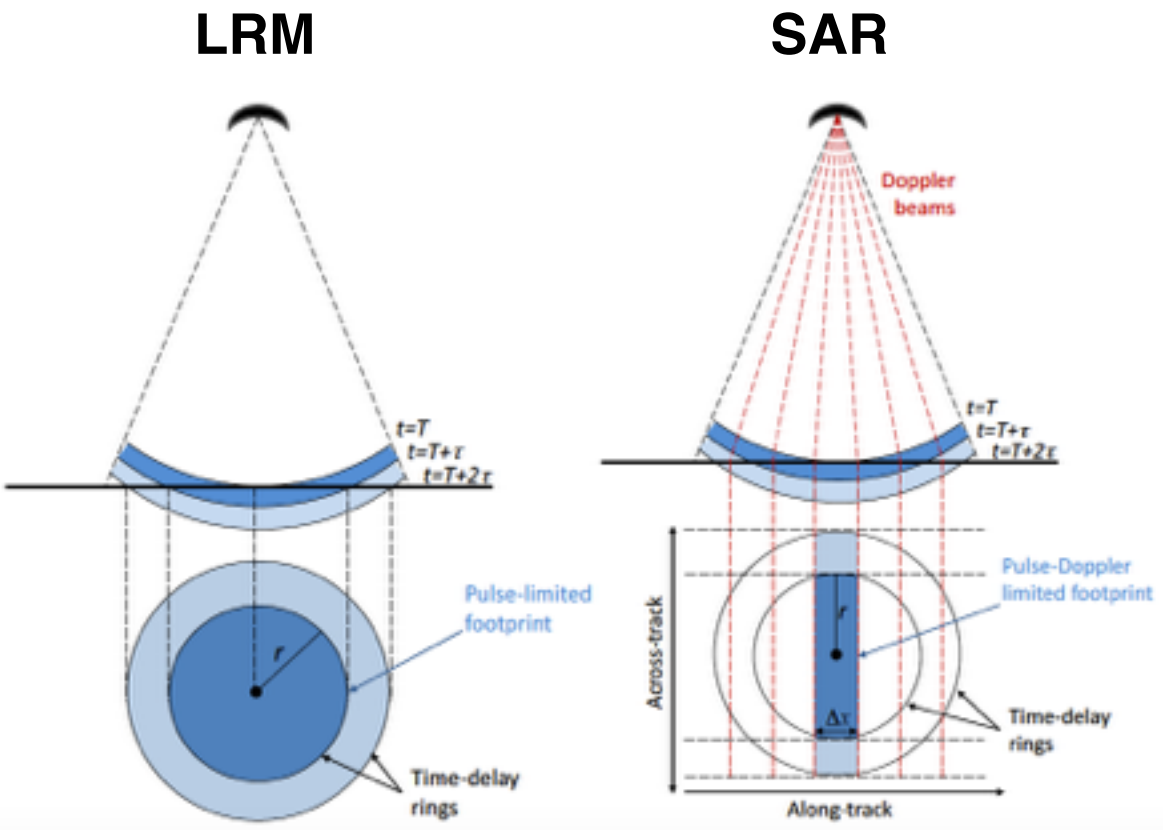






POCA is only a small sample of the data acquired

CryoSat - Improved spatial resolution

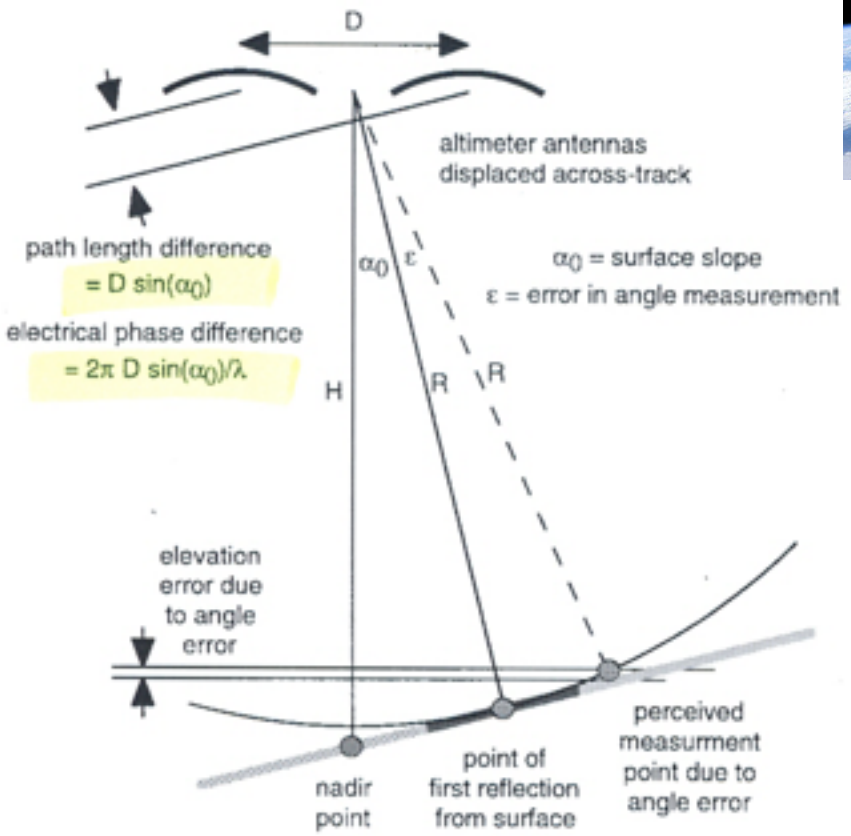


$$\Delta x = h\frac{\lambda}{2 \cdot N \cdot v}PRF$$

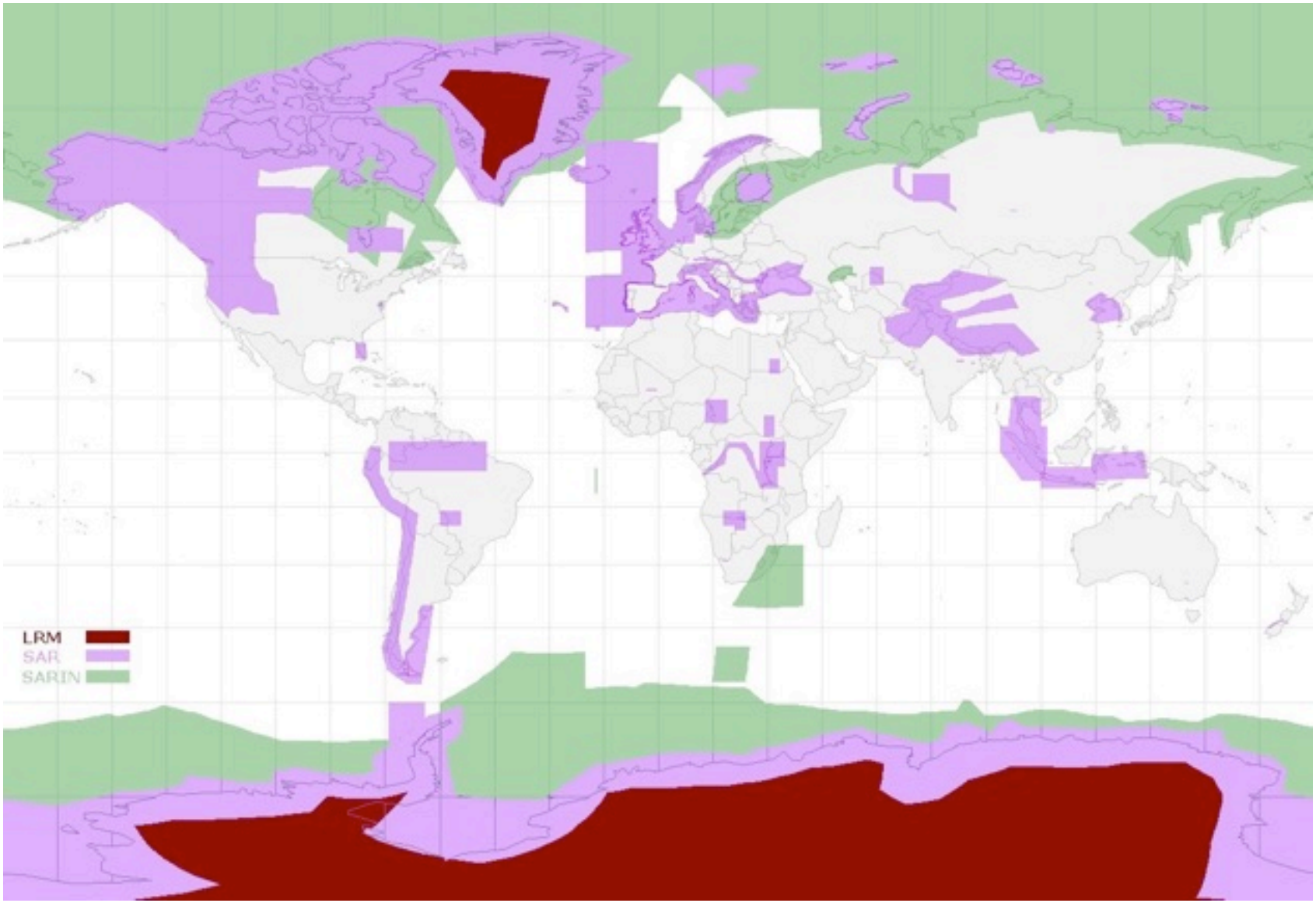
POCA is only a small sample of the data acquired

CryoSat - Improved echo localisation

Interferometric mode (SARIn)

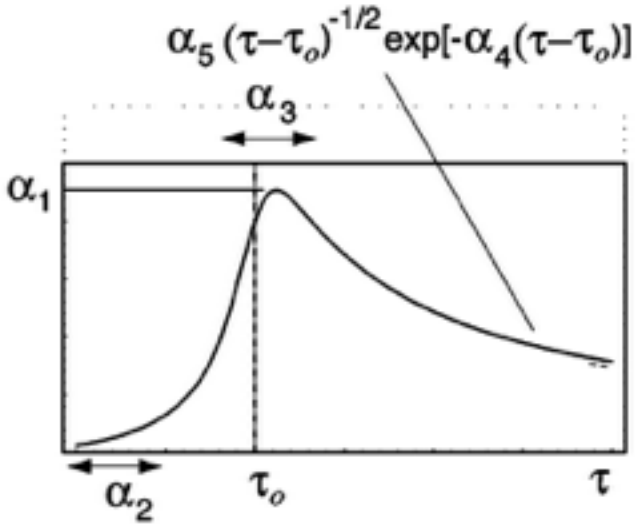


CryoSat - Modes mask



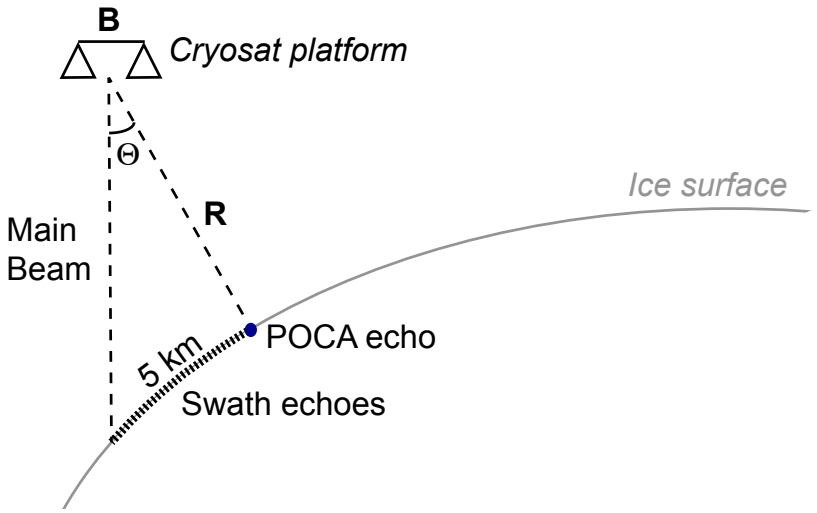
Single measurement vs full waveform, POCA elevation vs Swath elevation

Elevation at POCA

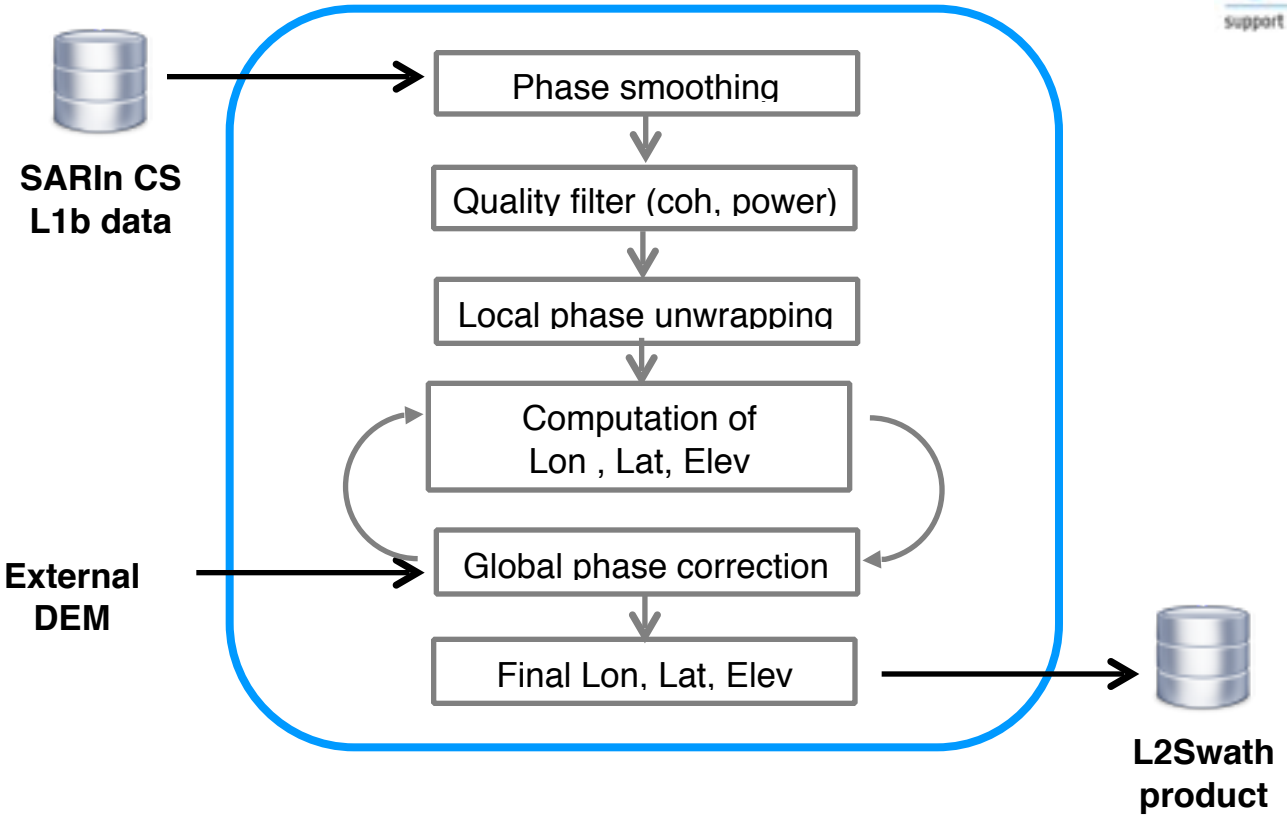


Wingham et al., 2006

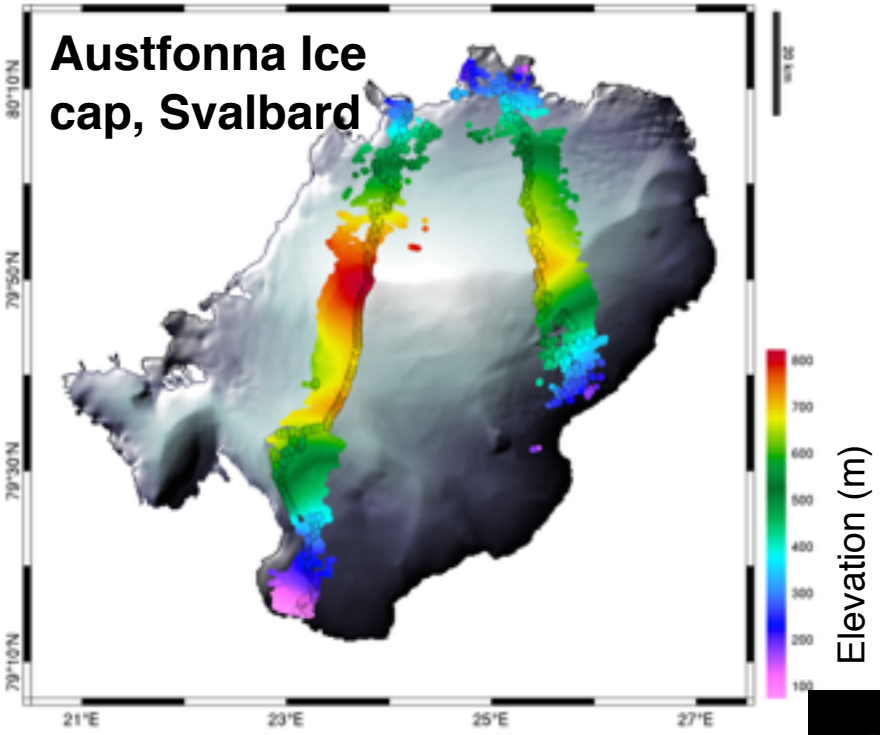
Elevation swath along the across track direction



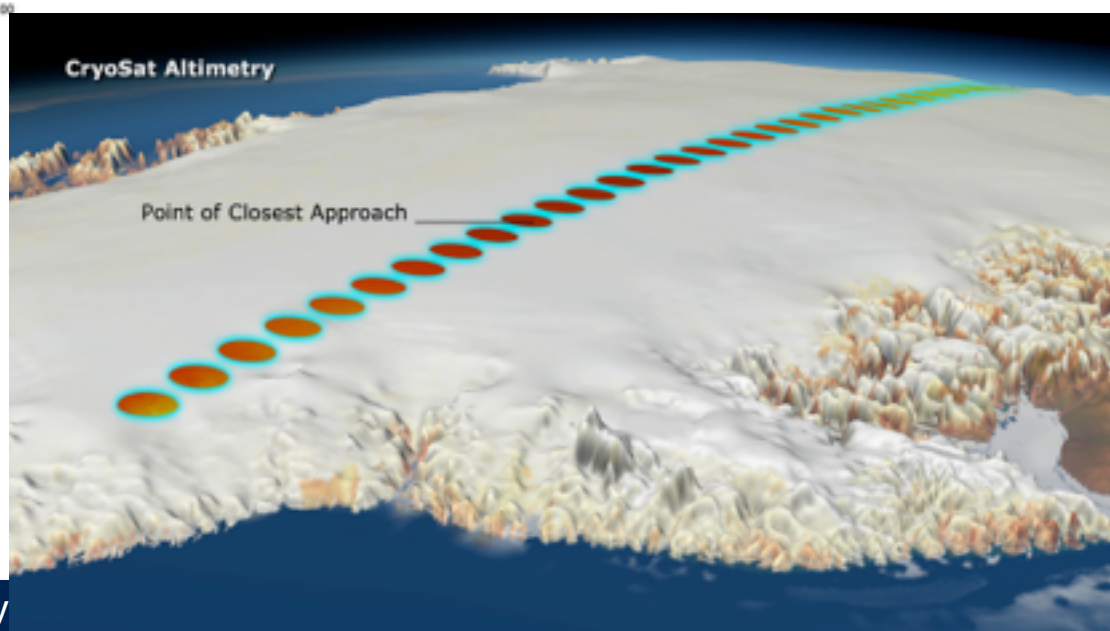
Strategy


SARIn CS
L1b data
Phase smoothing
Quality filter (coh, power)
Local phase unwrapping
Computation of
Lon , Lat, Elev
External
DEM
Global phase correction
Final Lon, Lat, Elev
L2Swath
product

Swath altimetry



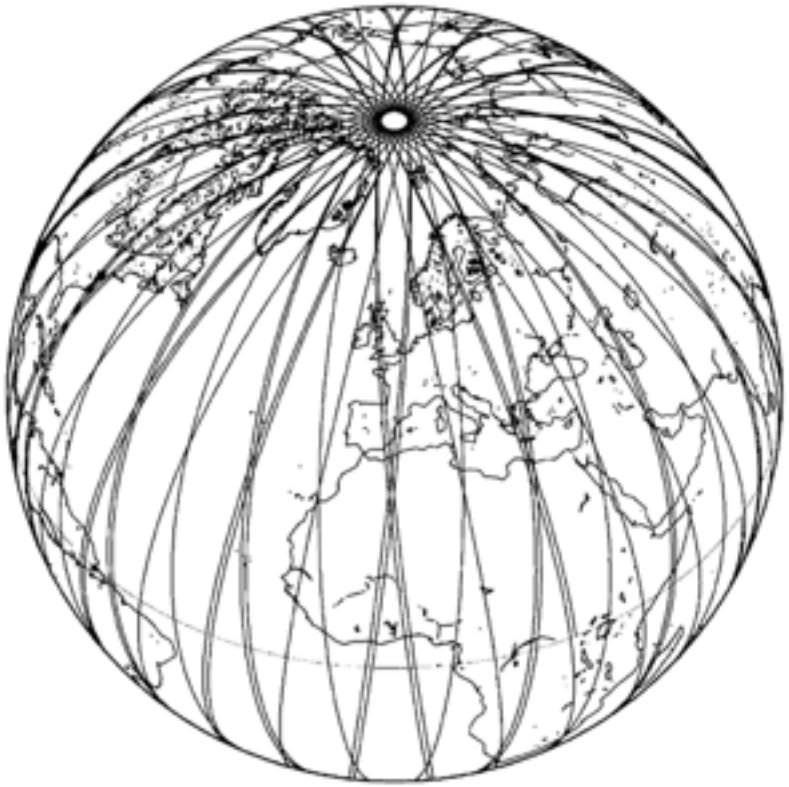
- Swath width of ~5 km
- 1 to 2 orders of magnitude more elevation than POCA



Ground track spacing

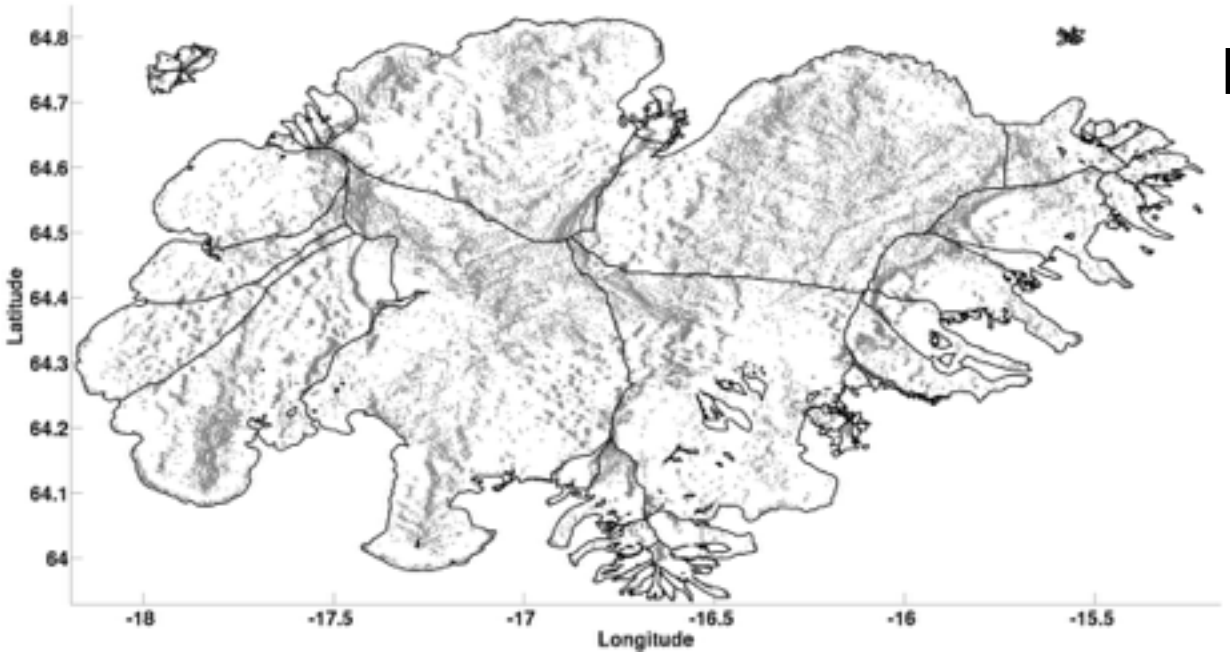
Ground tracks

At the equator: ERS: 90 km ; IceSat: 14.5 km
CryoSat: **7.5 km** (~**4km** at 60^{o} of latitude)



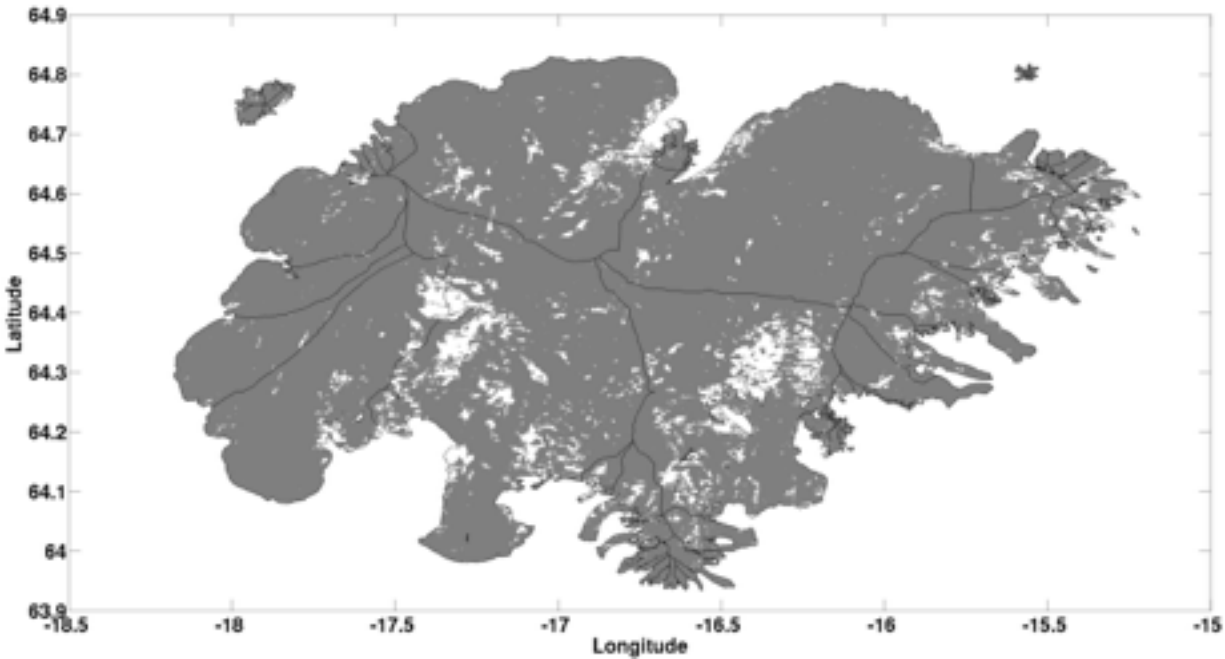
Wingham et al., 2006

Spatial coverage



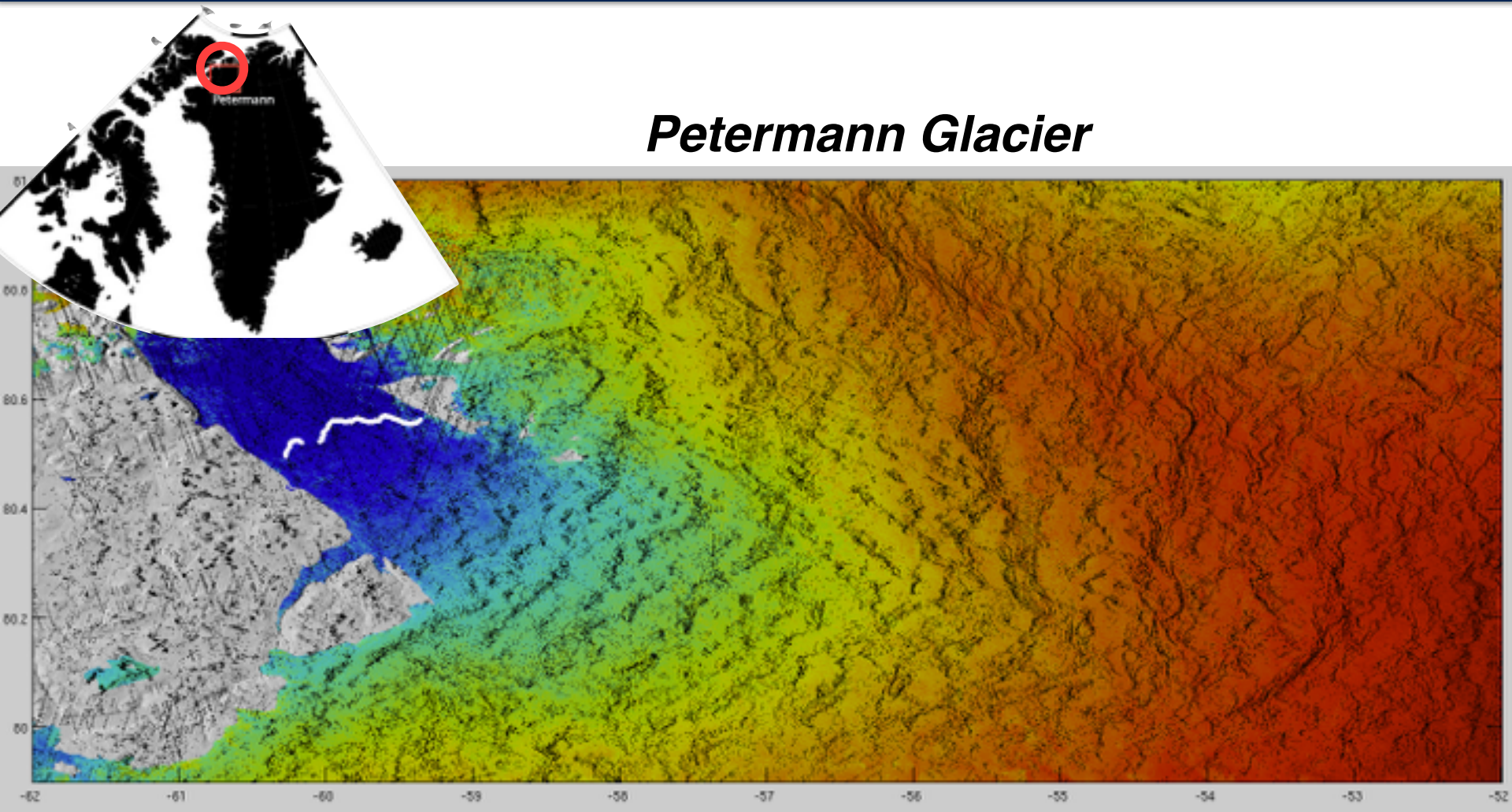
POCA

Vatnajokul ice cap

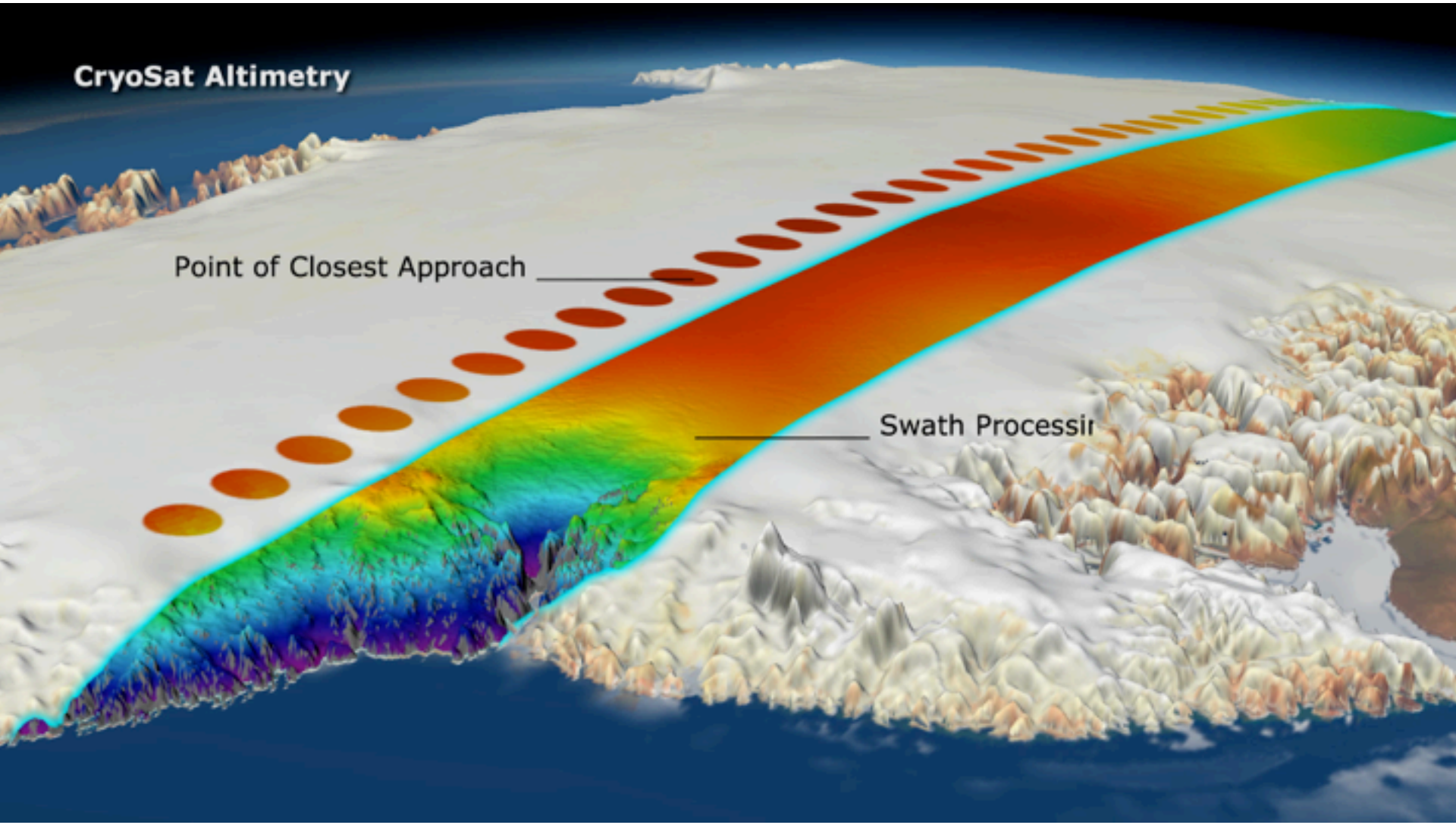


Swath

Spatial coverage



Swath allows near continuous spatial coverage



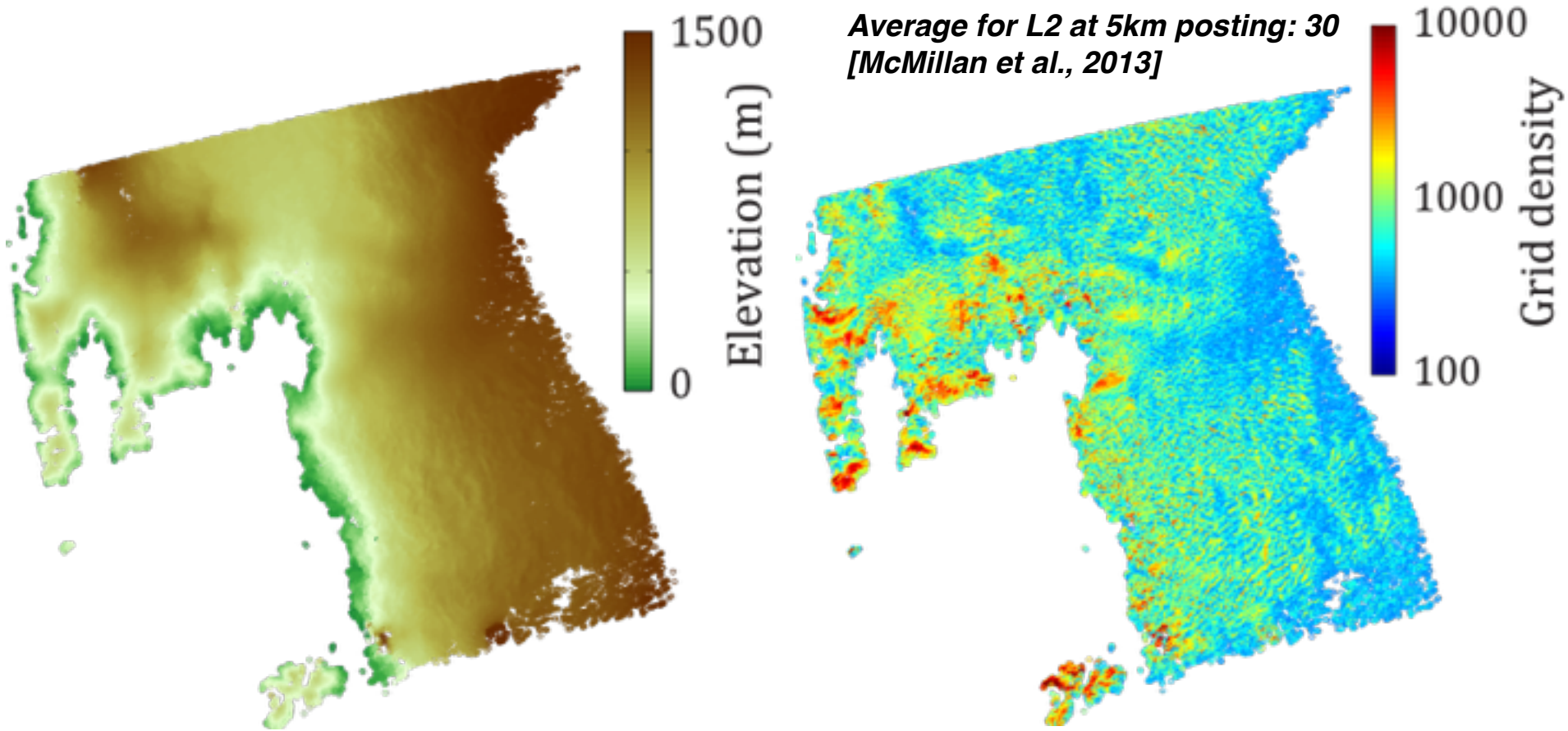
Surface topography

Spatial coverage - Gridded product

Deriving rates of surface elevation change and topography

1. Group data in grid cells

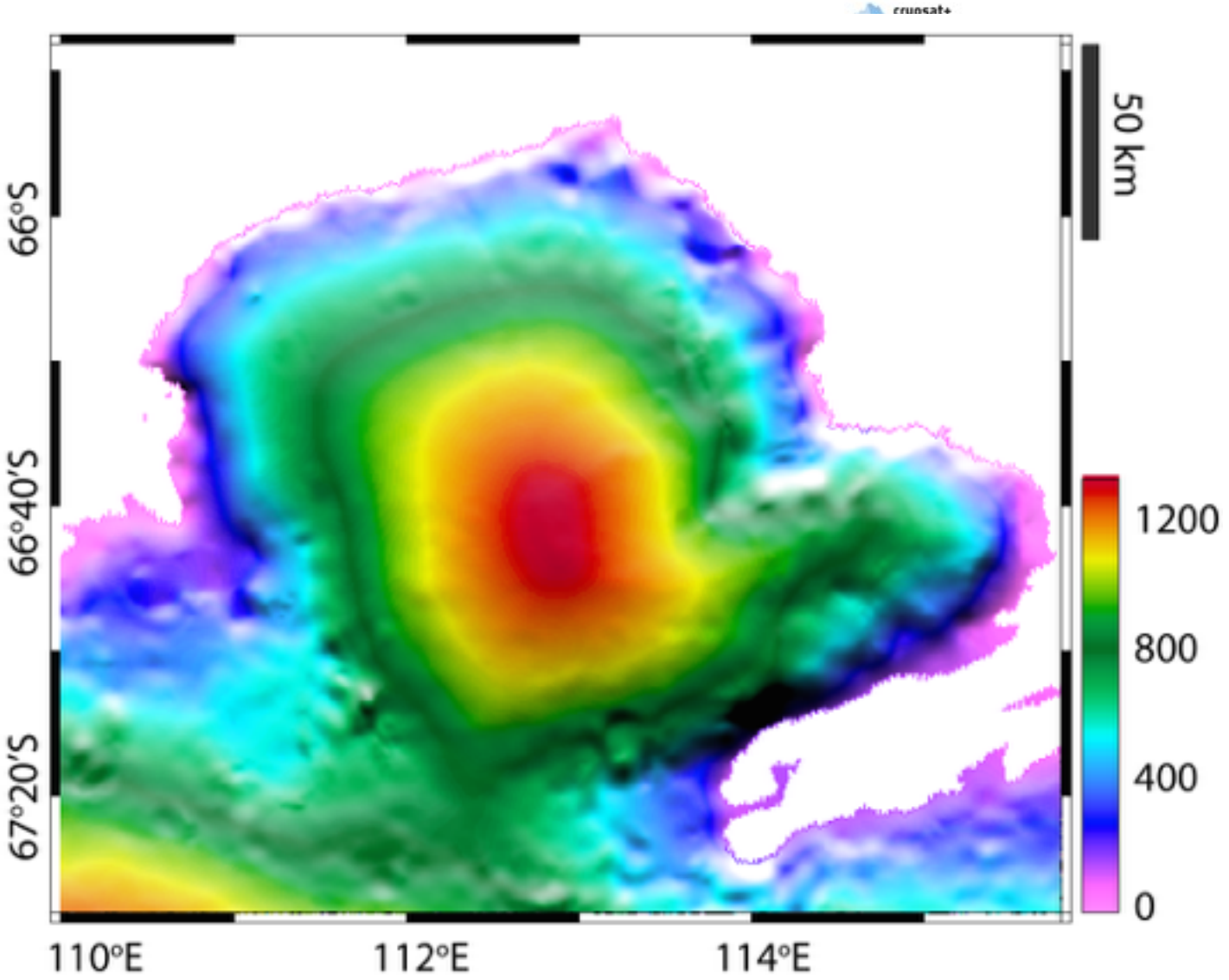
2. Solve a model of the type: Z(x,y,t)=ax+by+c+dt , where topography, Z, local terrain slope, (x, y), and rates of surface elevation change, dt, are conjointly resolved



Amundsen Sea Sector (1 km posting)

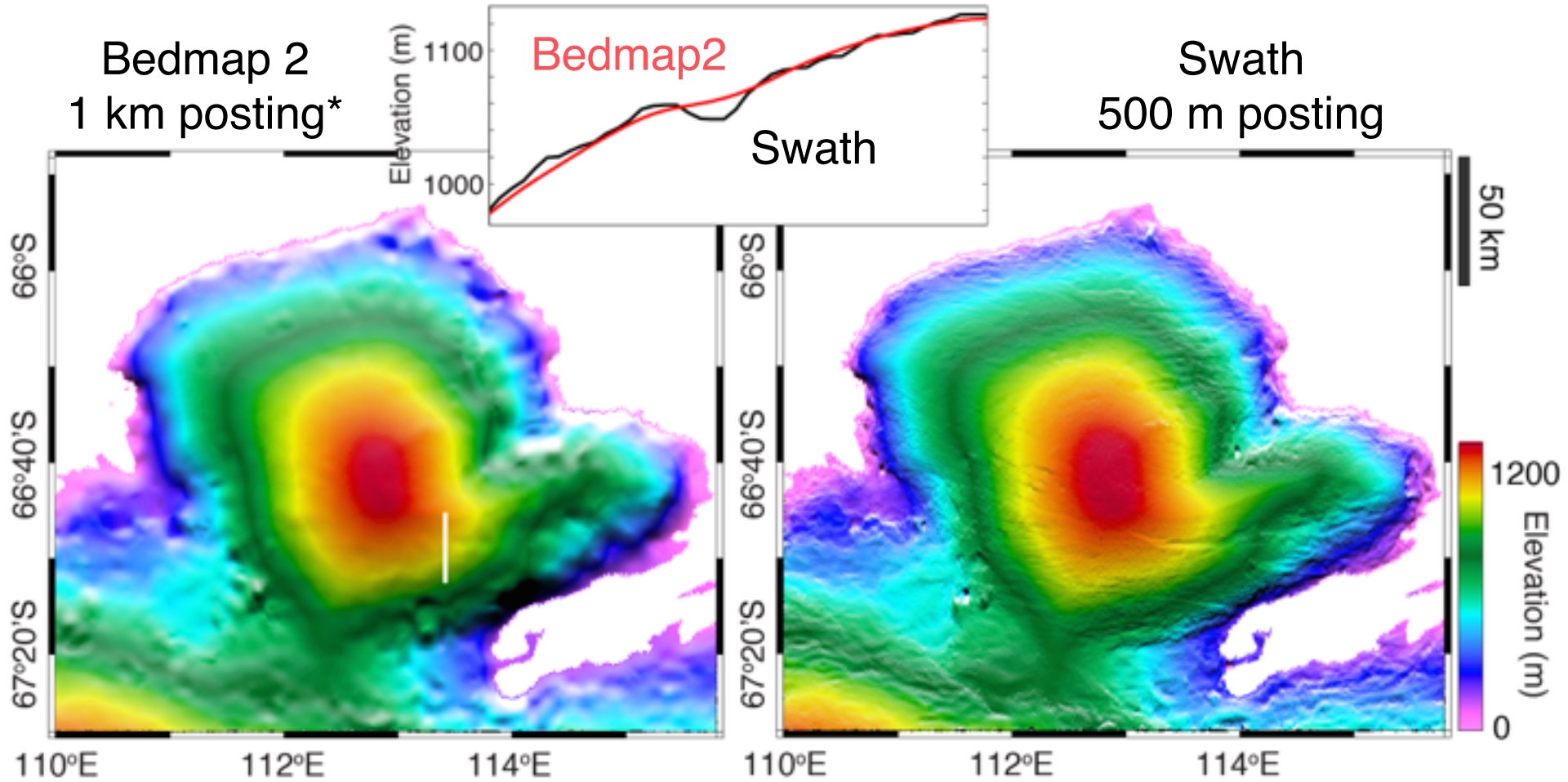
High resolution surface topography

Law dome, East Antarctica



High resolution surface topography

Law dome, East Antarctica

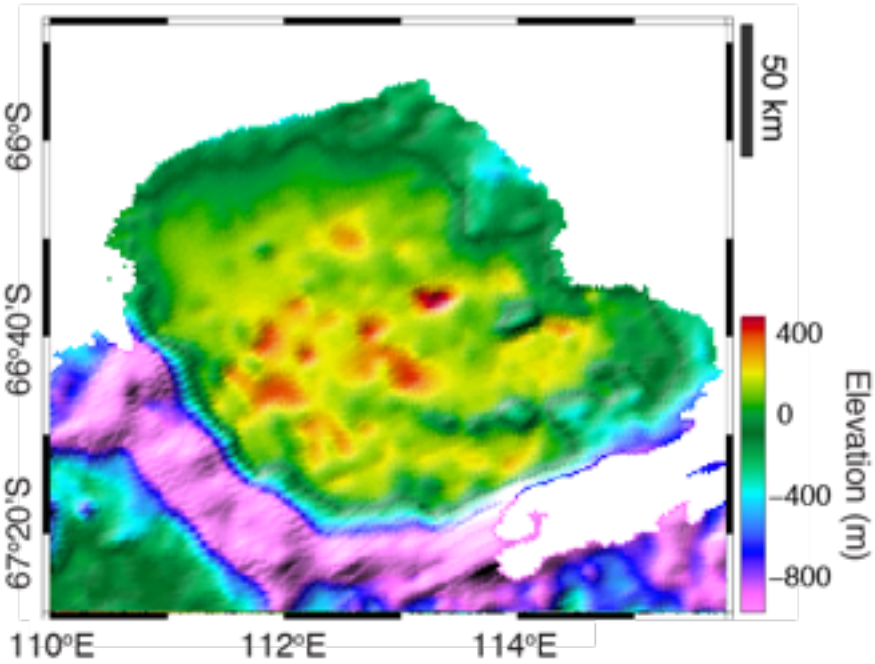


** true resolution is > 7.5 km*

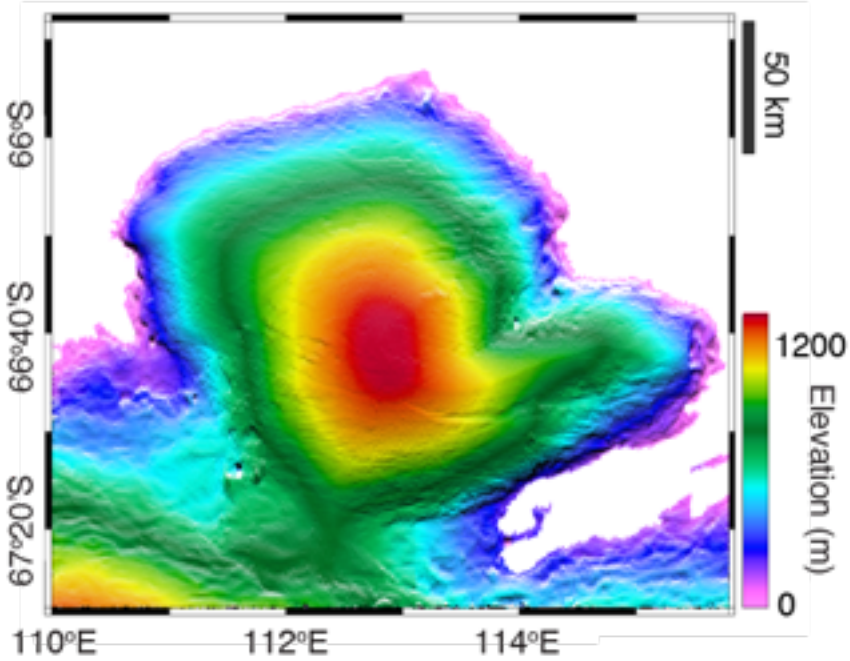
High resolution surface topography

Law dome, East Antarctica

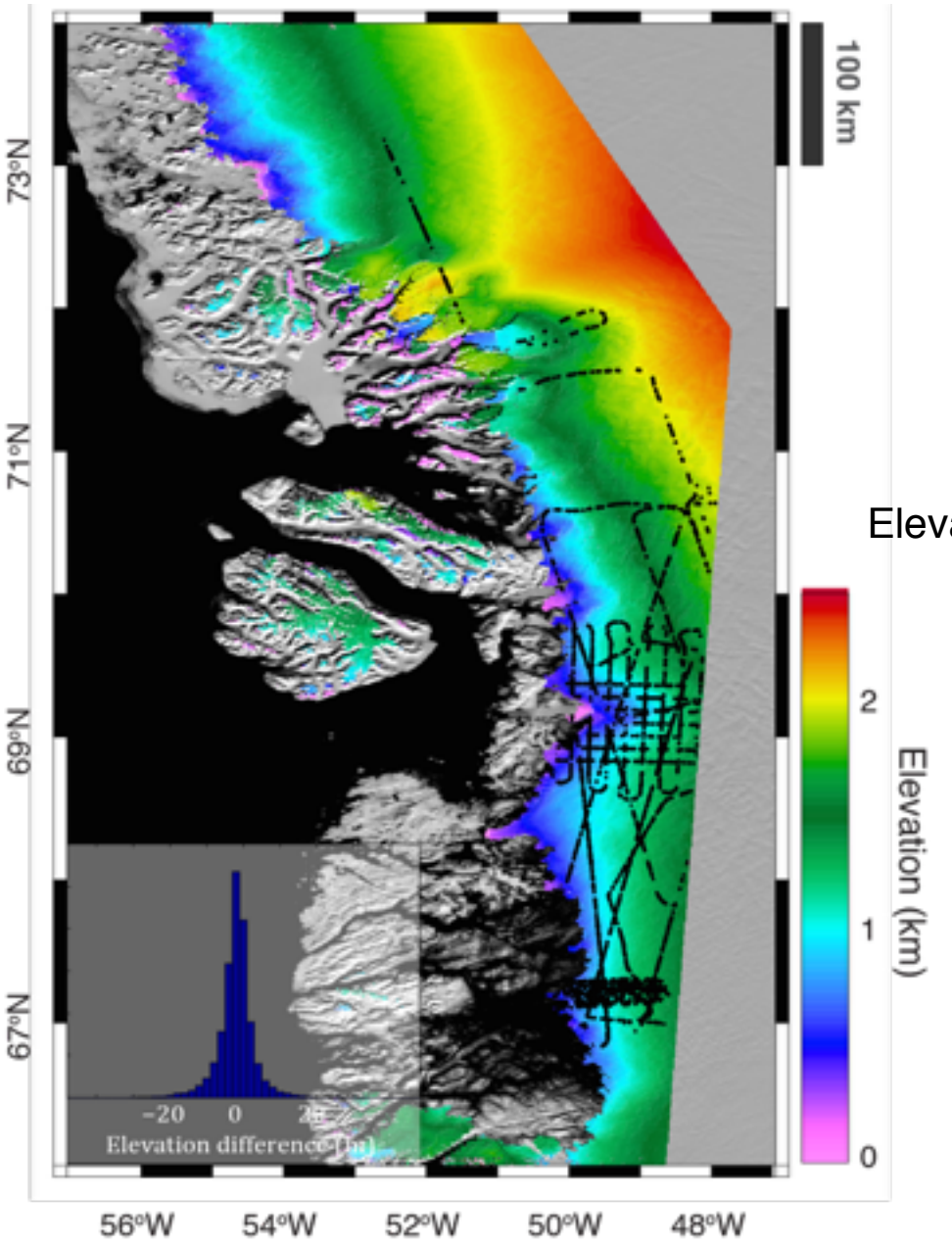
Bed topography



Surface topography



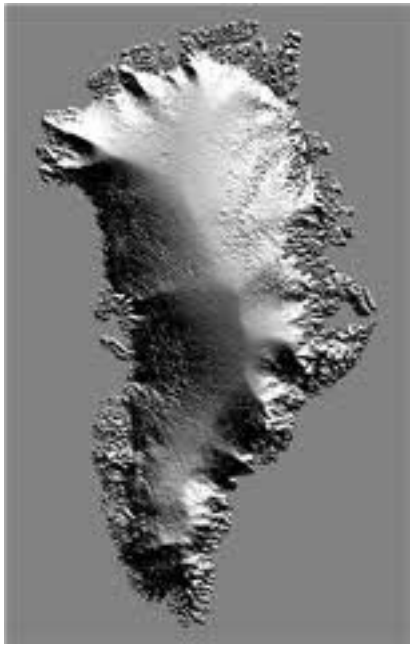
High resolution surface topography



Elevation difference with Ice Bridge ATM:

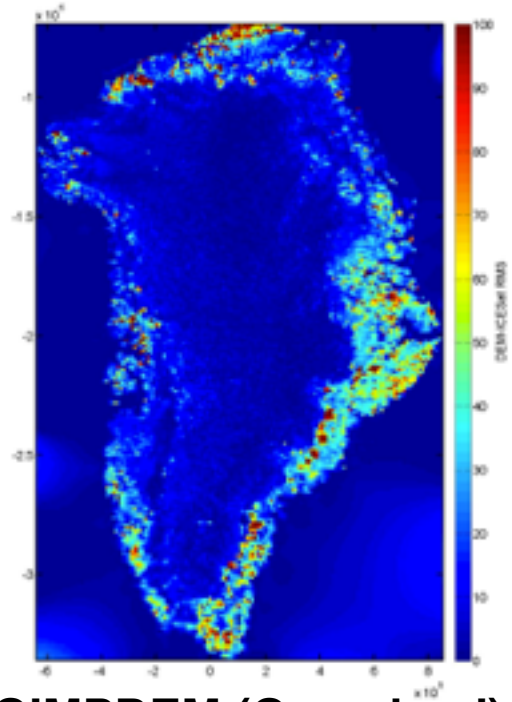
-1.2 ± 2 m.yr^{-1}

Best currently available DEM products



IceSat DEM (Greenland & Antarctica)

- 1km posting (real resolution ~ 7.5 km on average elsewhere)
- for slopes <0.1°: mean difference is 1 ±5 m;
- for regions 0.1°<slope<1.0° slopes, the mean difference is -24 ±20 m



GIMPDEM (Greenland)

- 30m posting (only on the margins, ~ 7.5km on average elsewhere)
- RMSE with IceSAT DEM, compared on grid of 10km bin size > 100m

Measurements accuracy and density

L2swath versus L2 - CryoTop study

Region	L2swath/L2 Bias (m)	L2swath/L2 Dispersion (m)	L2swath/L2 Number of measures (10^6)	Gain in spatial resolution
Petermann	-1.3/-1.1	1.2/0.8	44.9/1.4	5 folds
Jackobshavn	-1.2/-0.6	2.0/1.4	99.9/1.0	10 folds
Amundsen Sea Sector	-1.7/-1.1	2.0/1.3	199.3/3.3	8 folds

L2 - other studies

Reference		Bias (m)	Dispersion (m)
(L2) [RD1]	Greenland (below 2200m)	3.95	133.6
(L2) [RD2]	Cook Antarctic lake	-1.5	0.9
CryoVal RR	Jackobshavn	-0.15 to +0.41	2.44 to 2.76

RD1: Helm, V., Humbert, A. and Miller, H., 2014, Elevation and elevation change of Greenland and Antarctica derived from CryoSat-2, The Cryosphere, 8, 1539–1559, 2014 www.the-cryosphere.net/8/1539/2014/ doi:10.5194/tc-8-1539-2014

RD2: McMillan, M, Shepherd, A, Corr, H, Ridout, A, Laxon, S and Cullen, R., 2013, Three-dimensional mapping by CryoSat-2 of subglacial lake volume changes. Geophysical Research Letters, 40 (16). 4321 – 4327, http://dx.doi.org/10.1002/grl.50689

Distribution of supraglacial lakes

Geophysical Research Letters
AN AGU JOURNAL
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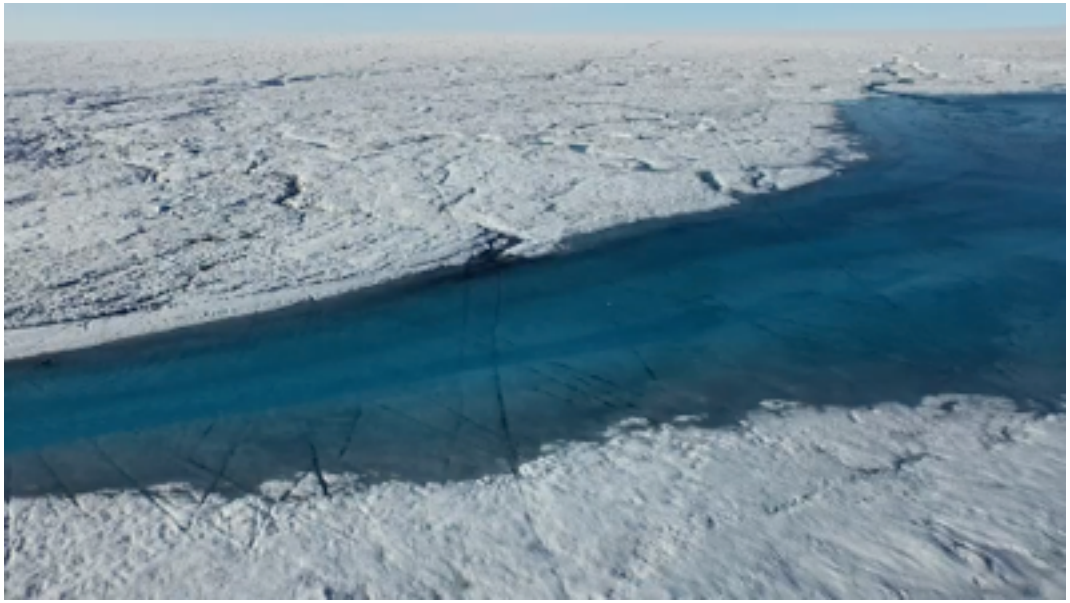
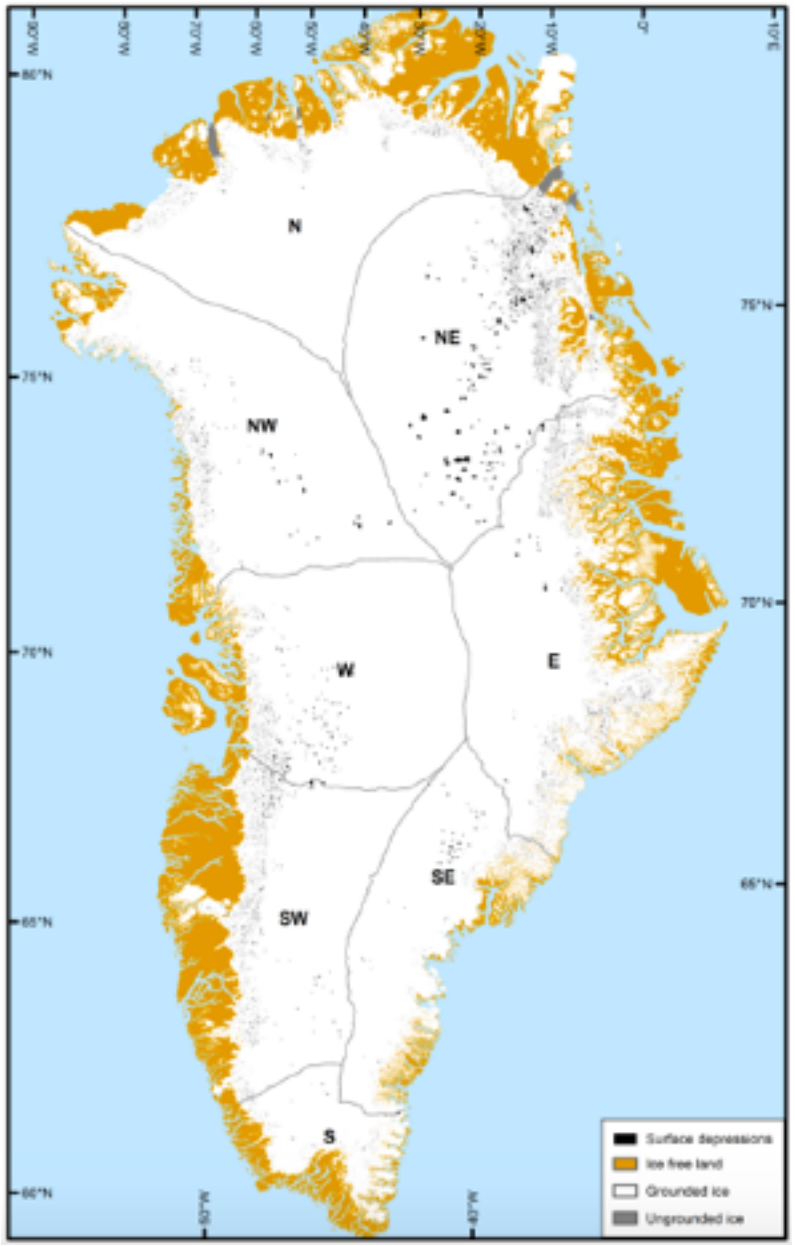
Research Letter

North-east sector of the Greenland Ice Sheet to undergo the greatest inland expansion of supraglacial lakes during the 21st century†

Ádám Ignéczi, Andrew J. Sole, Stephen J. Livingstone, Amber Leeson, Xavier Fettweis, Nick Selmes, Noel Gourmelen, Kate Briggs



NYT, 2015



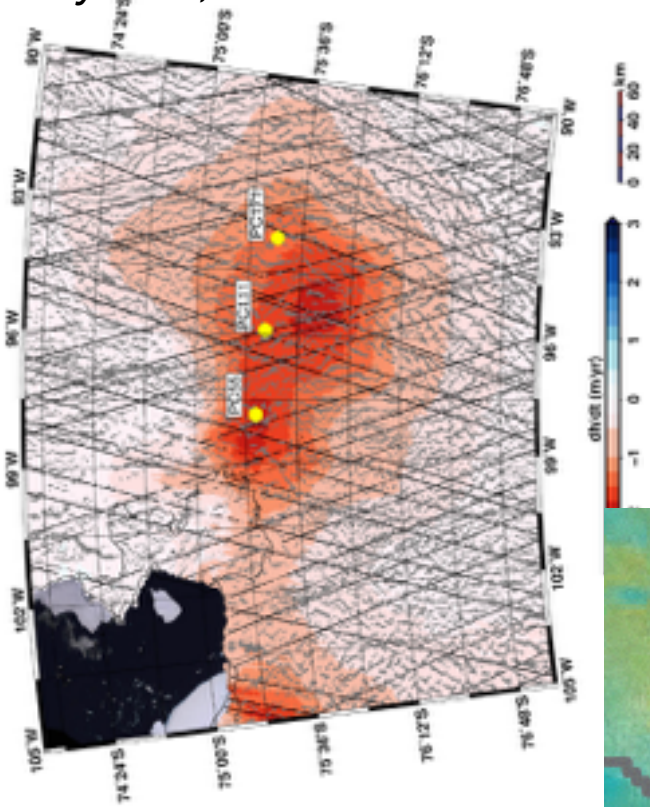
Igneczi et al., 2016

Rates of surface elevation change

Surface elevation change

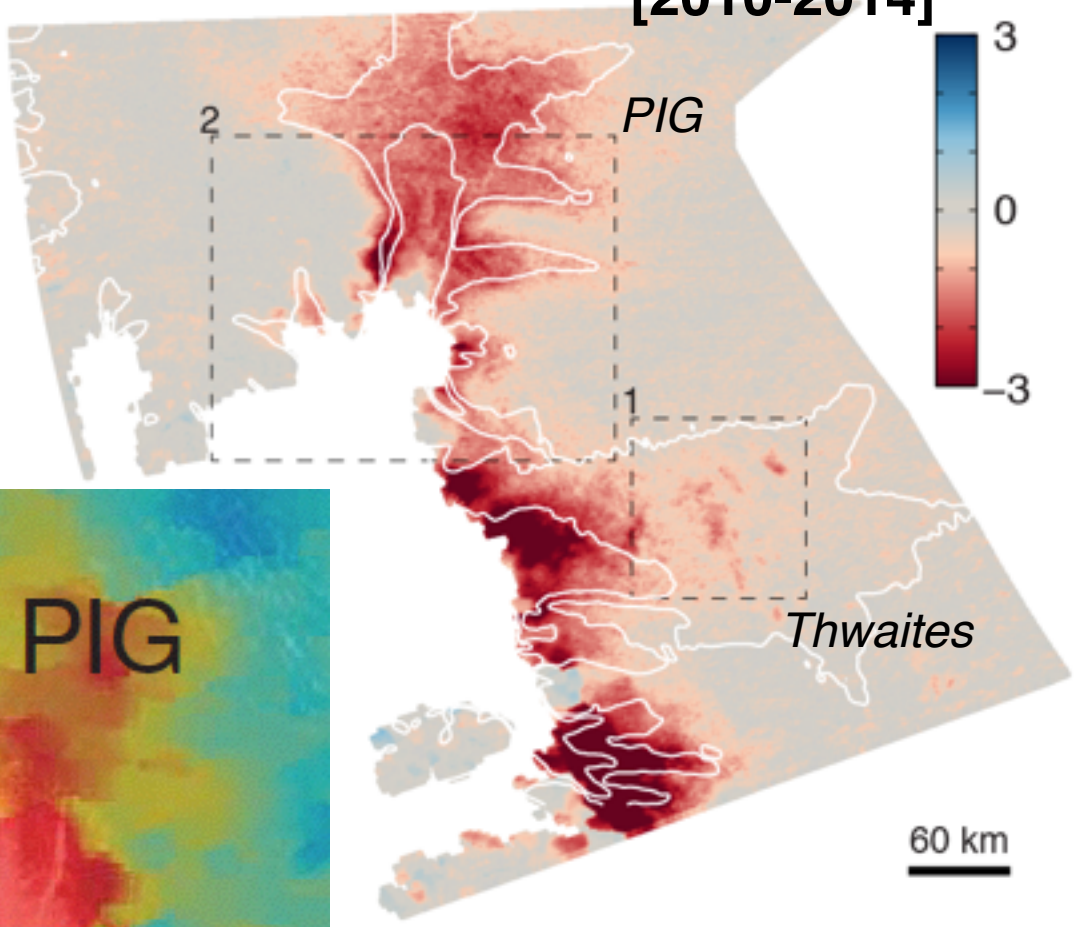
Amundsen Sea Sector

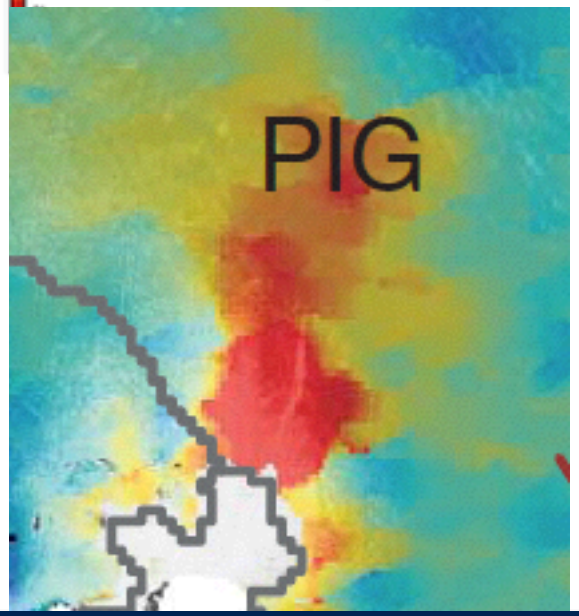
CryoSat, 'POCA' solution at 1km posting



Helm et al., 2014

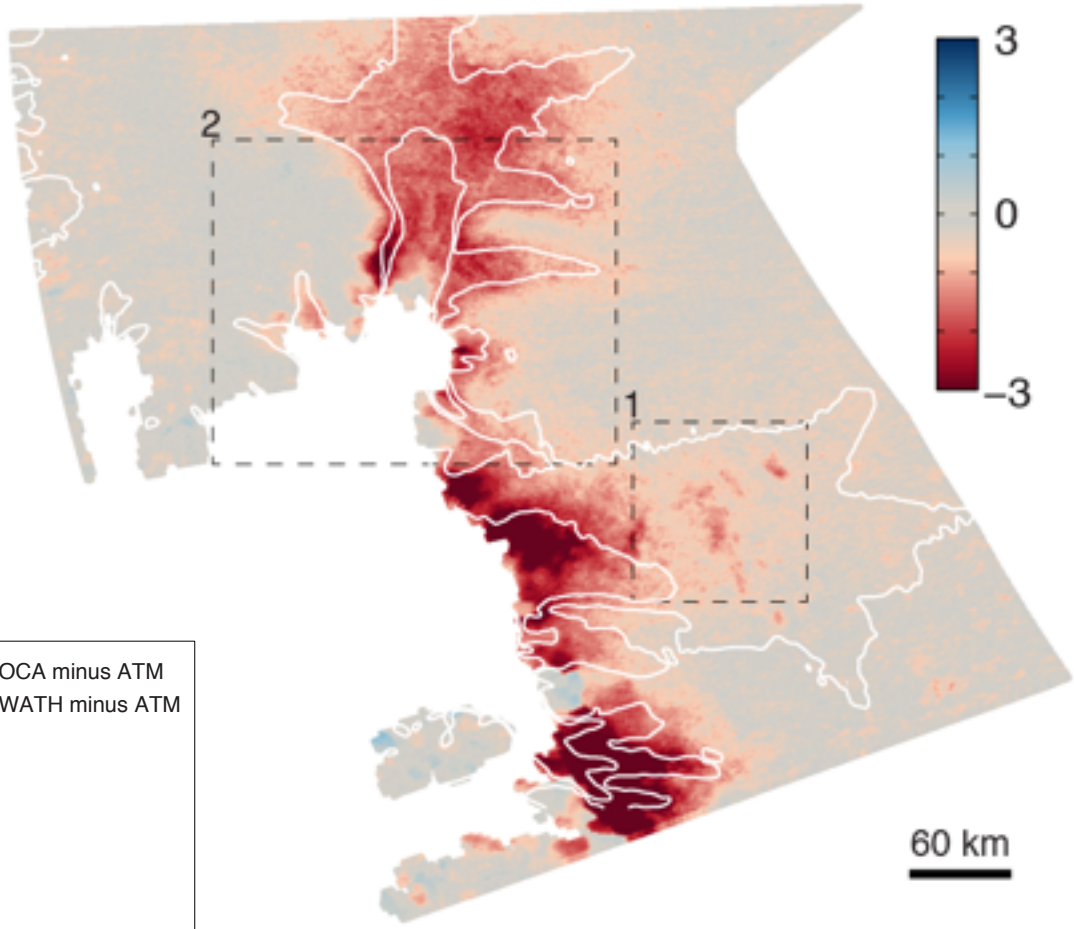
Swath - 500 m posting [2010-2014]

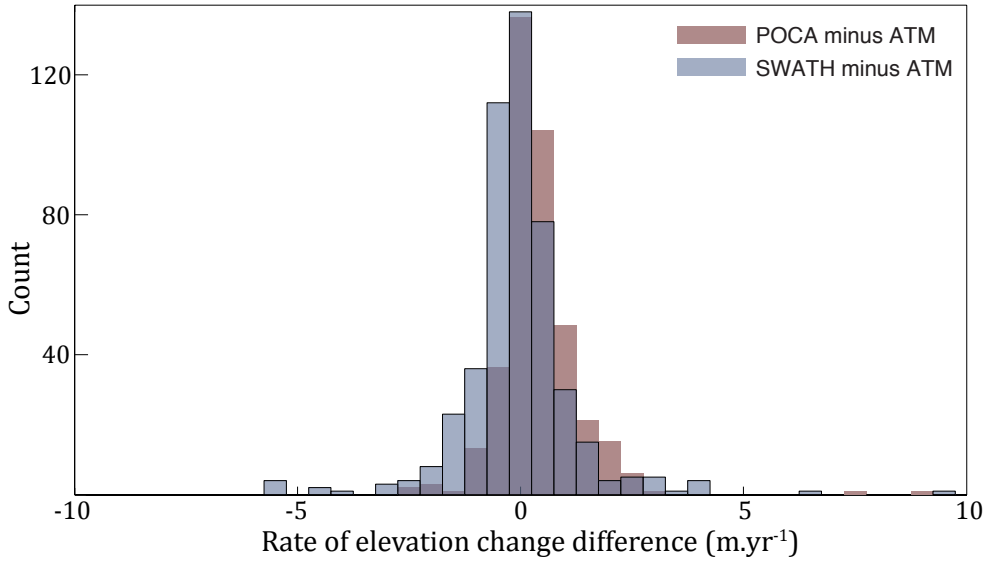




Pritchard et al., 2009

Surface elevation change - Amundsen Sea Sector



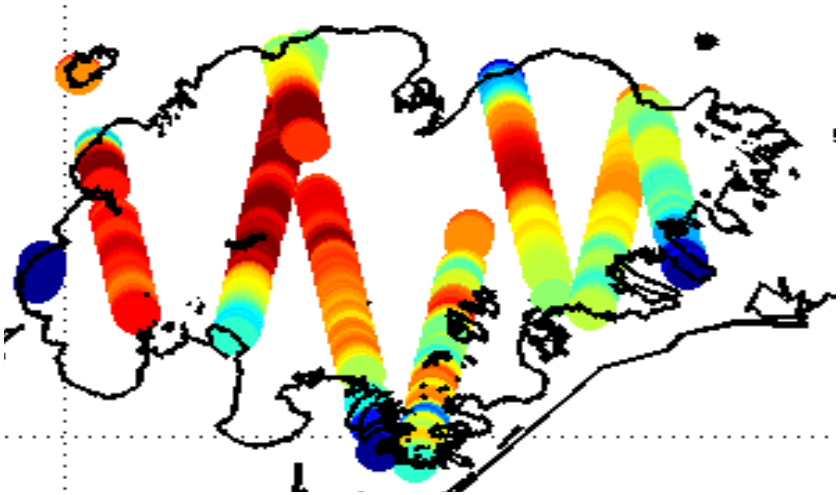


Swath: bias: 0.10 m.yr^{-1} dispersion: 0.93 m.yr^{-1}

POCA: bias: 0.40 m.yr^{-1} dispersion: 0.76 m.yr^{-1}

Surface elevation change - Vatnajokul Ice Cap, Iceland

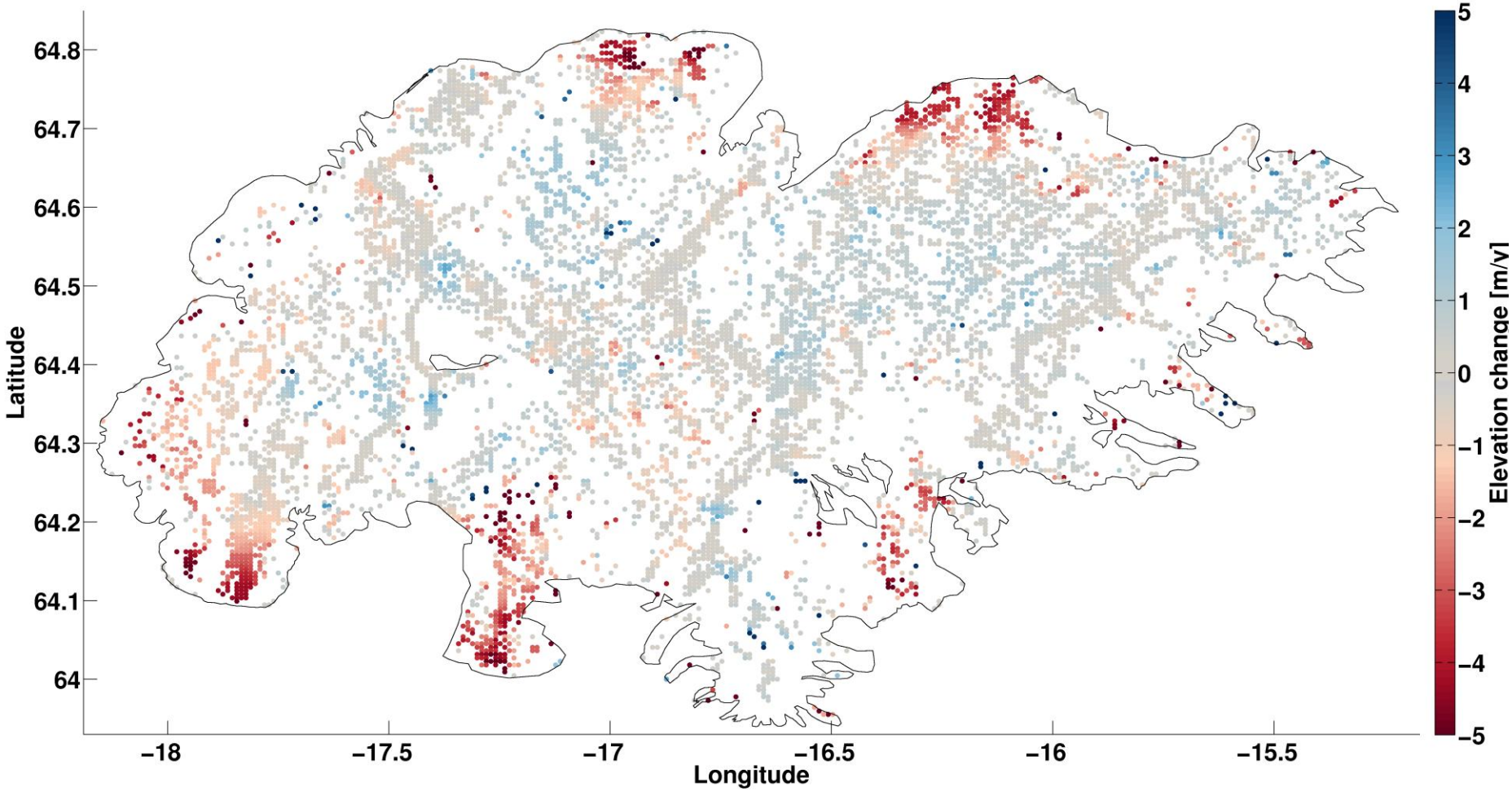
Icesat rates of surface elevation change



[*Nilsson et al., 2015*]

Surface elevation change - Vatnajokul Ice Cap, Iceland

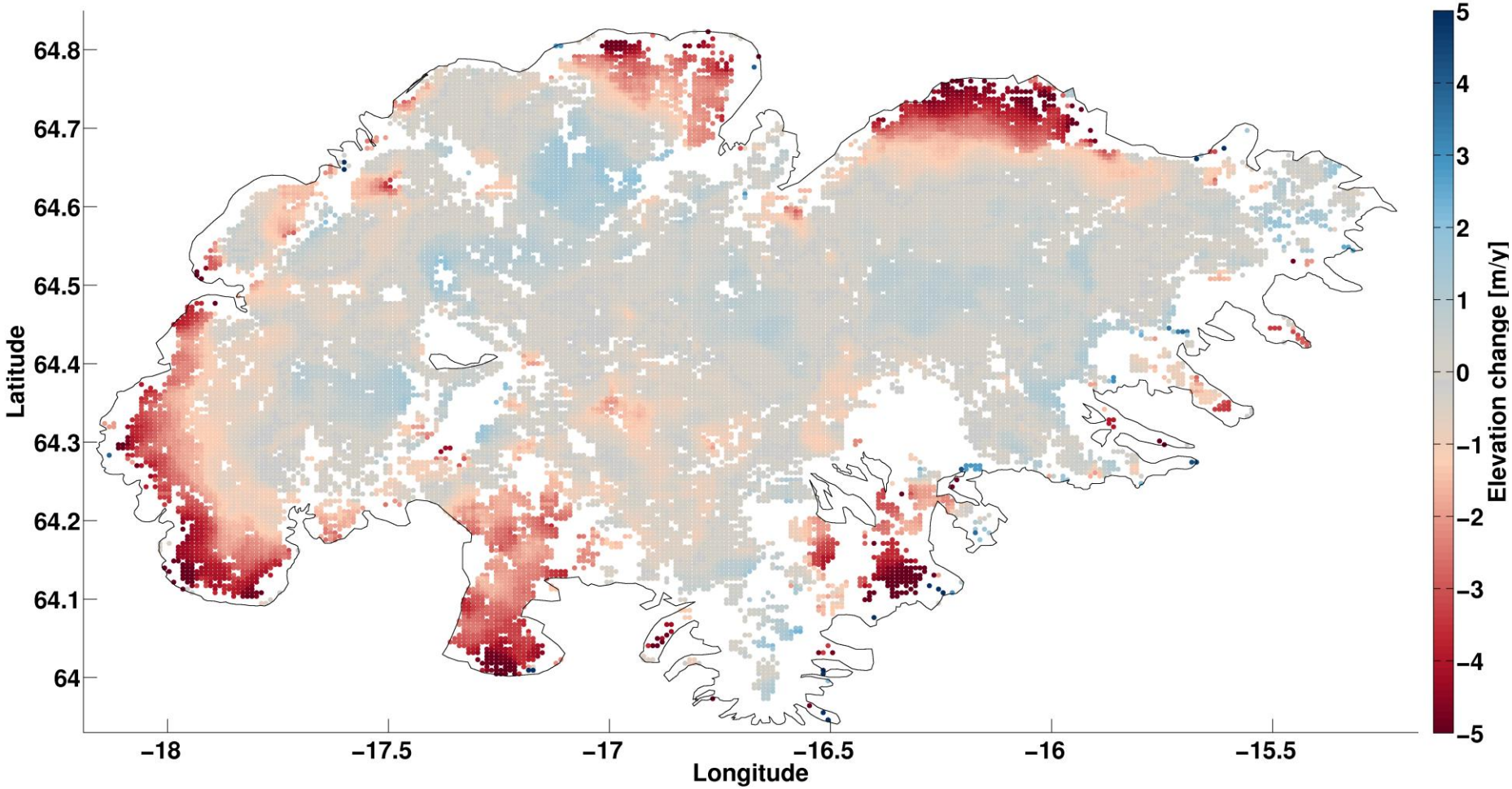
CryoSat, 'POCA' solution



Foresta et al., 2016

Surface elevation change - Vatnajokul Ice Cap, Iceland

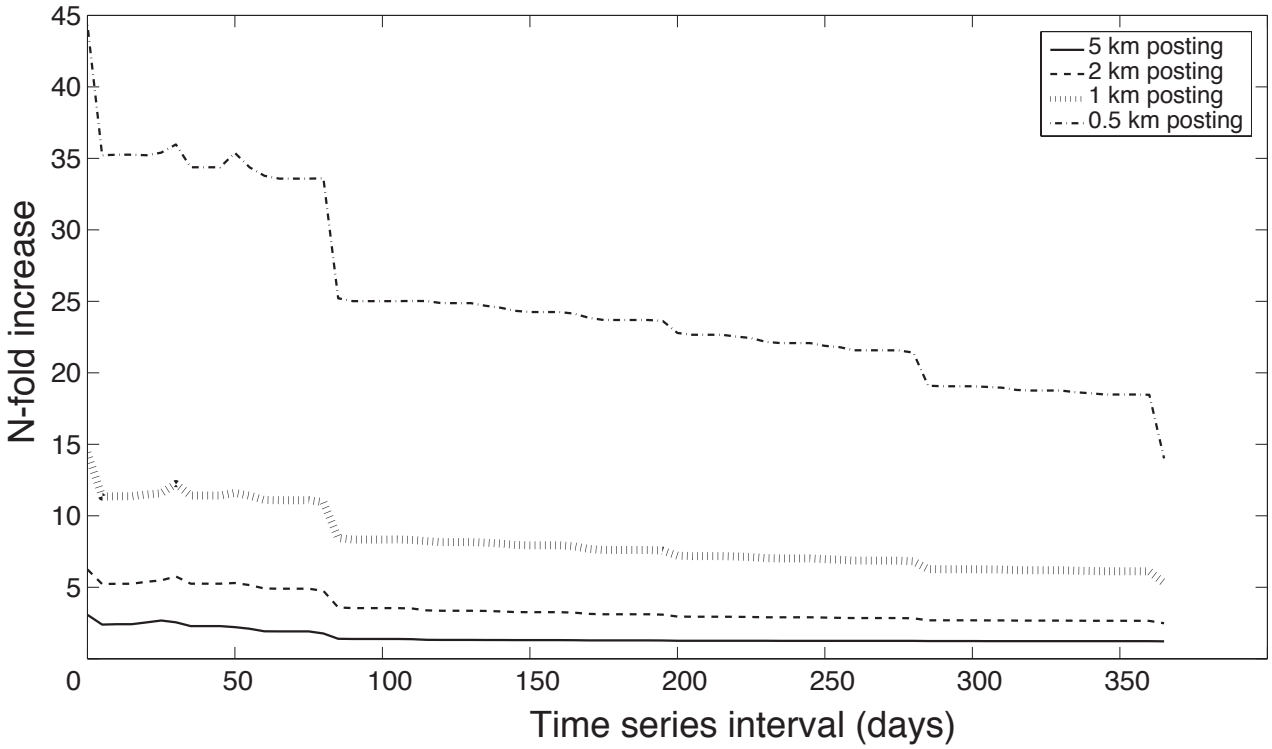
CryoSat, 'Swath' solution



Foresta et al., 2016

Temporal coverage

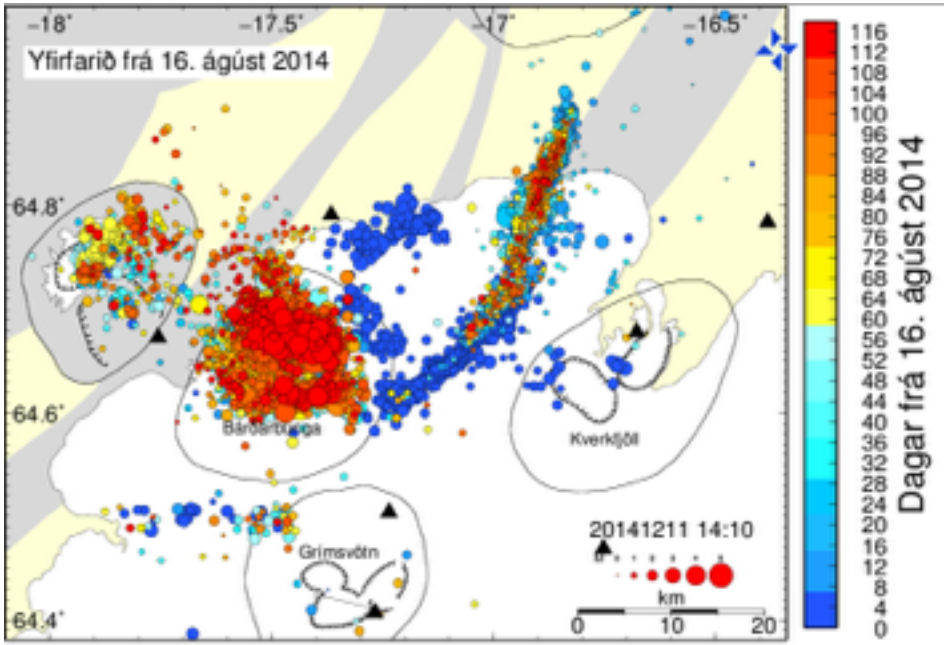
CryoSat repeat cycles: 369 days with 30 day sub-cycle

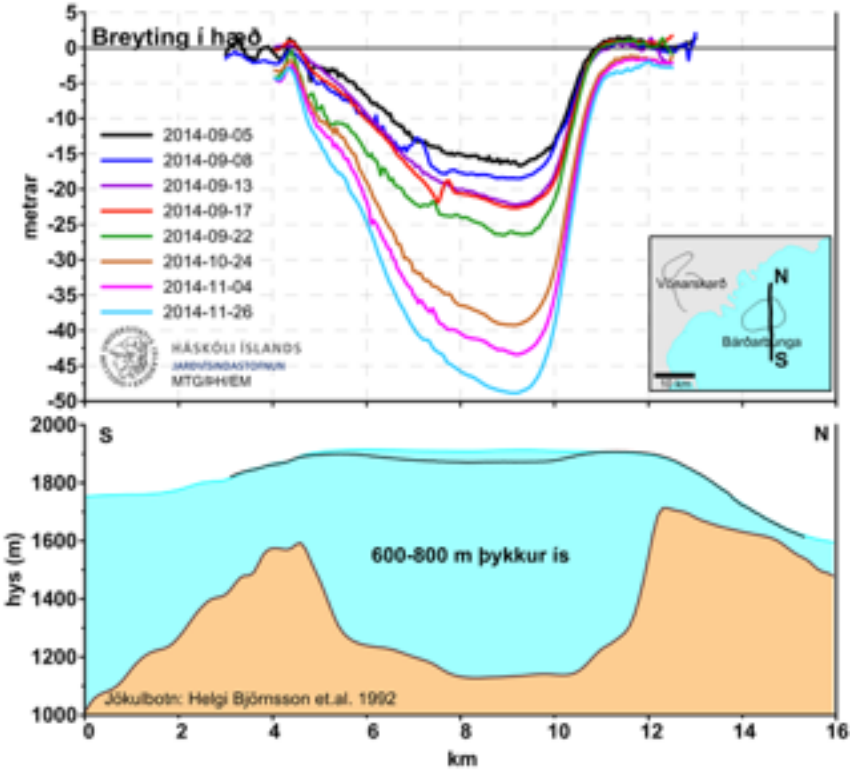


Small scale, rapid, elevation change

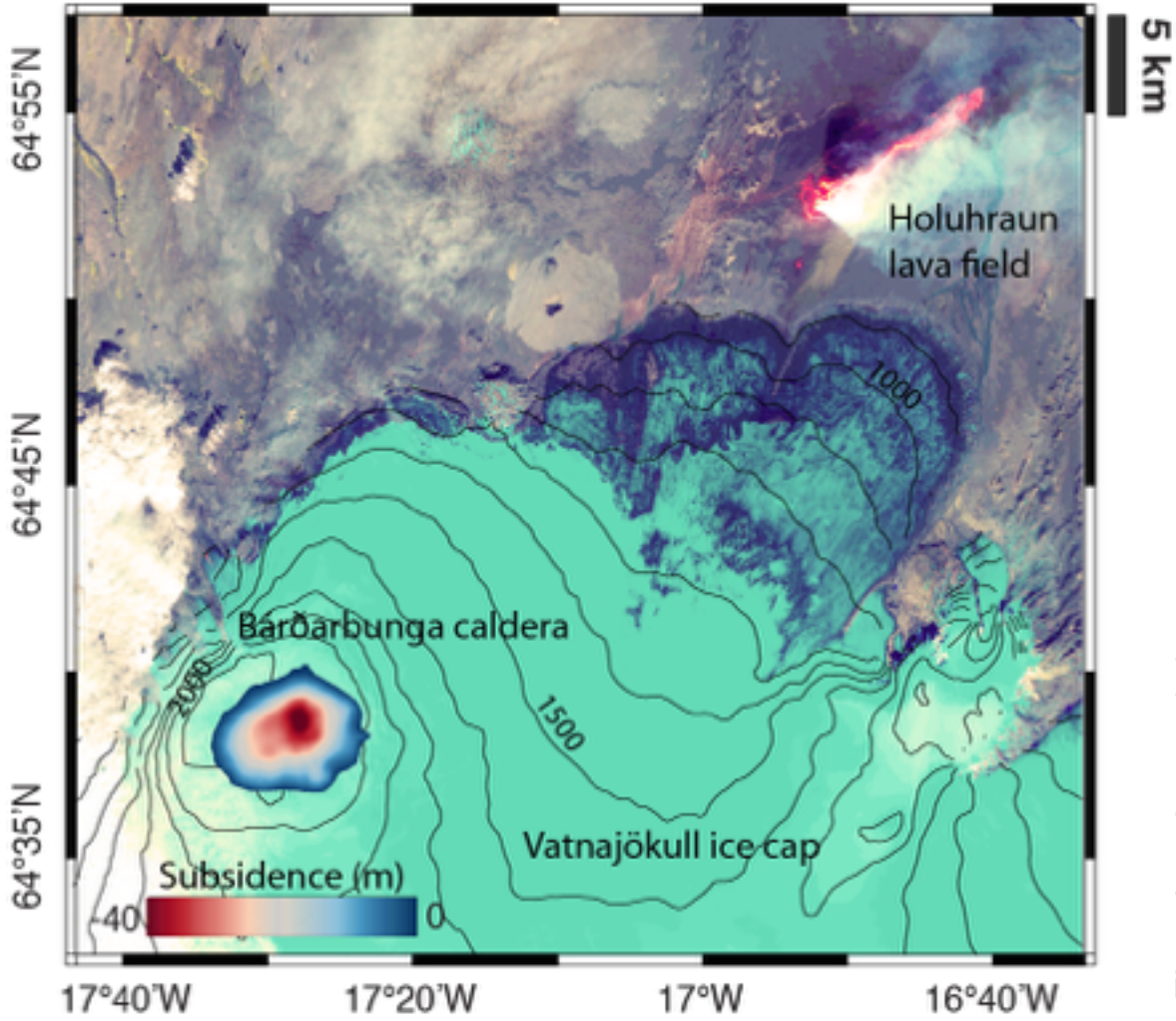
The gasplume above the eruption site in Holuhraun 19.09.2014 at 20:05. Photo: Gro B.M. Pedersen.

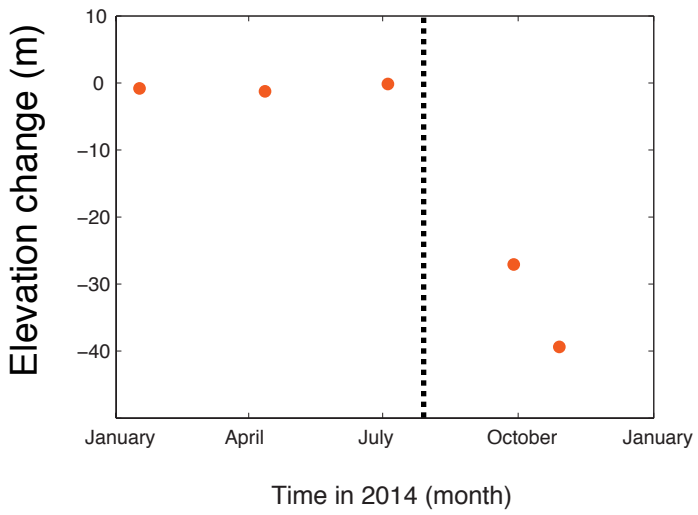
Ice subsides above the caldera

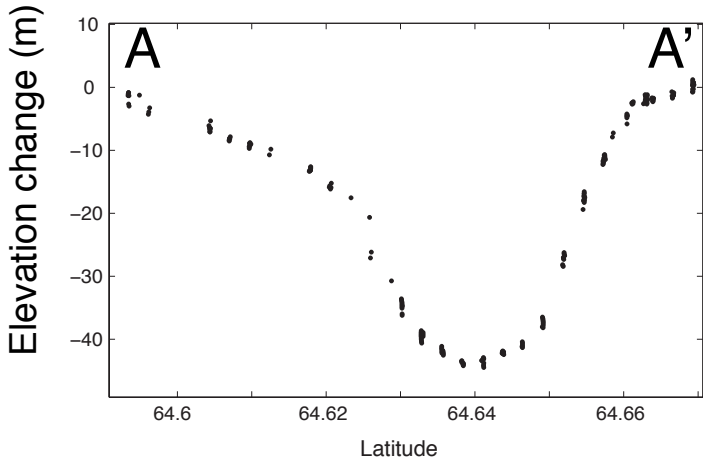




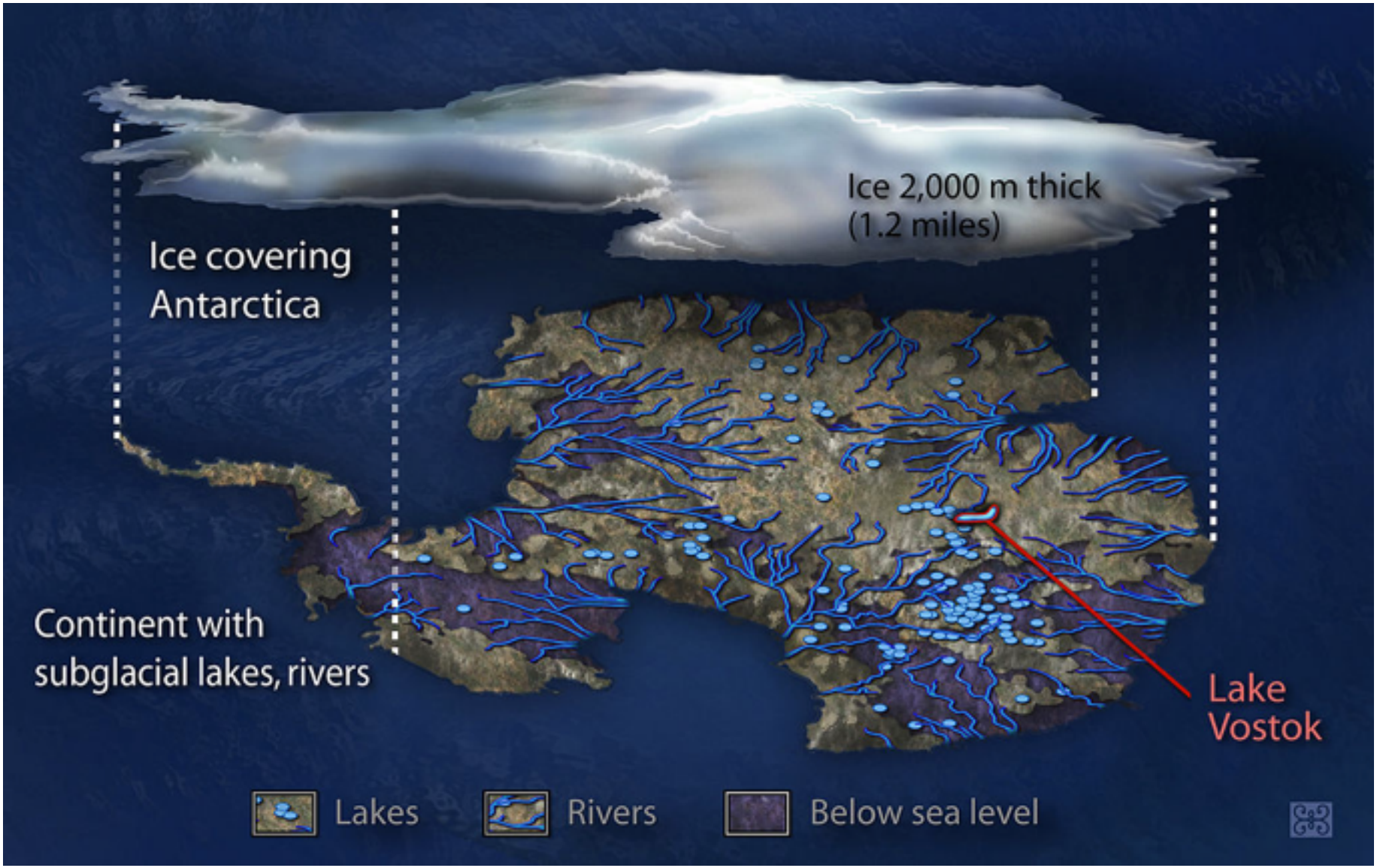
Small scale, rapid, elevation change





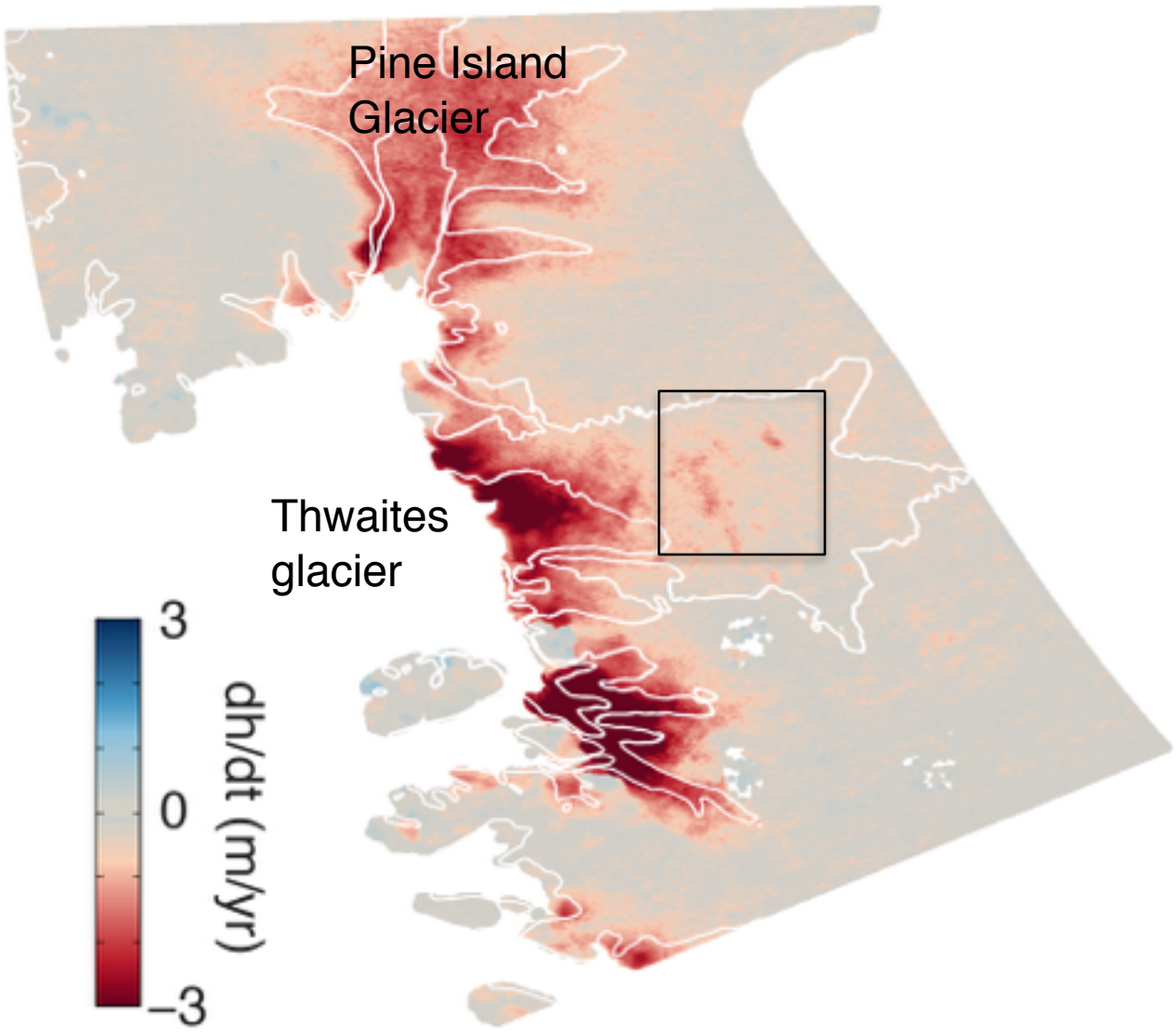


Sub-glacial lake drainage

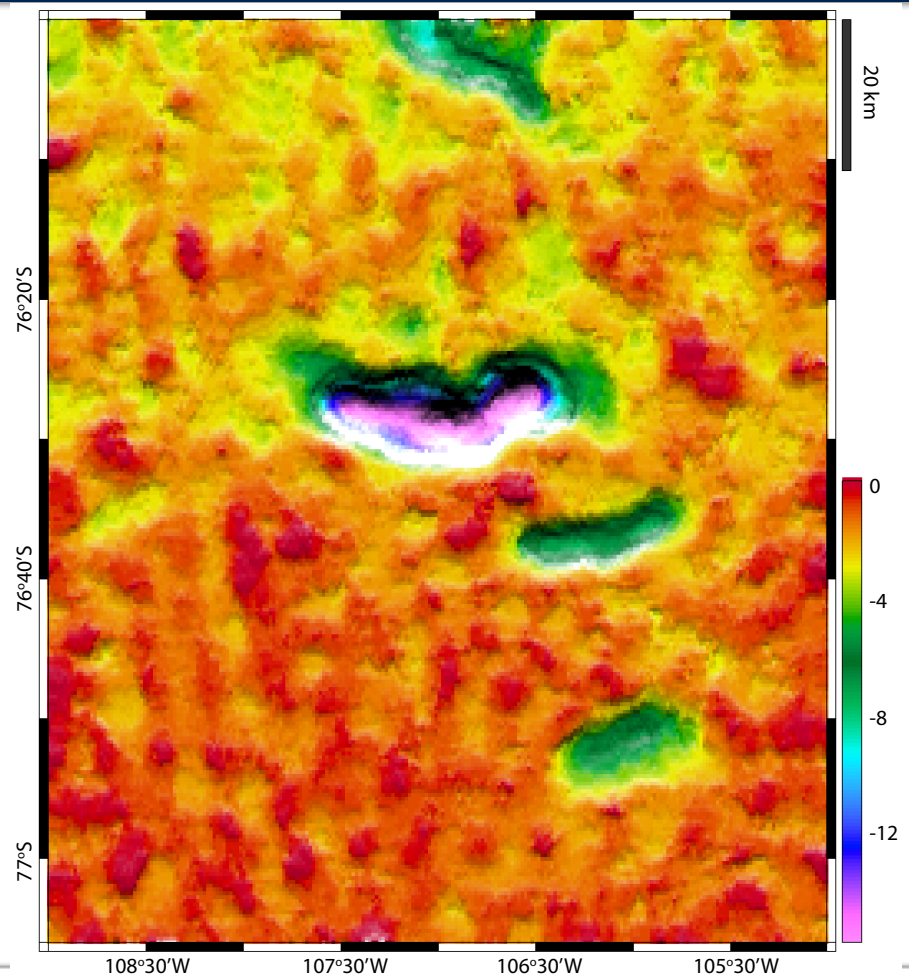


Zina Deretsky / NSF

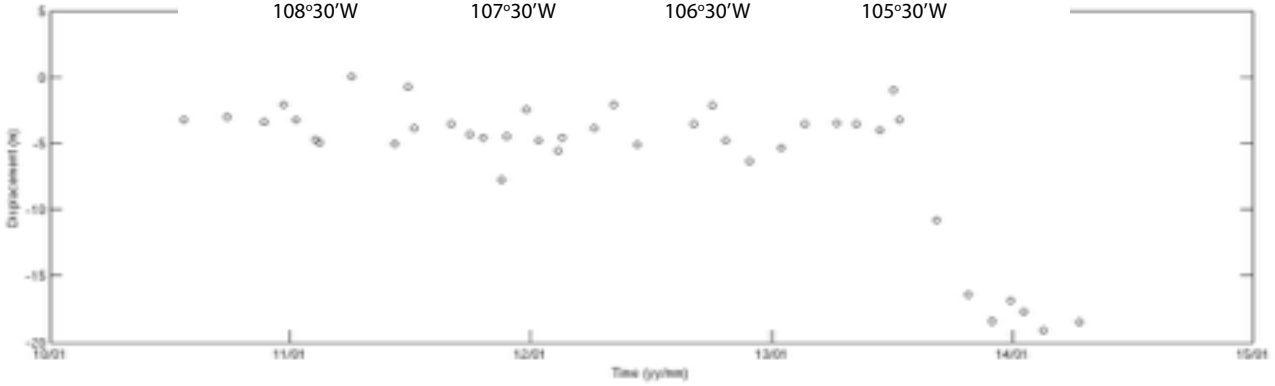
Sub-glacial lake drainage



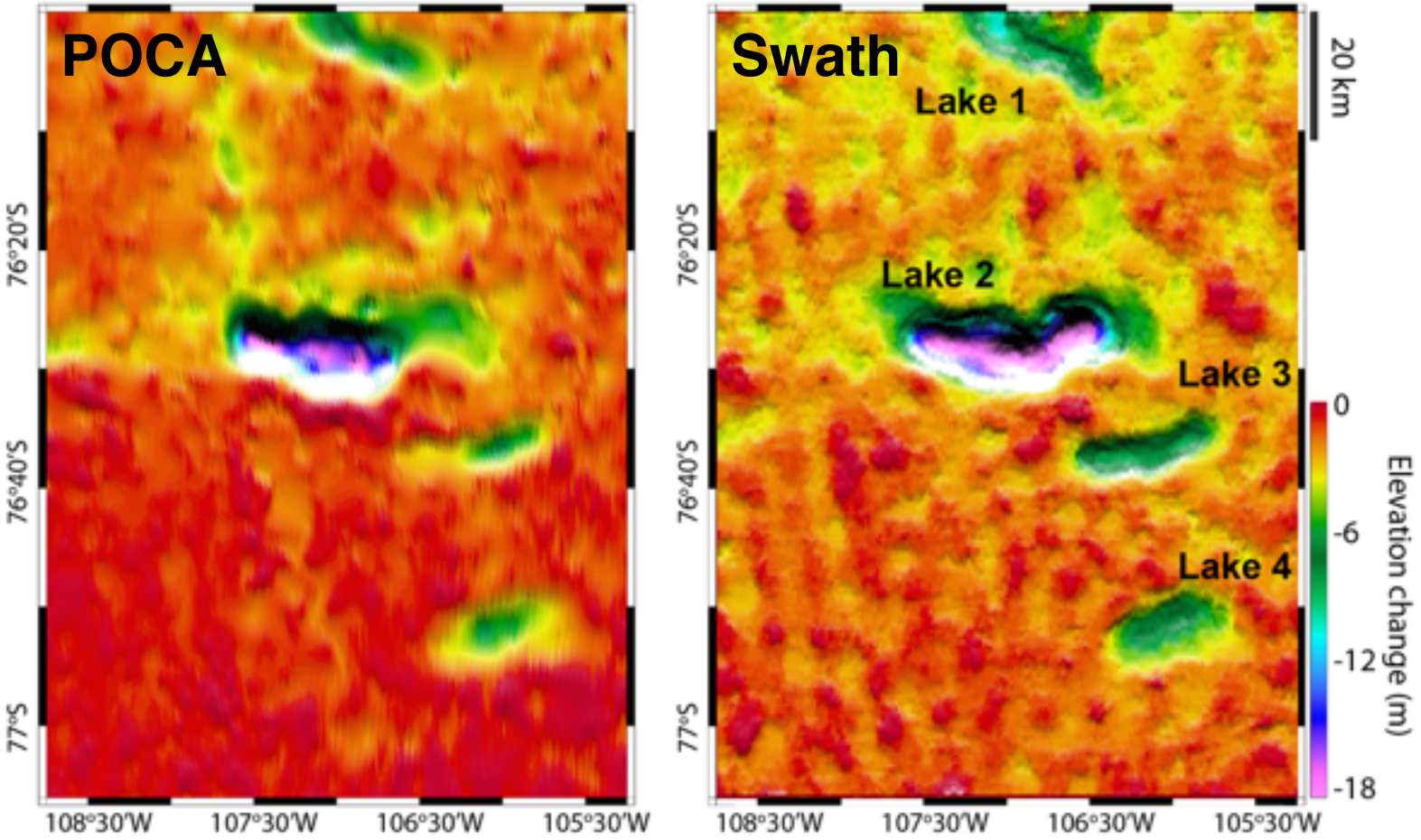
Subglacial lake drainage at Thwaites glacier



Smith et al., TCD, 2016

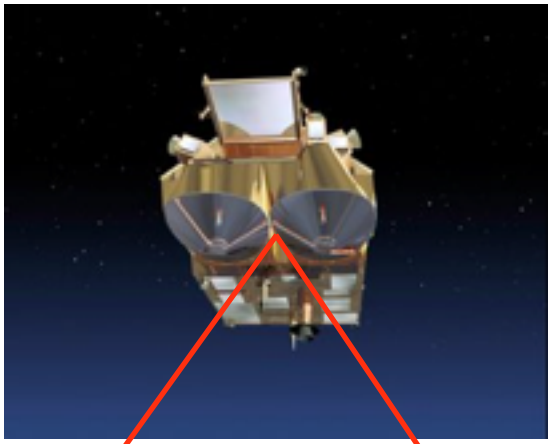


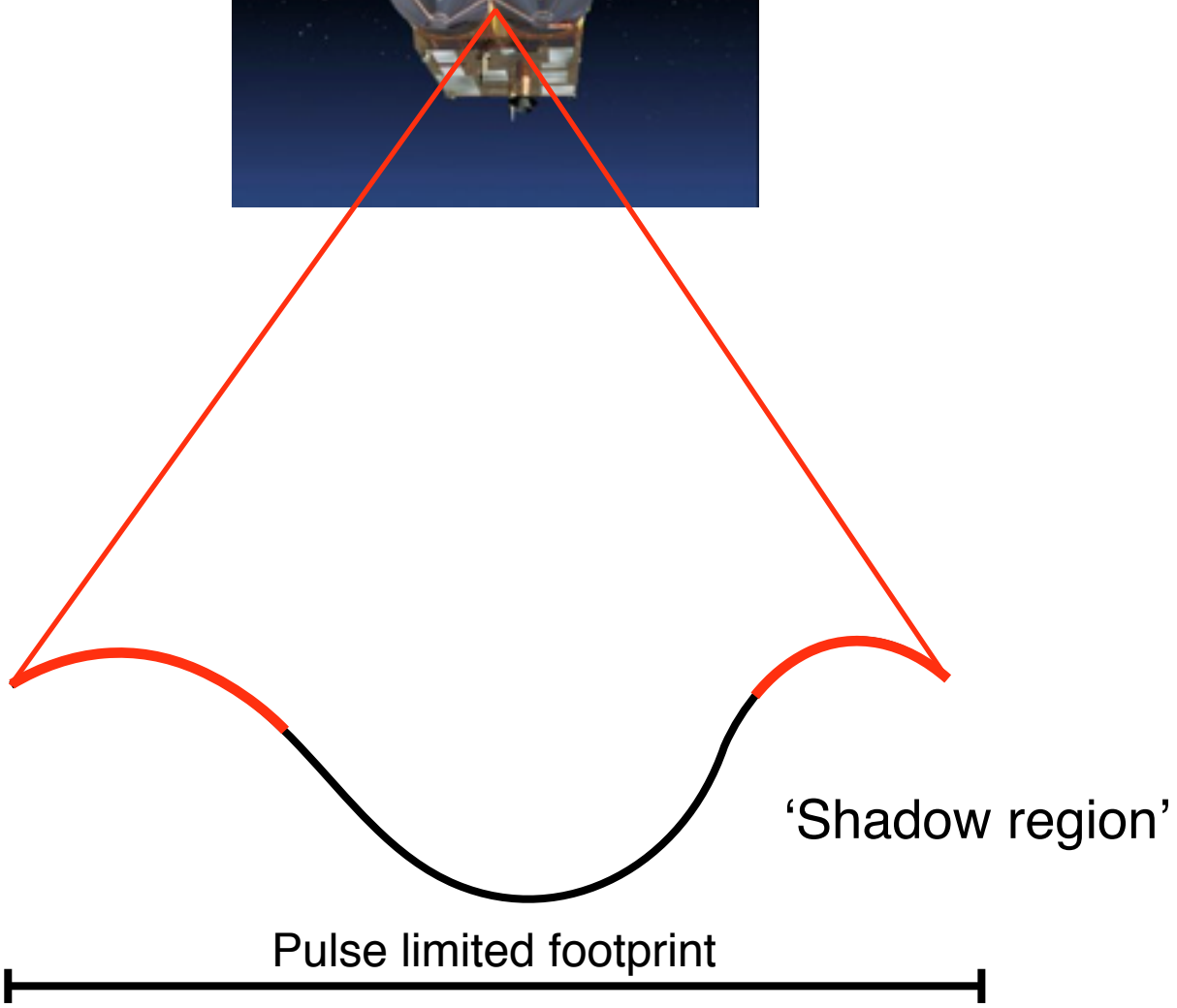
Thwaites glacier - subglacial lakes

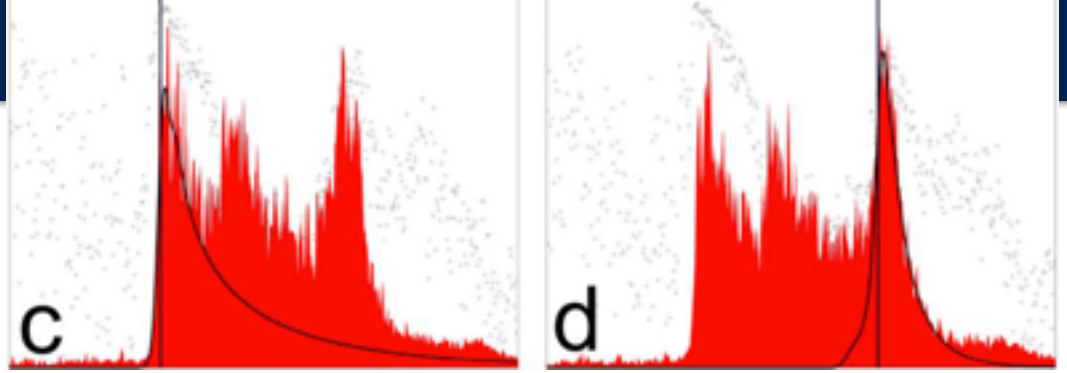


Smith et al., TCD, 2016

Radar altimeters ‘blind spot’

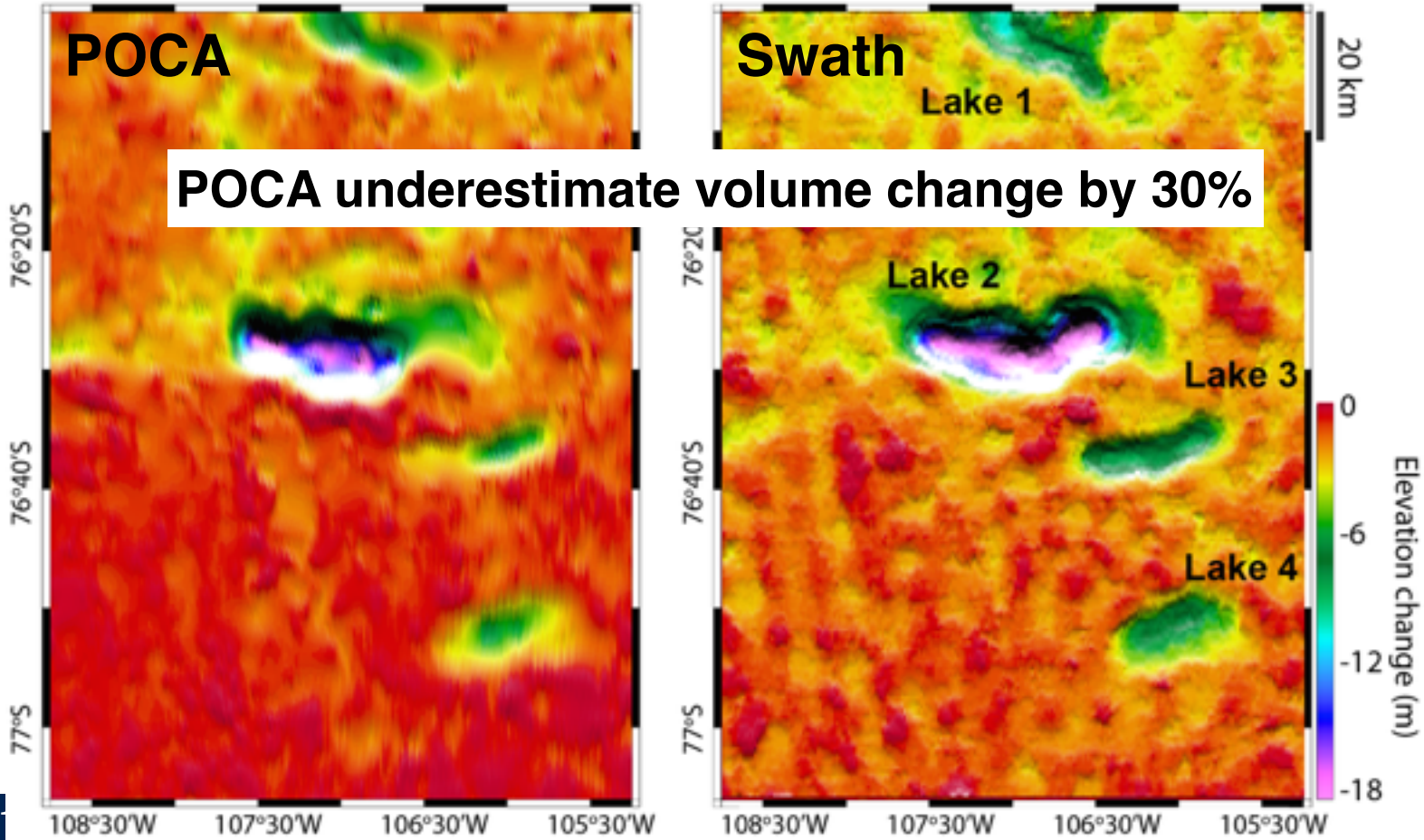






McMillan et al., 2013

Thwaites glacier - subglacial lakes



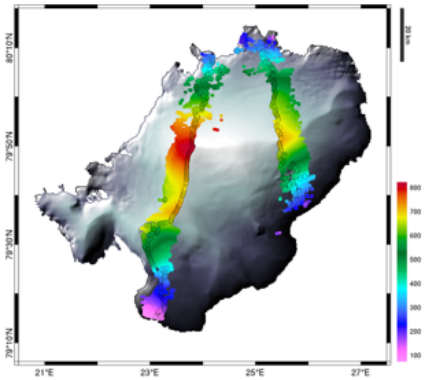
Smith et al., TCD, 2016

Cryotop Evolution project
http://cryotop-evolution.org/

Products (2017):

- 1. Swath elevation
- 2. DEM (500m resolution)
- 3. DhDT (500m resolution)
- 4. Experimental products
  - Grounding line
  - Subglacial lakes
  - Calving front position
  - Ice shelf thickness

1.



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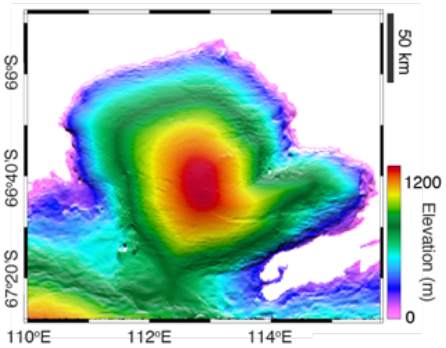

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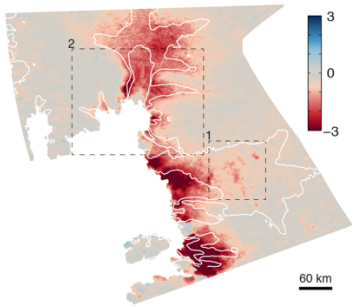

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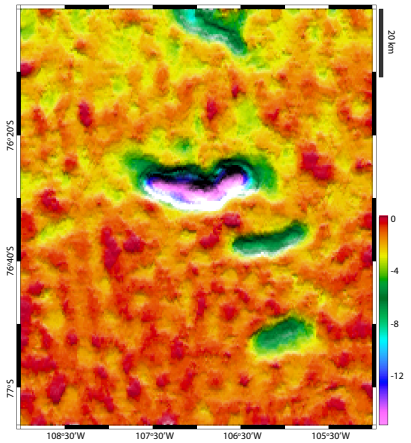

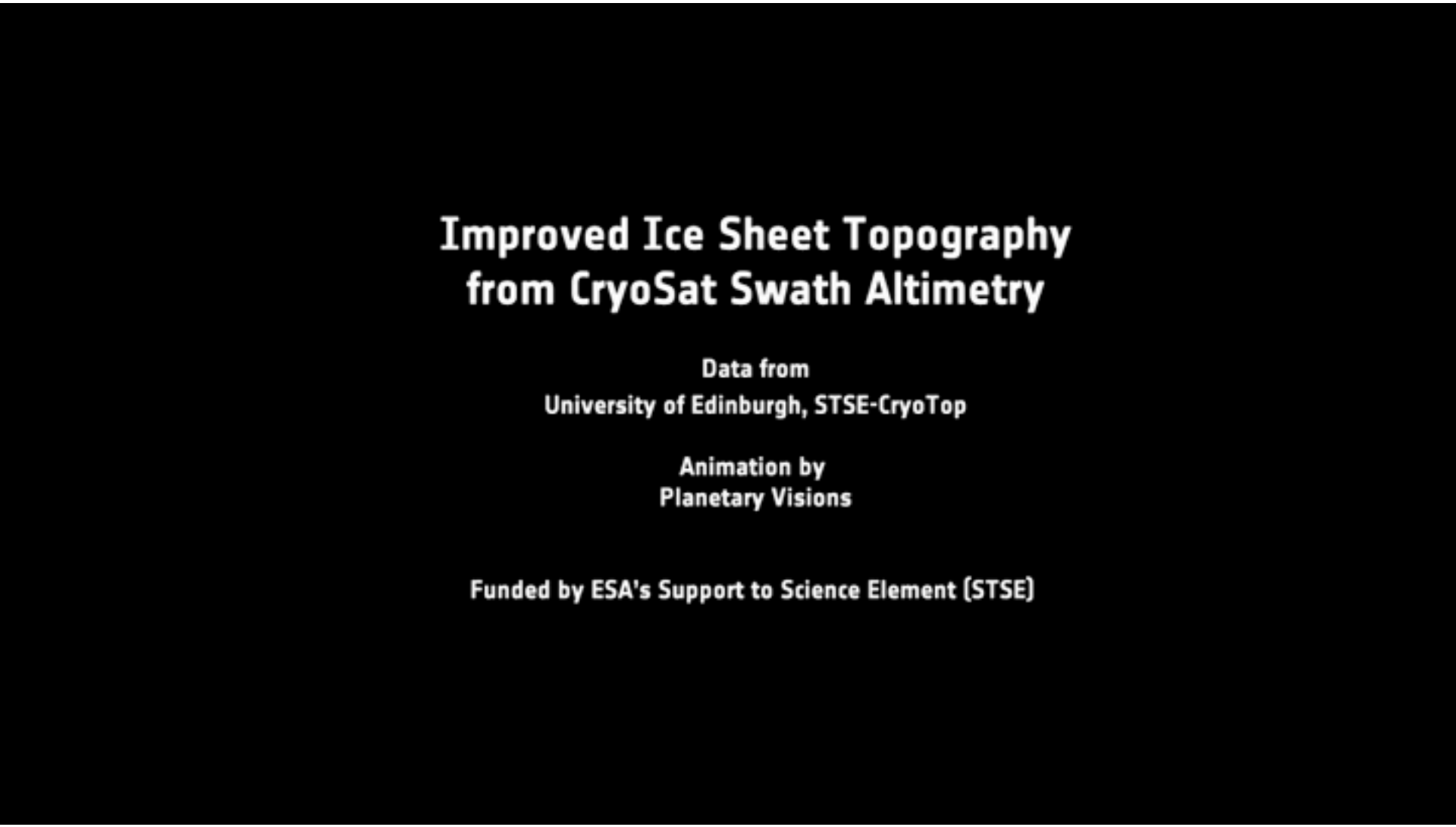
Improved Ice Sheet Topography
from CryoSat Swath Altimetry
Data from
University of Edinburgh, STSE-CryoTop
Animation by
Planetary Visions
Funded by ESA's Support to Science Element (STSE)