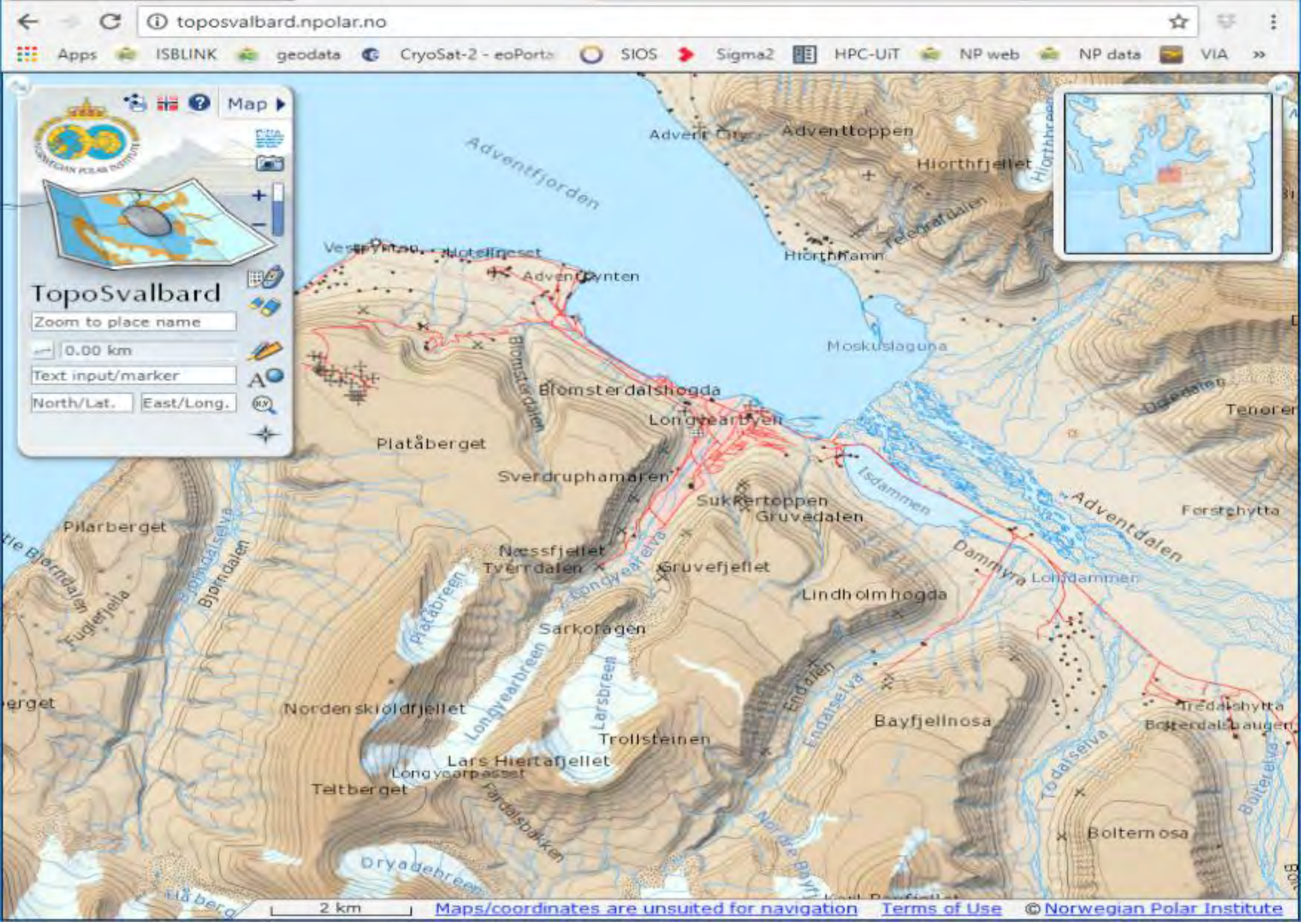
Land-ice altimetry

Geir Moholdt

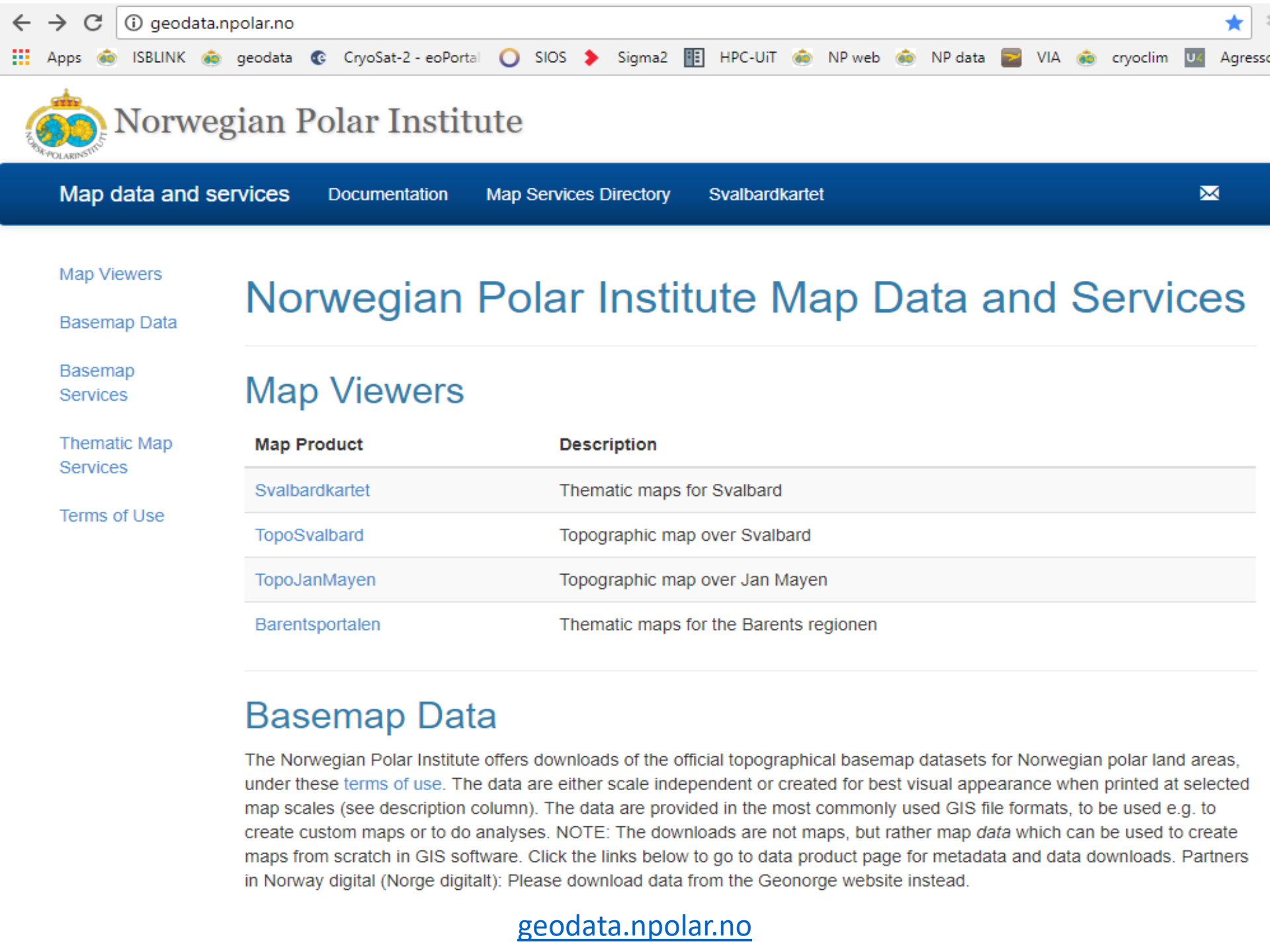
Norwegian Polar Institute

ESA cryos. summer school
Svalbard, 11-16 June 2018

Basin-3, Austfonna (T. Dunse)



toposvalbard.npolar.no



geodata.npolar.no

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A free GIS package for Antarctica

Quantarctica is a collection of Antarctic geographical datasets which works with the free, cross-platform, open-source software QGIS. It includes community-contributed, peer-reviewed data from ten different scientific themes and a professionally-designed basemap. Best of all, Quantarctica is free to download and re-distribute. See what's included in Quantarctica and download it now!

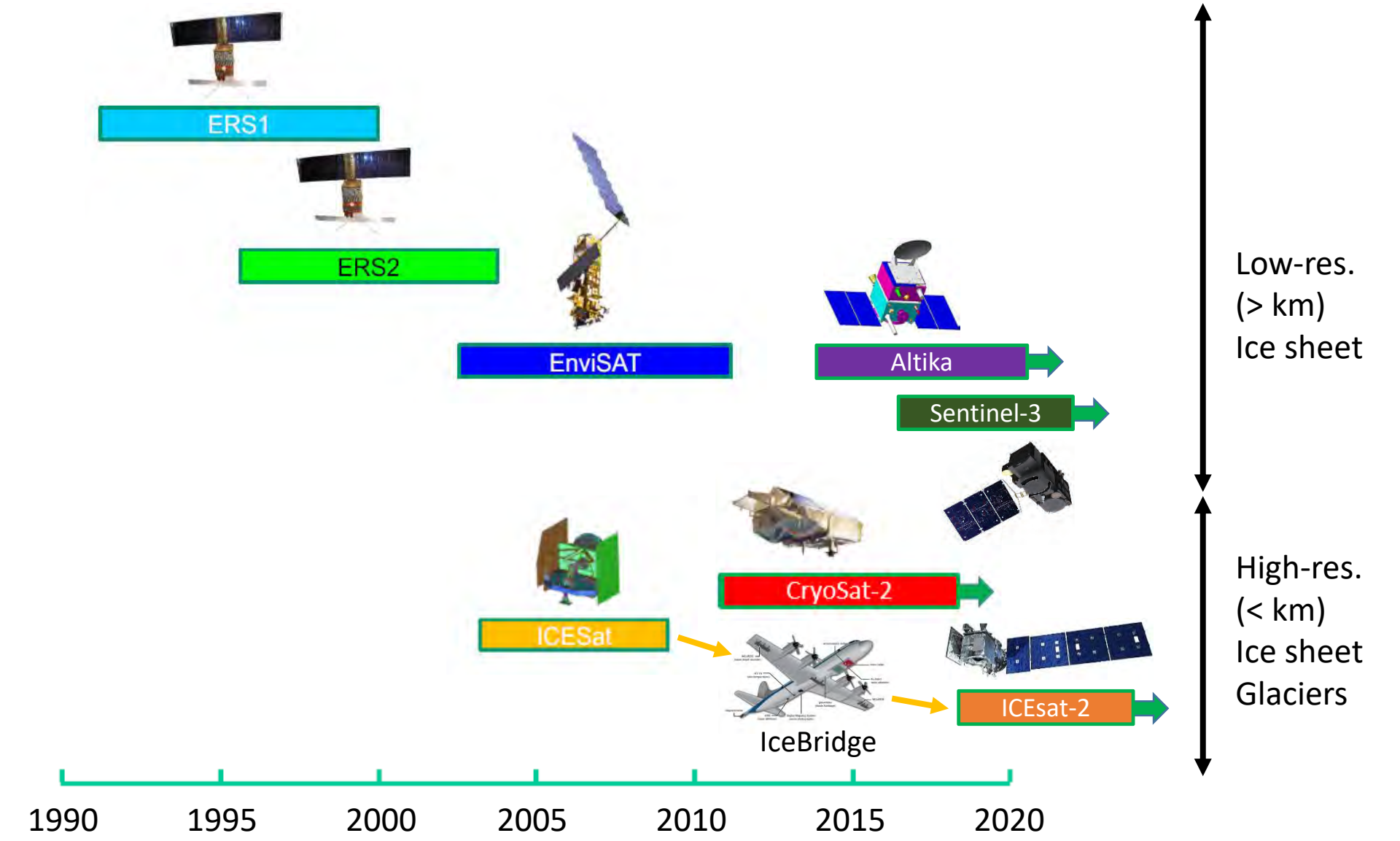
quantarctica.npolar.no

Altimetry for land-ice

- Known satellite position + satellite-surface range
  => Surface elevation
- Repeated measurements
  => Surface elevation changes
- Extrapolation within glacier inventory
  => Volume change
- Assumption of glacier density changes
  => Mass balance (and sea level contr.)

- Fun applications…
  => Grounding lines, ice shelf rifts, lake drainages, etc.

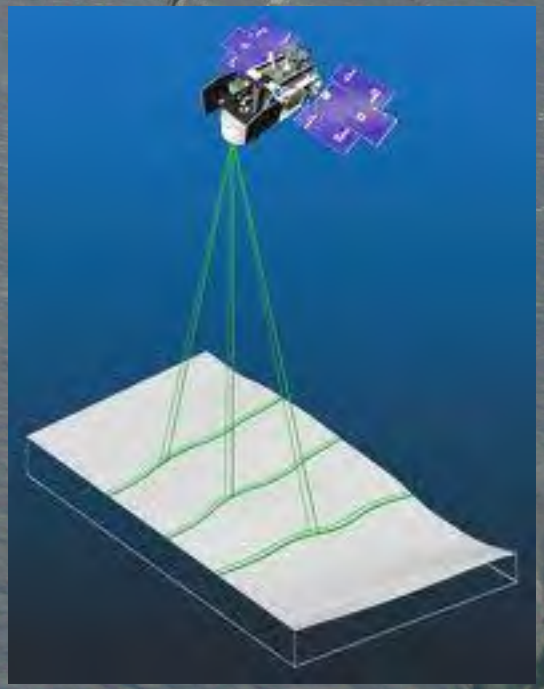
Altimeters for land-ice



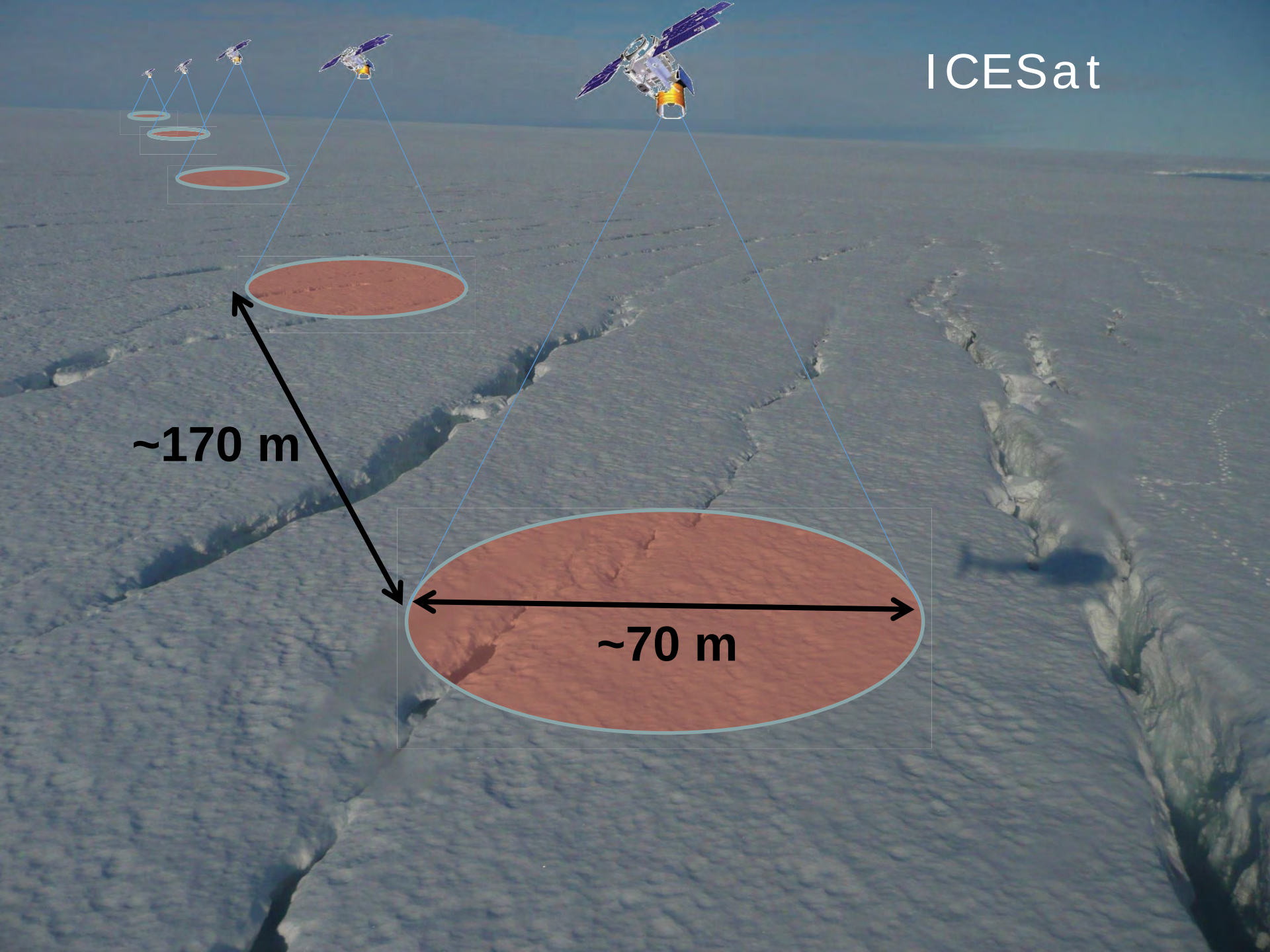
High-resolution altimeters

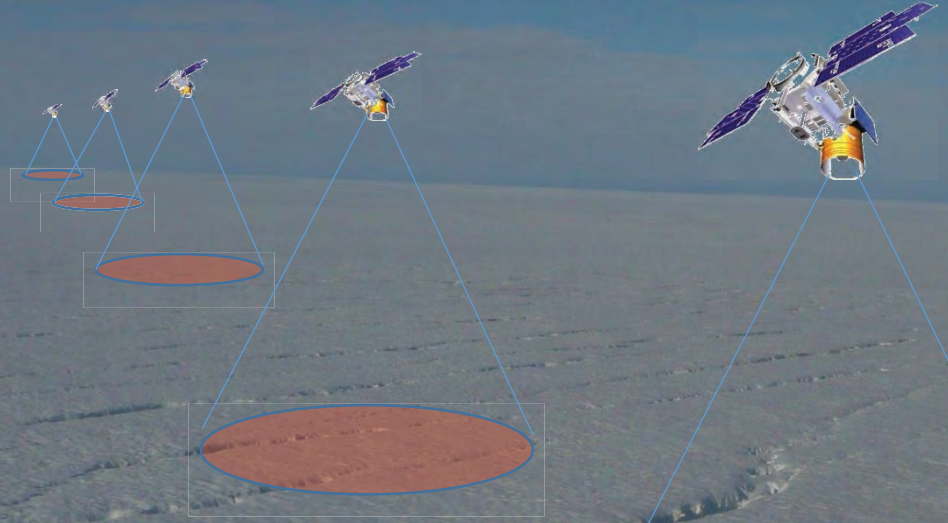
ICESat
2003-2009

CryoSat-2
2010 ➔



ICESat-2
2018 ➔


ICESat
~170 m
~70 m



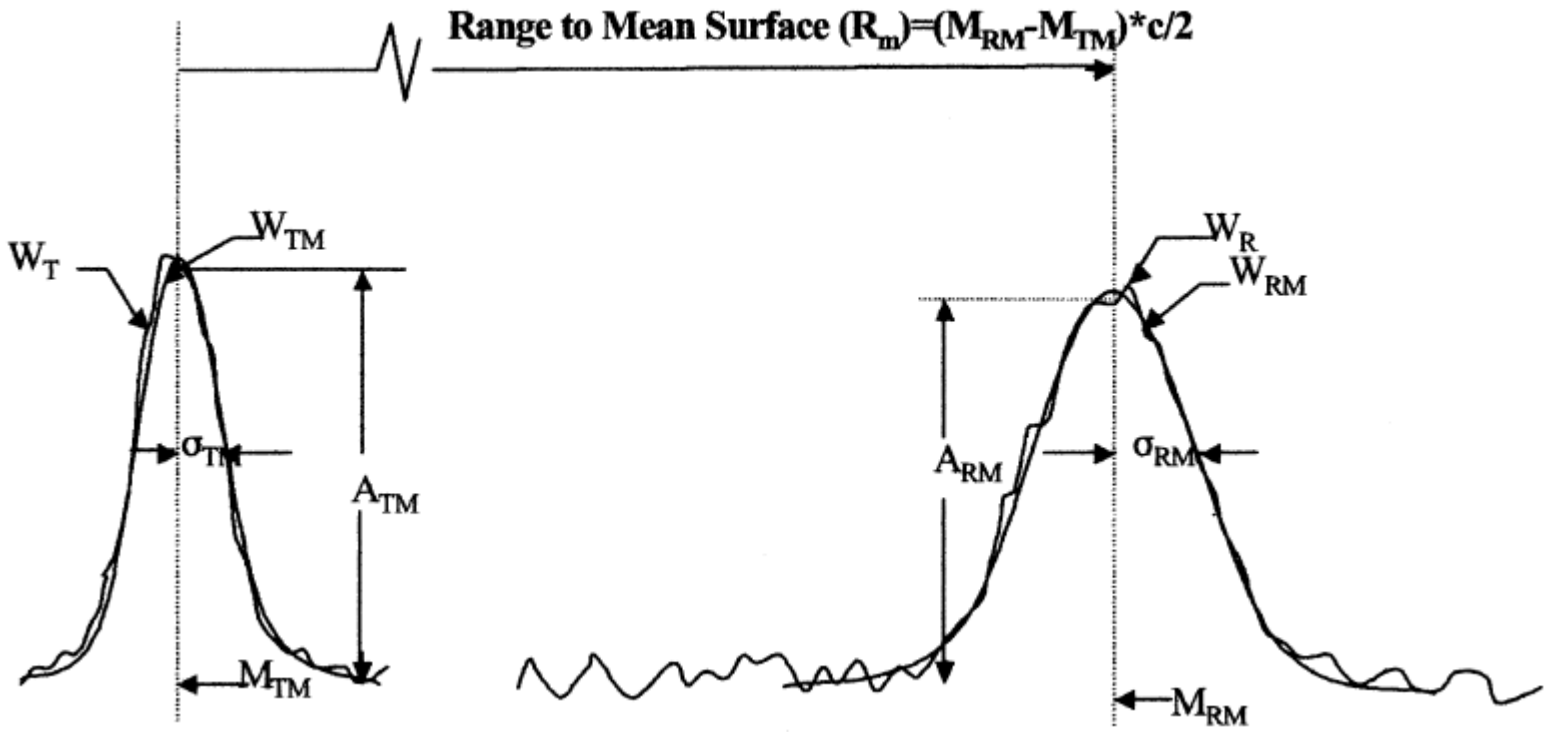
ICESat campaigns

- Laser 1 (8-day repeat)
- Laser 2 (91-day repeat)
- Laser 3 (91-day repeat)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Des
2003		L1								L2		
2004		L2			L2					L3		
2005		L3			L3					L3		
2006		L3			L3					L3		
2007			L3							L3		
2008		L3								L3	L2	
2009			L2							L2		

But 20-50% of the data lost due to clouds…

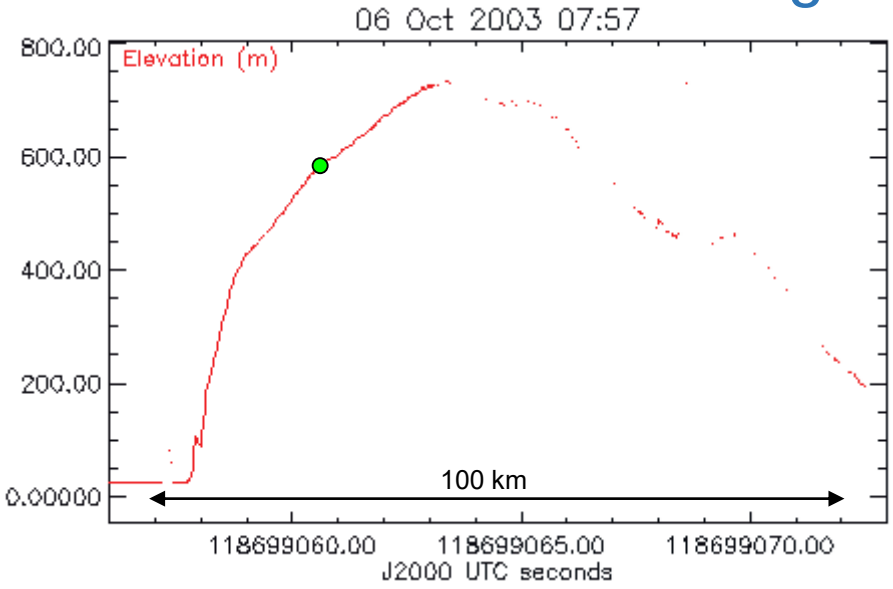
Laser pulse waveform

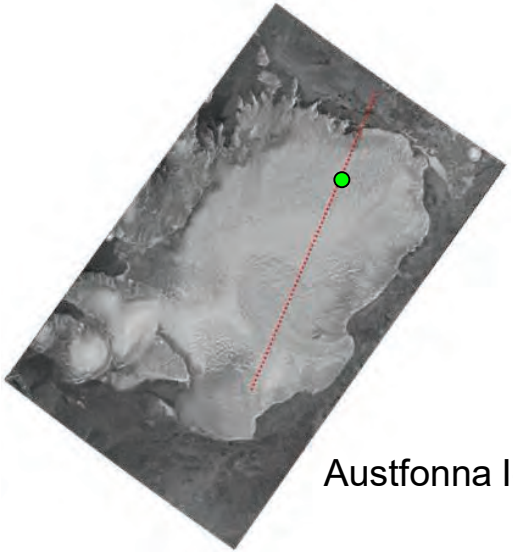


Transmitted

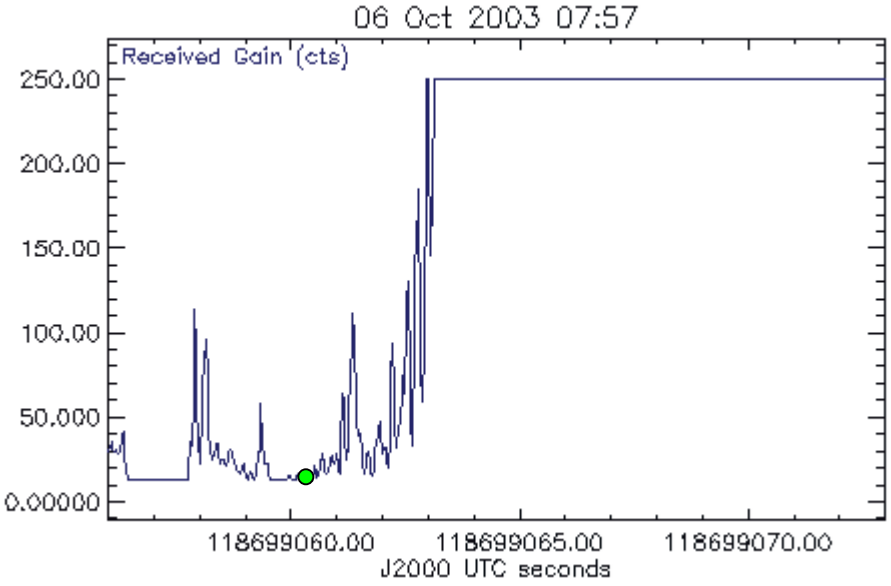
Returned

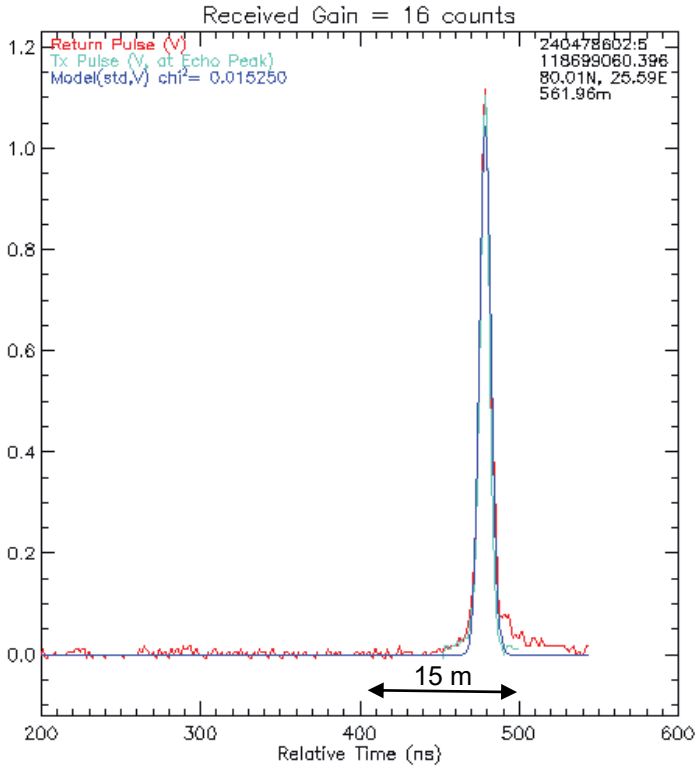
Gain as a proxy for cloud scattering



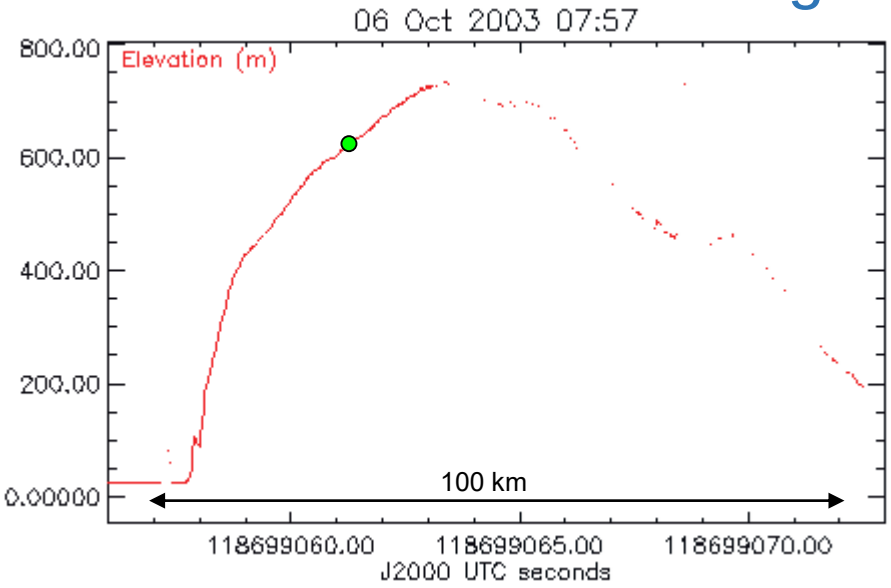


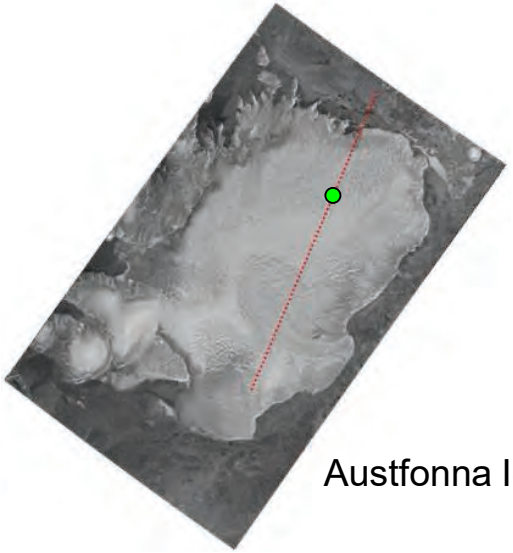
Austfonna Ice Cap



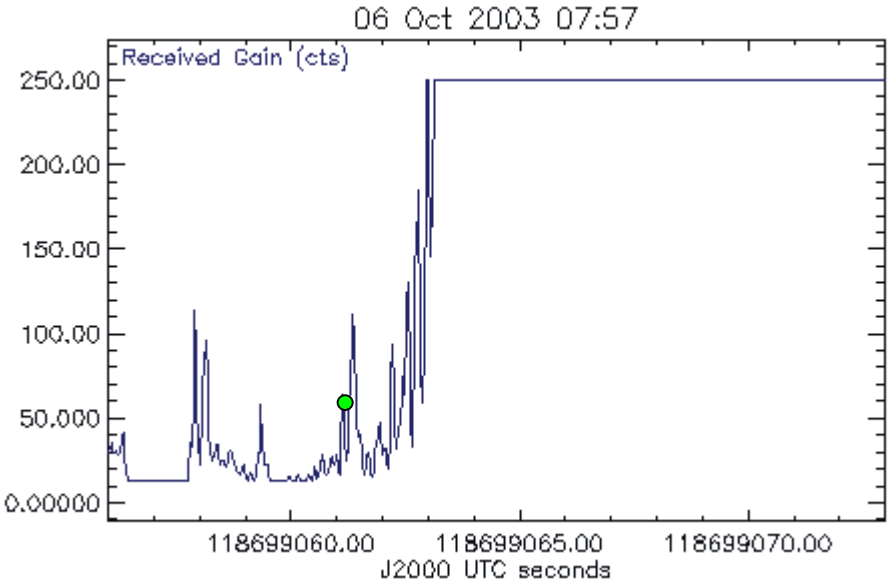


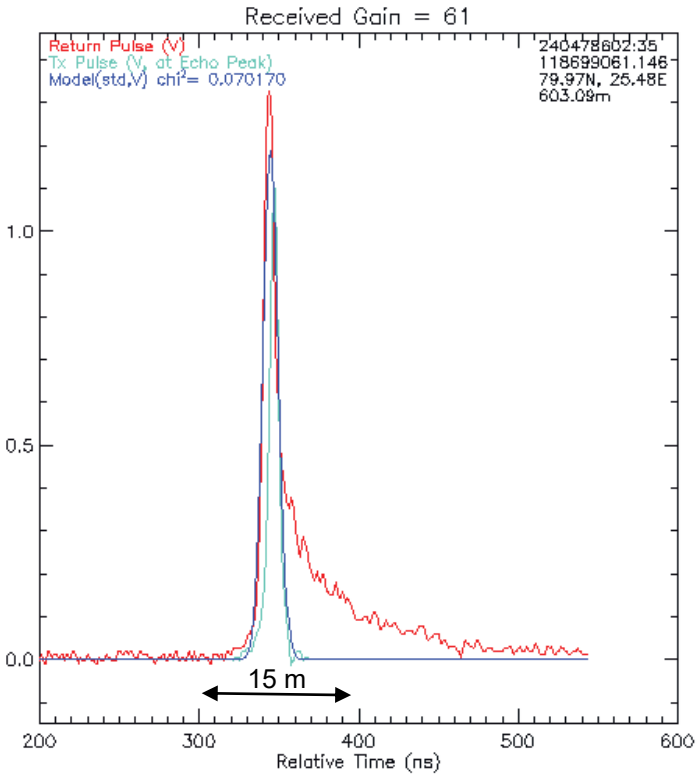
Gain as a proxy for cloud scattering



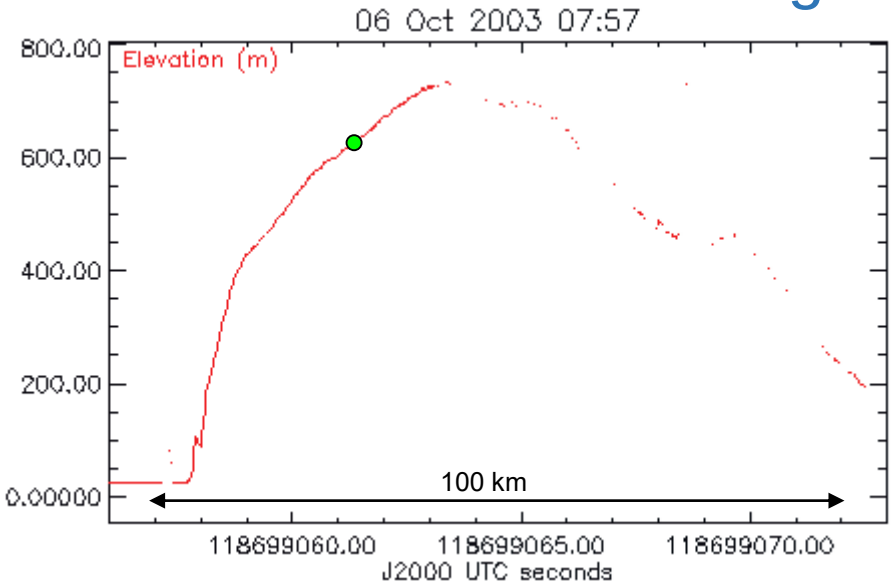


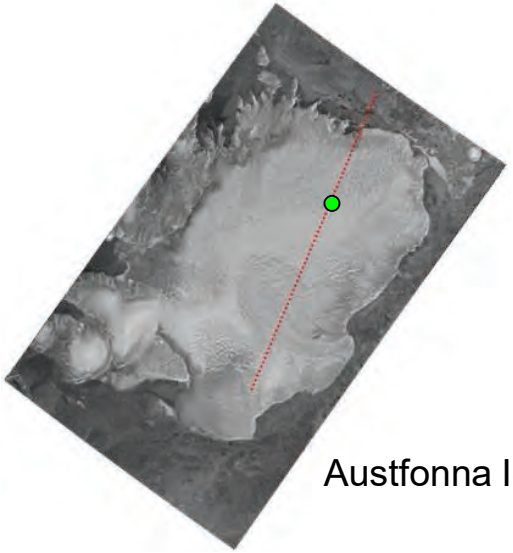
Austfonna Ice Cap



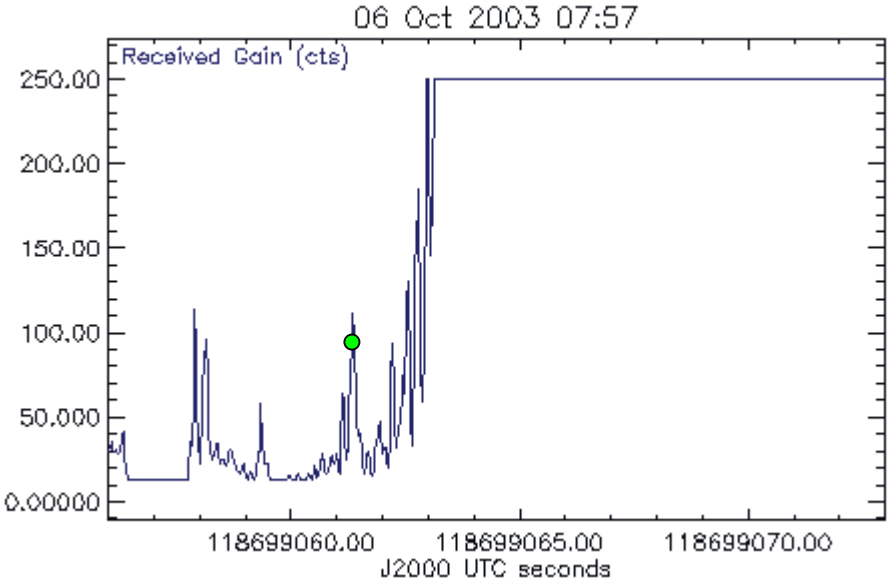


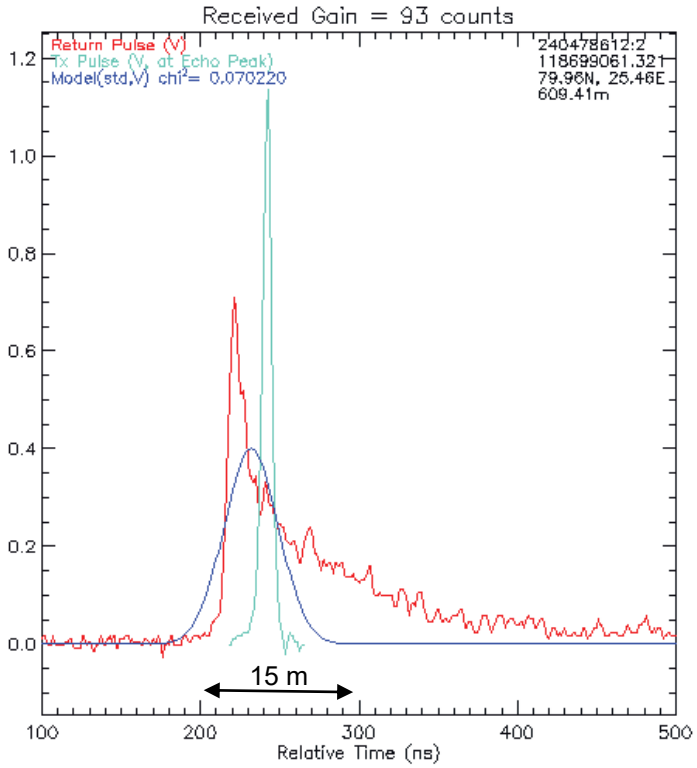
Gain as a proxy for cloud scattering



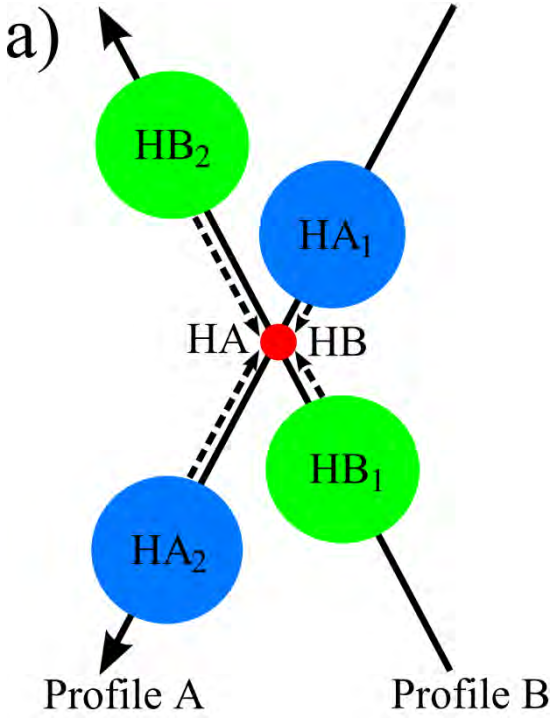


Austfonna Ice Cap

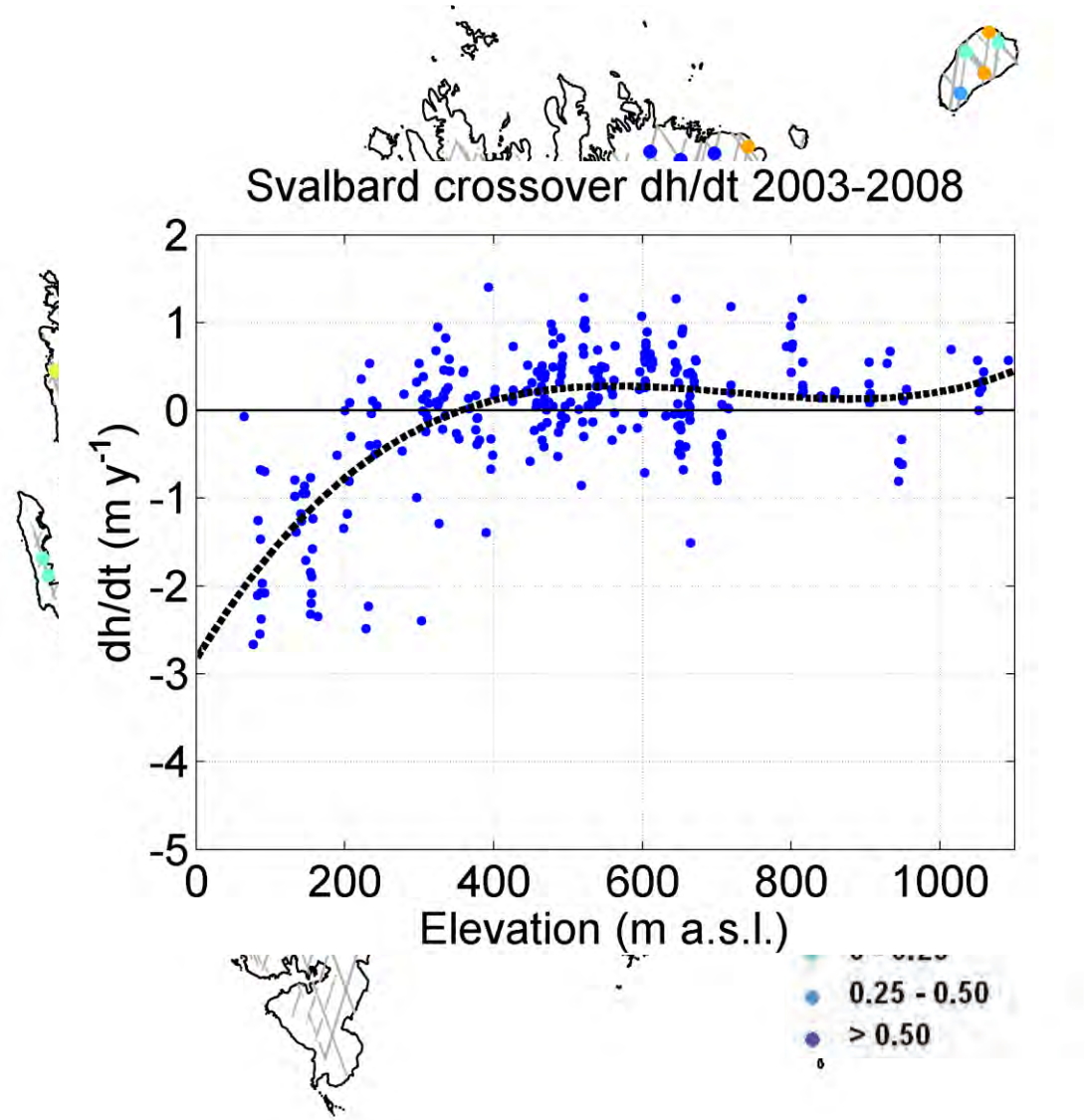




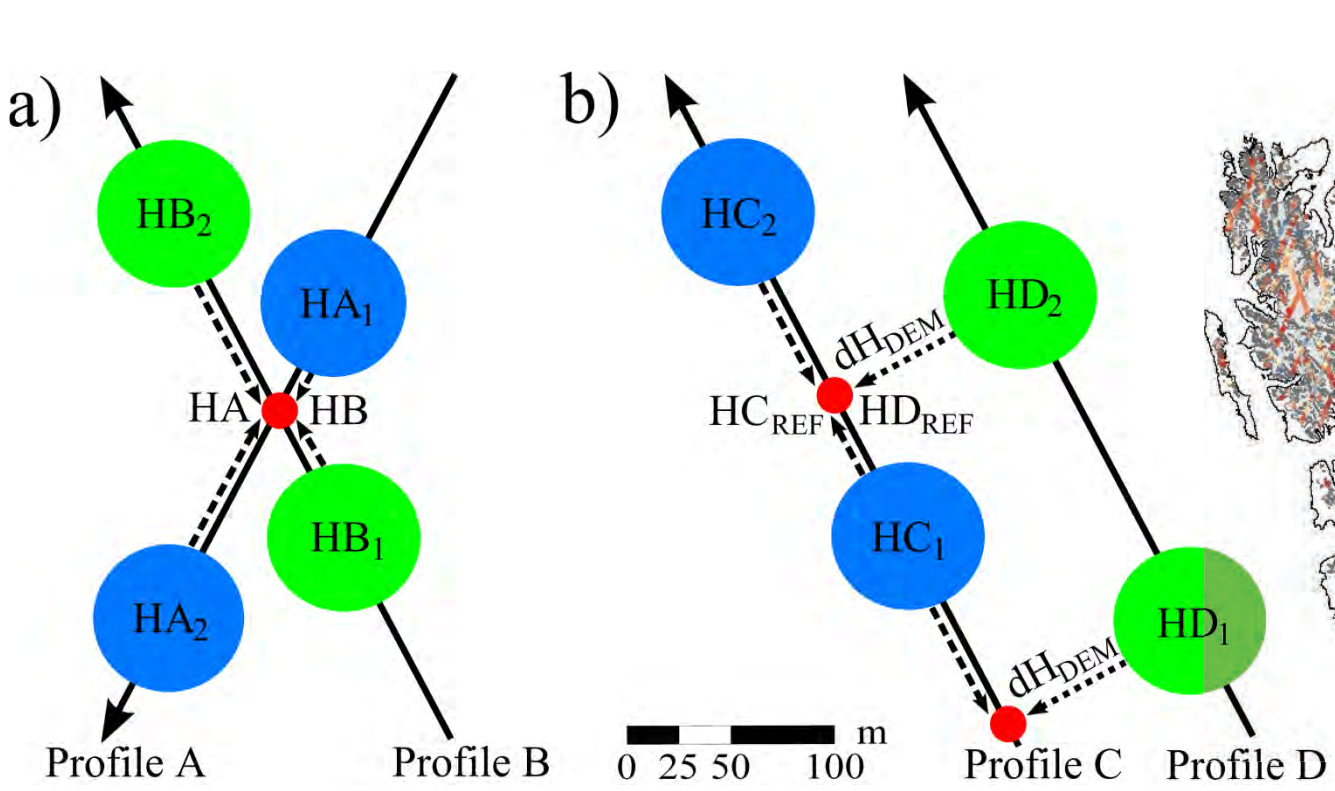
Elevation change – 3 methods

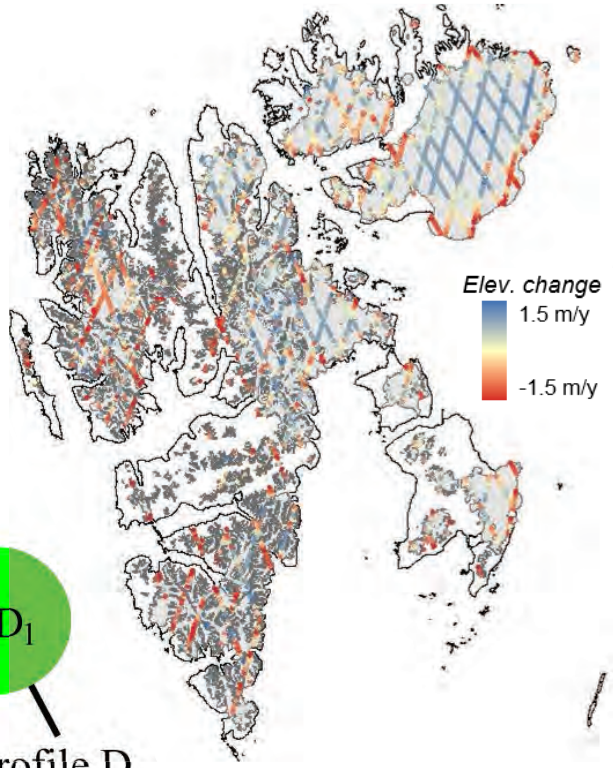


Linear interpolation of crossover points



Elevation change – 3 methods

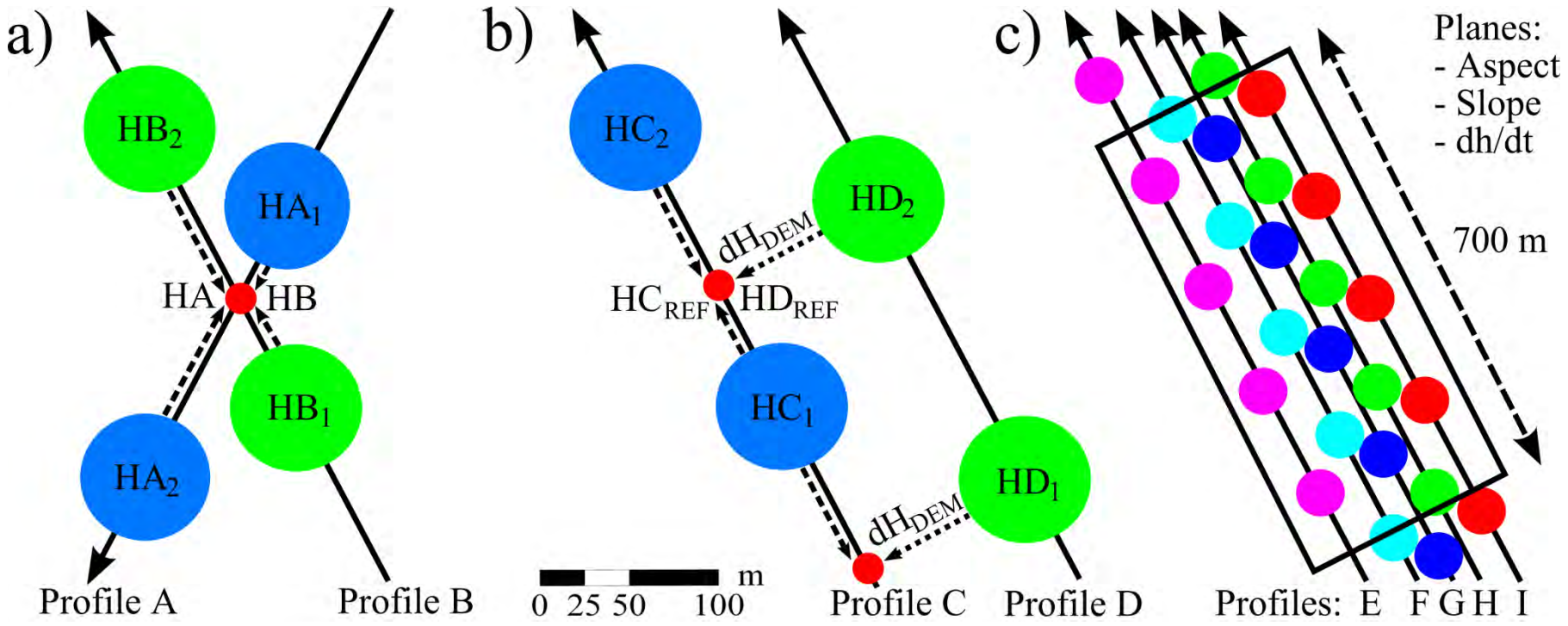




Linear interpolation of crossover points

DEM projection of near repeat-tracks

Elevation change – 3 methods

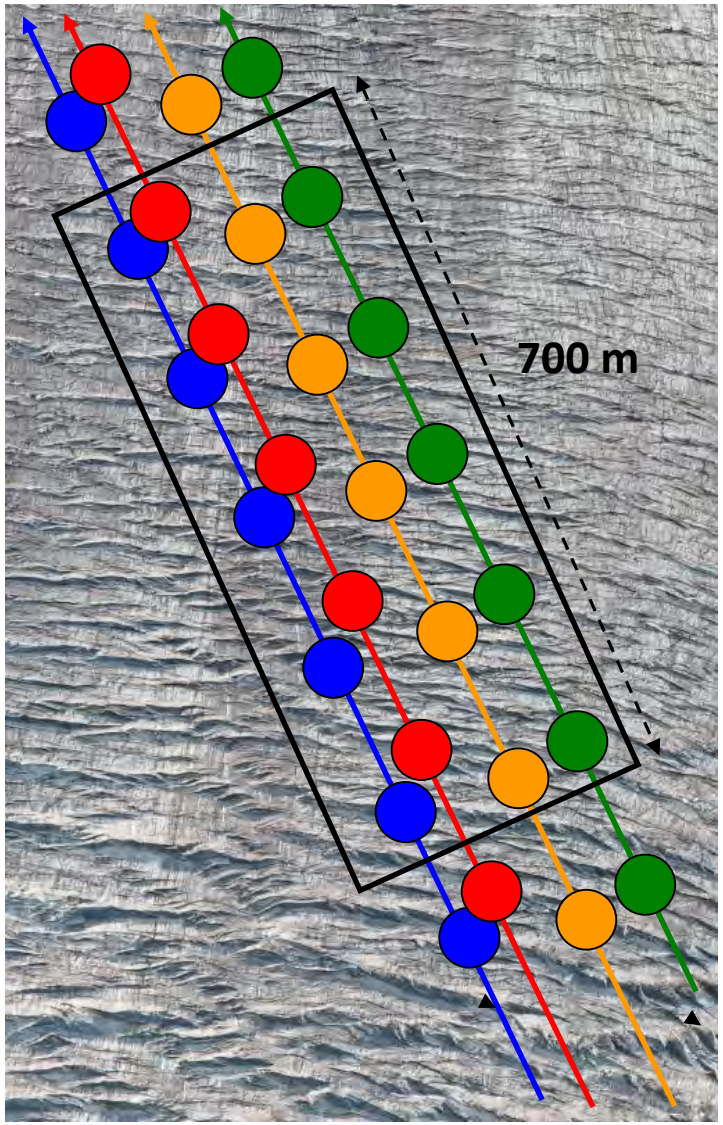


Linear interpolation of crossover points

DEM projection of near repeat-tracks

Least-squares fitting of plane surfaces

Elevation change – 3 methods



Least-squares estimation of slope (α_E,α_N) and average elevation change rate (*dh/dt*):

$$\begin{bmatrix} dH_1 \\ \vdots \\ dH_n \end{bmatrix} = \begin{bmatrix} dE_1 & dN_1 & dt_1 \\ \vdots & \vdots & \vdots \\ dE_n & dN_n & dt_n \end{bmatrix} \cdot \begin{bmatrix} \alpha_E \\ \alpha_N \\ dh/dt \end{bmatrix} + \begin{bmatrix} r_1 \\ \vdots \\ r_n \end{bmatrix}$$

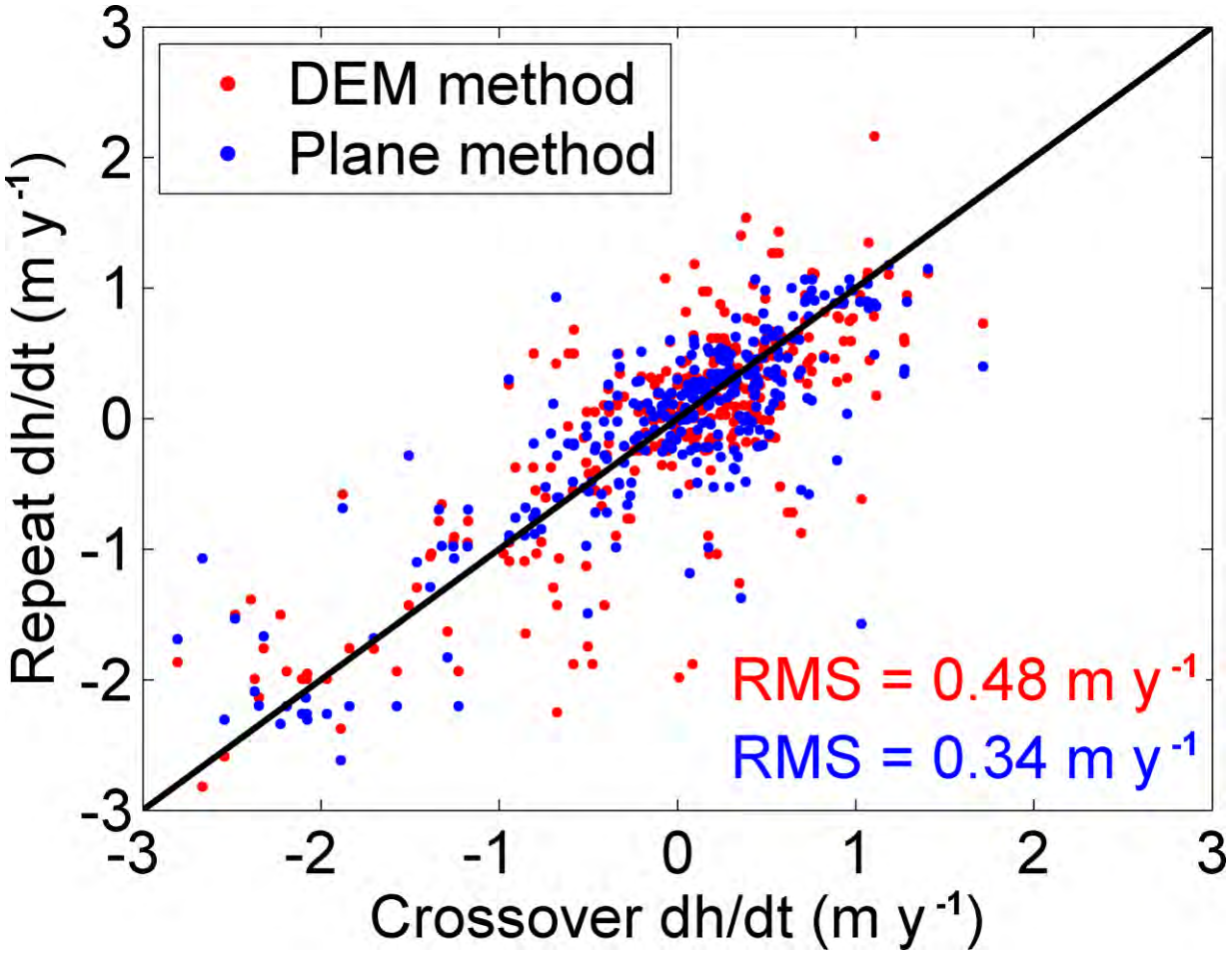
where *E,N,H and t* are the position and time for each of the *n* observations in the plane.

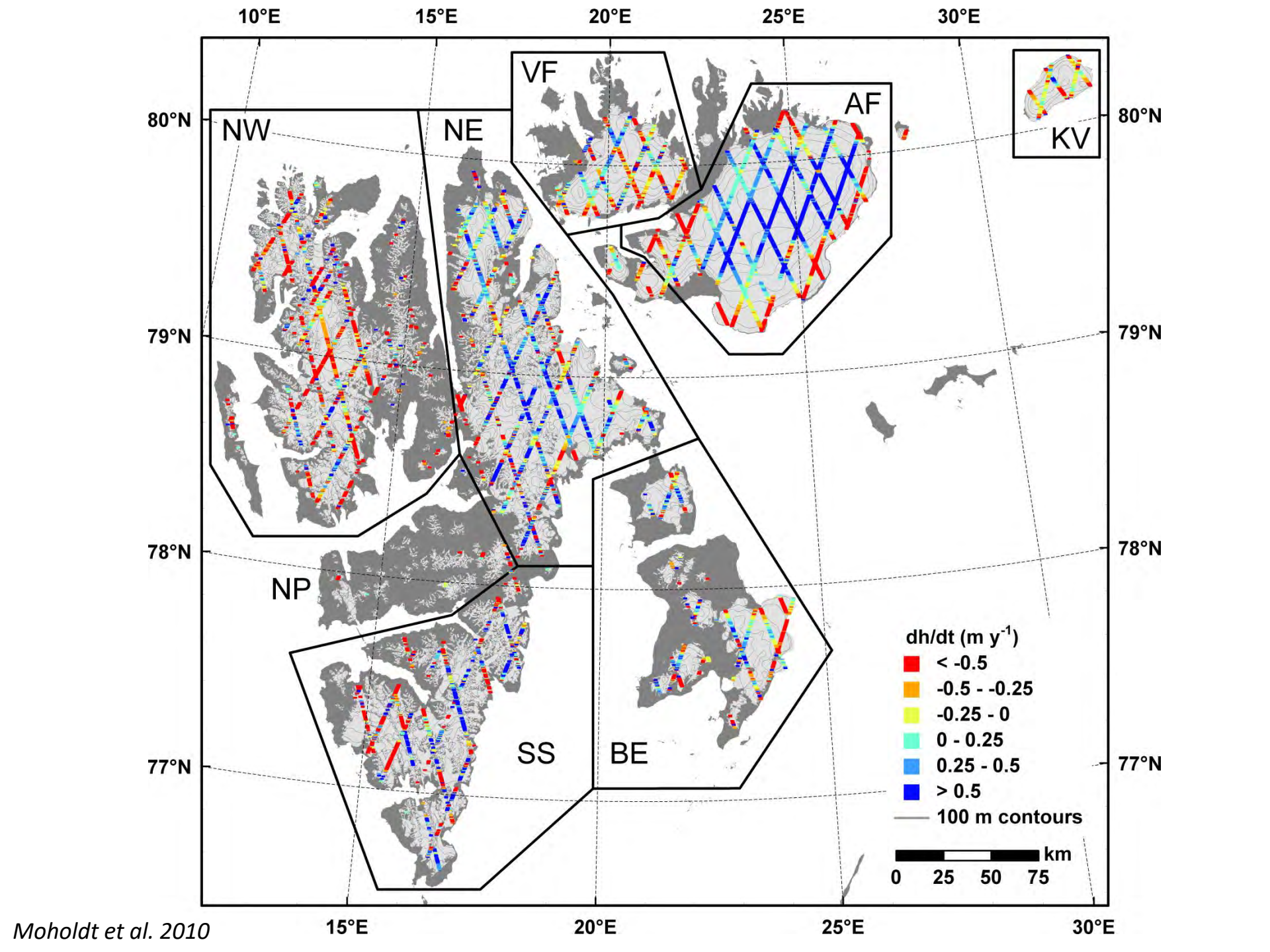
Campaign-to-campaign elevation changes are estimated from the residuals (*r*):

$$dh_{12} = (\bar{t}_2 - \bar{t}_1) \cdot dh/dt + (\bar{r}_2 - \bar{r}_1)$$

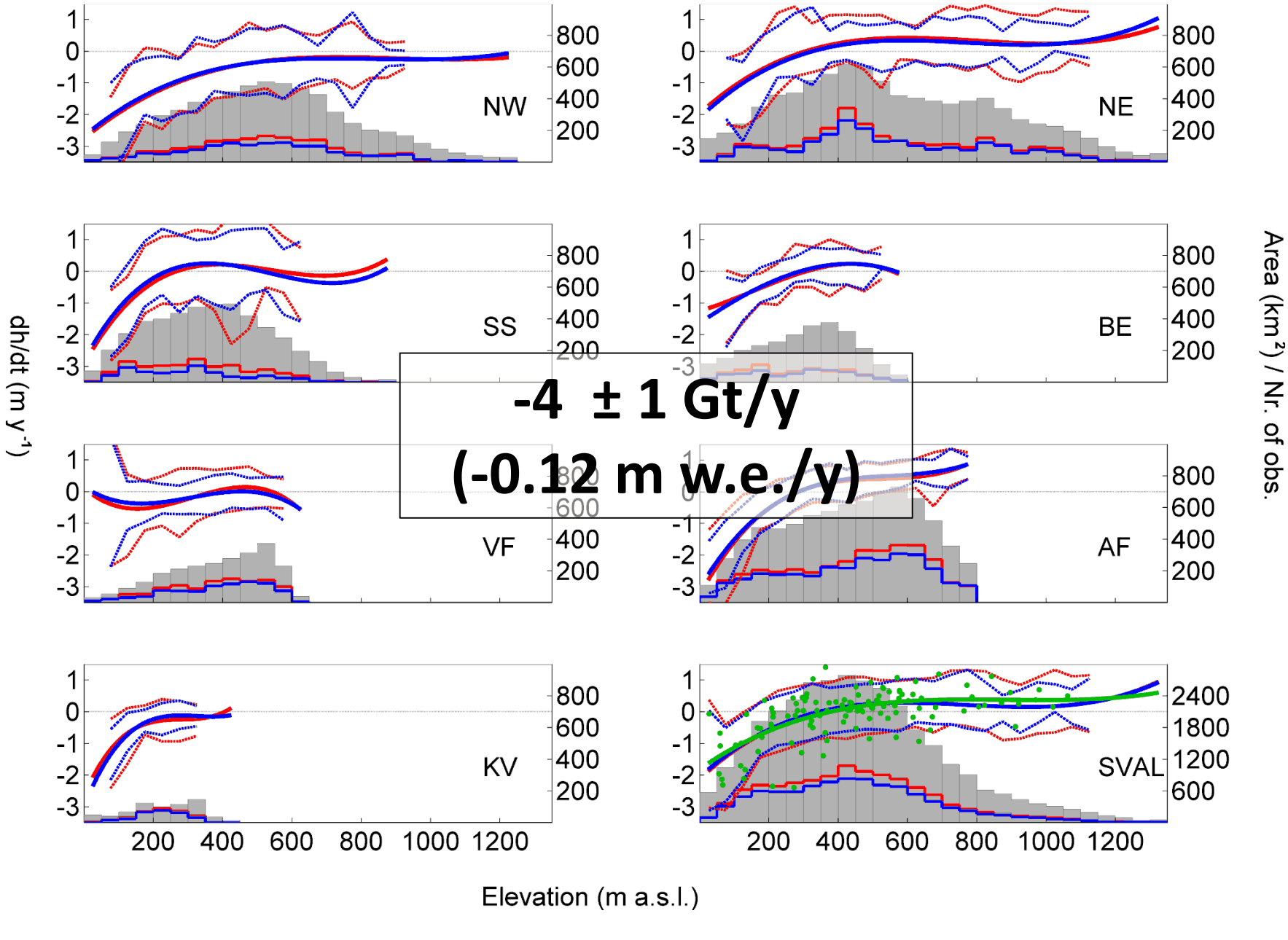
where *t* is the time of campaign *1* and *2*.

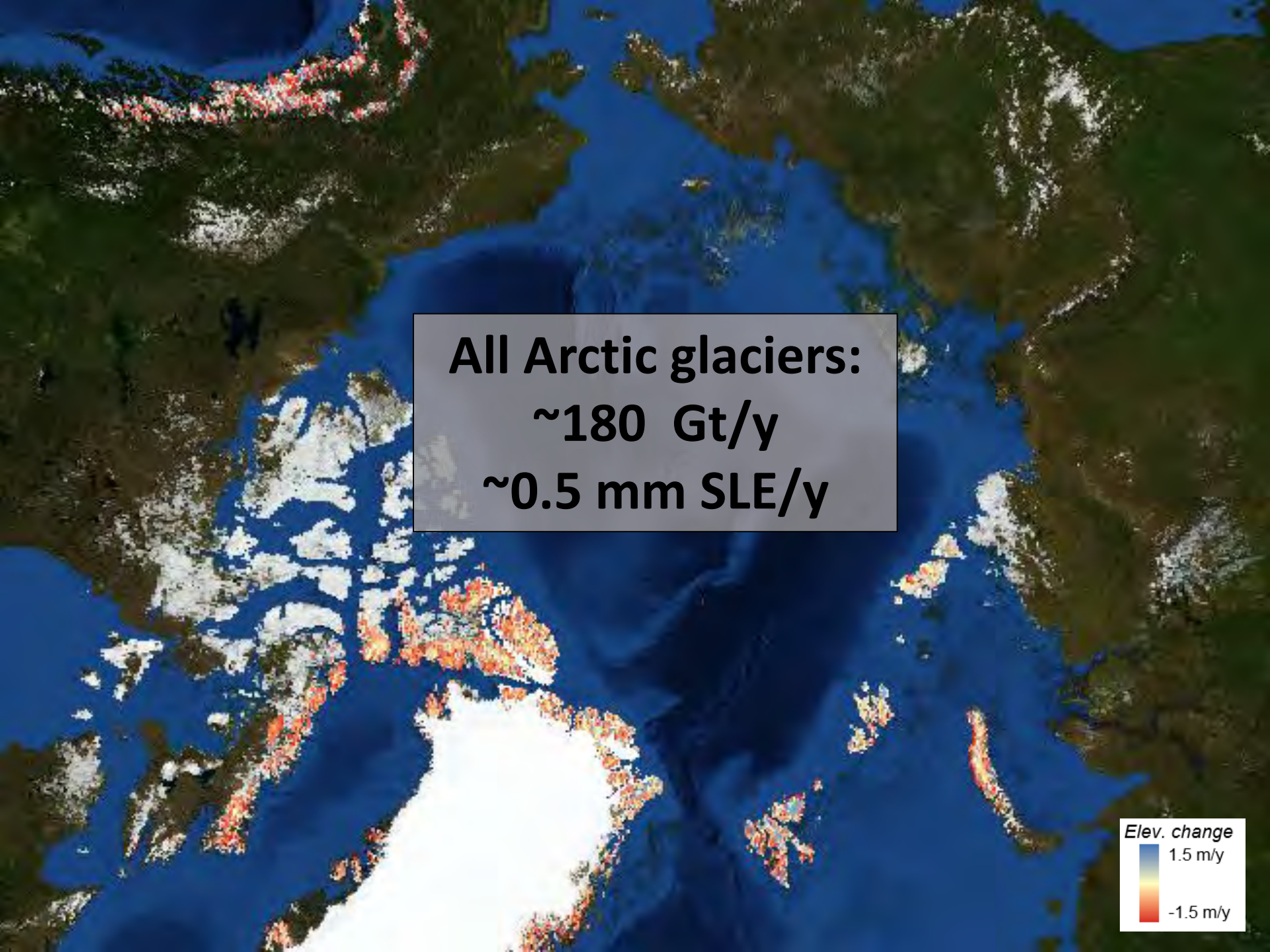
Repeat-tracks vs. crossovers

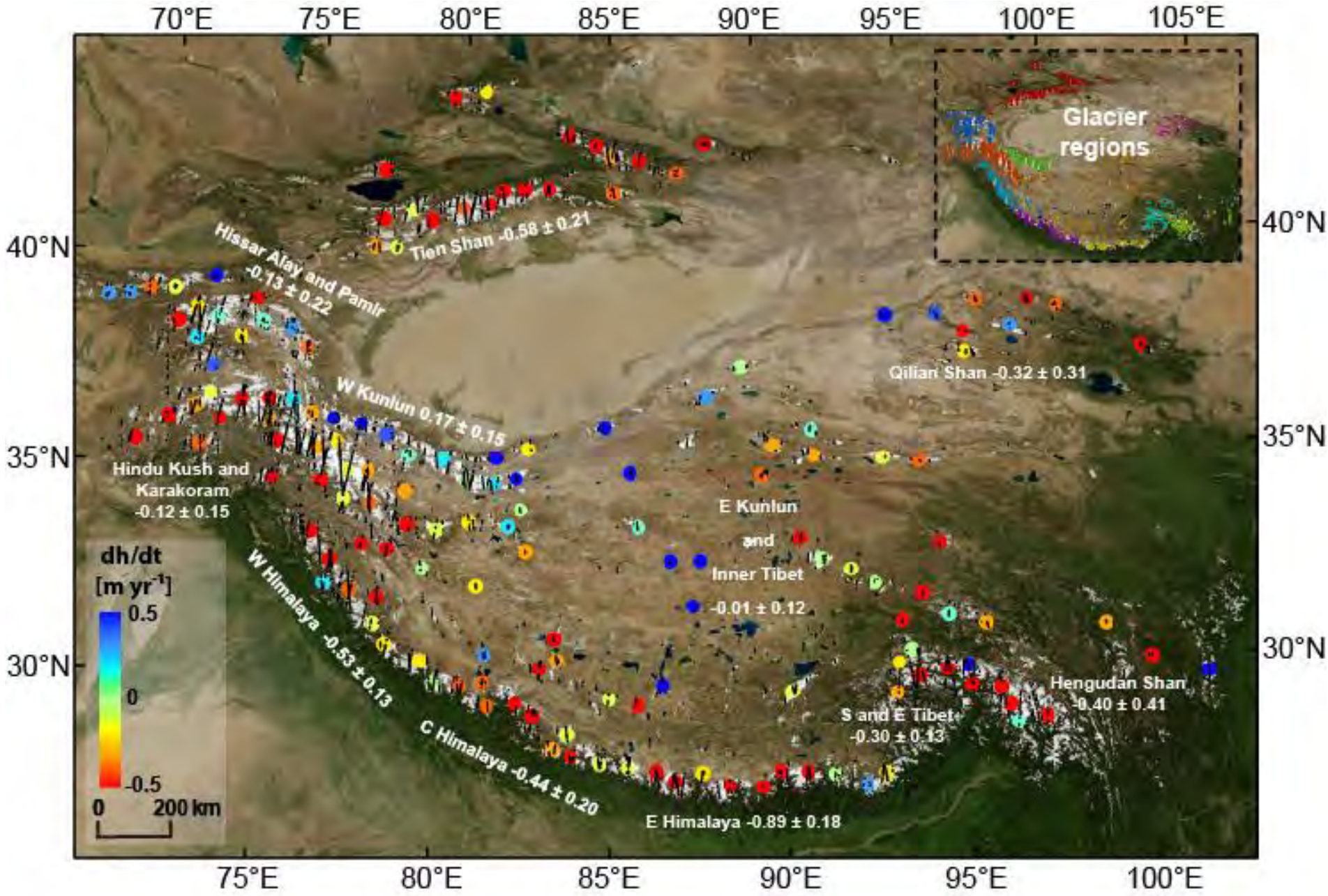




Moholdt et al. 2010

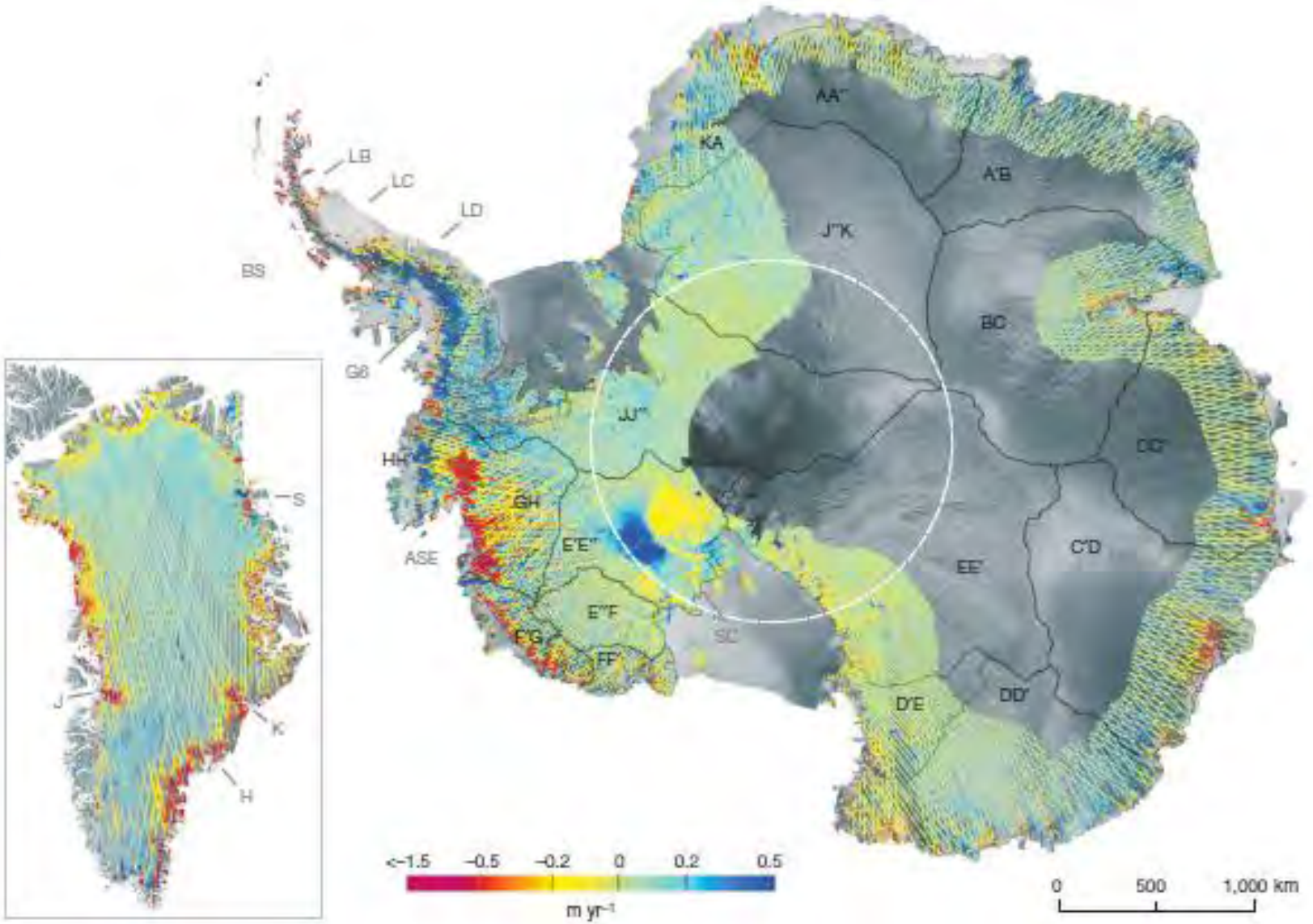

NW
NE
SS
BE
VF
AF
KV
SVAL
dh/dt (m y-1)
Area (km²) / Nr. of obs.
Elevation (m a.s.l.)
-4 ± 1 Gt/y
(-0.12 m w.e./y)
Crossovers
DEM method
Plane method


All Arctic glaciers:
~180 Gt/y
~0.5 mm SLE/y
Elev. change
1.5 m/y
-1.5 m/y



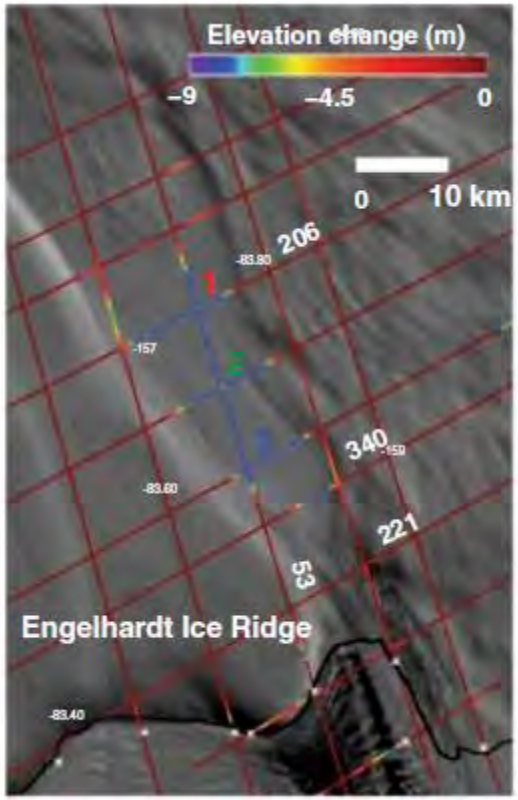
Gardner et al. 2013, Science

Greenland and Anatrctica

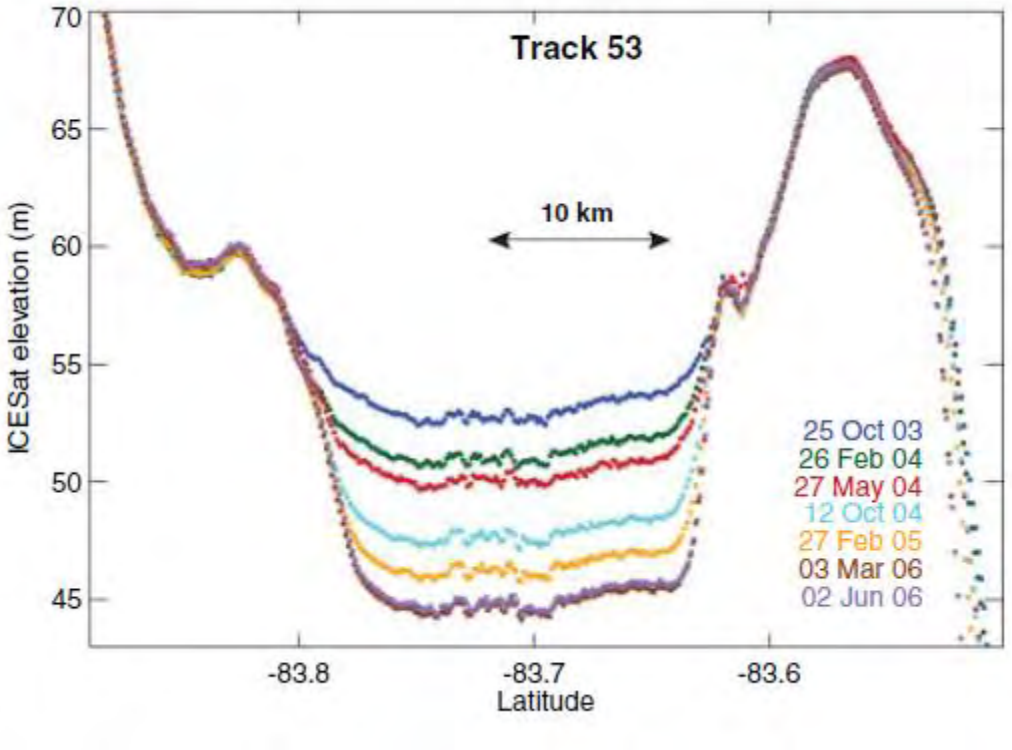


Pritchard et al. 2009, Nature

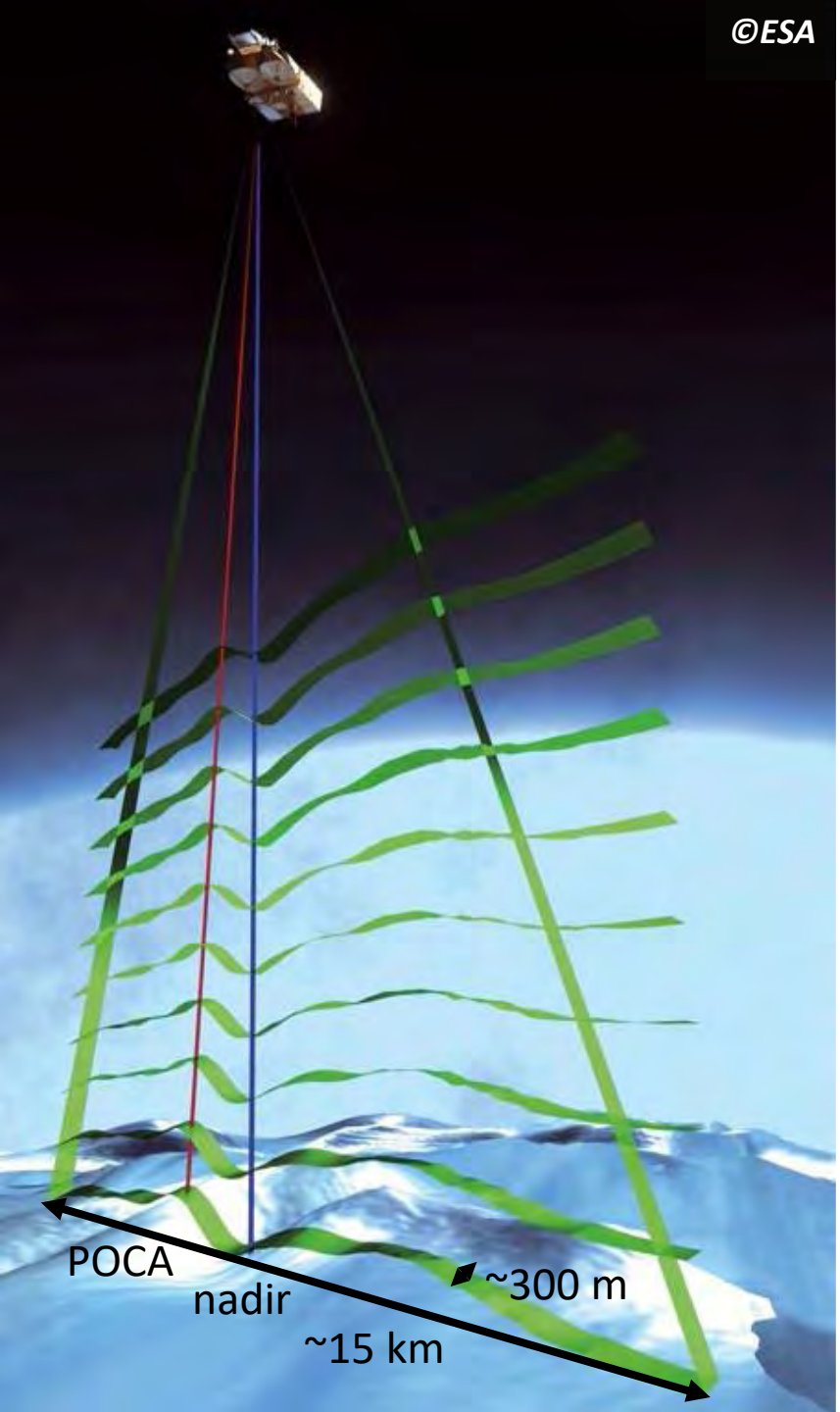
Detection of active subglacial lakes



Fricker et al. 2007



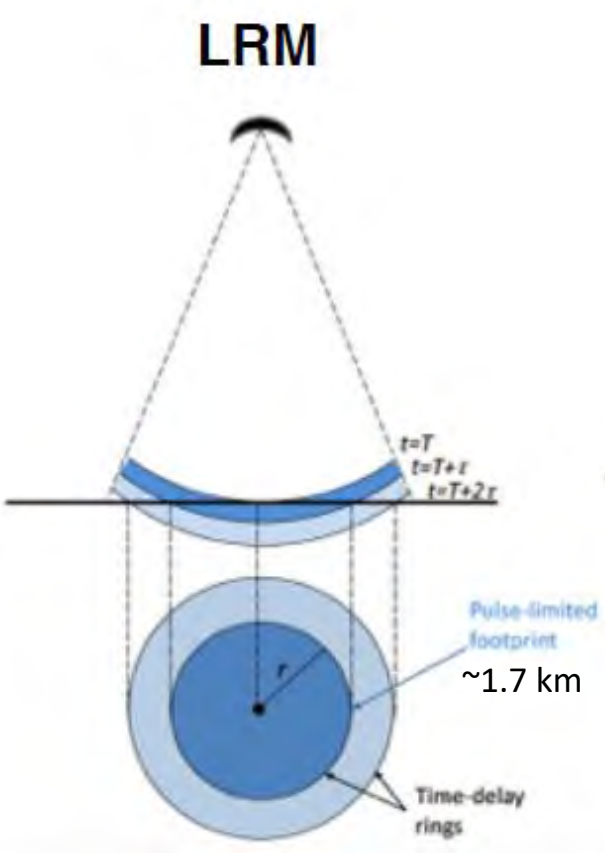
Subglacial lake activity can be inferred from surface elevation changes



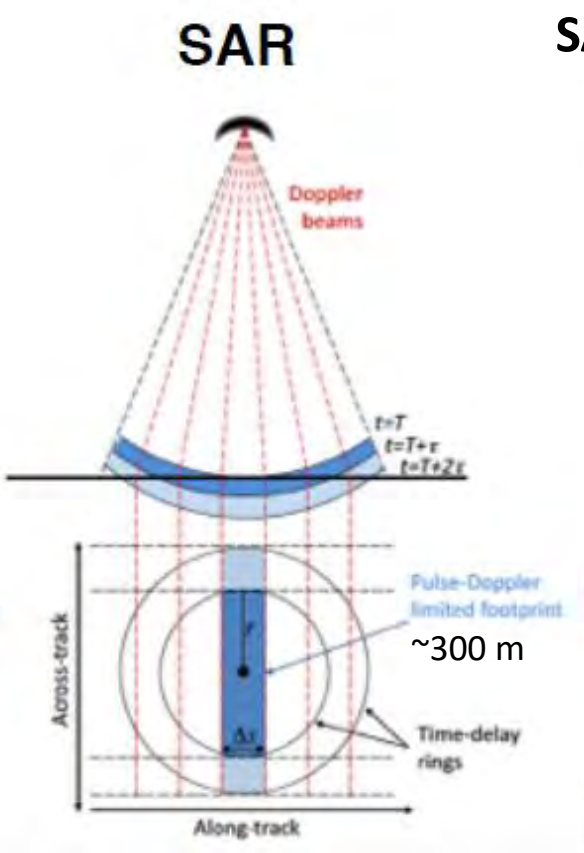
CryoSat-2

- Ku-band radar (13 Ghz)
- Repeat cycle 369 days
- Beam footprint ~15 km
- Doppler processing of pulse bursts for improved along-track resolution (~300 m)
- SAR interferometric processing of phase differences between two receiving antennas for across-track mapping of the point-of-closest approach (POCA) and unambiguous parts of the swath

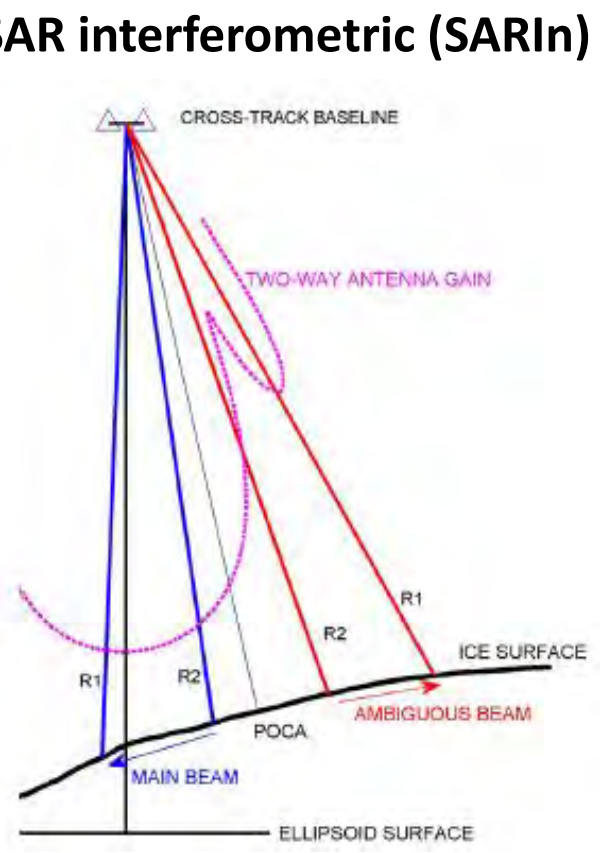
CryoSat-2 – observation modes



©ESA



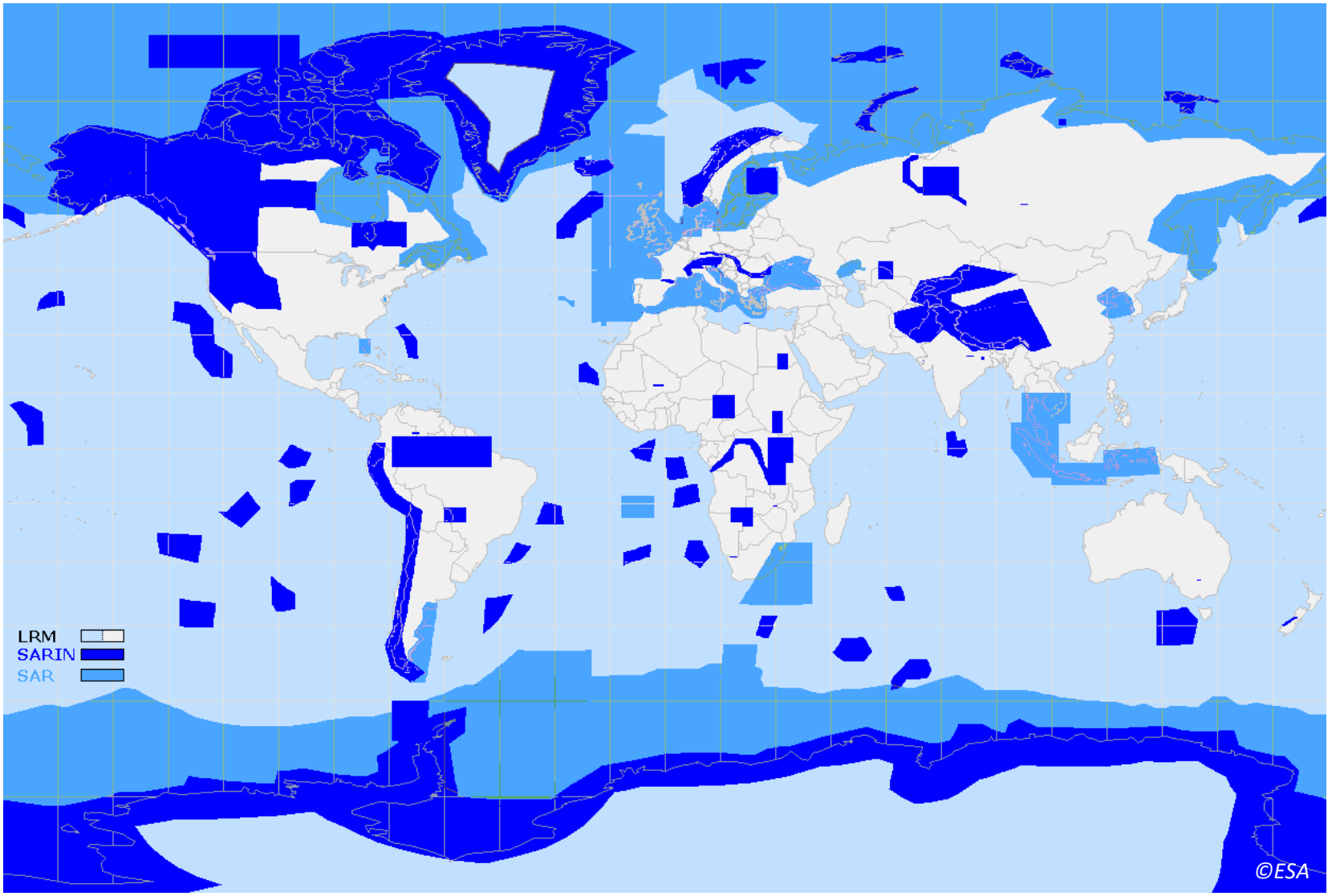
©ESA



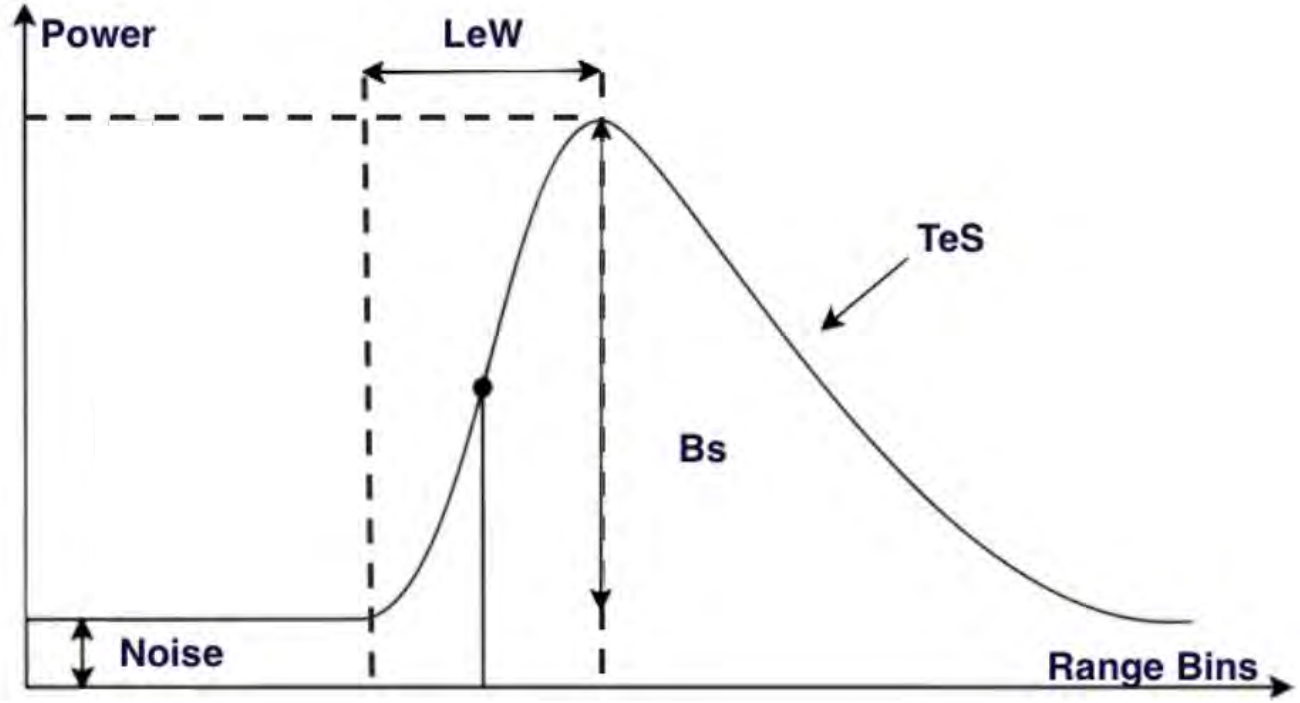
Gray et al. 2013

CryoSat-2 has three different resolution modes: Low resolution mode (LRM), synthetic aperture radar (SAR) mode, SAR interferometry (SARIn) mode

CryoSat-2 – observation modes



Waveform retracking

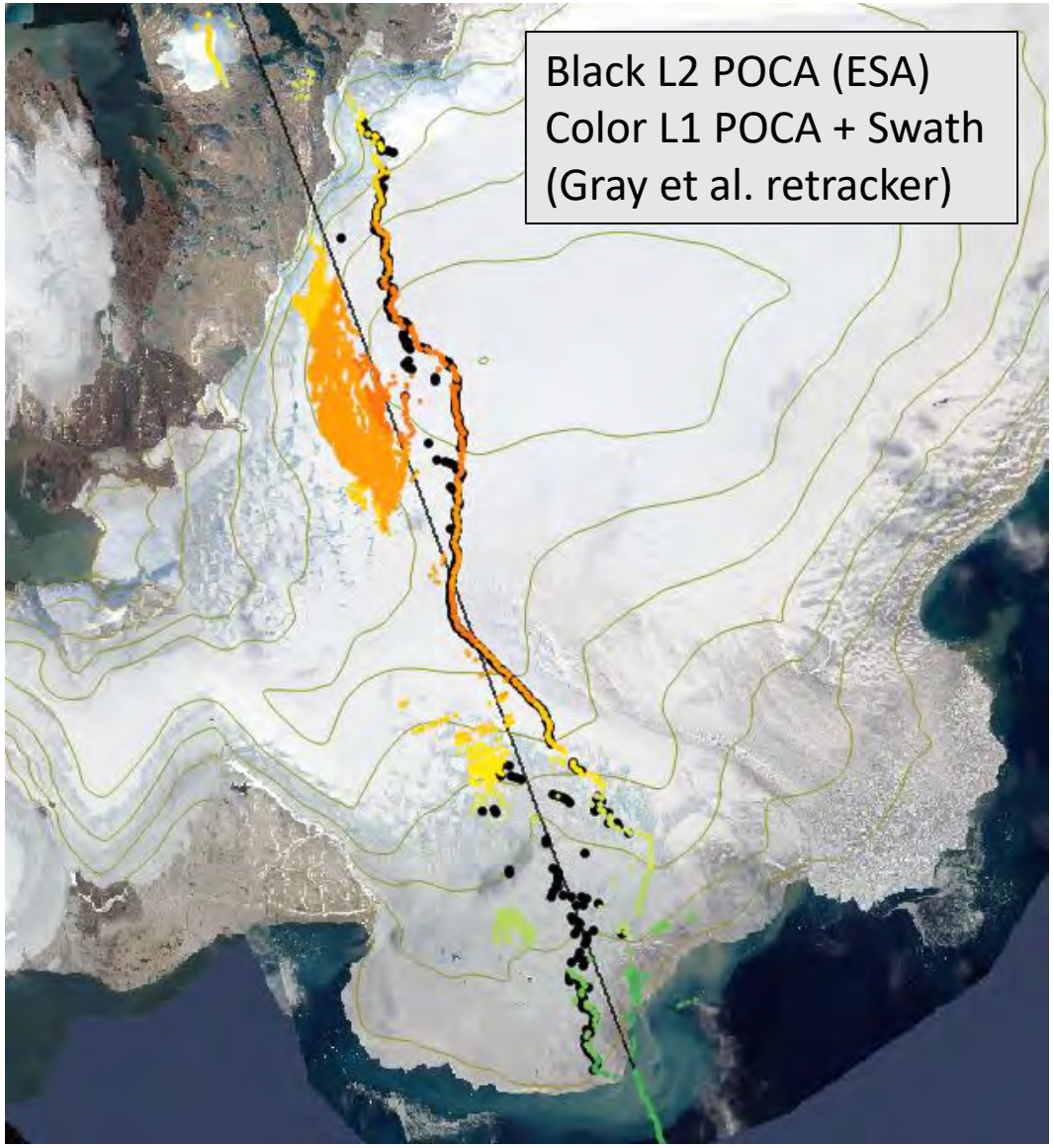


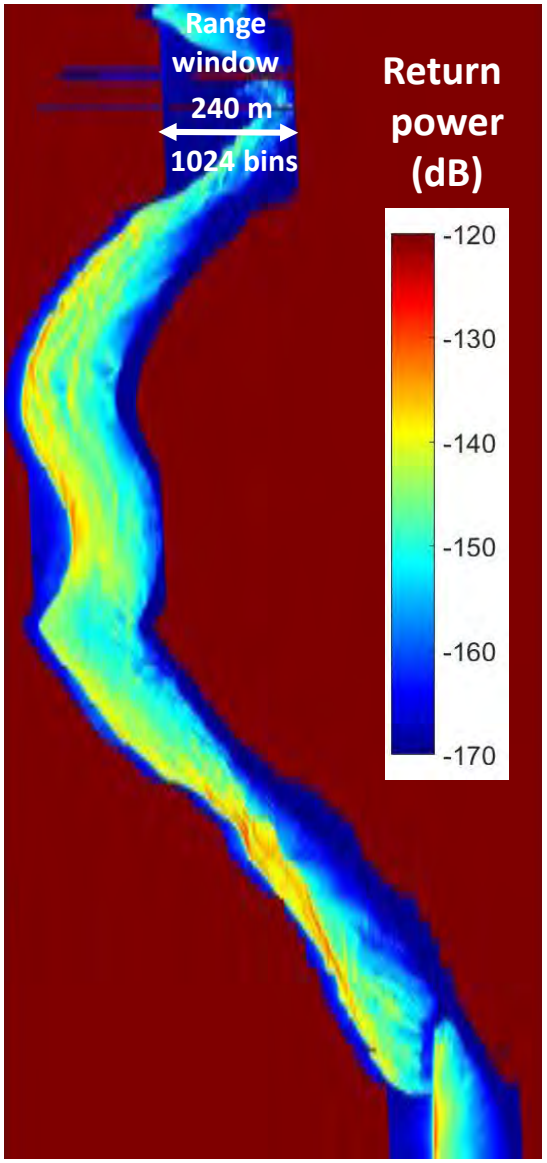
Nilsson et al. 2015

Retracking is an estimation technique to determine the range to the point of closest approach (POCA) on the surface based on the return waveform.

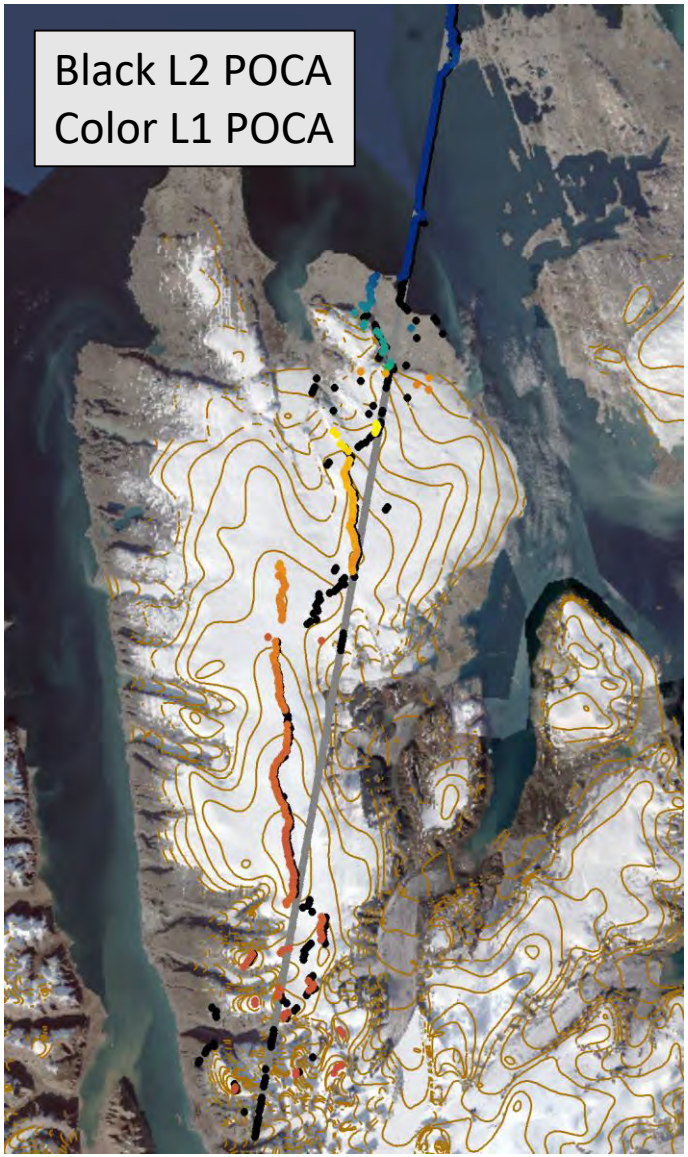
Various methods: Model fits, leading edge threshold, maximum slope etc.

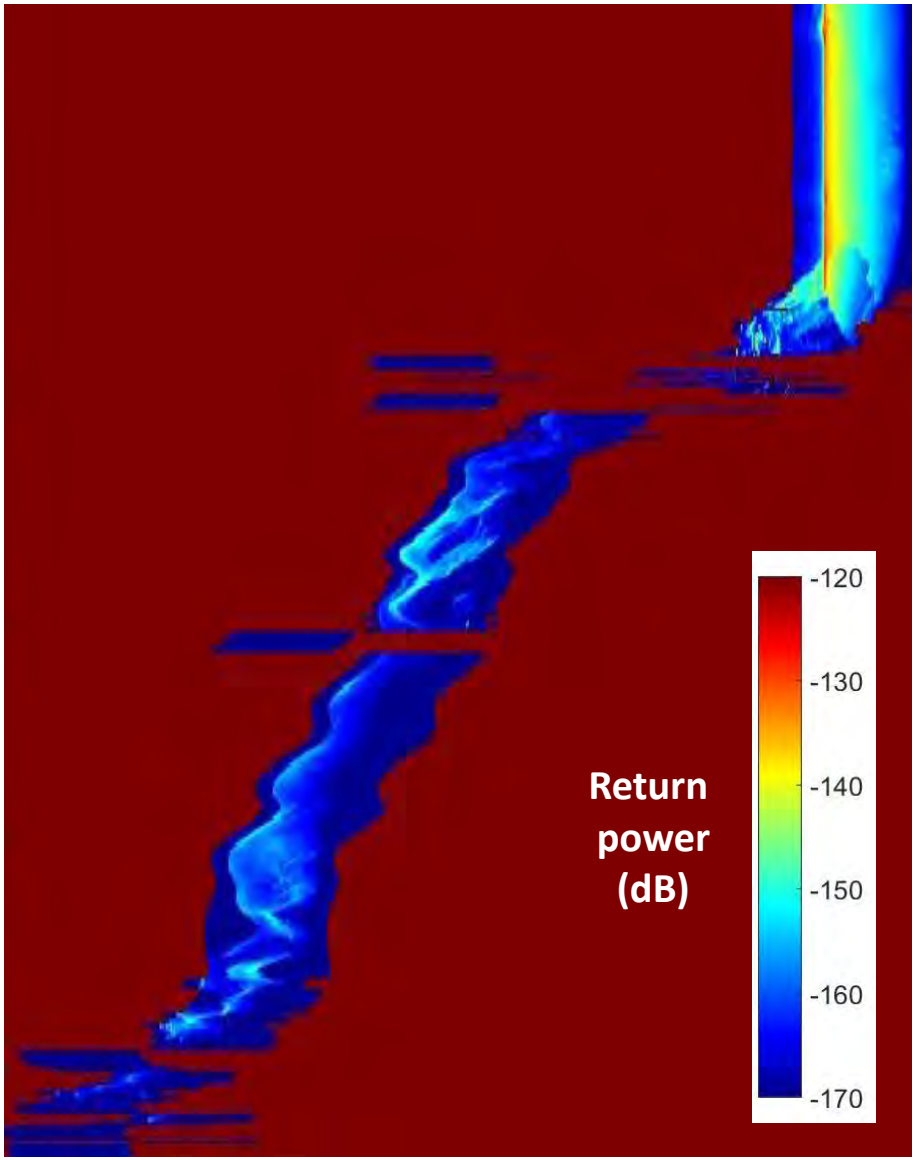
CryoSat-2 data – example Svalbard



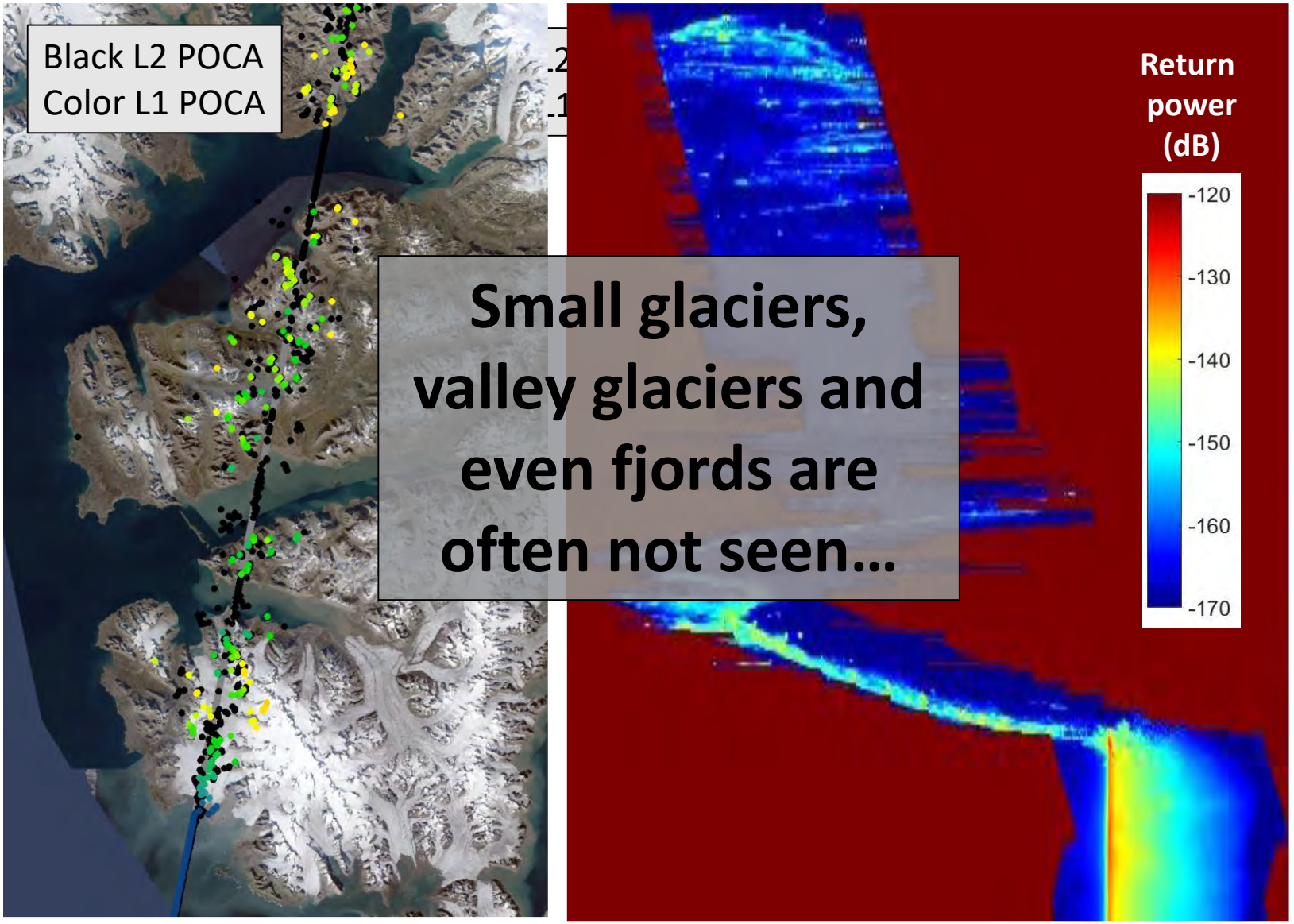


CryoSat-2 data – example Svalbard

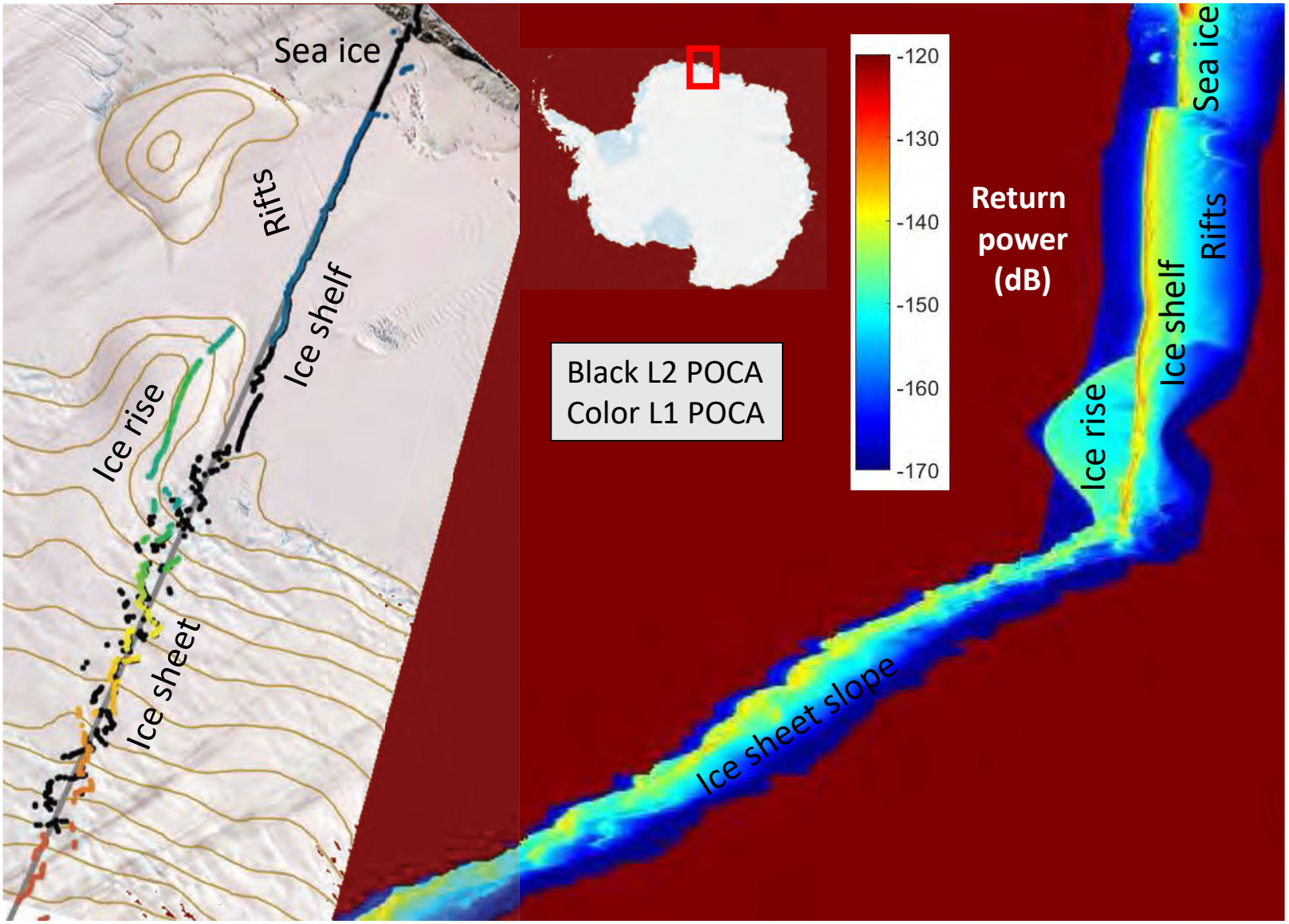




CryoSat-2 data – example Svalbard

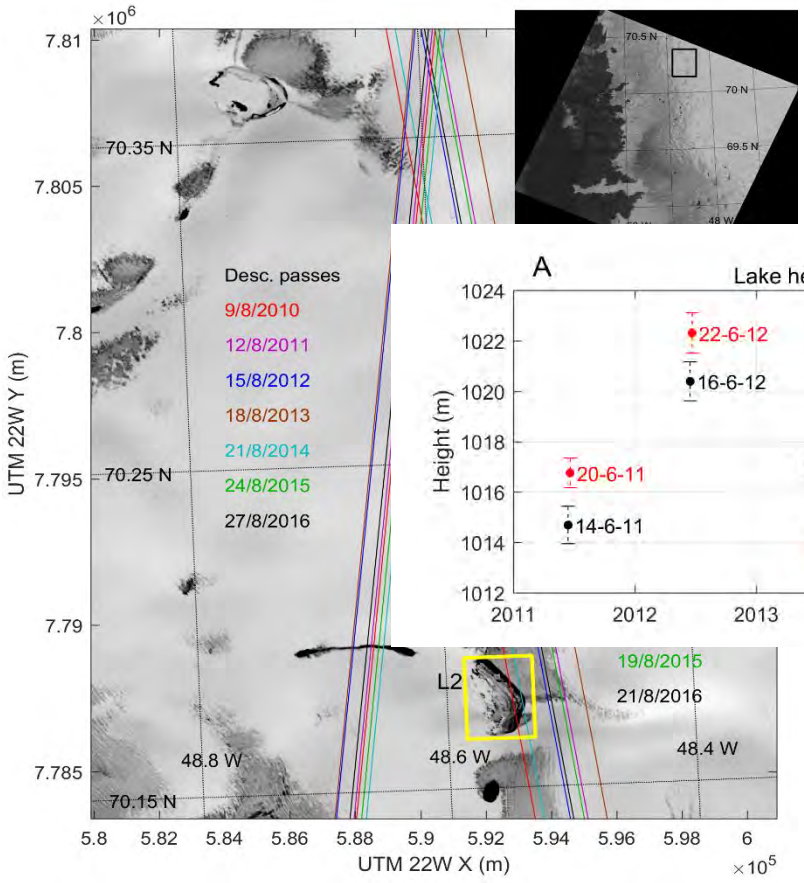


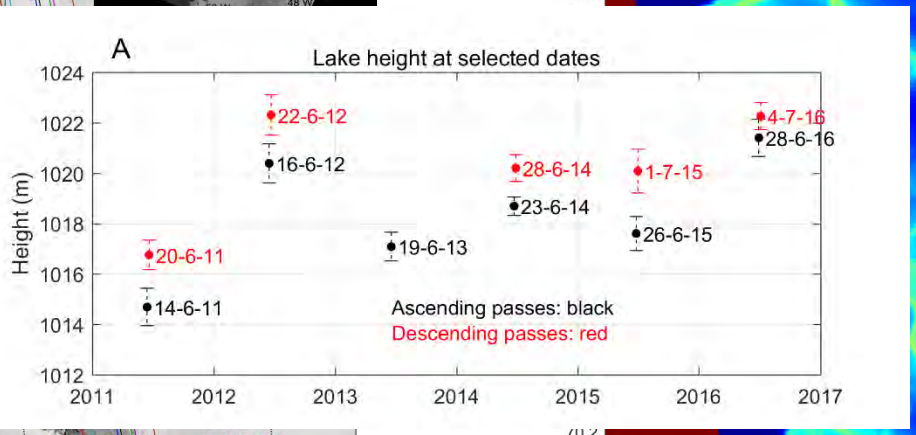
CryoSat-2 data – example Antarctica



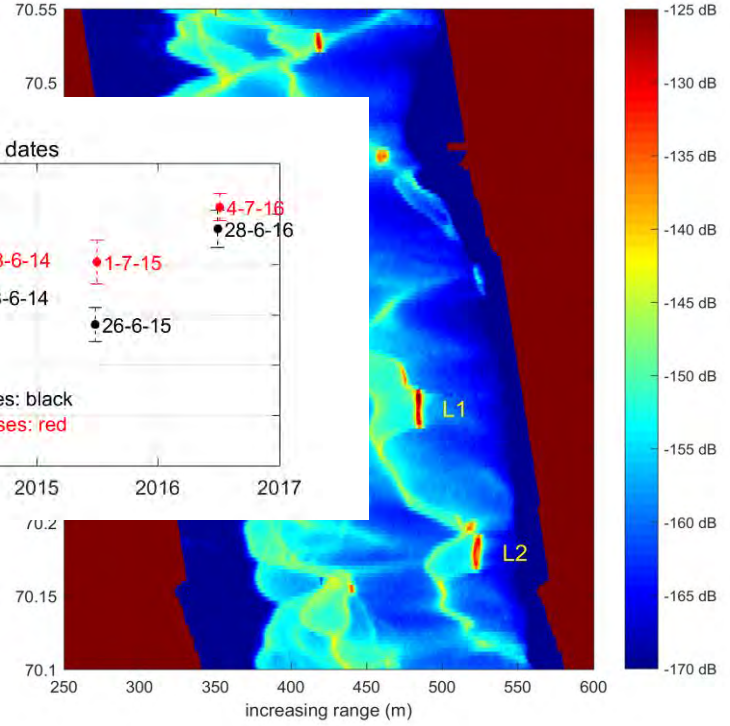
CryoSat-2 data – example Greenland

Landsat 8 image from July 6 2016



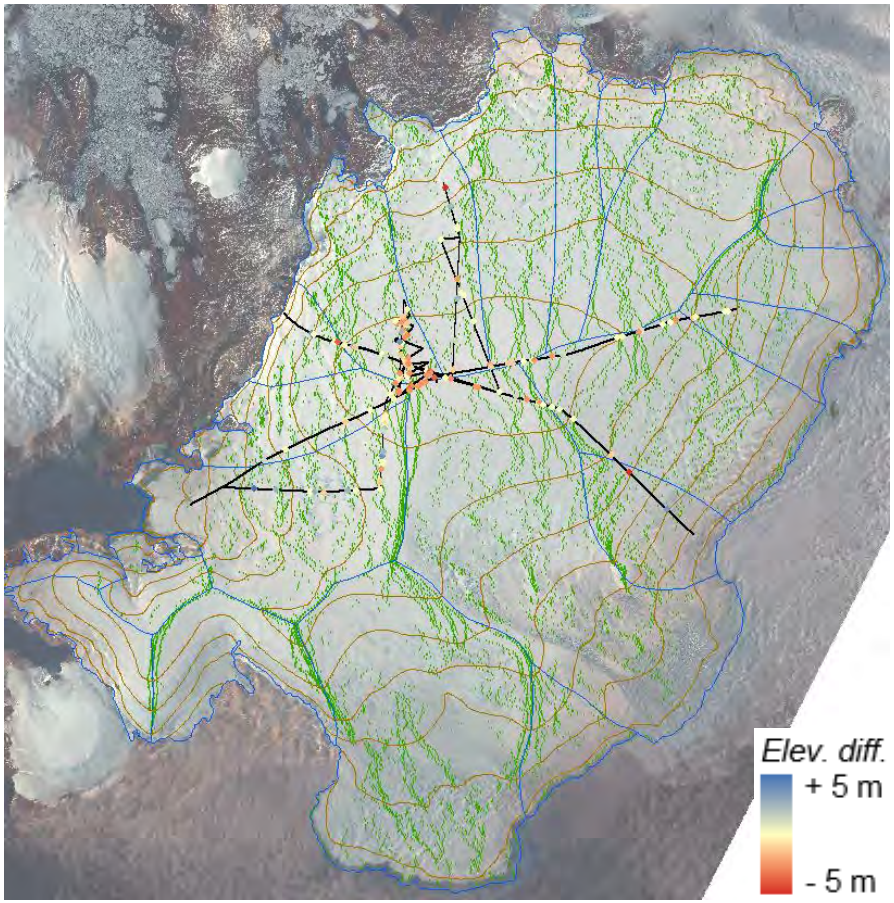


CryoSat waveforms from an ascending pass on Aug. 7 2011

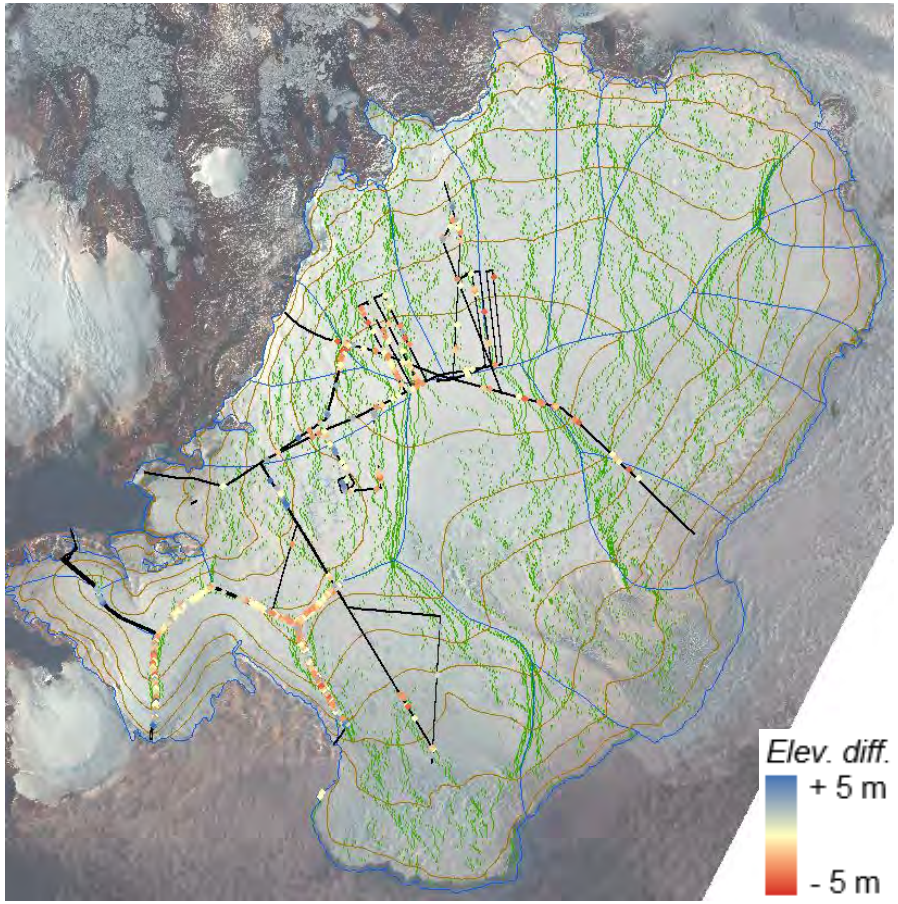


Gray et al. 2017

CryoSat-2 POCA vs. GPS



Example spring 2014: GPS profiling along traditional CryoVEX/SMB transects

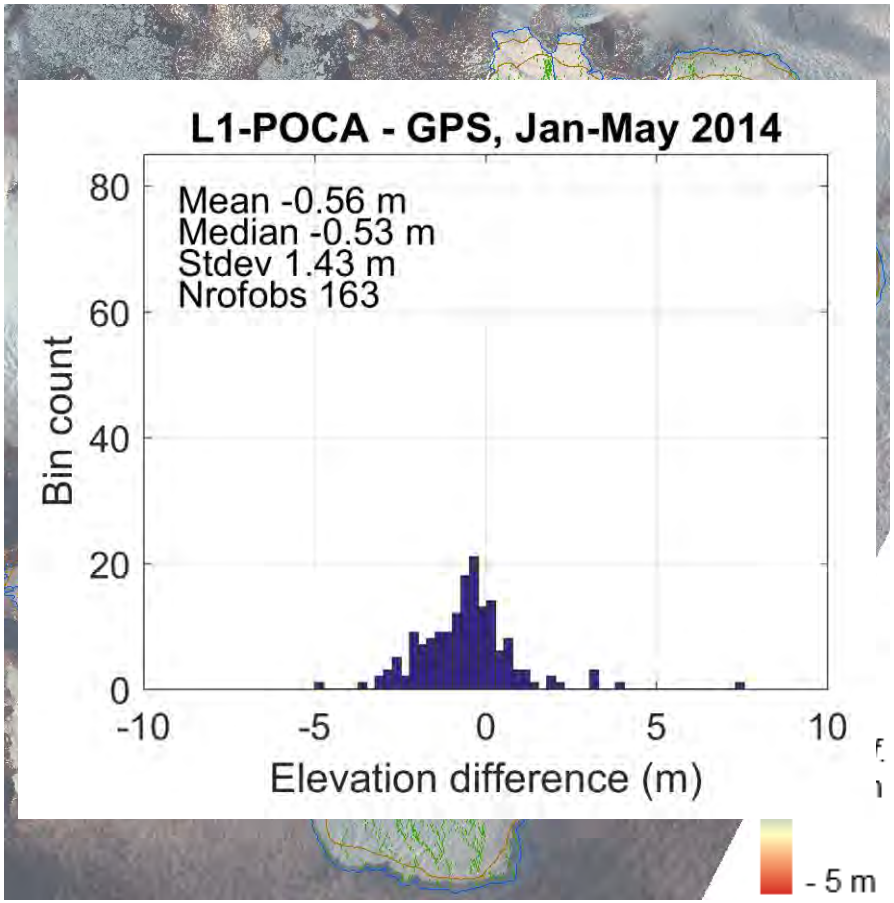


Example spring 2015: Additional GPS profiling along ice divides with high-density POCA data

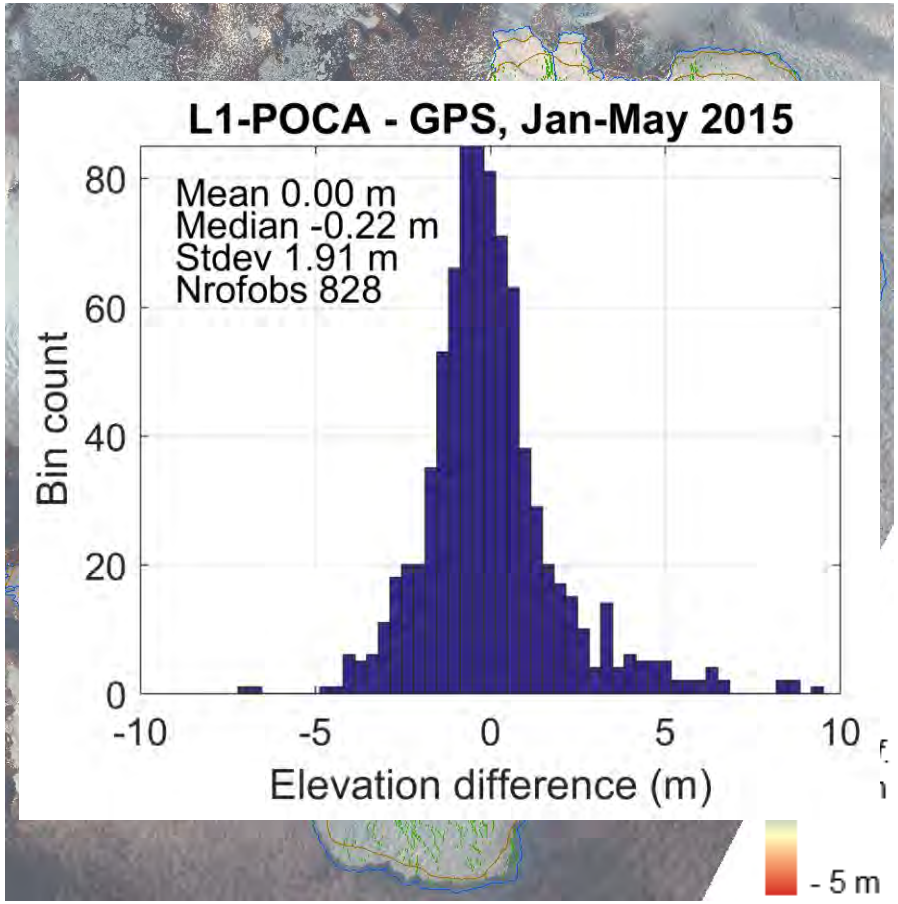
CryoSat-2

GPS profiles

CryoSat-2 POCA vs. GPS



Example spring 2014: GPS profiling along traditional CryoVEX/SMB transects

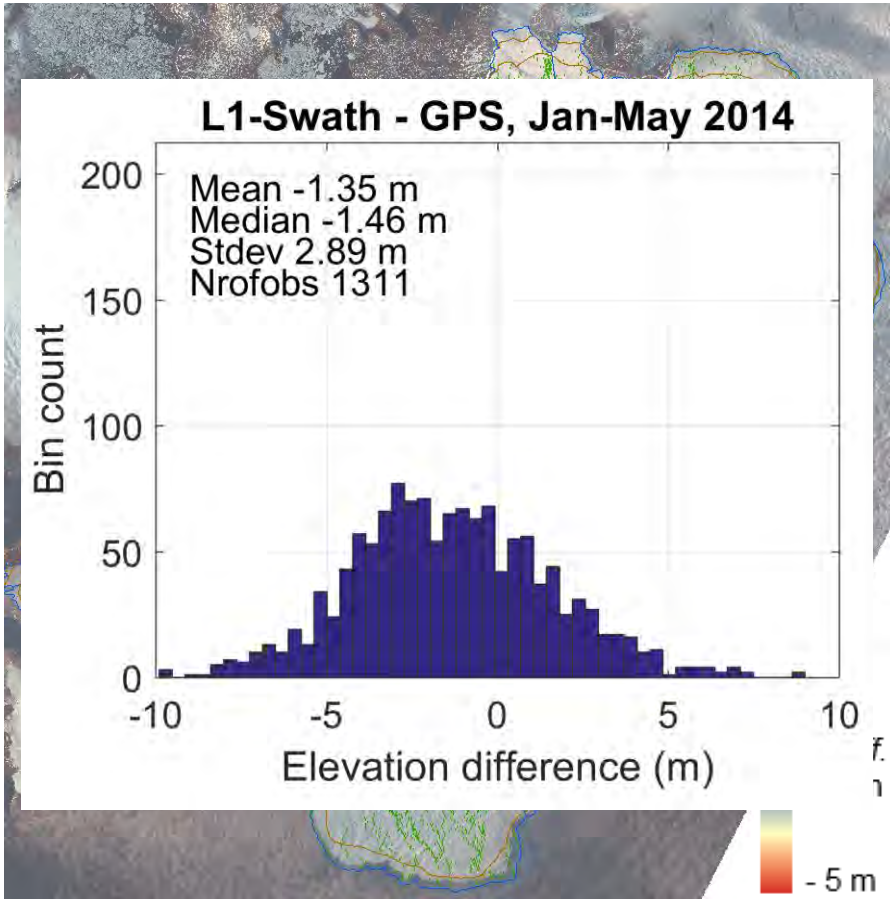


Example spring 2015: Additional GPS profiling along ice divides with high-density POCA data

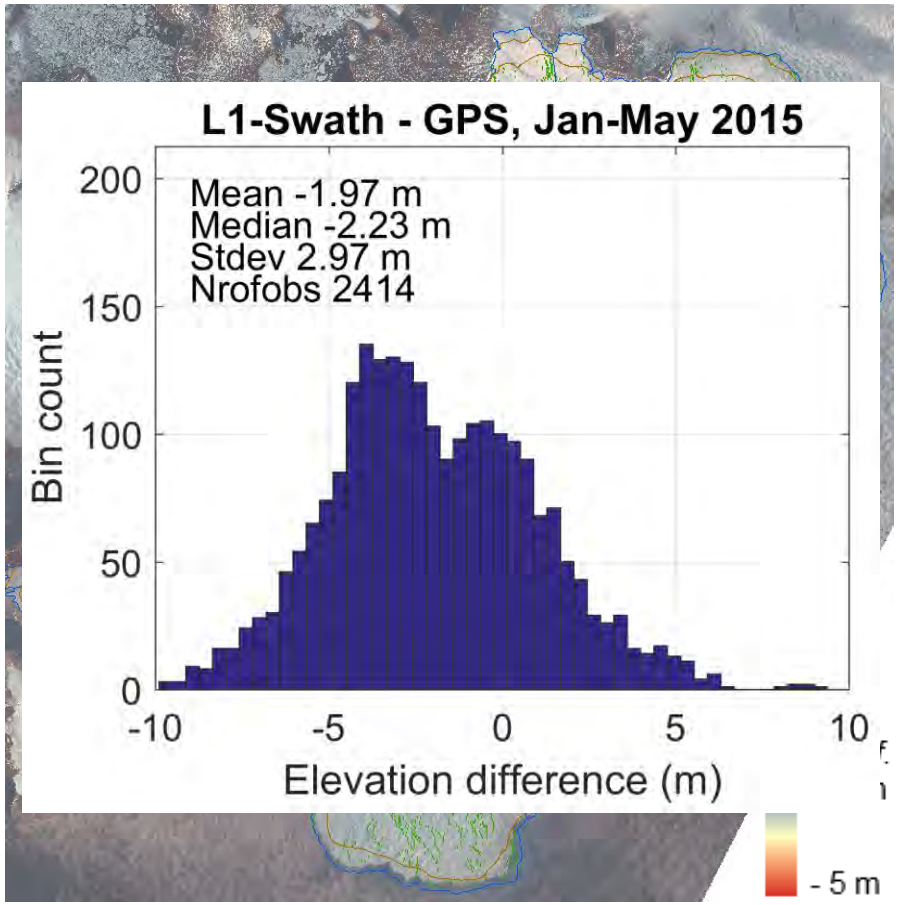
CryoSat-2

GPS profiles

CryoSat-2 Swath vs. GPS



Example spring 2014: GPS profiling along traditional CryoVEX/SMB transects

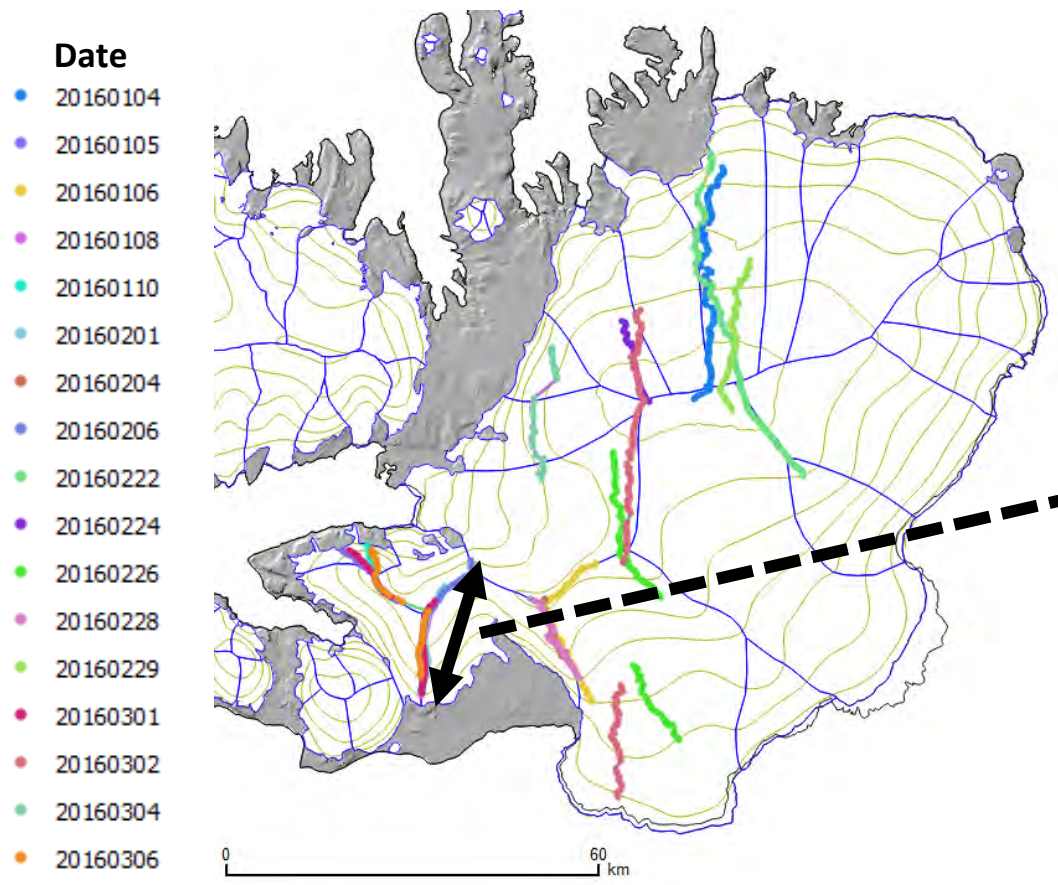


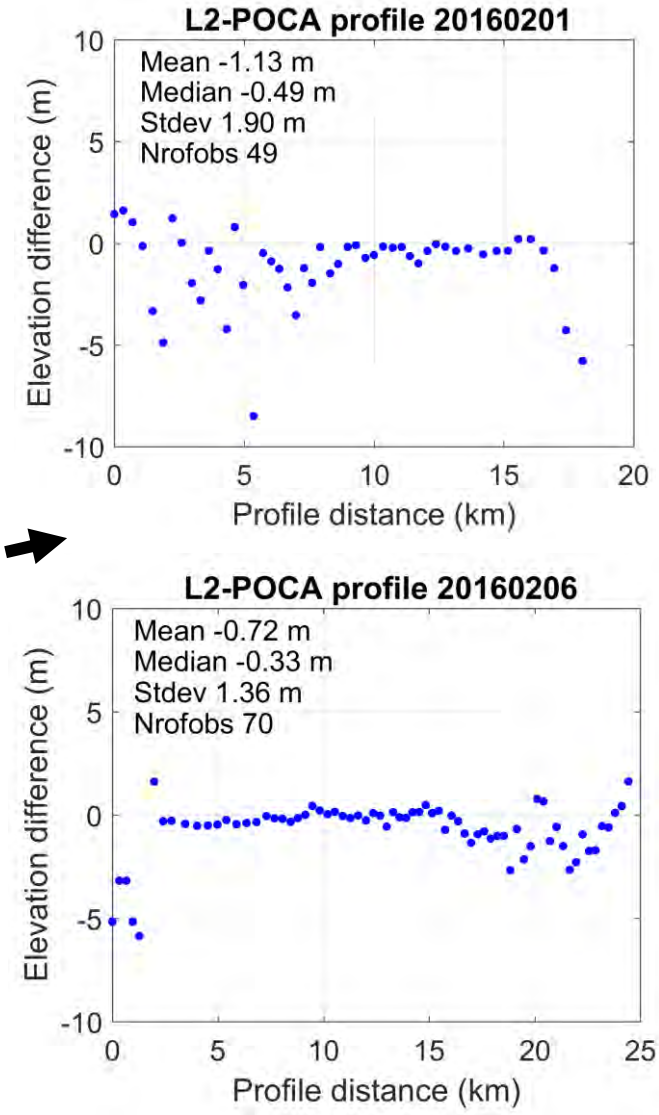
Example spring 2015: Additional GPS profiling along ice divides with high-density POCA data

CryoSat-2

GPS profiles

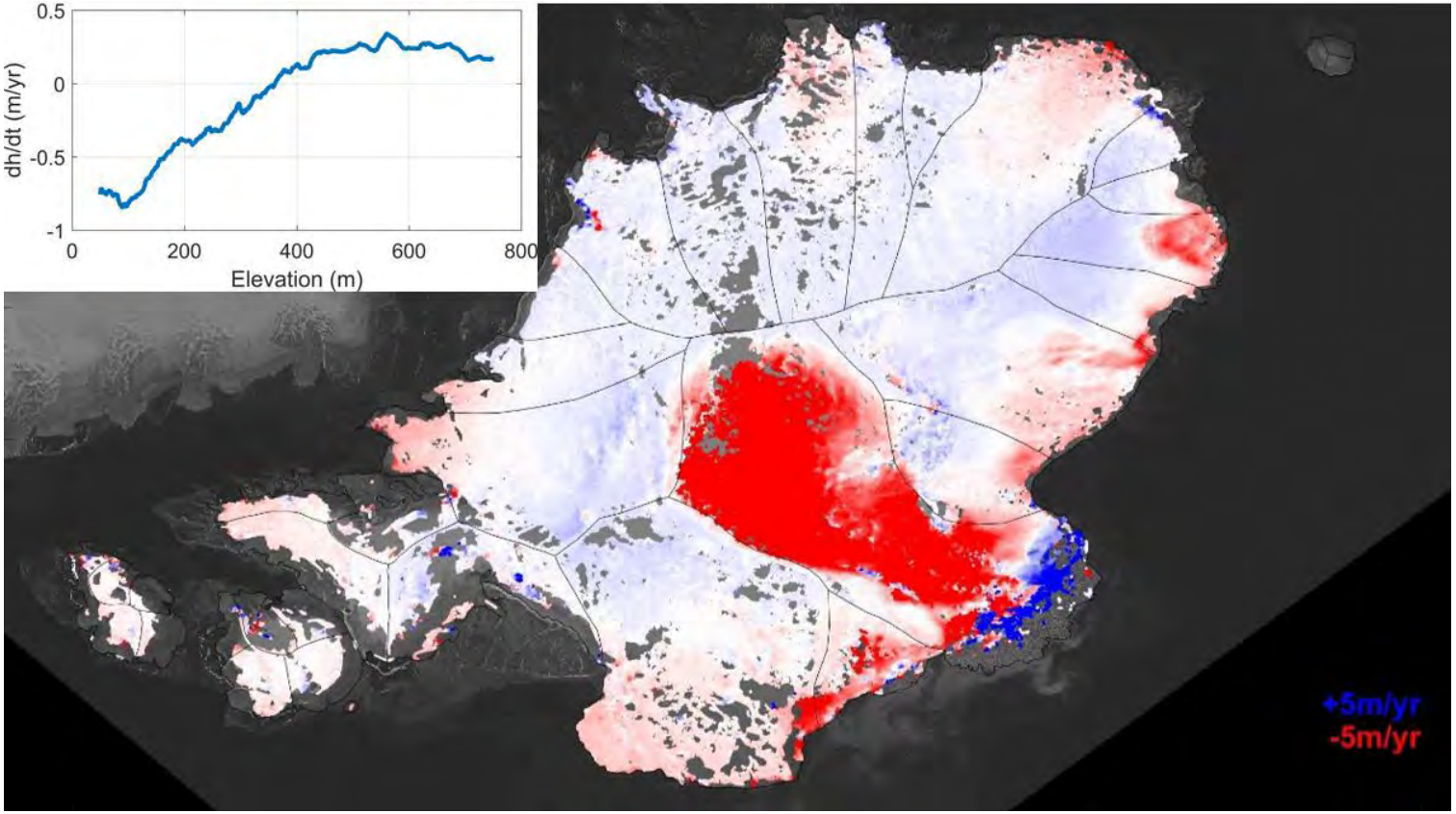
Direct validation of POCA profiles





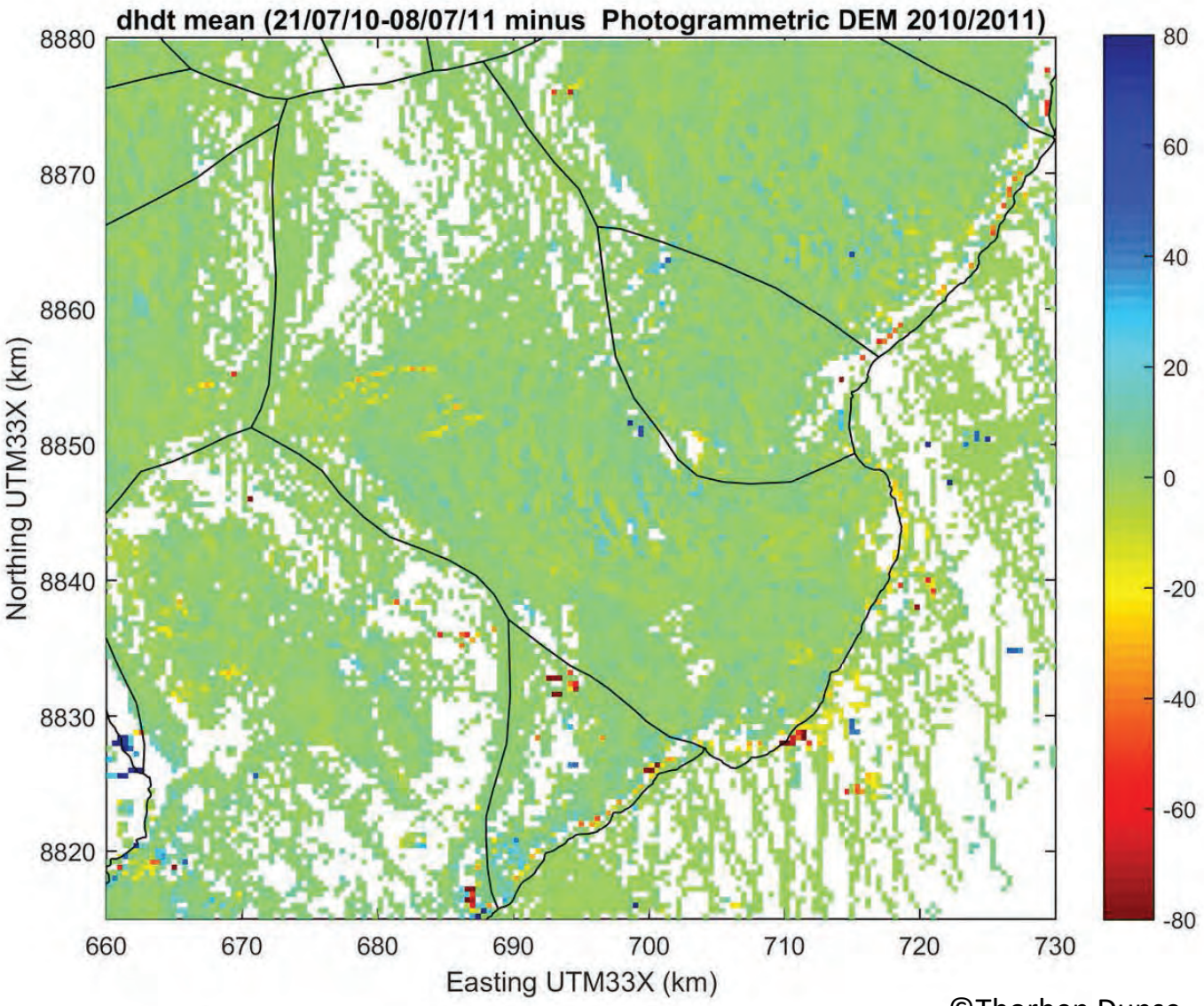
Example of POCA ground tracks from 2016 that were suitable for direct ground validation

CryoSat-2 for elevation changes

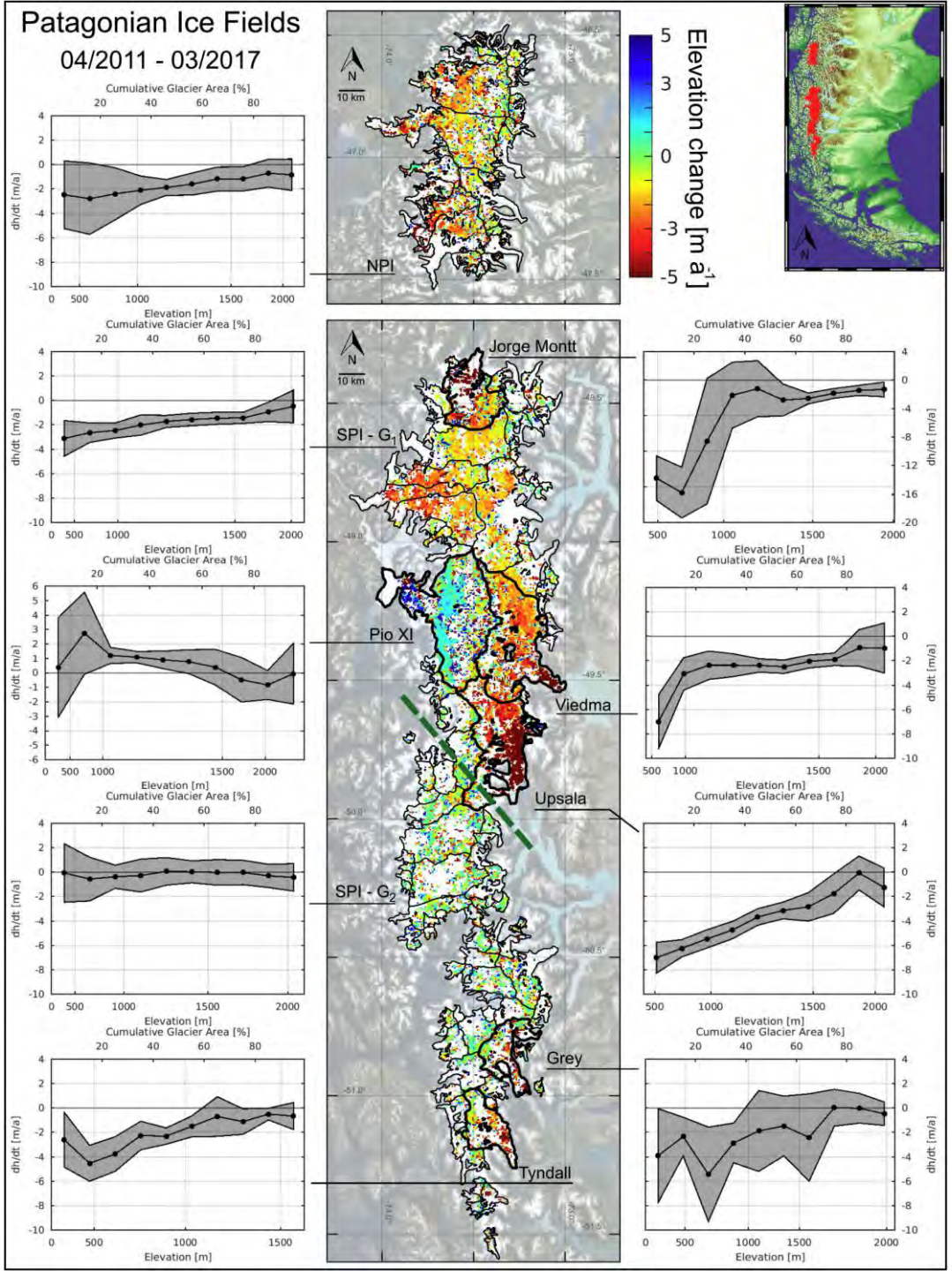


Plane fitting and estimation of dh/dt from CryoSat-2 POCA and Swath (©Ashley Morris)

CryoSat-2 for elevation changes

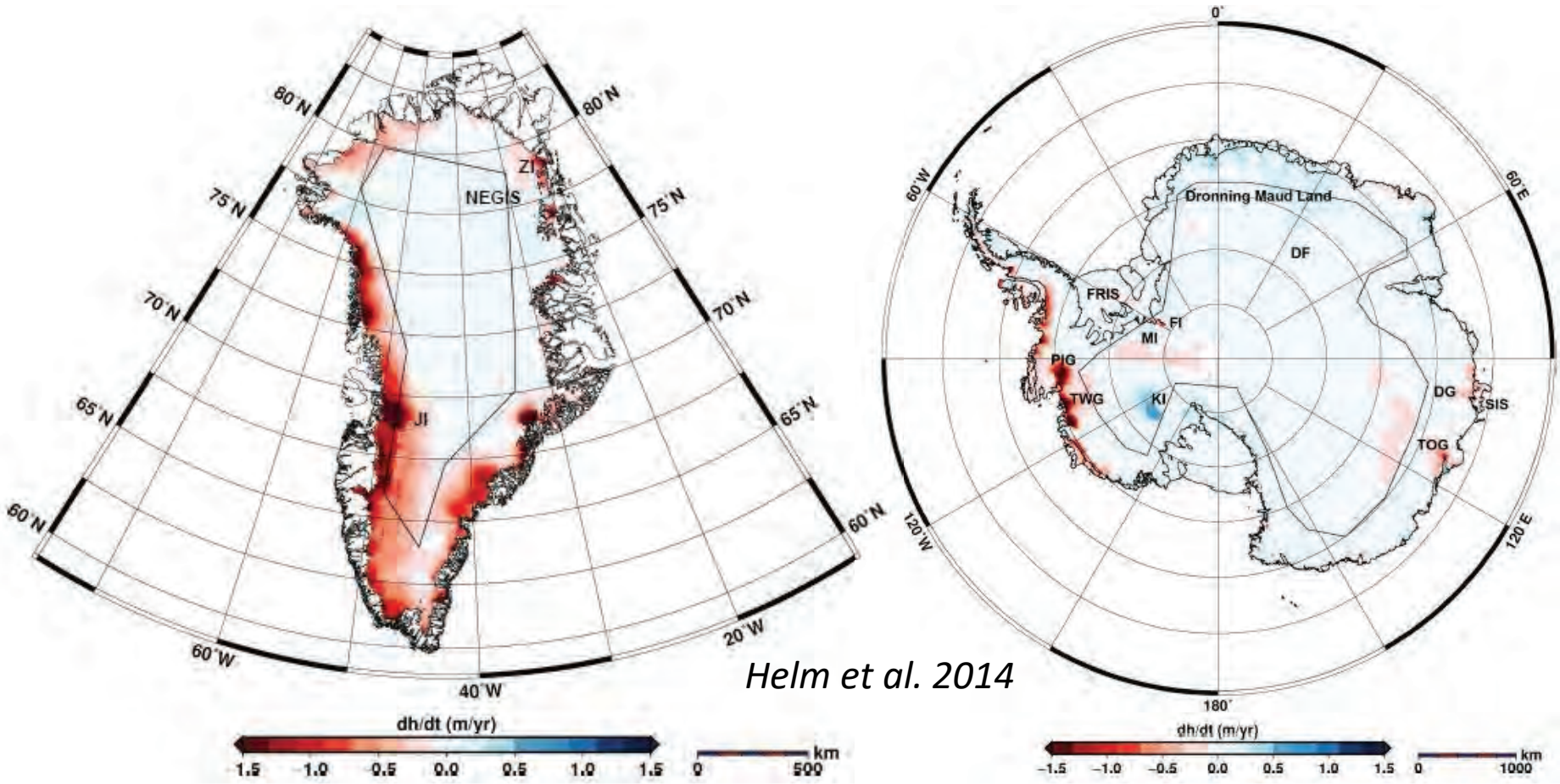


©Thorben Dunse



Foresta et al. 2018

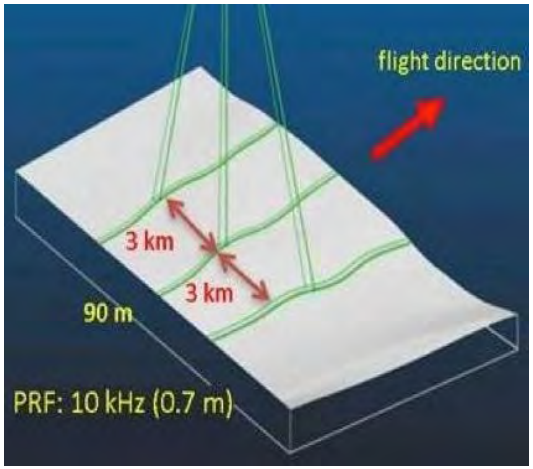
Greenland and Antarctica

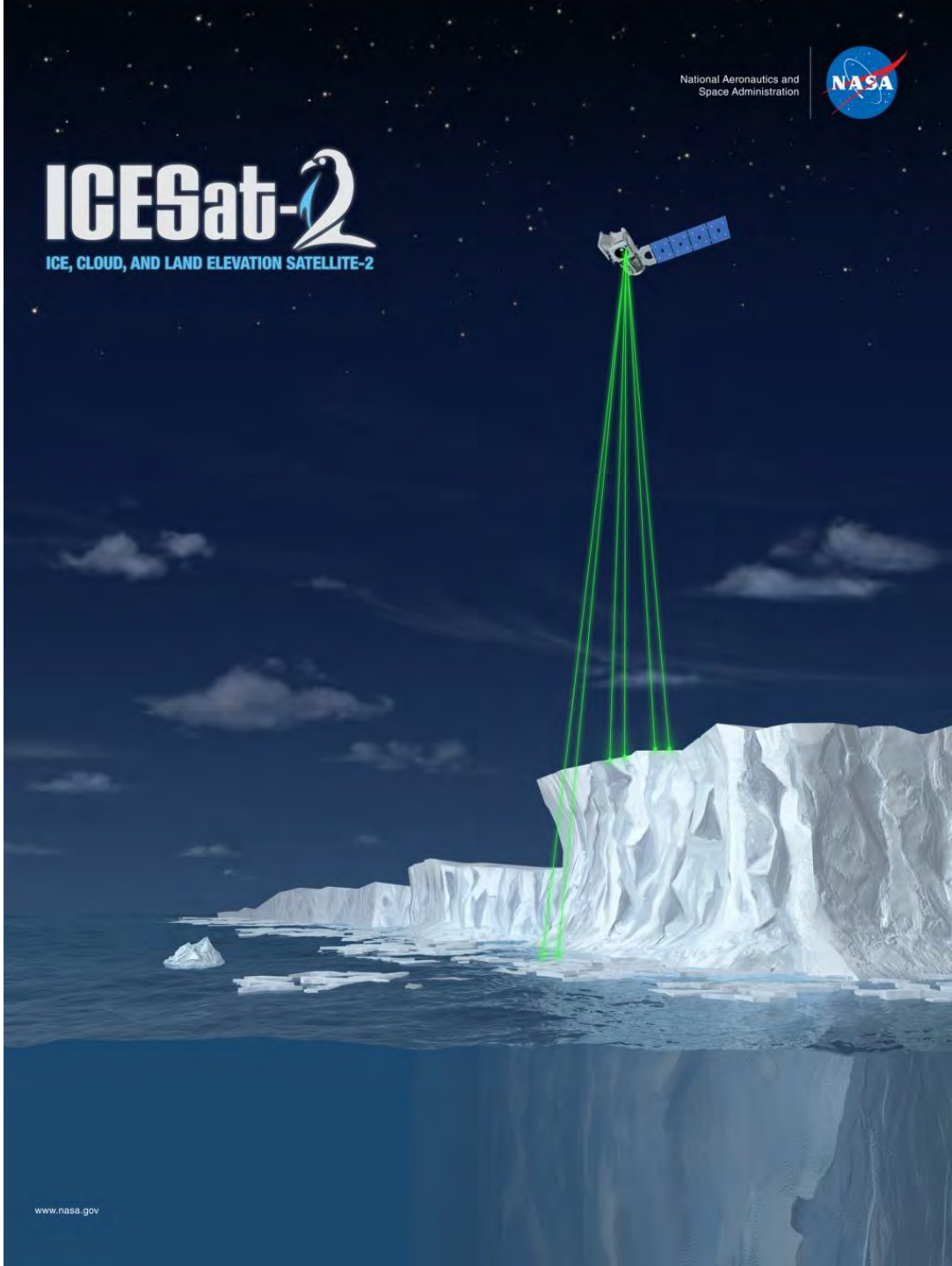


Helm et al. 2014

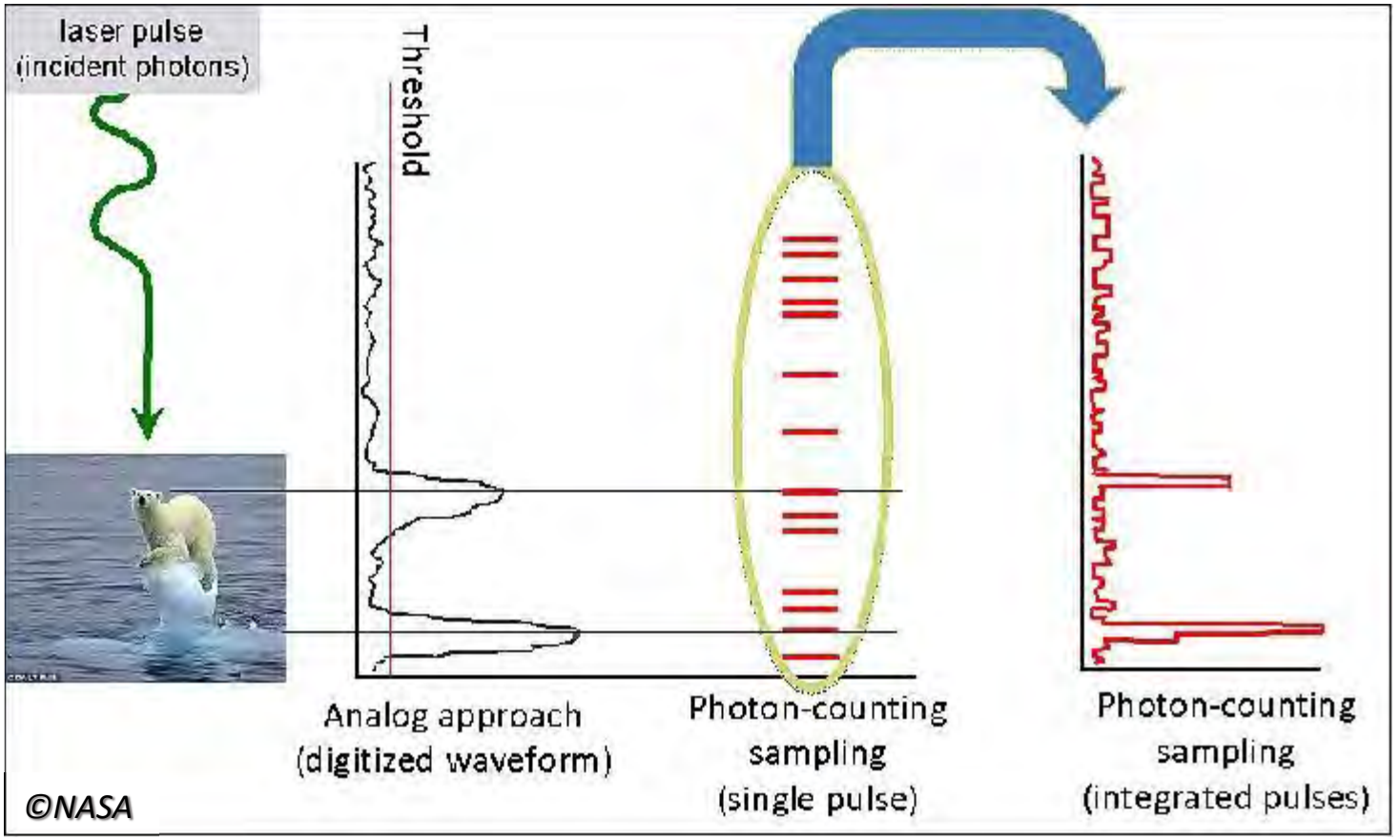
ICESat-2

- Green laser
- Micro-pulse photon-counting
- 3 beam pairs (strong/weak)



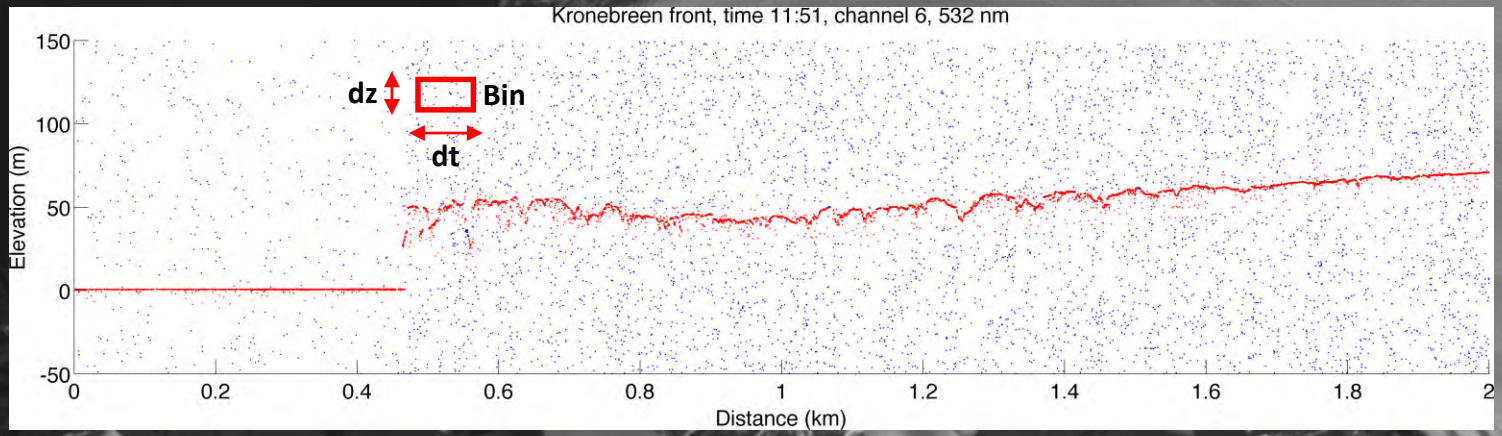


ICESat-2 photon counting

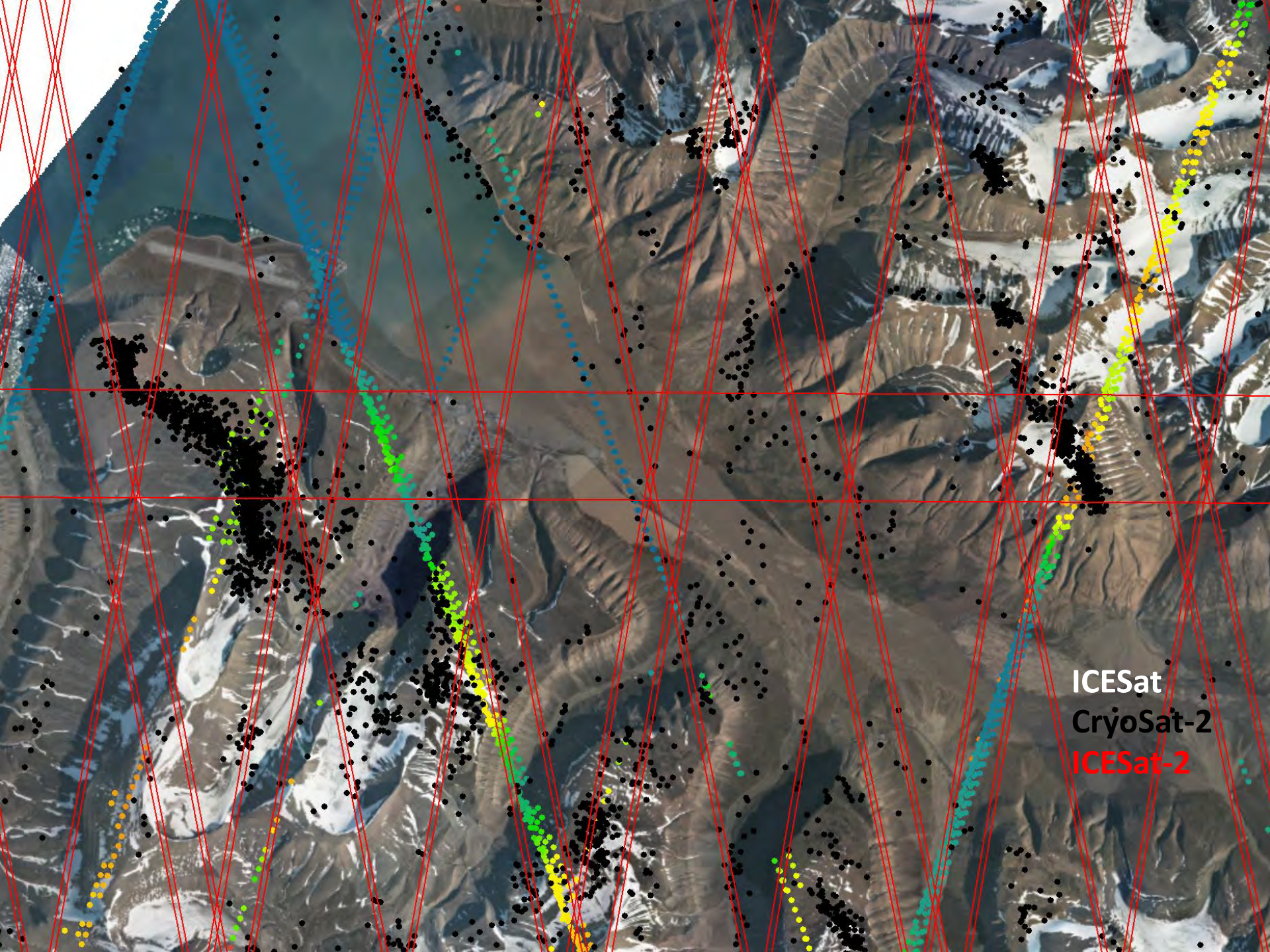


ICESat-2 photon counting

NASA Mabel campaign
(2km segment)



Kronebreen, Svalbard


ICESat
CryoSat-2
ICESat-2


ICESat-2 at UNIS!