Friedrich-Alexander-Universität
Naturwissenschaftliche Fakultät

FAU

Geodetic Mass Balance of Glaciers and Icecaps in Northern High Latitudes

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NHR FAU

Funded by DFG priority program

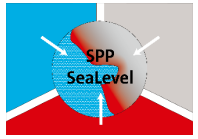
SPP SeaLevel

scientific use opportunity

TanDEM

Research objective

Deriving Geodetic Mass Balance of Glaciers and Ice Caps in RGI regions at Higher Latitudes



FAU

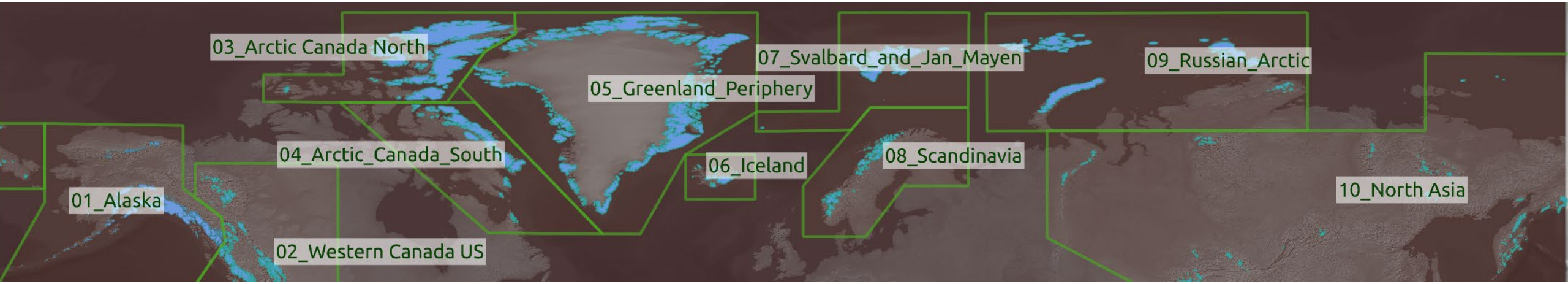
Objective of this study:

observe the Surface Elevation Change on Glaciers and Icecaps via microwave remote sensing and thus derive Geodetic Mass Balance

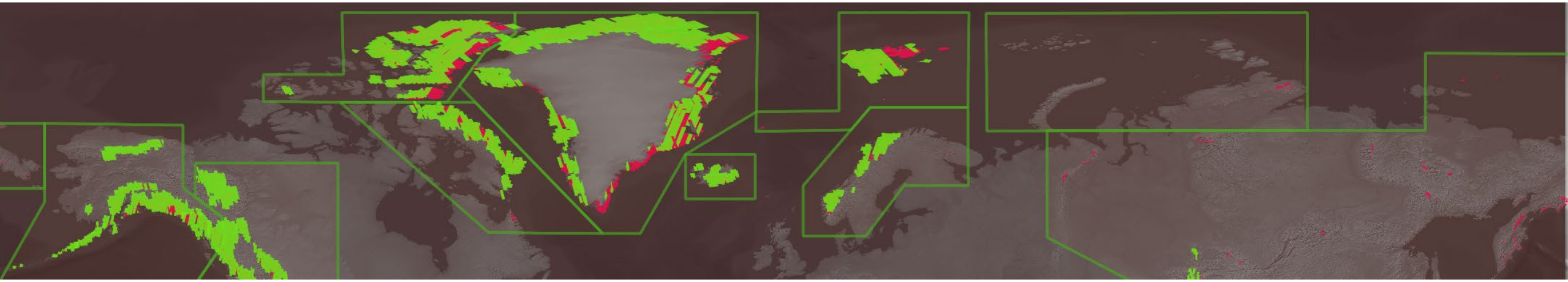
- method: DEM differencing of mosaicked TanDEM-X products – based on own selection of archive data, not the global DEM products
- satellite mission products: TanDEM-X Strip Map CoSSc data to do differential interferometry, TanDEM-X 90m DEM as global reference product.
- time scale: the years of 2011 to 2019 comprising most of the missions live-time
- spatial scale: Raster datasets of 30m ground resolution (footprint 30x60 km) mosaicked to cover all Glaciers in the Latitudes >60 of the Randolph Glacier Inventory regions 1 to 10

Satellite Data – distribution in space

Over 11 000 scenes of TanDEM-X CoSSC processed to date … and rising



1) Glacier area (blue) regions (green line) and labels according to Randolph Glacier Inventory (RGI) Consortium



2) Satellite data coverage intersect for t1 and t2 on glacier (green) uncovered Ice bodies appear red

TanDEM-X Data – acquisition time specifications

Puzzle to solve: timing matters in elevations change rates

Mission: TanDEM-X

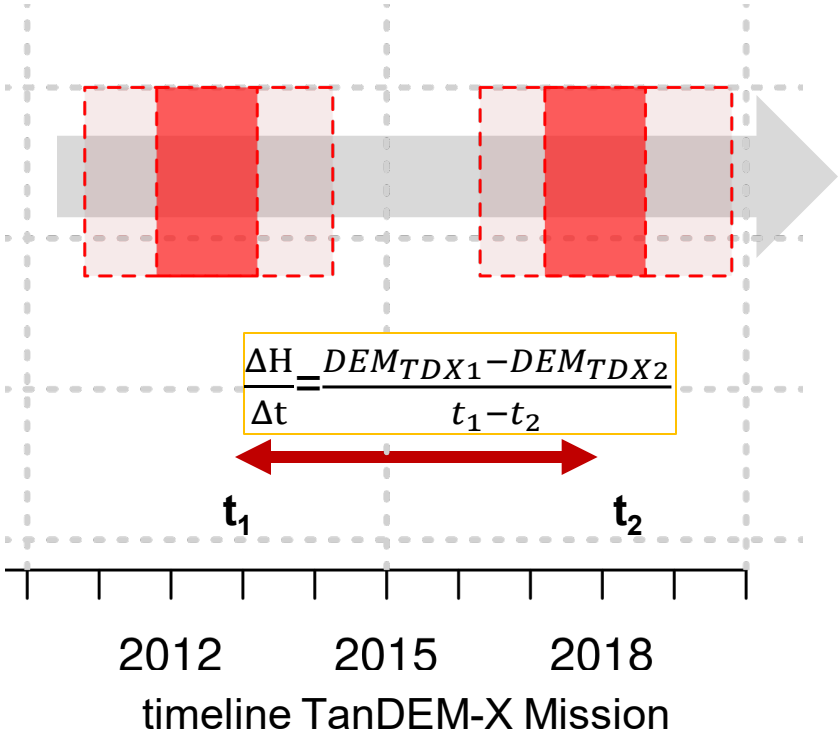
Image: DLR

TerraSar-X Add On for Digital Elevation Measurement

- acquisition from end 2010
- Theoretically on a 11 d repeat cycle but only selected acquisitions only !
- CoSSC Archive Data from two core periods of global coverage (red) used

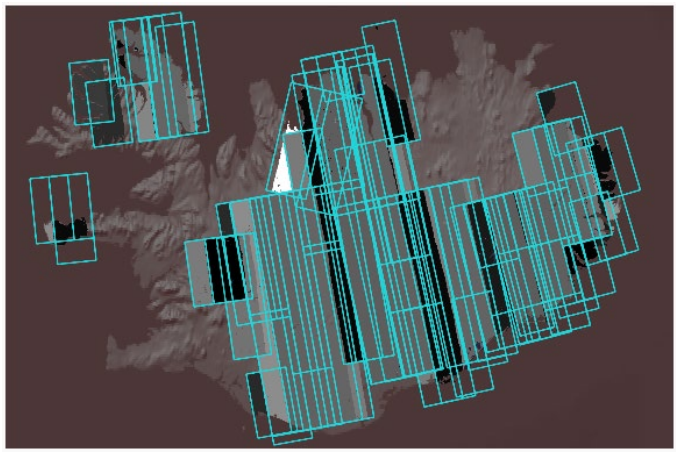
Requirements for ΔT to derrive Glacier mass balance

ΔT of a 5 to 6 years distance and a full glaciological year to avoid seaonal bias



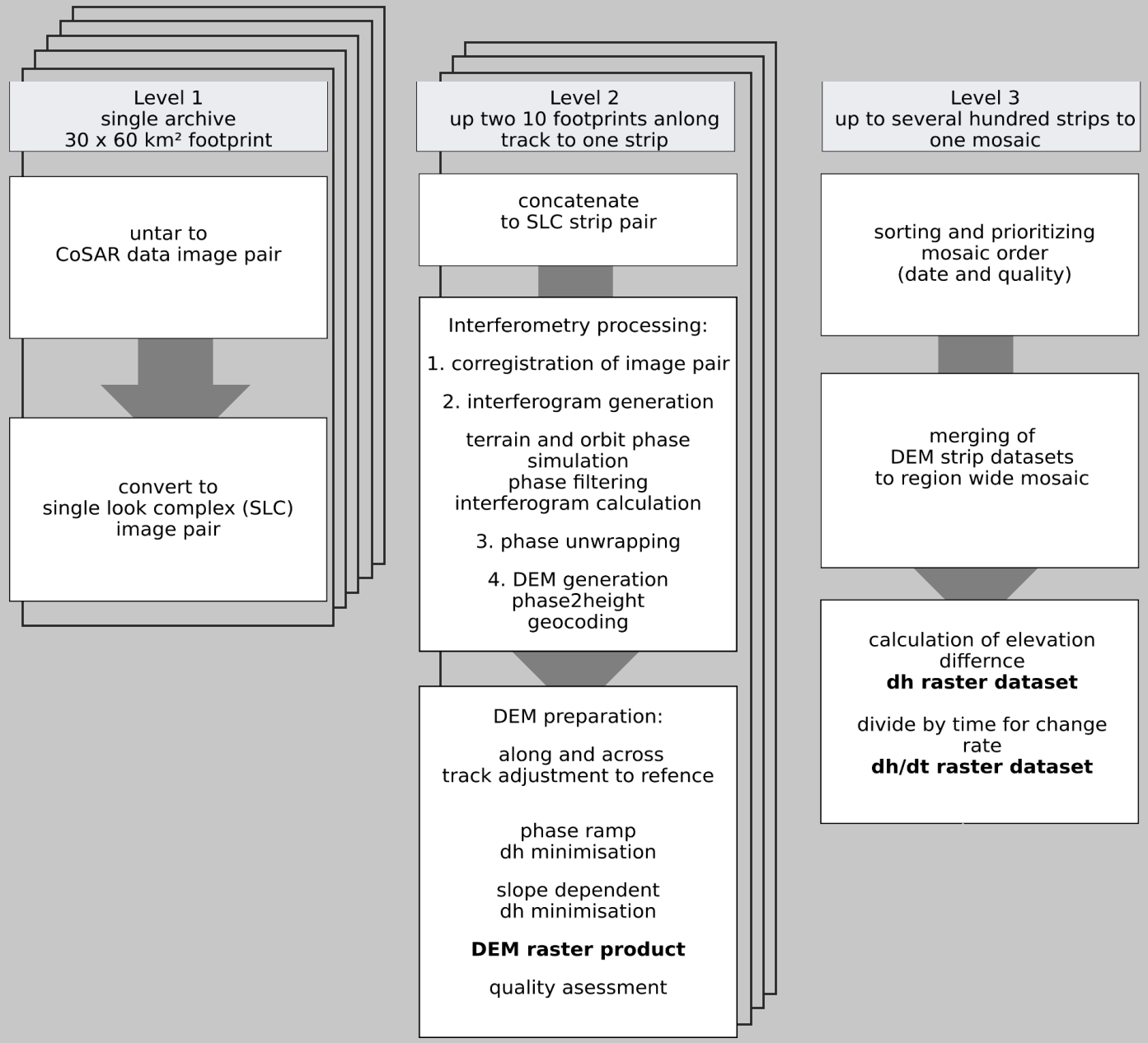
Data download and processing:

- along-track concatenation
  - □ same aquisition timing
- - across track mosaicing
  - □ aquisition timing available



Cyan: footprint outline of along-track strips

Greyscale: deviation of central aquisiton date



Methods:

Processing pipeline of Satellite data:

- Interferometry processing at level 2: GAMMA software
  - Differential Interferometry with TanDEM-X reference elevations
  - Re-added terrain phase to create full DEM product

- raster operations: R / GDAL
  - resampled and projected to
  - 30x30m resolution Polar Stereographic North datasets
  - Corrected to reference DEM according to Nuth and Kääb (2011)
  - Merged to regional datasets according to date priorities

Level 1
single archive
30 x 60 km² footprint

untar to
CoSAR data image pair

convert to
single look complex (SLC)
image pair

Level 2
up two 10 footprints anlong
track to one strip

concatenate
to SLC strip pair

Interferometry processing:
1. corregistration of image pair
2. interferogram generation
terrain and orbit phase
simulation
phase filtering
interferogram calculation
3. phase unwrapping
4. DEM generation
phase2height
geocoding

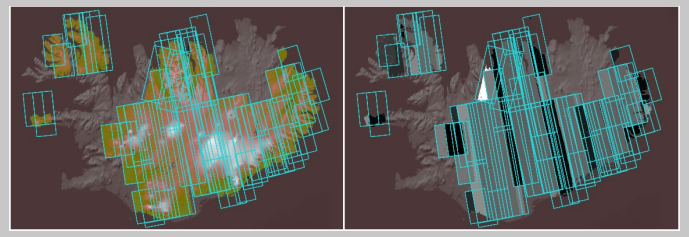
DEM preparation:
along and across
track adjustment to refence
phase ramp
dh minimisation
slope dependent
dh minimisation
DEM raster product
quality asessment

Level 3
up to several hundred strips to
one mosaic

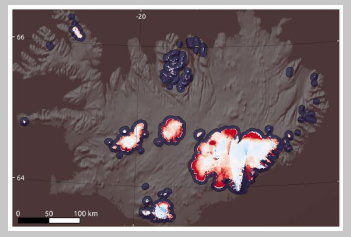
sorting and prioritizing
mosaic order
(date and quality)

merging of
DEM strip datasets
to region wide mosaic

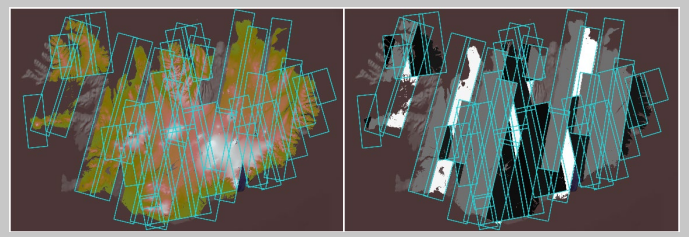
calculation of elevation
differnce
dh raster dataset
divide by time for change
rate
dh/dt raster dataset



DEM1 Mosaic of ~ t1 (date mosaic)



Dh/dt
dataset



DEM2 Mosaic of ~ t2 (date mosaic)

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30 x 60 km² footprint

untar to
CoSAR data image pair

convert to
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image pair

Level 2
up two 10 footprints anlong
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calculation of elevation
differnce
dh raster dataset
divide by time for change
rate
dh/dt raster dataset

Level 4
numeric stage: pixel based to
region wide

hypsometric change rate
calculation

hypsometric filtering

gap filling

corrections:
seasonal corrections
radar penetration
compensation

region-wide change
assesment:
volume change
mass change
SLR contribution

slope dependent
height error calculation

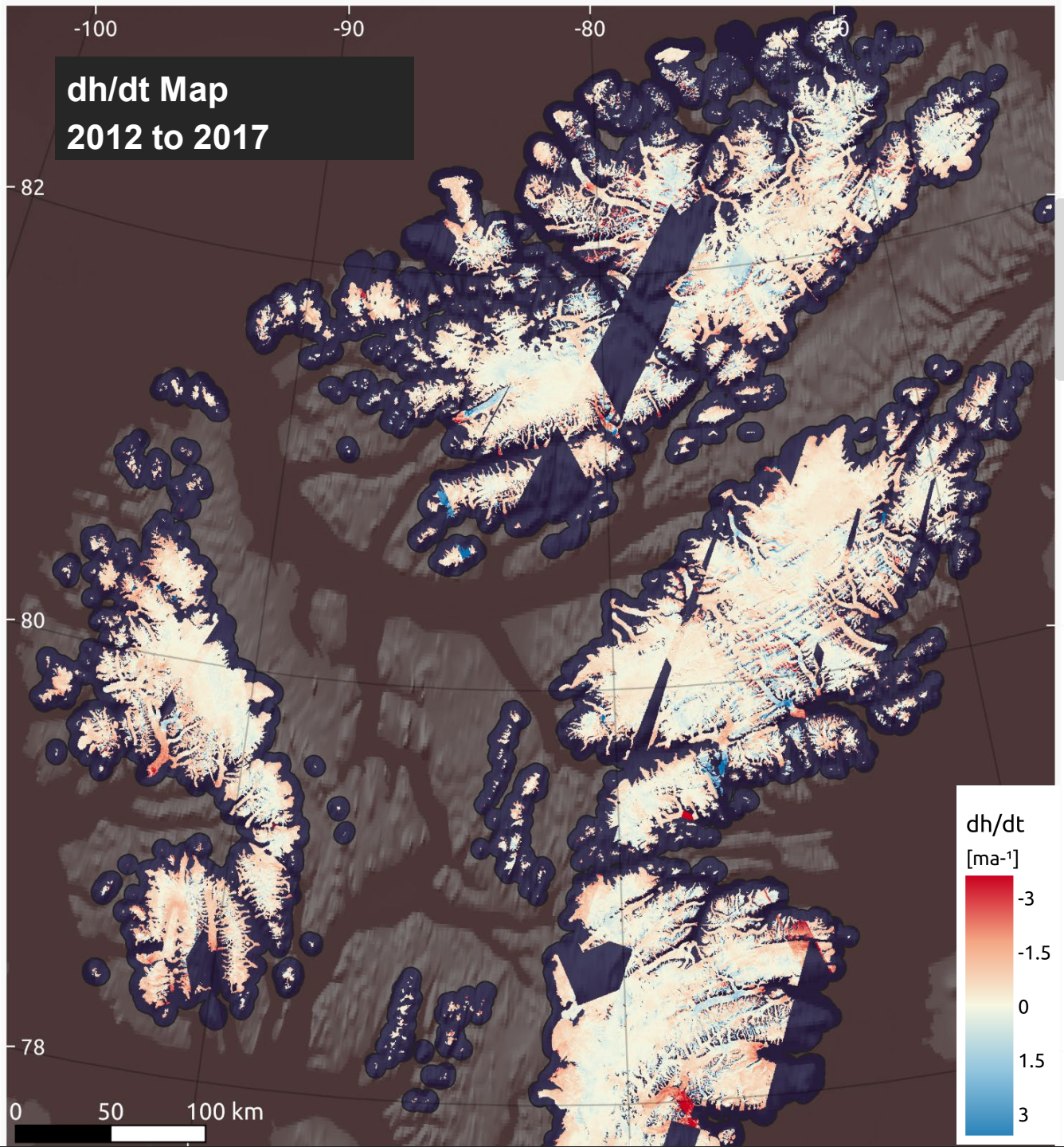
region wide uncertainty
asessment

Methods:

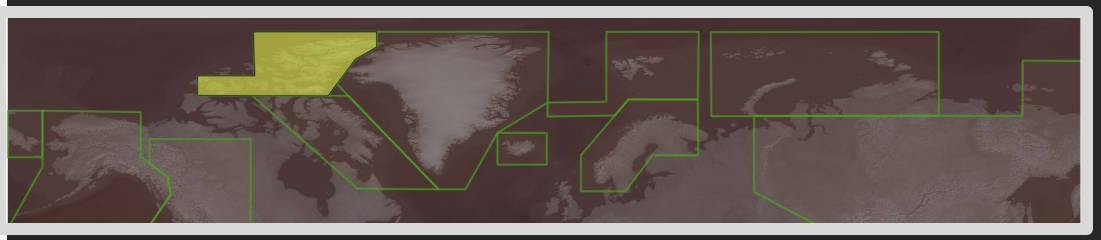
Increase of software efficiency courtesy to processing opportunity on HPC

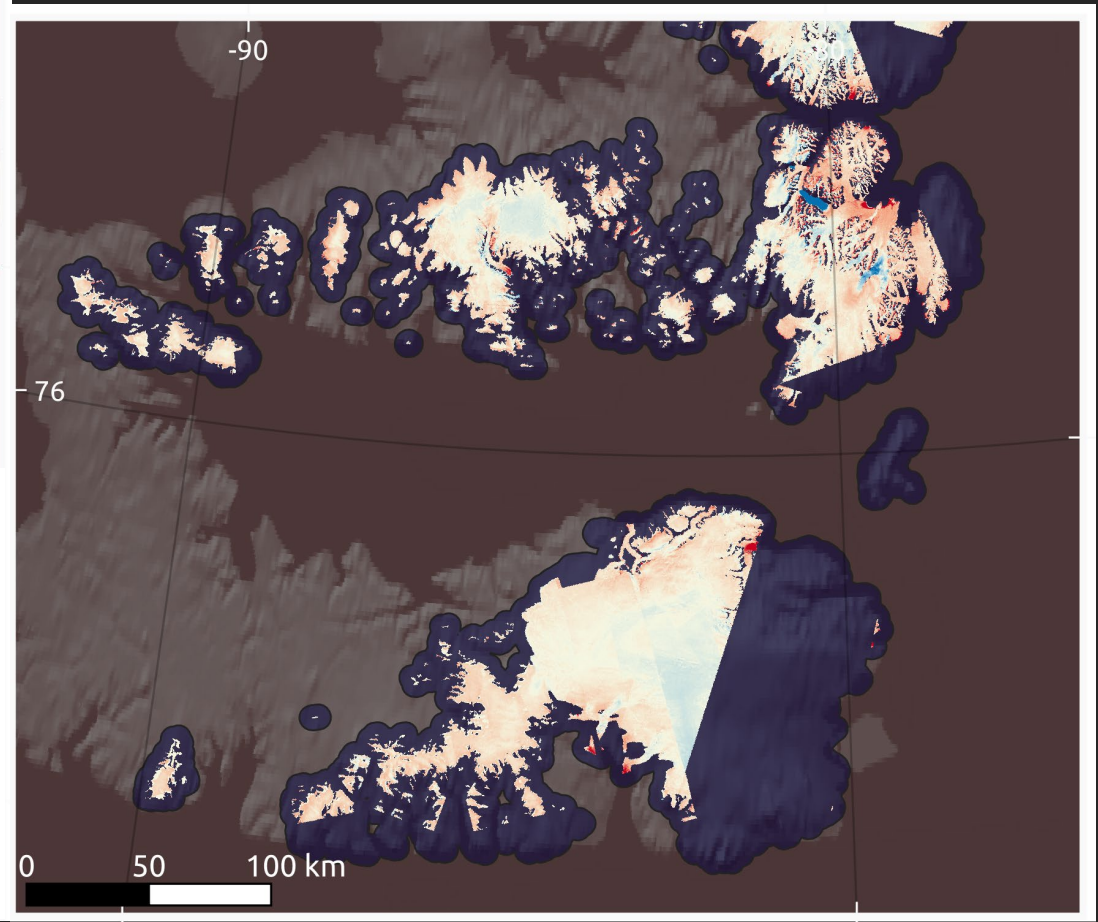
National High Performace Computing Center @ FAU

NHR FAU



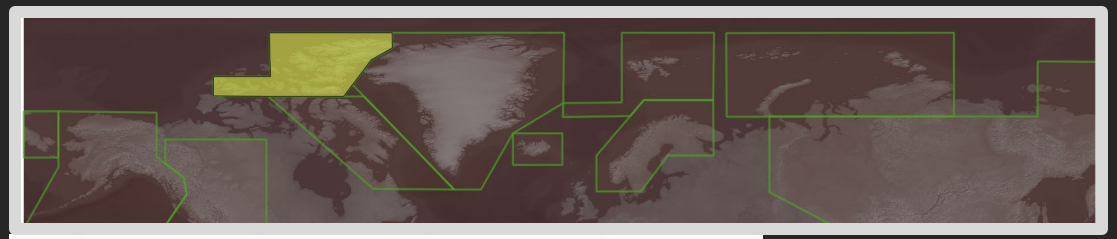
Results RGI 03
Arctic Canada North

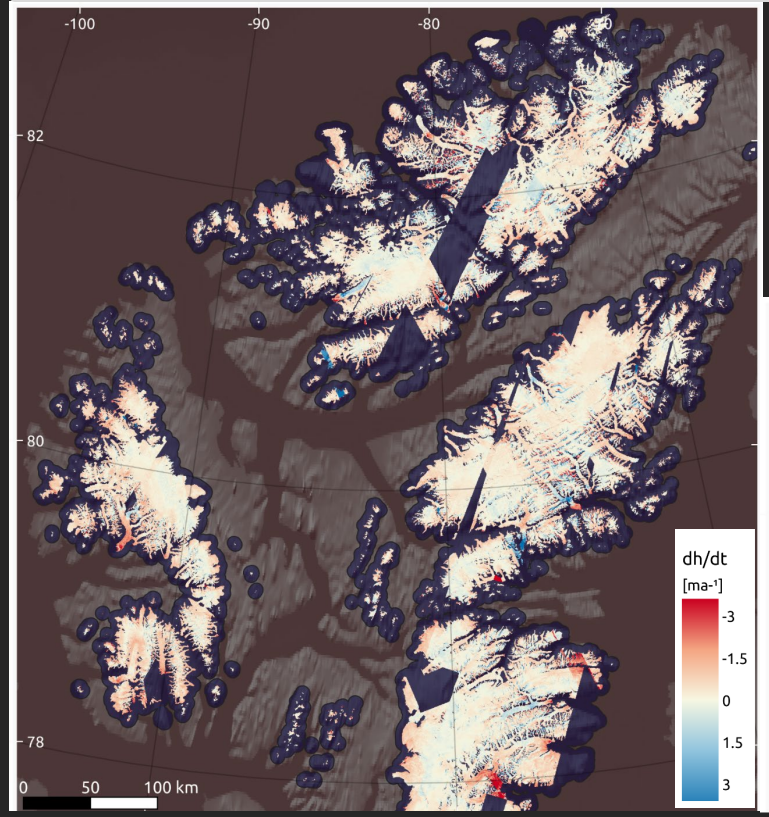




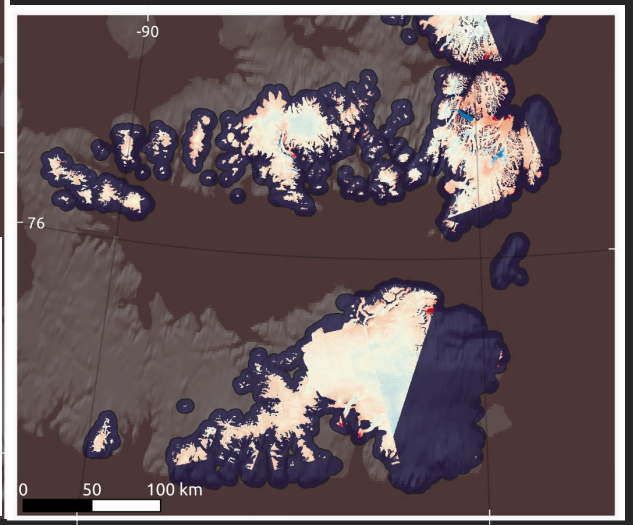
Results RGI 03
Arctic Canada North

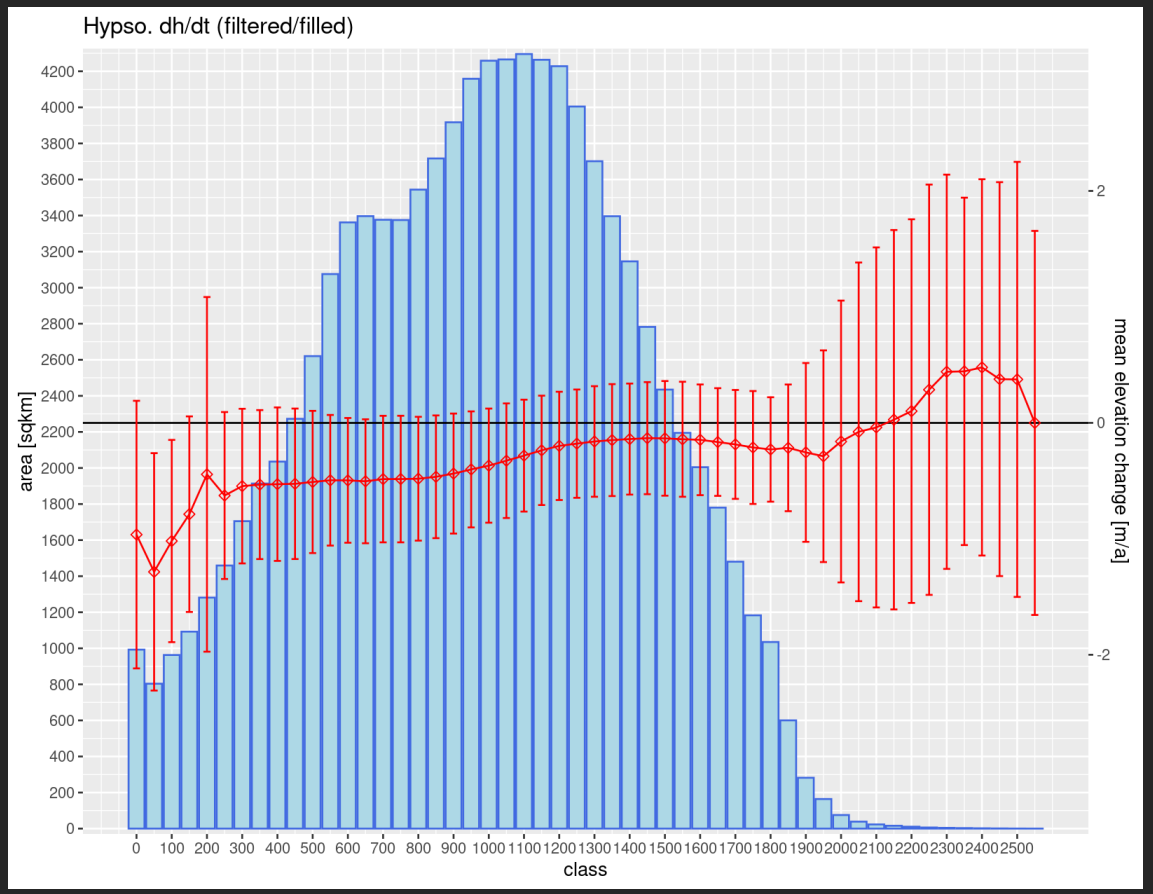
egions 01, 03 and 07





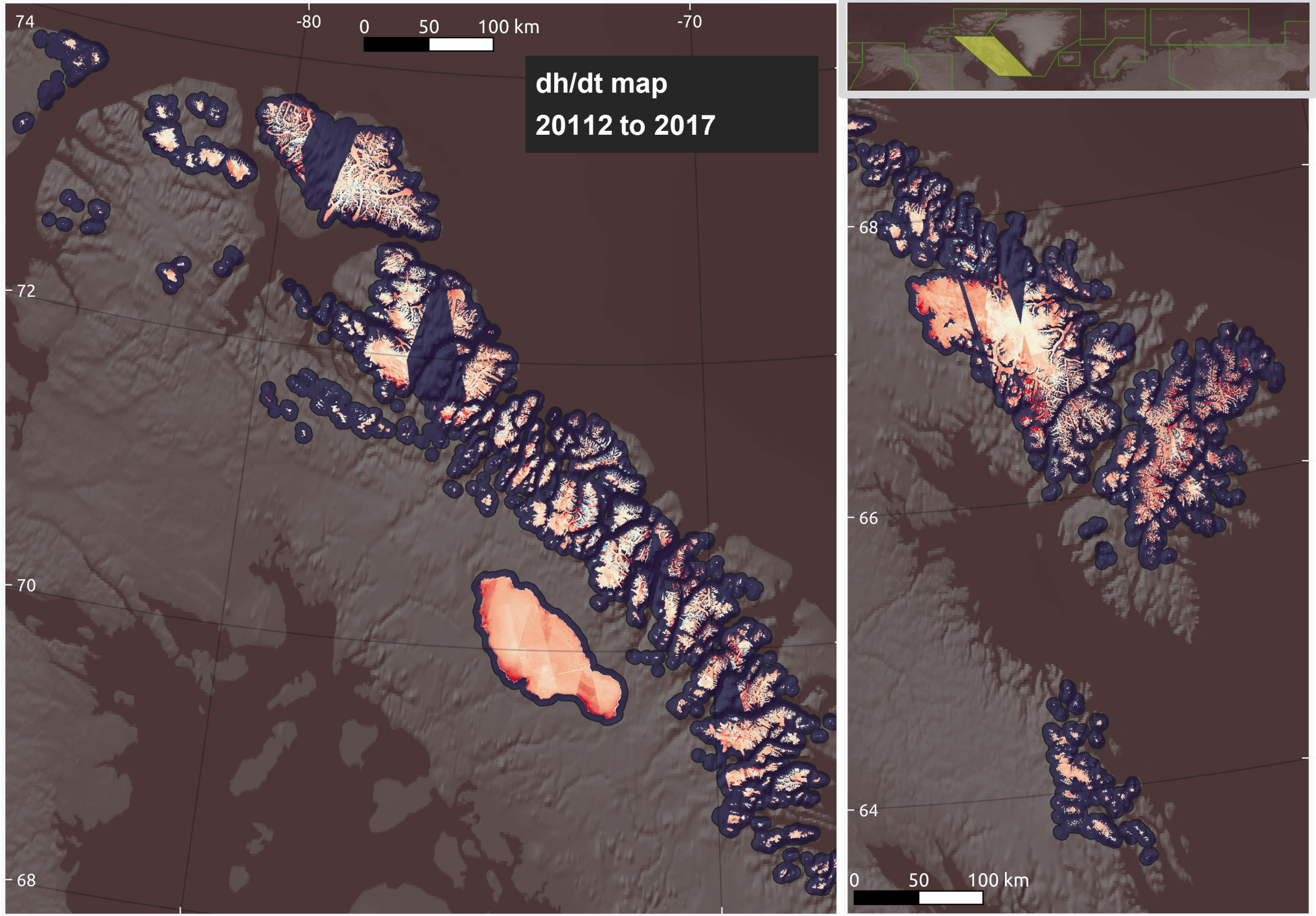
RGI 03 Arctic Canada North
Dh/dt Map
2012 to 2017





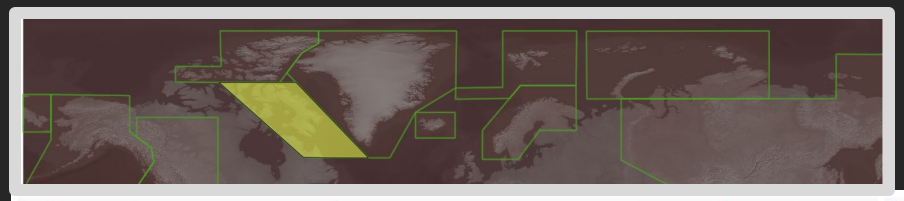
ΔT median [yr]	area [km²]	area covered [%]	dh/dt [ma⁻¹]			dM/dt [Gt a⁻¹]		
5.53	105,111	0.83	-0.36	±	0.11	-31.22	±	8.97

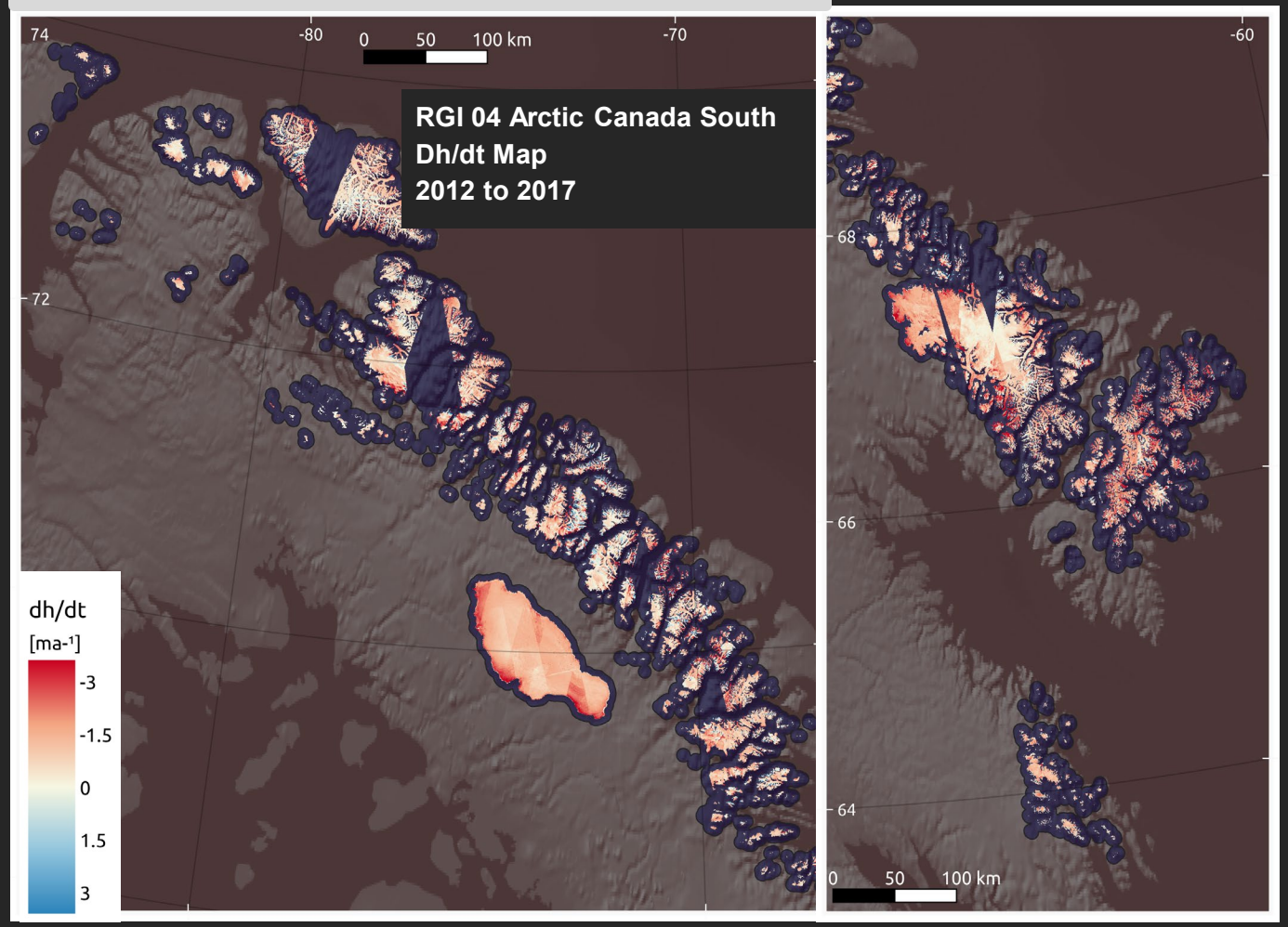
Results RGI 04
Arctic Canada South

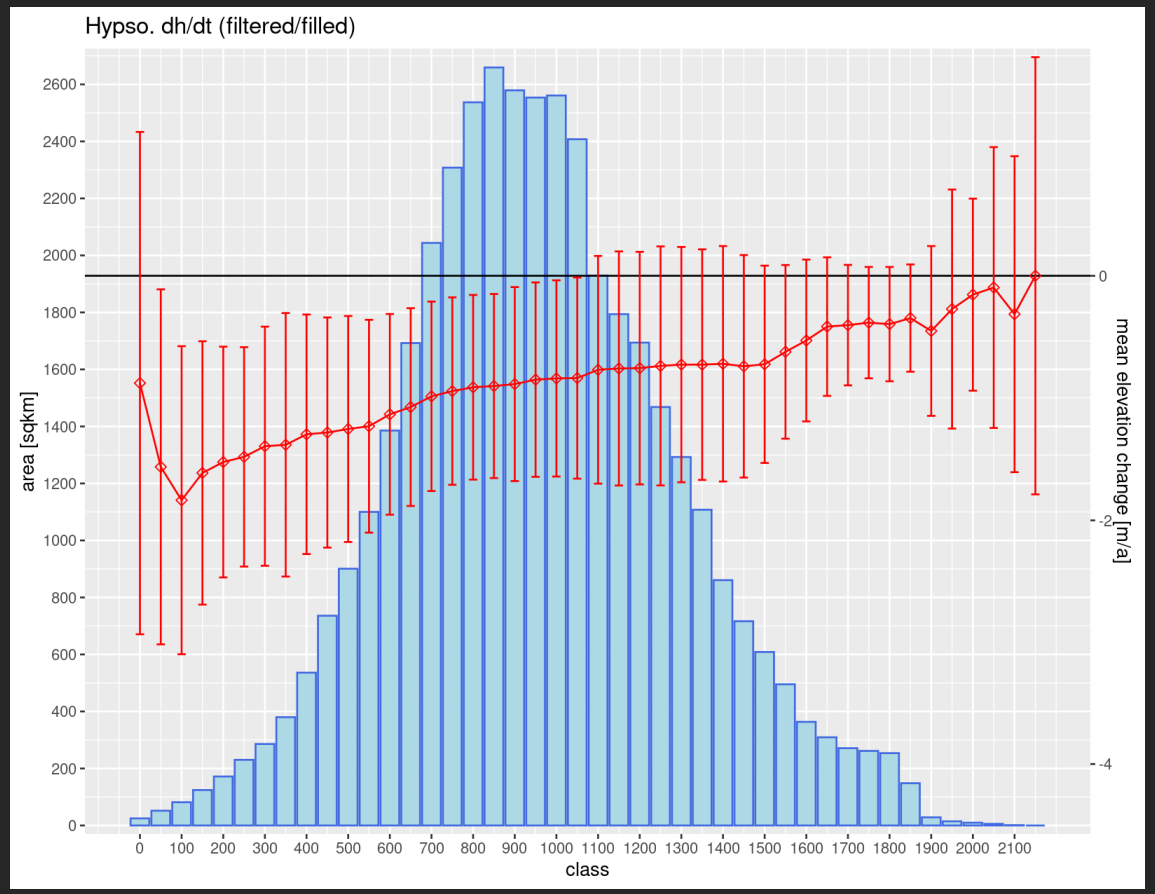


Results RGI 04
Arctic Canada South

3 – elevation change dataset
of dh/dt in arctic RGI regions 01, 03 and 07

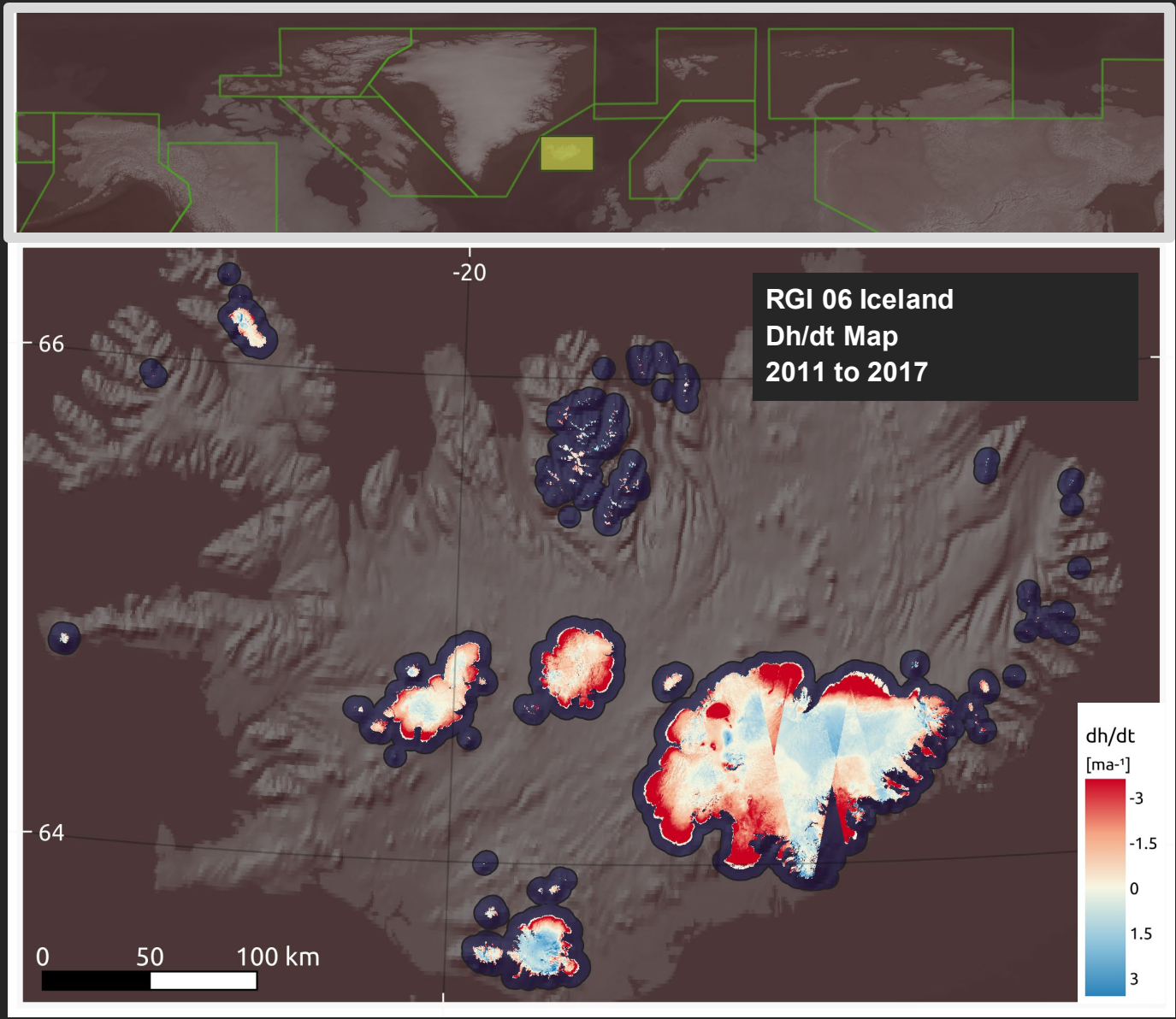


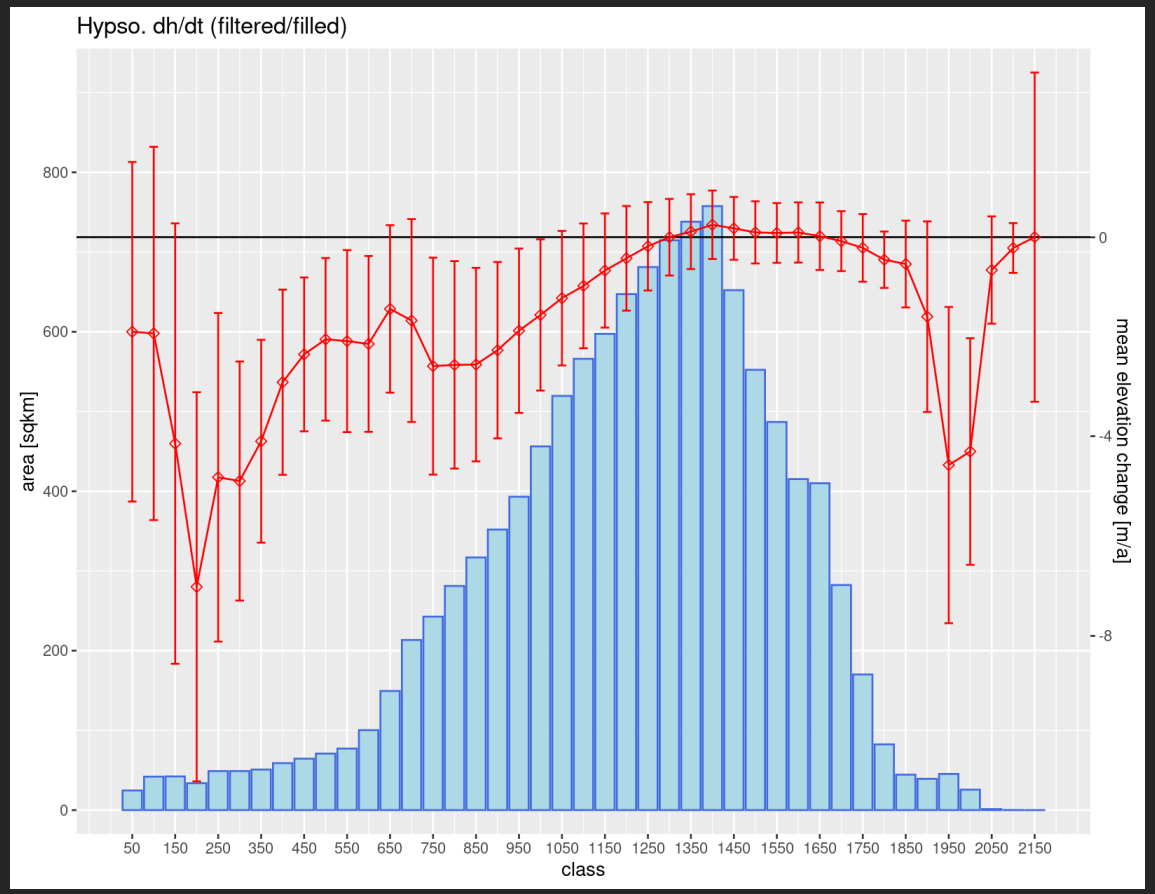




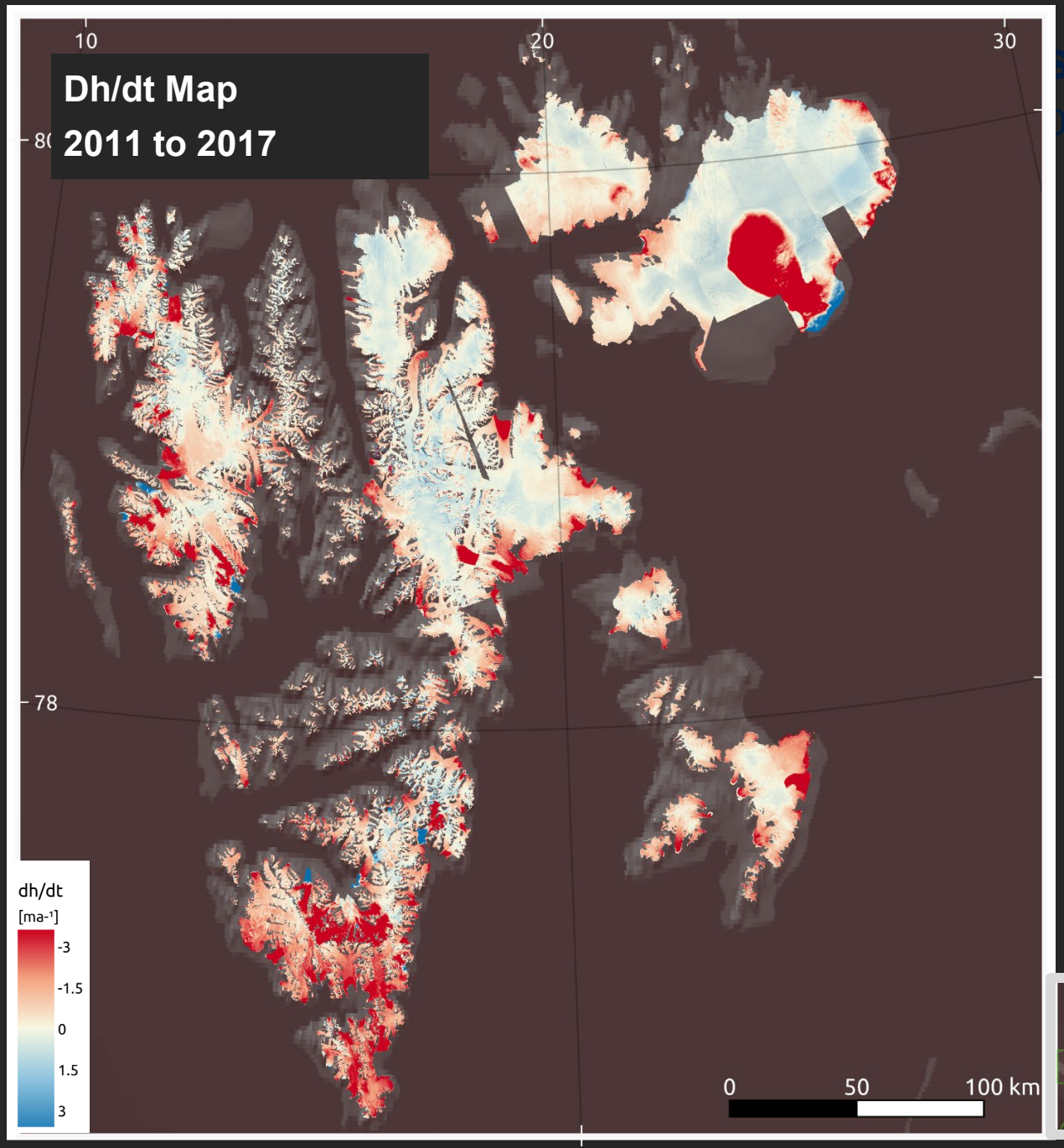
ΔT median [yr]	area [km²]	area covered [%]	dh/dt [ma-1]			dM/dt [Gt a-1]		
3.79	40,888	0.88	-0.89	±	0.21	-31.11	±	6.14

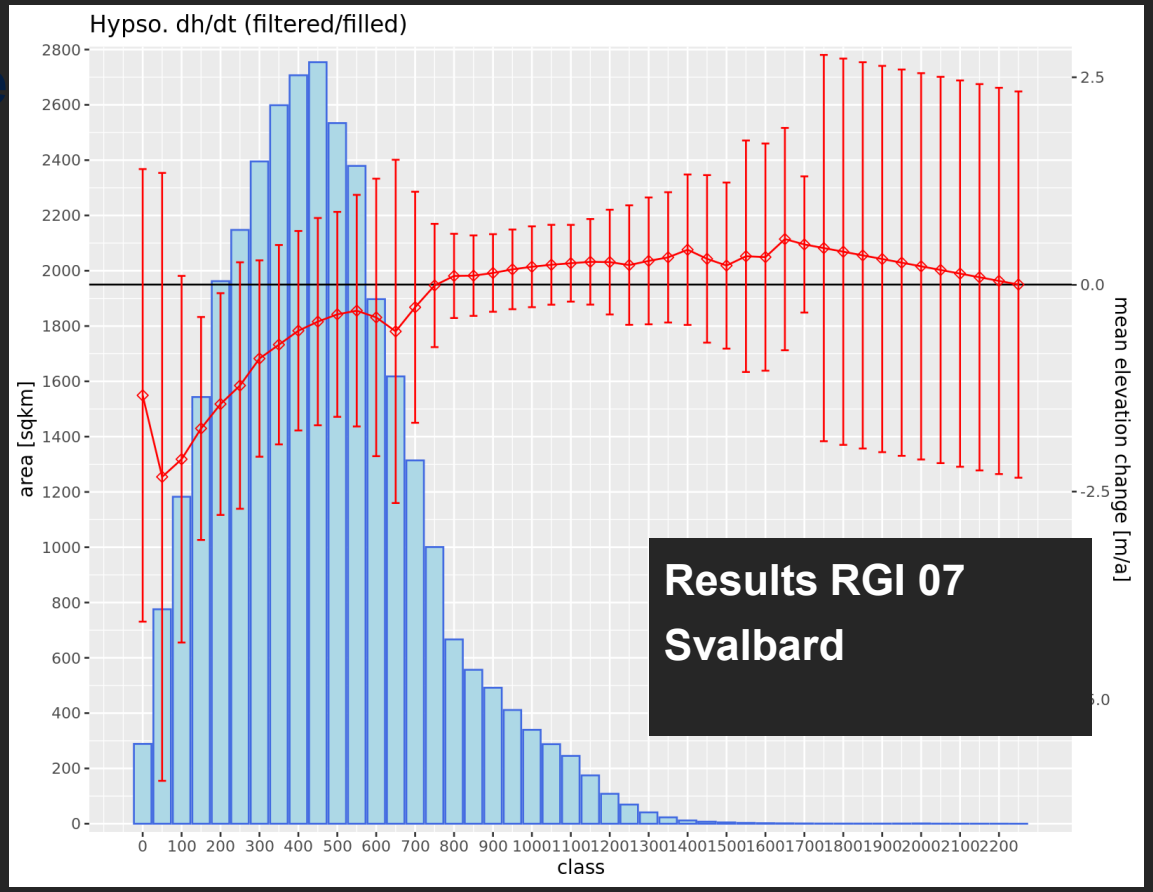
Results RGI 06
Iceland



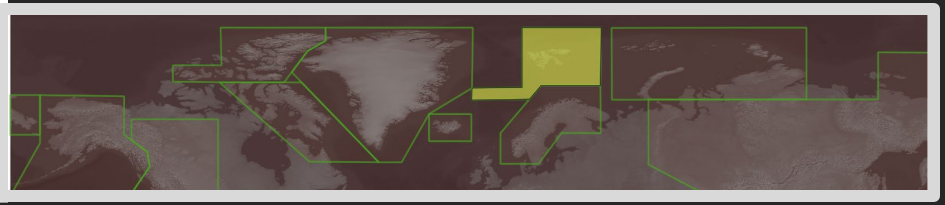


ΔT median [yr]	area [km²]	area covered [%]	dh/dt [ma⁻¹]			dM/dt [Gt a⁻¹]		
5.71	11,060	0.98	-0.65	±	0.12	-6.31	±	1.16



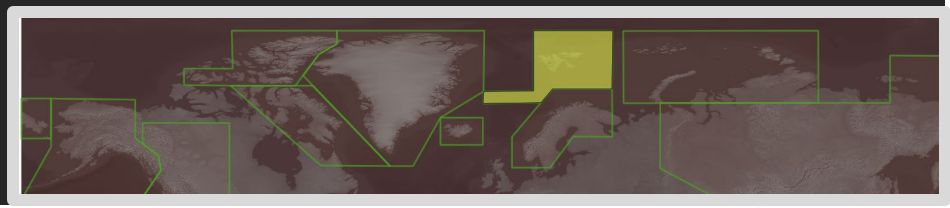


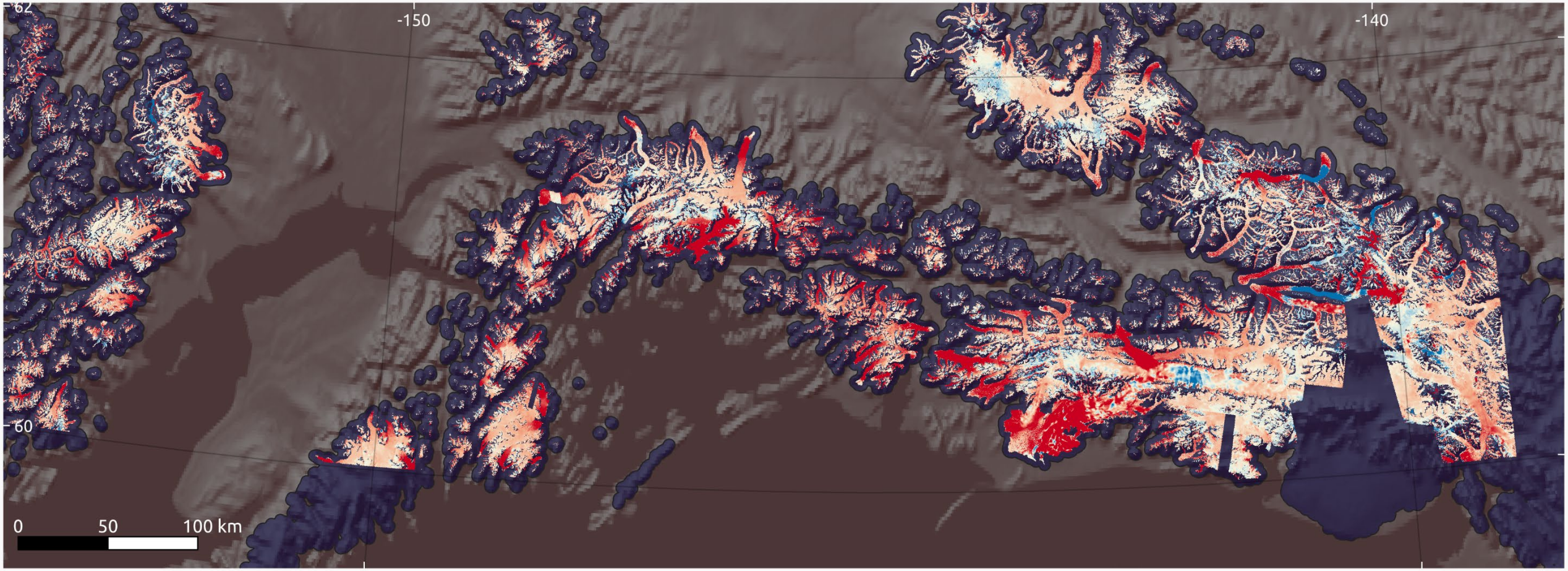
ΔT median [yr]	area [km²]	area covered [%]	dh/dt [ma⁻¹]			dM/dt [Gt a⁻¹]		
6.02	33,959	0.92	-0.70	±	0.08	-19.24	±	2.11



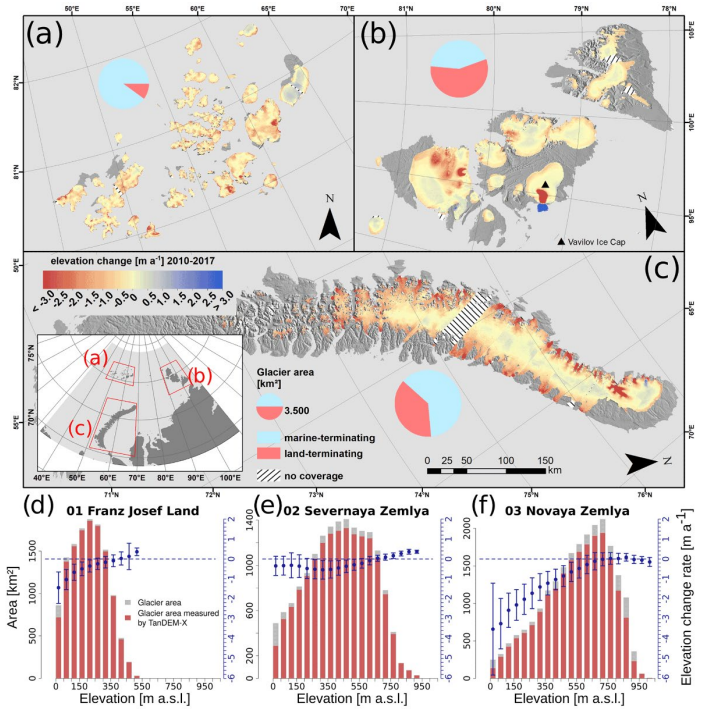
Results RGI 01
Alaska

Dh/dt Map
2011 to 2017





Results level 4 – dM/dt overview table



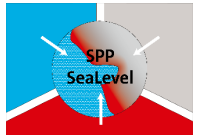
Sommer et al. 2022

RGI ID	RGI Region Name	ΔT median [yr]	area [km²]	area covered [%]	dh/dt [ma⁻¹]			dM/dt [Gt a⁻¹]		
03*	Arctic Canada North	5.53	105,111	0.83	-0.36	±	0.11	-31.22	±	8.97
04*	Arctic Canada South	3.79	40,888	0.88	-0.89	±	0.21	-31.11	±	6.14
06*	Iceland	5.71	11,060	0.98	-0.65	±	0.12	-6.31	±	1.16
07*	Svalbard and Jan Mayen	6.02	33,959	0.92	-0.70	±	0.08	-19.24	±	2.11
08*	Scandinavia	5.48	2,949	0.85	-0.23	±	0.44	-0.58	±	0.90
09	Russian Arctic		51,592	0.93	-0.52		0.24	-22.19	±	6.41
*Total			245,559					-110.65		

*** Perliminary results**

Conclusions

Deriving Geodetic Mass Balance of Glaciers and Ice Caps



FAU

- TanDEM-X Stripmap InSAR DEMs are suitable to apply DEM differencing on large scale, i.e.up to the largest RGI regions
- Mission properties of TanDEM-X do not allow for region wide mosaicked DEM datasets comprehensively evolving from one exact aqisition period (year /season) – with these datasets dh/dt calculation can be successfully performed.
- For the regions examined so far – Canadian Arctic, Iceland, Svalbard,Scandinavia and Russian Arctic - we find mass loss rates adding to 110.65 Gt /a on ~ 245 000 km².

Thank you

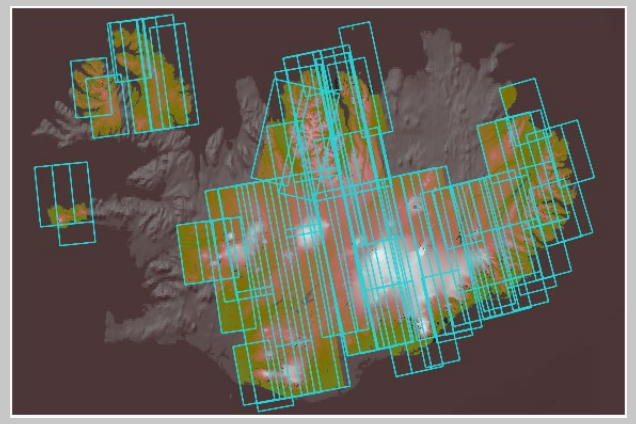
for your attention!

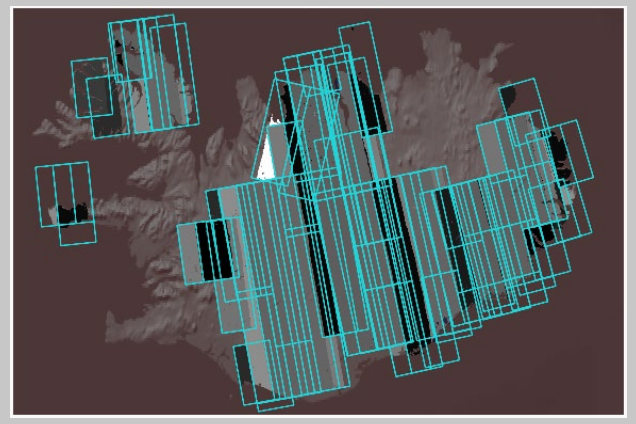
Conclusions and outlook

Deriving Geodetic Mass Balance of Glaciers and Ice Caps and respective SLR signal

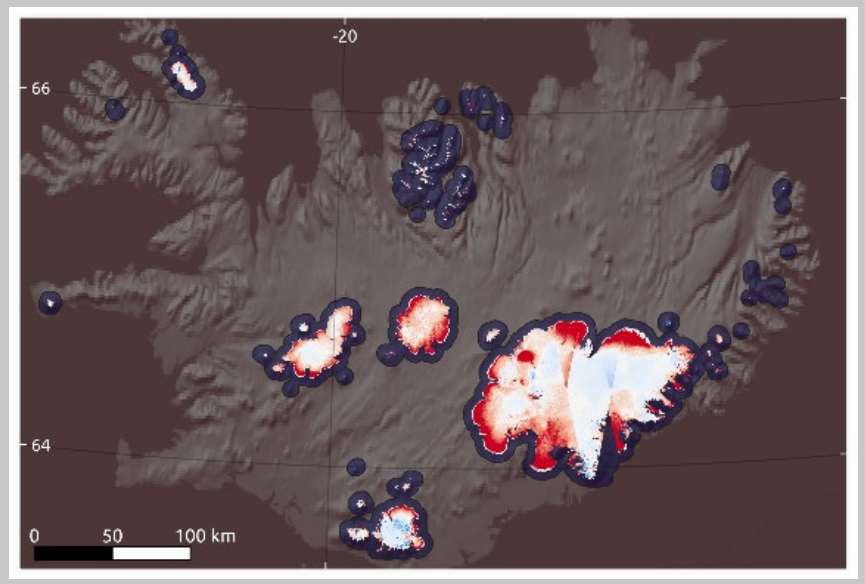
References:

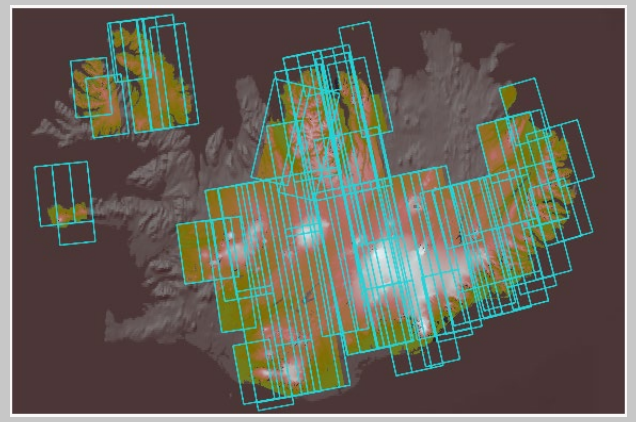
1. Sommer, C., Seehaus, T., Glazovsky, A. & Braun, M. H. Brief communication: Increased glacier mass loss in the Russian High Arctic (2010–2017). The Cryosphere 16, 35–42 (2022).
2. Braun, M. H. et al. Constraining glacier elevation and mass changes in South America. Nature Climate Change 9, 130–136 (2019).
3. Sommer, C. et al. Rapid glacier retreat and downwasting throughout the European Alps in the early 21st century. Nat Commun 11, 3209 (2020).

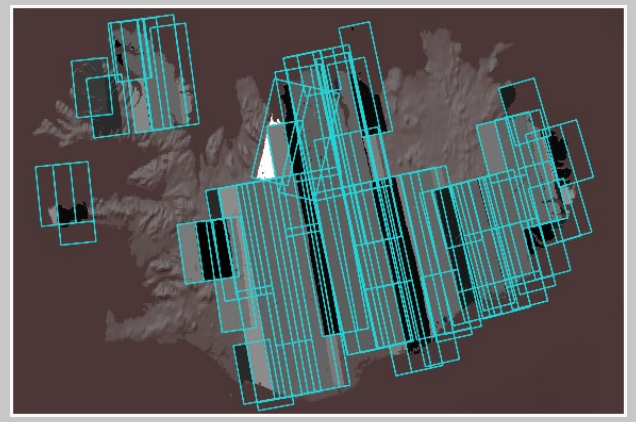




DEM1 Mosaic of ~ t1 (date mosaic)







DEM2 Mosaic of ~ t2 (date mosaic)