Svalbard glacier mass balance derived from annual Arctic DEMs, 2013-2017

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Geir Moholdt
Ash Morris

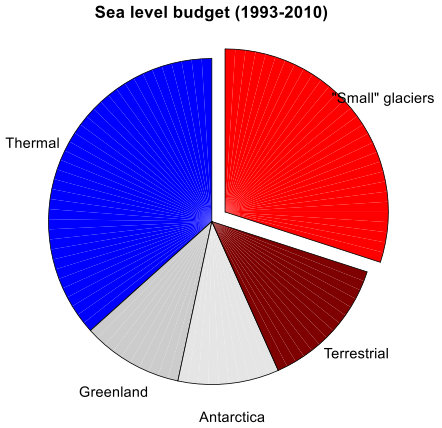
Norwegian Polar Institute

Why investigate Svalbard glacier mass balance?

- **Sea level**

  Current sea level rise = ca. 3.2 mm/yr

  - **Thermal expansion** — **1.1 mm/yr**
  - **Greenland** — **0.3 mm/yr**
  - **Antarctica** — **0.3 mm/yr**
  - **Terrestrial Water Storage** — **0.4 mm/yr**
  - **"Small" Glaciers** — **0.9 mm/yr**



- **Future scenarios**

  Need to understand current balance to model future retreat

- **Downstream impact**

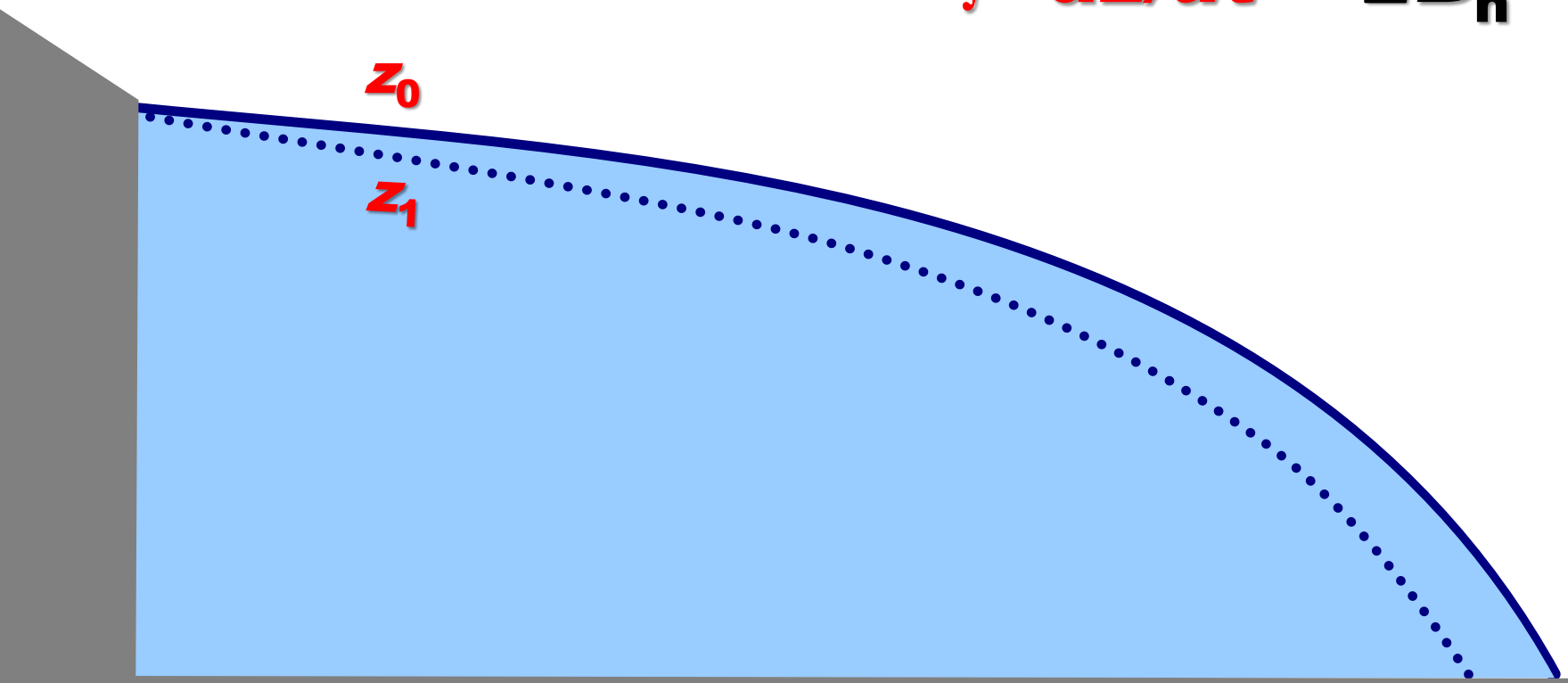
  Tidewater glacier retreat impacts fjord circulation, ecosystems

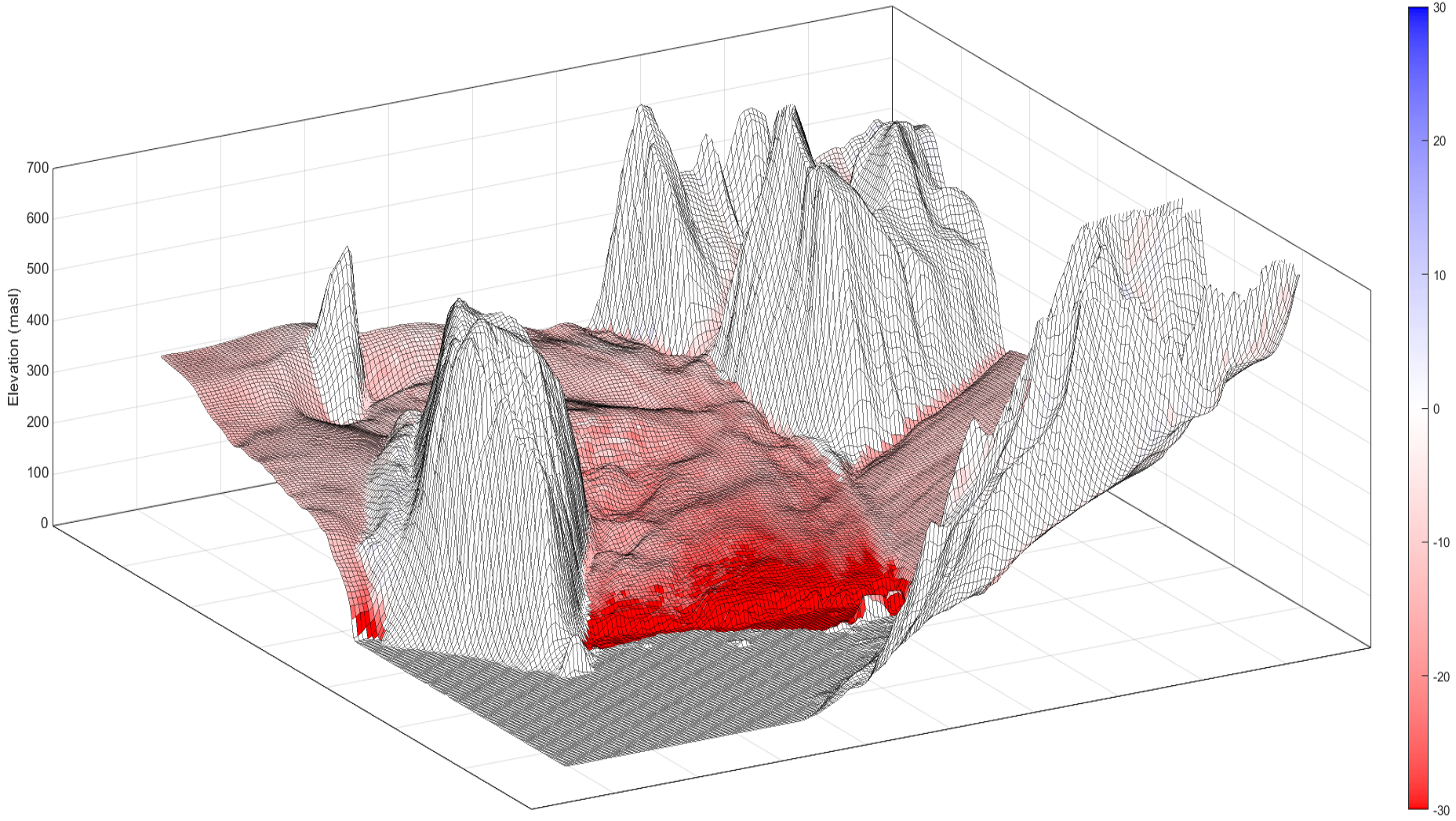
  Increased melt " "

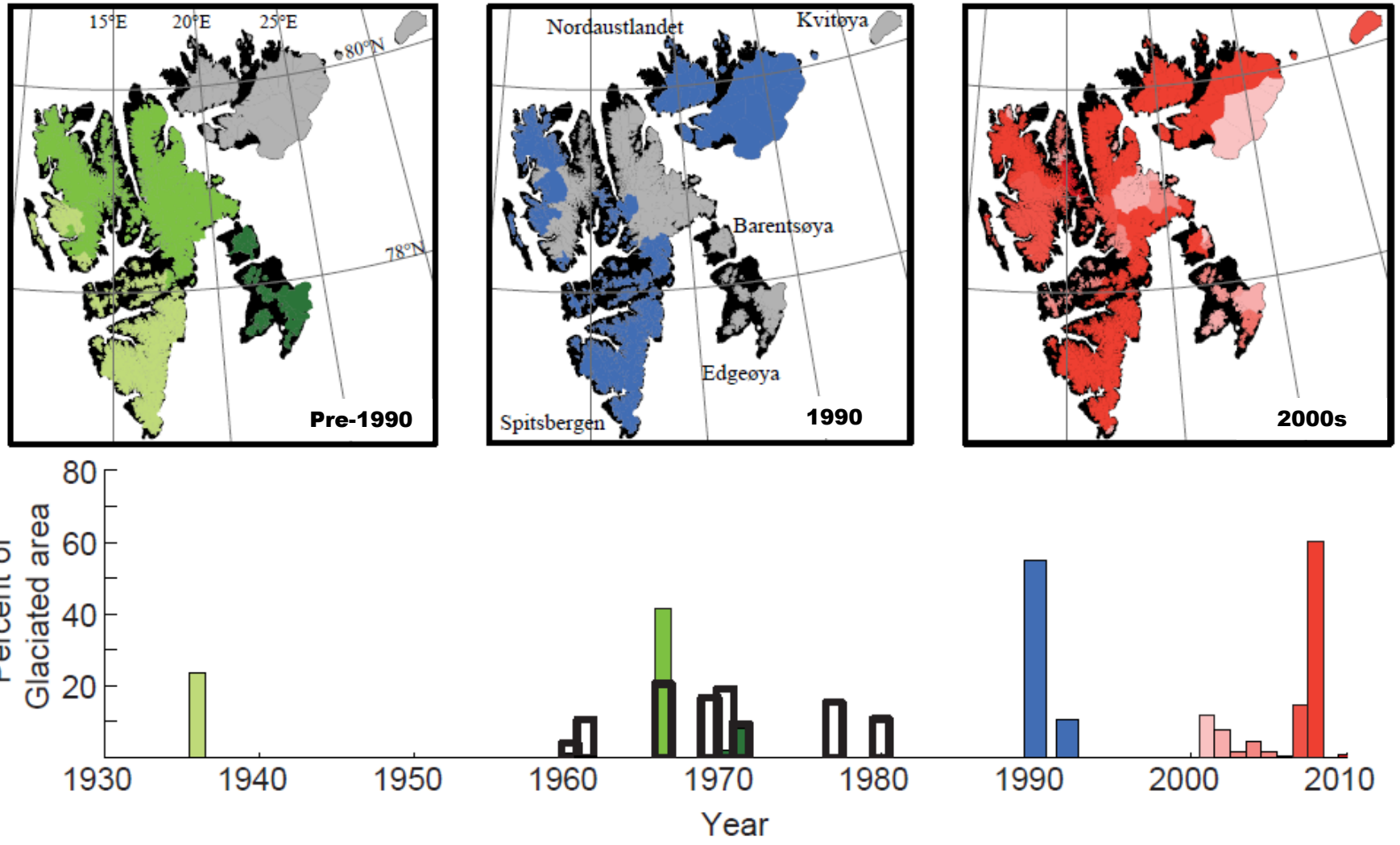
Geodetic mass balance

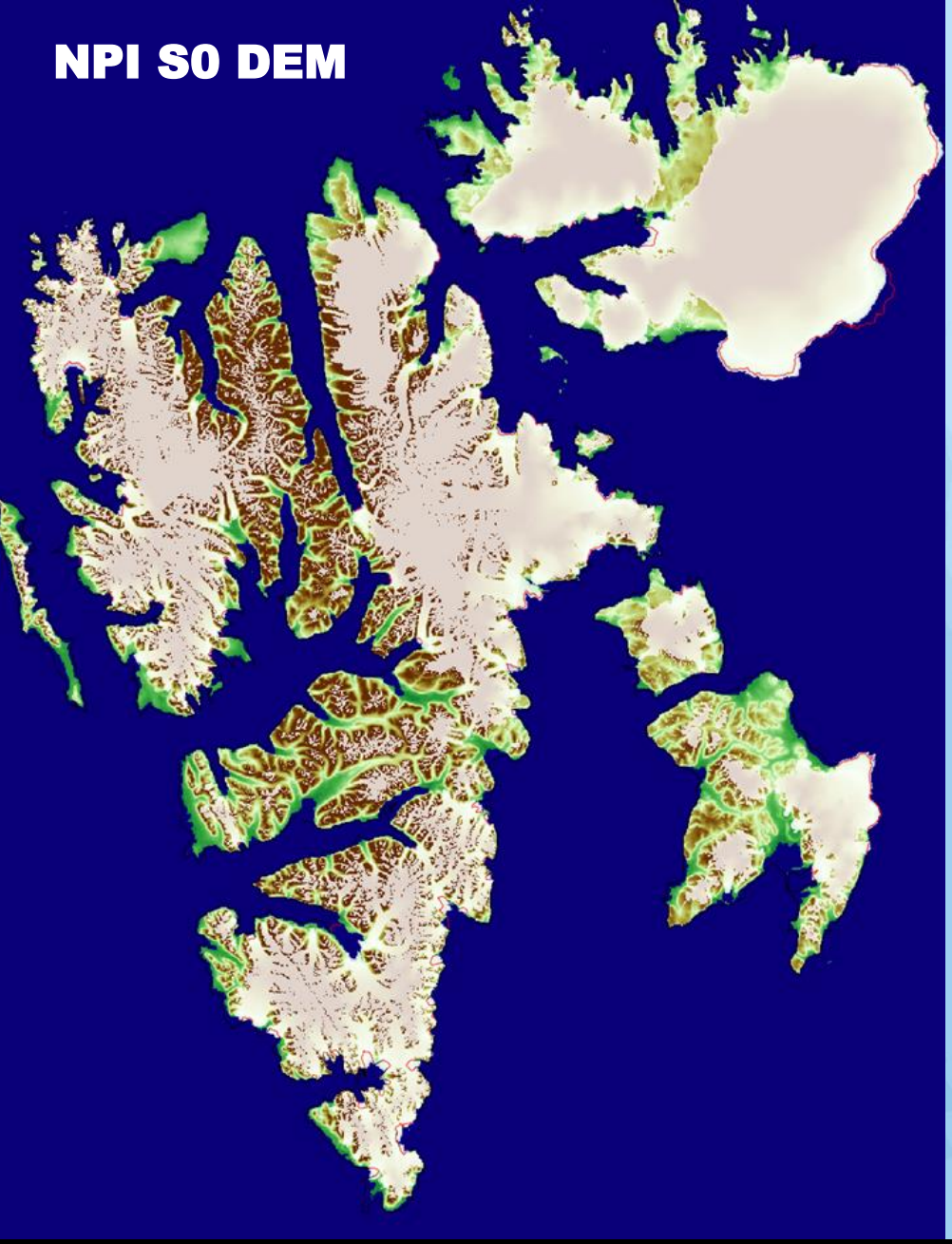
$$dz/dt = (z_1 - z_0)/\Delta t$$

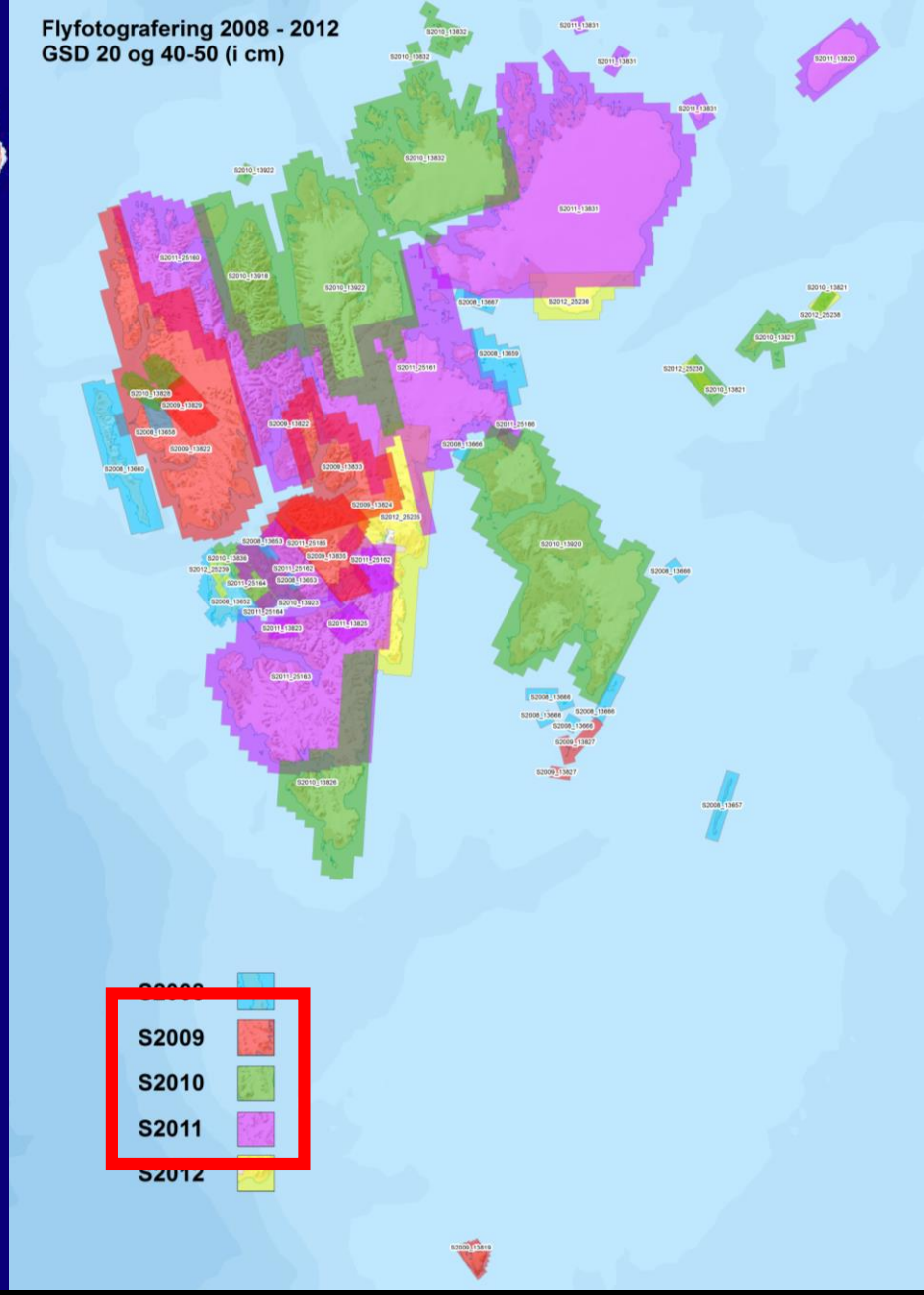
$$\int^A dz/dt = \Sigma B_n$$

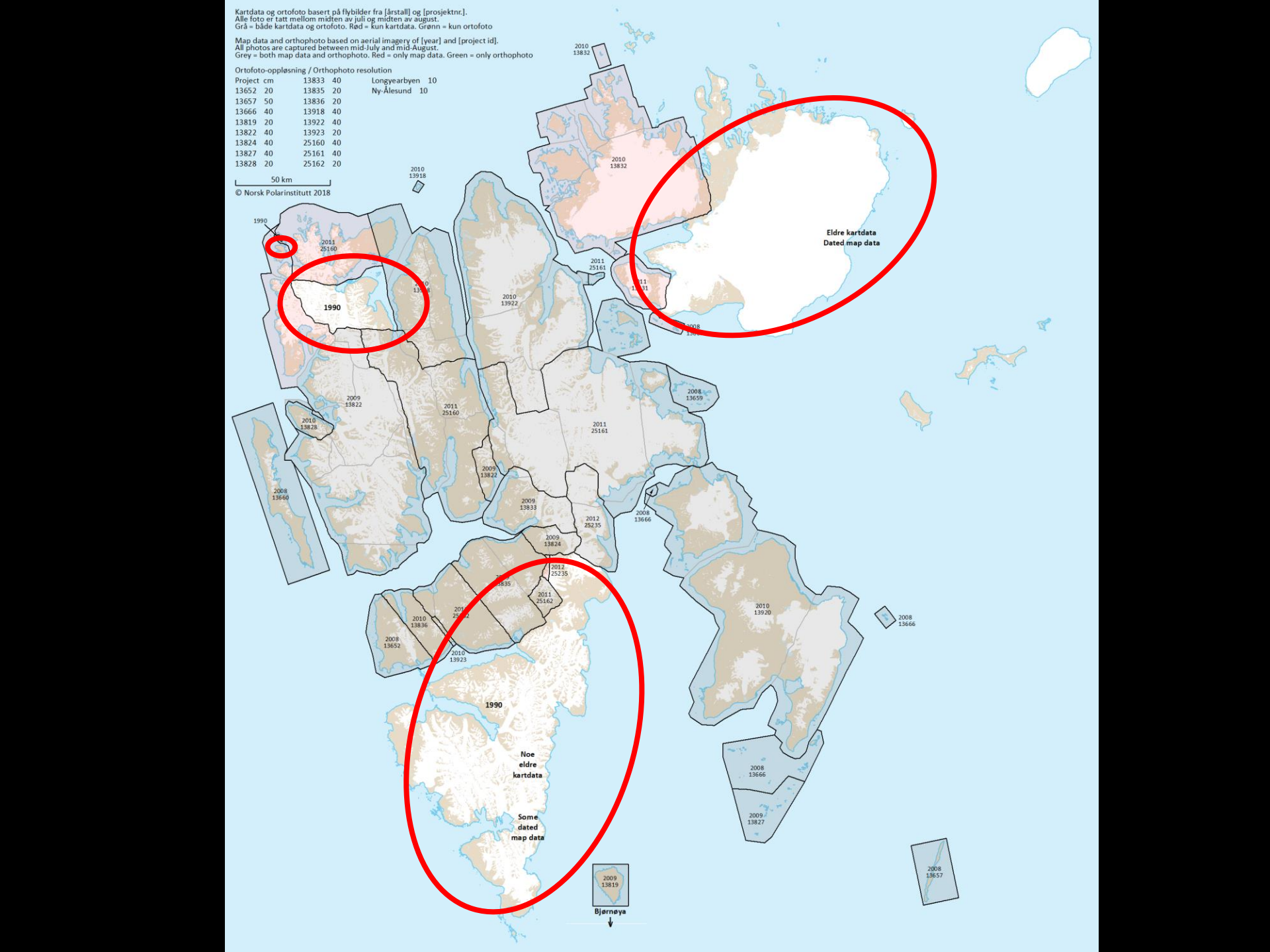



Elevation (masl)
700
600
500
400
300
200
100
0
30
20
10
0
-10
-20
-30


15°E
20°E
25°E
80°N
78°N
Pre-1990
Nordaustlandet
Kvitøya
Barentsøya
Edgeøya
Spitsbergen
1990
2000s
Percent of Glaciated area
80
60
40
20
1930
1940
1950
1960
1970
1980
1990
2000
2010
Year


NPI S0 DEM


Flyfotografering 2008 - 2012
GSD 20 og 40-50 (i cm)
S2009
S2010
S2011
S2012


Kartdata og ortofoto basert på flybilder fra [årstall] og [prosjektnr.].
Alle foto er tatt mellom midten av juli og midten av august.
Grå = både kartdata og ortofoto. Rød = kun kartdata. Grønn = kun ortofoto
Map data and orthophoto based on aerial imagery of [year] and [project id].
All photos are captured between mid-July and mid-August.
Grey = both map data and orthophoto. Red = only map data. Green = only orthophoto
Ortofoto-oppløsning / Orthophoto resolution
Project cm
13652 20
13657 50
13666 40
13819 20
13822 40
13824 40
13827 40
13828 20
13833 40
13835 20
13836 20
13918 40
13922 40
13923 20
25160 40
25161 40
25162 20
Longyearbyen 10
Ny-Ålesund 10
50 km
© Norsk Polarinstitutt 2018
Eldre kartdata
Dated map data
1990
Noe eldre kartdata
Some dated map data
Bjørnøya

Arctic DEM

University of Minnesota
Driven to Discover℠

One Stop MyU For Students, Faculty, and Staff

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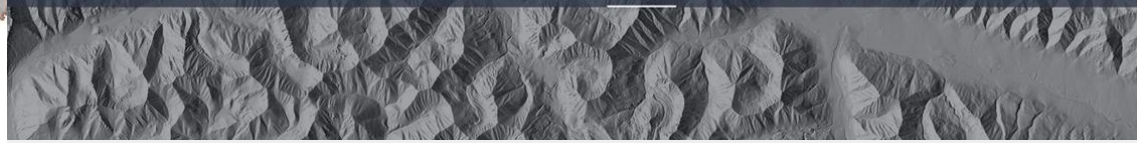
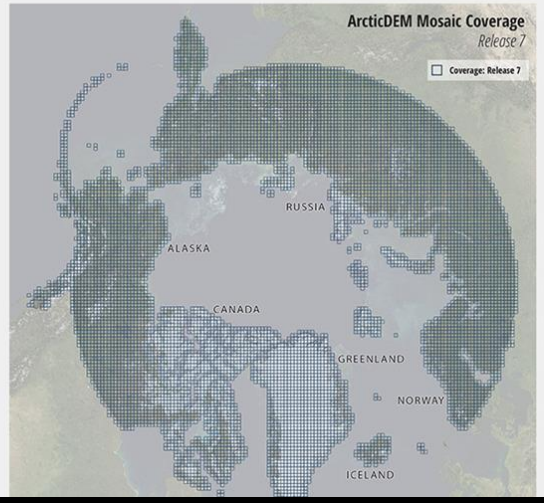
Overview Maps Satellite Aerial Elevation ArcticDEM REMA Web Apps Request



ArcticDEM Mosaic

Mosaicked DEM files are compiled from from the best quality strip DEM files which have been blended and feathered to reduce void areas and edge-matching artifacts. Filtered IceSAT altimetry data has been applied to the raster files to improve absolute accuracy.

Mosaicked DEM files are distributed in 50 km x 50 km sub-tiles. Mosaicked DEMs are provided at 2-meter spatial resolution in 32-bit GeoTIFF format. Reduced resolution versions are also available at 10 meter, 32 meter, 100 meter, 500 meter, and 1 kilometer resolutions. Elevation units are meters and are referenced to the WGS84 ellipsoid.



STATISTICS

TILES
2,488

SUB-TILES
9,228

AREA
23,070,000 km^2

DOWNLOAD

ArcticDEM Tile Index (Esri Shapefile)
2 meter DEMs (full resolution)
10 meter DEMs
32 meter DEMs
100 meter DEM
500 meter DEM
1 kilometer DEM

Arctic DEMs constructed from in-track and cross-track high-resolution (~0.5 meter) imagery acquired by the DigitalGlobe constellation of optical imaging satellites, WorldView-1, WorldView-2, and WorldView-3, which collect stereoscopic imagery of the Arctic.

Imagery processed into 2-meter posting DEMs using Ohio State University's software package Surface Extraction with TIN-based Search-space Minimization (SETSM).

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The Surface Extraction from TIN based Search-space Minimization (SETSM) algorithm

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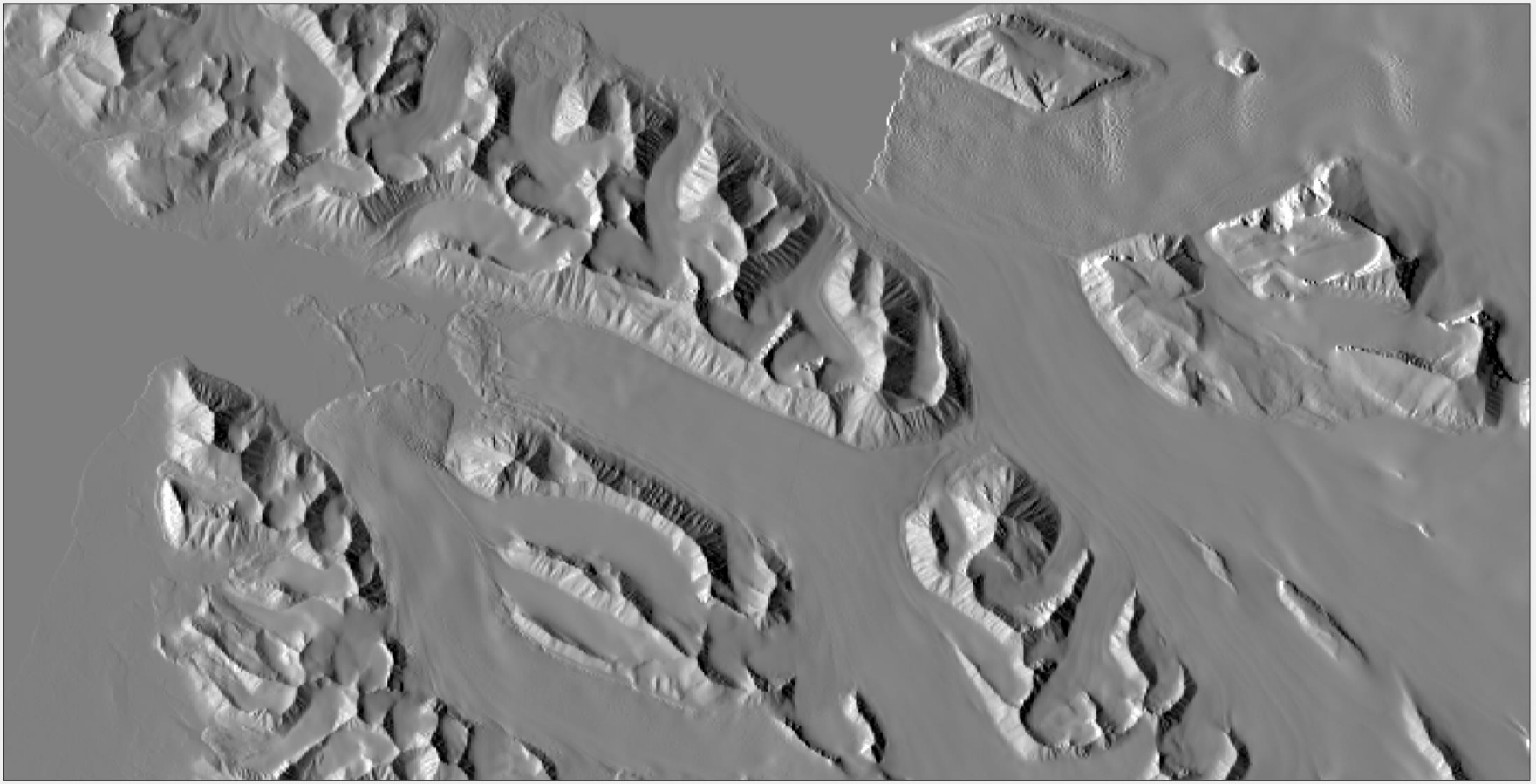
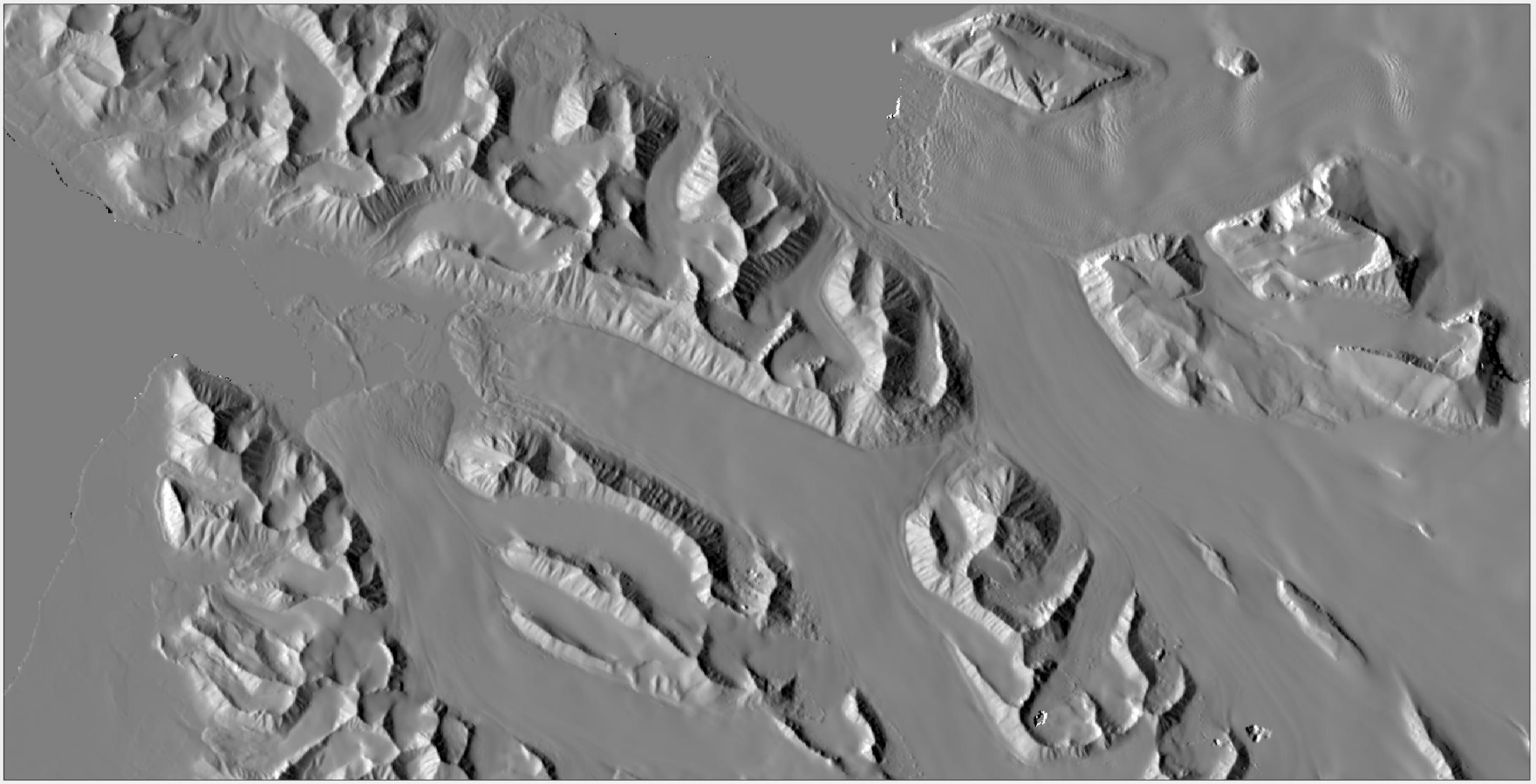
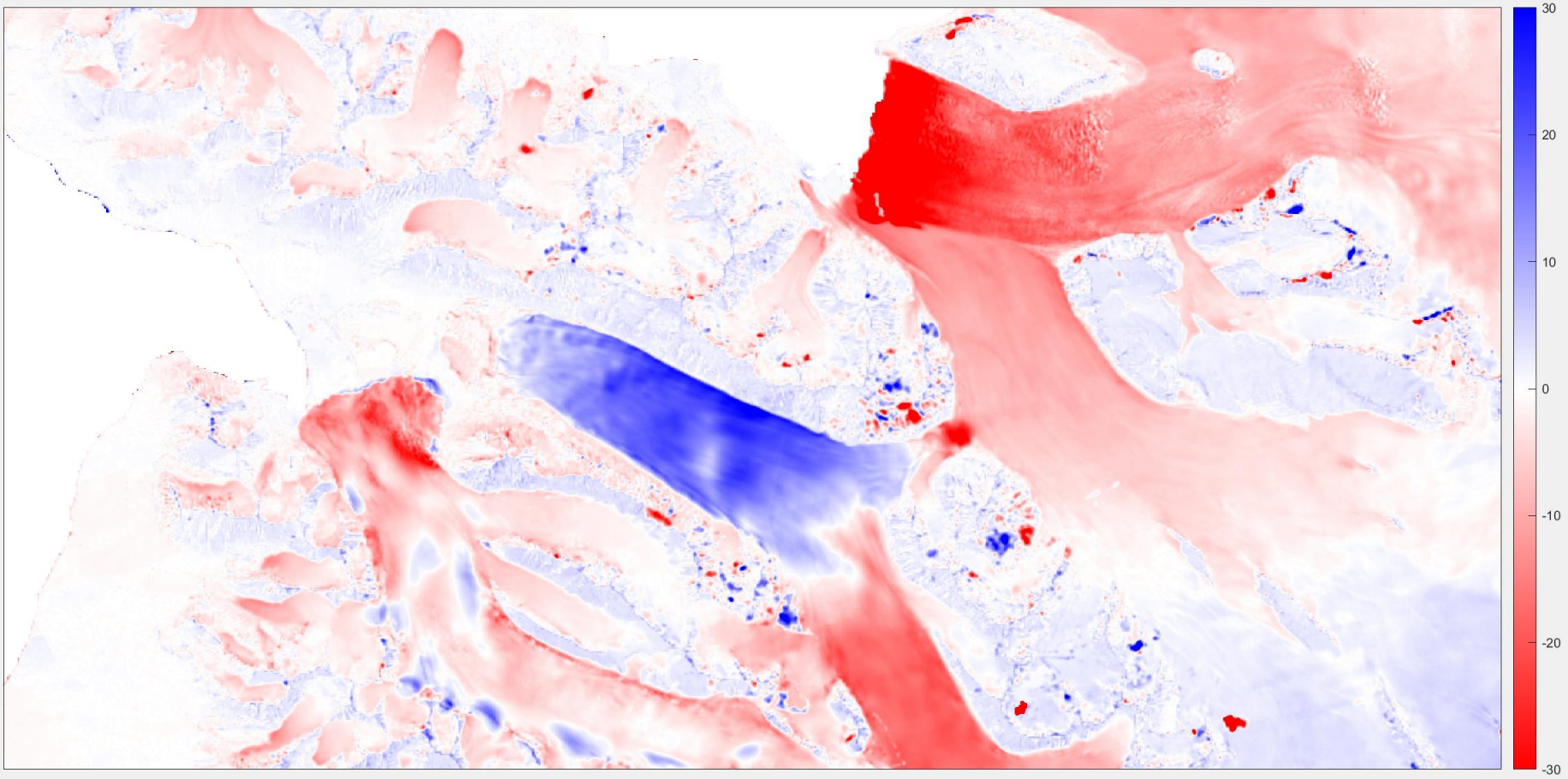
[b] School of Earth Sciences, The Ohio State University, 125 S Oval Mall, Columbus, OH 43210, USA



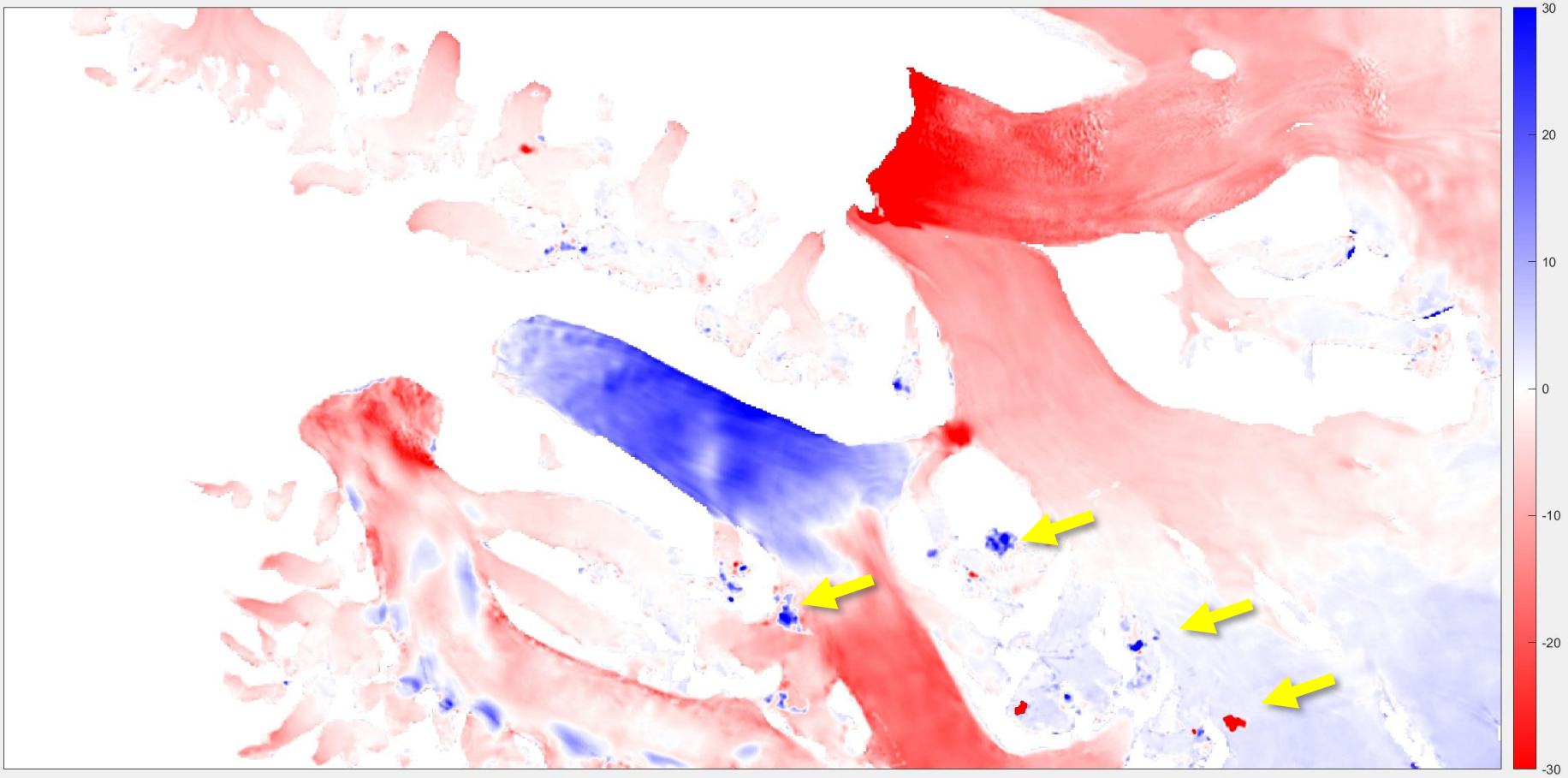
NPI 50-m DEM (2009-10)



ADEM 32-m mosaic (2012-2017)



NP DEM – ADEM



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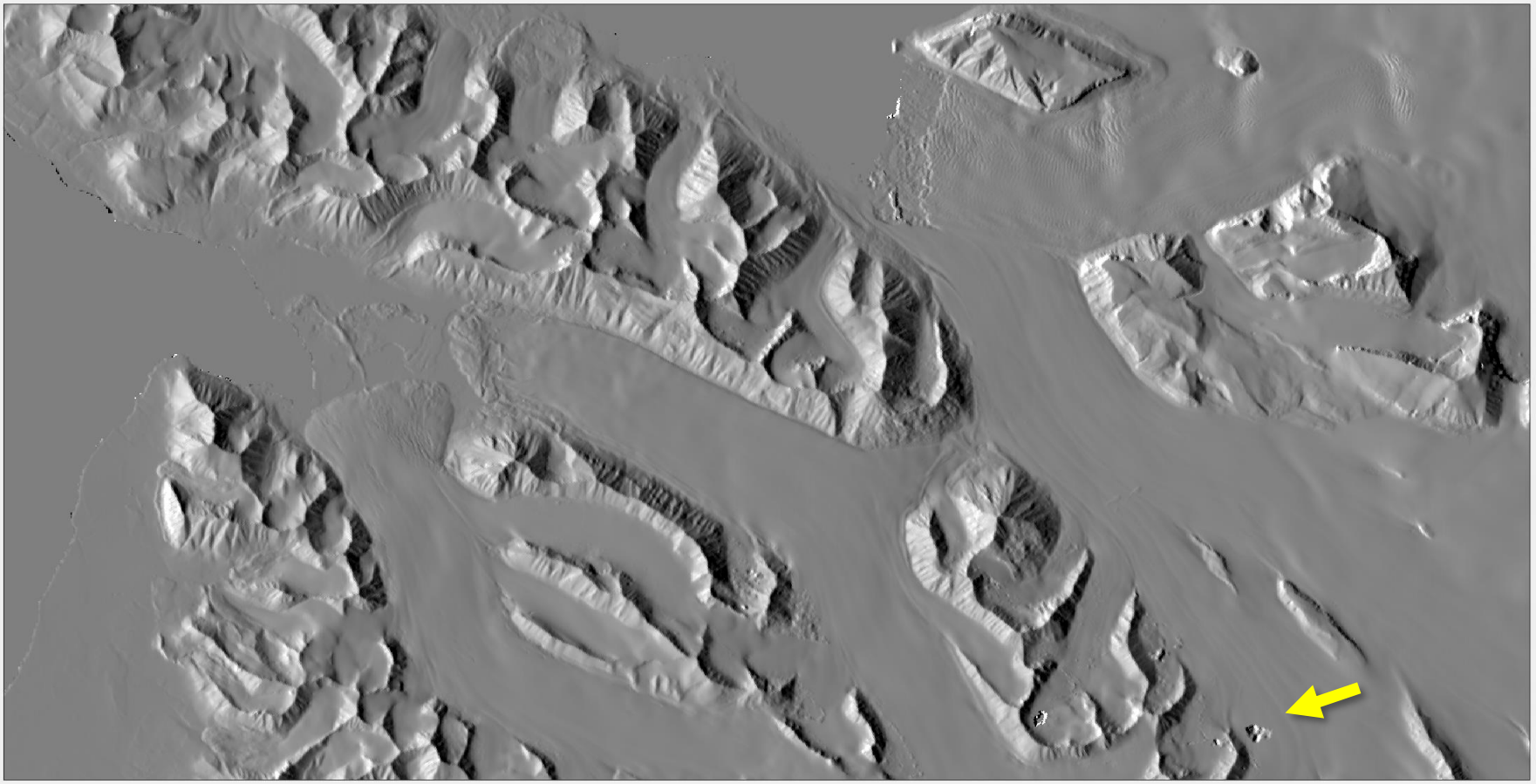
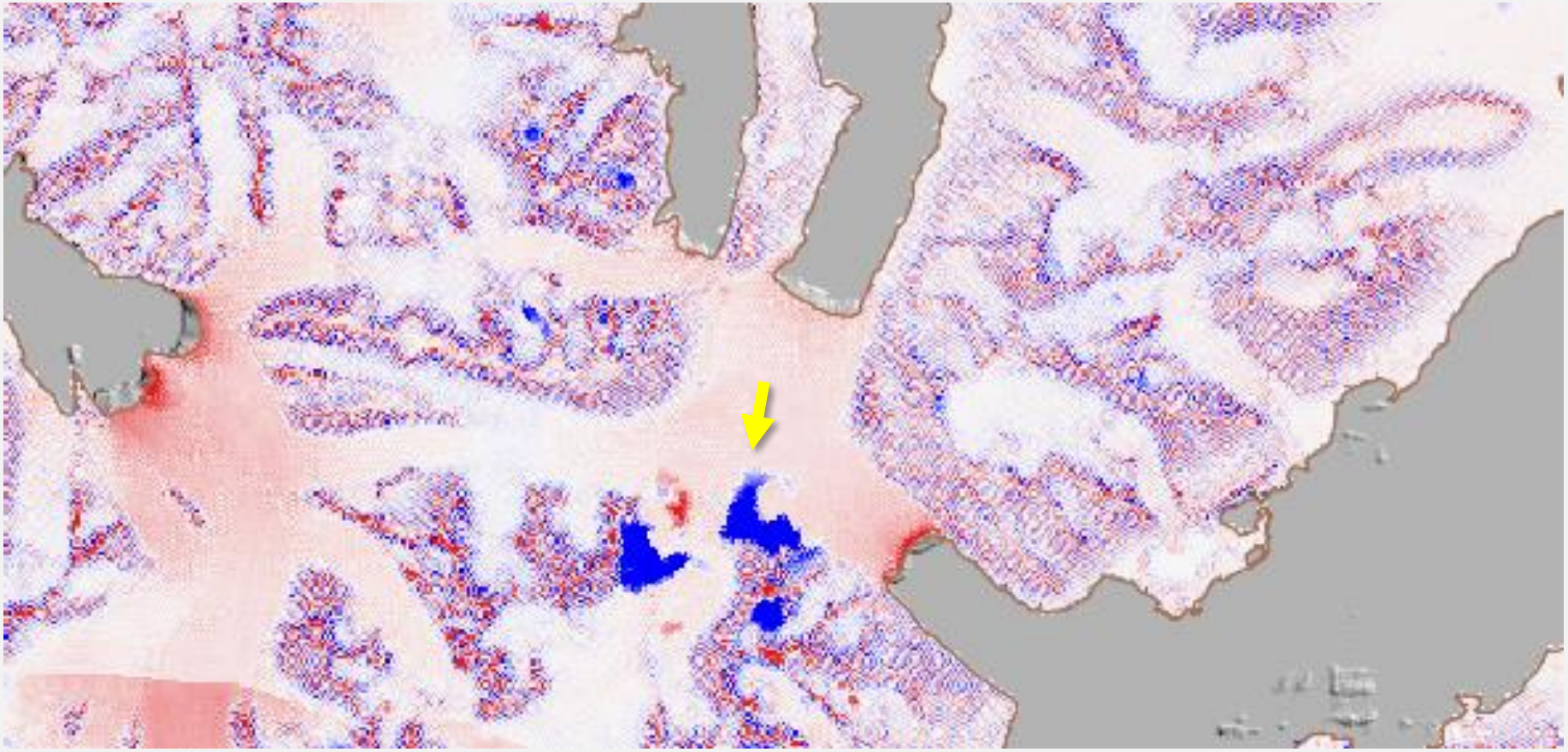
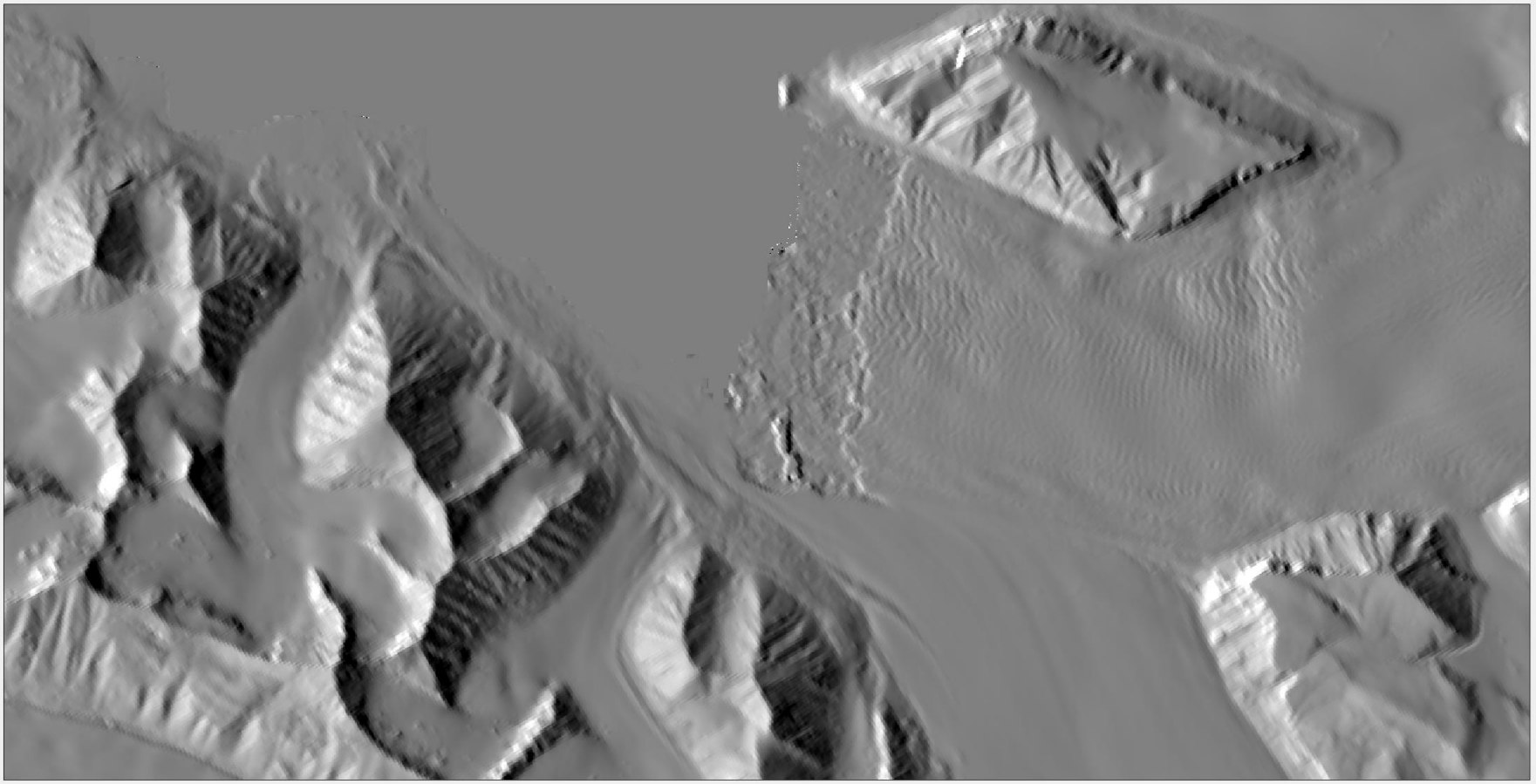


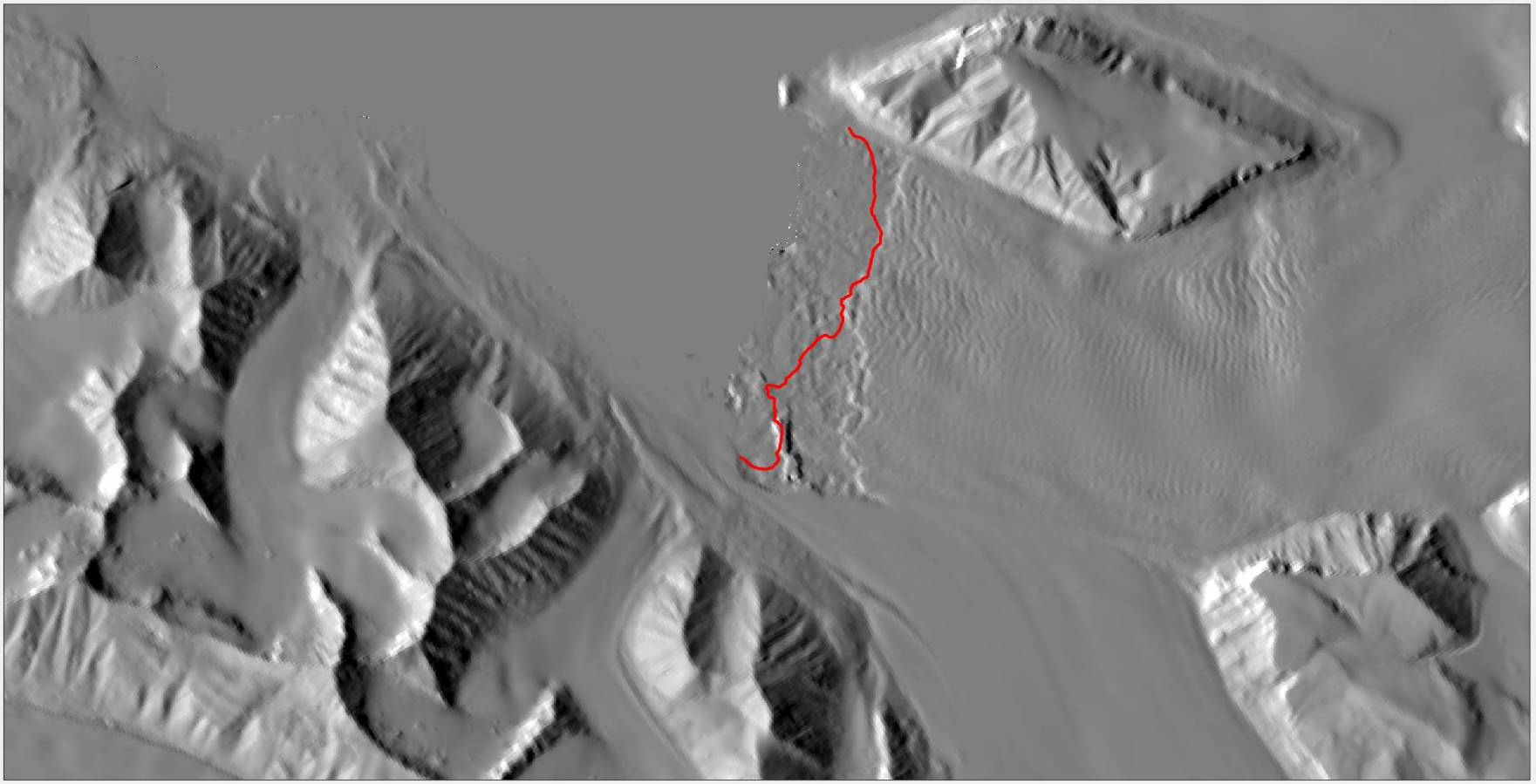
ADEM 32-m mosaic (2012-2017)



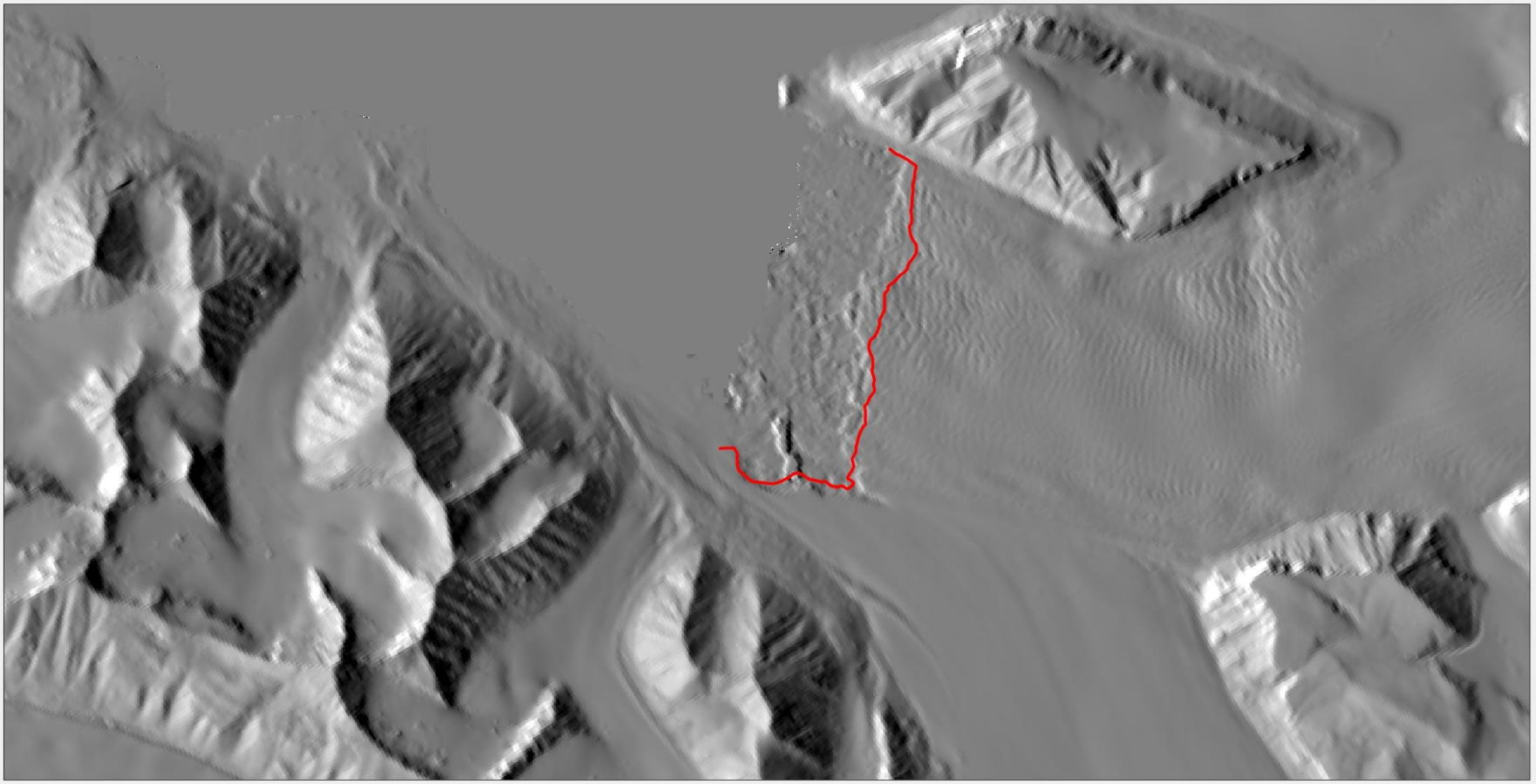
NP DEM – ADEM



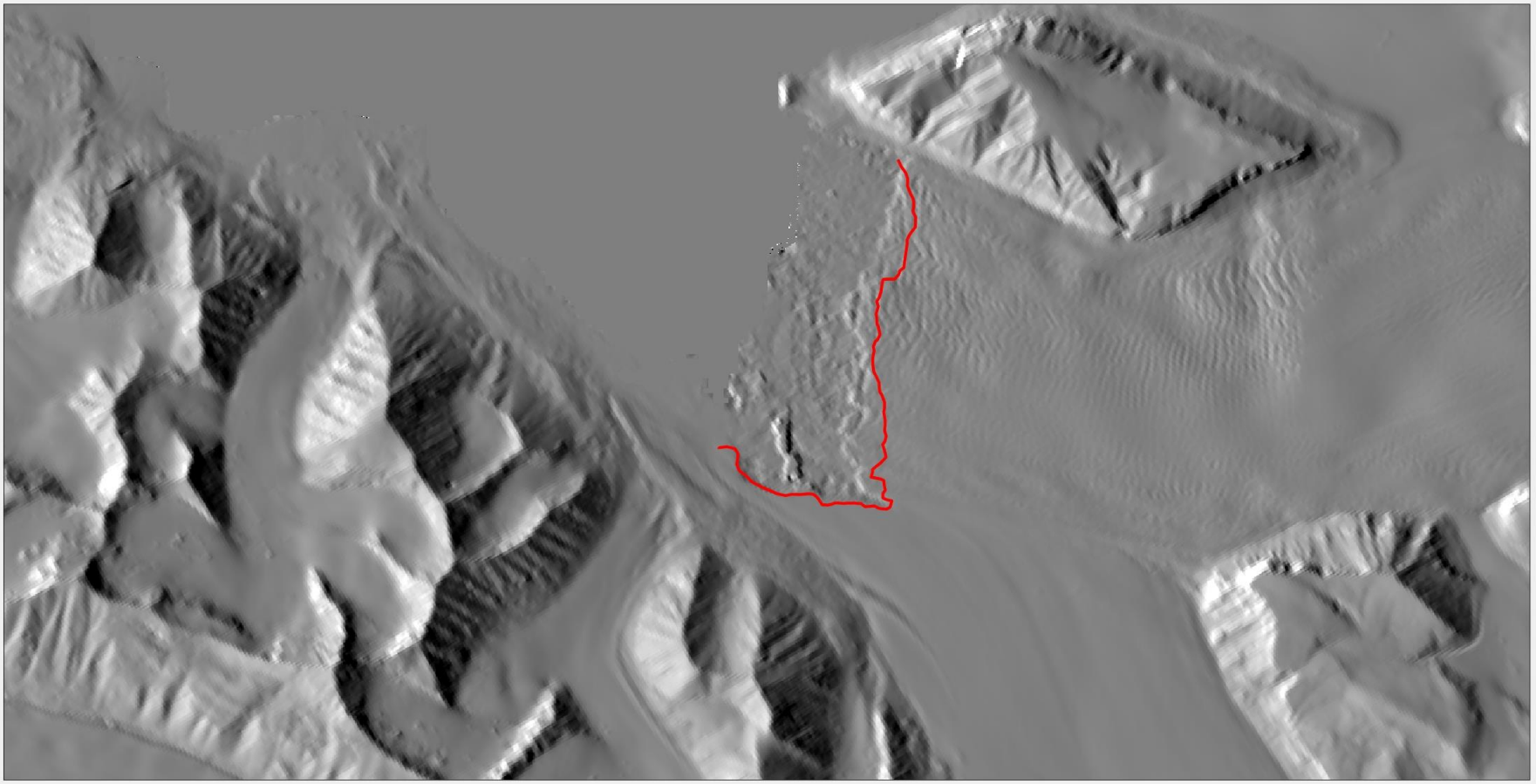
ADEM 32-m mosaic



ADEM 32-m mosaic, 2013 front position



ADEM 32-m mosaic, 2014 front position



ADEM 32-m mosaic, 2015 front position

34_51_32m_v3.0_dem_meta.txt - Notepad

File Edit Format View Help

```
ArcticDEM Mosaic Tile Metadata
Creation Date: 23-Jul-2018 22:37:56
Version: 3.0

Mosaicking Alignment Statistics (meters) in rank order
strip, rmse, dz, dx, dy
WV02_20150715_10300100466F5300_1030010046AB9400_seg1_2m 0.00 0.0000 0.0000 0.0000
WV01_20160709_1020010050144E00_1020010053E2CA00_seg1_2m 0.28 -3.1237 2.4141 -1.8052
WV02_20170419_1030010067438B00_10300100671EB100_seg1_2m 0.92 -5.3396 -14.0297 2.1281
WV03_20150813_104001000F1ED400_104001000E0E0F00_seg1_2m 0.24 -3.0477 -5.6291 2.4500
WV02_20130919_1030010027219F00_1030010026CE5F00_seg1_2m 0.23 -4.0466 -3.1224 5.4391
W2W2_20130407_10300100202A6400_1030010021283C00_seg1_2m 0.38 -3.6019 -0.6059 1.2227
W1W2_20110805_1020010014988F00_103001000C34EB00_seg3_2m 0.54 -6.2718 -7.3877 5.3198
W1W1_20150731_10200100418A7E00_10200100424B0200_seg1_2m 0.74 -0.6140 -4.6441 -1.7512
WV02_20130413_1030010021274F00_1030010021A69700_seg1_2m 0.80 1.3322 -1.7609 -0.7395
WV02_20140406_103001003020BE00_103001002FA0CF00_seg1_2m 0.78 -7.0707 -2.6936 0.7584
WV01_20130401_10200100205DE400_10200100203CEF00_seg1_2m 0.61 -5.0819 -5.7693 -1.7446
WV01_20130830_10200100262B5000_1020010024408300_seg1_2m 0.74 -4.2435 -4.8621 3.7914
WV02_20160709_1030010057C93000_1030010057B1FA00_seg3_2m 0.60 -6.3494 5.1153 3.5308
WV03_20150630_104001000E95D100_104001000E3E4C00_seg1_2m 0.81 -1.0605 0.4104 1.2710
WV02_20150715_10300100466F5300_1030010046AB9400_seg6_2m 0.25 -0.3632 -0.0914 0.0341
W1W1_20150319_102001003B4AA900_102001003BE4E900_seg5_2m 0.33 -0.4661 3.0205 -2.9524
WV01_20160809_1020010052B1F400_1020010052B26700_seg2_2m 0.44 -0.8798 -0.9279 0.5552
WV01_20160429_102001004DD94200_1020010050EA3A00_seg6_2m 0.71 -0.4583 1.4858 -2.1393
WV01_20120407_1020010001978F500_102001001B8F7200_seg1_2m 0.80 -5.7806 0.0340 -5.3451
WV03_20170429_104001002C197500_104001002C8D8D00_seg11_2m 0.94 -3.1829 -10.0782 -0.4476
WV01_20130321_1020010021D06300_102001002145EE00_seg2_2m 0.88 -2.9764 -5.1715 -0.2146
WV01_20130602_10200100221D0000_102001002342D100_seg1_2m 0.94 -5.6416 -4.7750 2.4961
WV01_20140424_102001002FC3D300_102001002FCADA00_seg4_2m 0.91 -1.1812 -14.3108 -2.1981
WV03_20160506_104001001C0FE200_104001001C747700_seg1_2m 0.98 -0.8760 2.3191 -0.6111
WV01_20140316_102001002BE44000_102001002B57D400_seg1_2m 0.95 -5.9558 -5.1272 -2.0929
WV01_20150501_102001003D710A00_102001003D05ED00_seg1_2m 0.88 -1.9091 -6.3826 -1.8653
WV02_20150703_10300100449C4100_1030010045B22400_seg1_2m 0.90 -8.0850 -9.4588 -4.1344
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WV01_20150909_1020010045582400_1020010044D9F700_seg3_2m 1.01 -2.3957 1.7672 -0.6738
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WV03_20170510_104001002B76A800_104001002D347400_seg3_2m 1.32 -3.7167 0.3730 1.5573
WV01_20150801_1020010041BF4800_102001003E7E6300_seg1_2m 1.18 -1.4292 -12.3526 -2.4813
WV01_20150703_102001003FA29800_1020010042C79B00_seg2_2m 1.03 -3.5476 -6.0899 -0.8888
W1W1_20150801_1020010041153E00_1020010041BF4800_seg3_2m 0.95 -1.6248 -11.5578 -1.7799
```
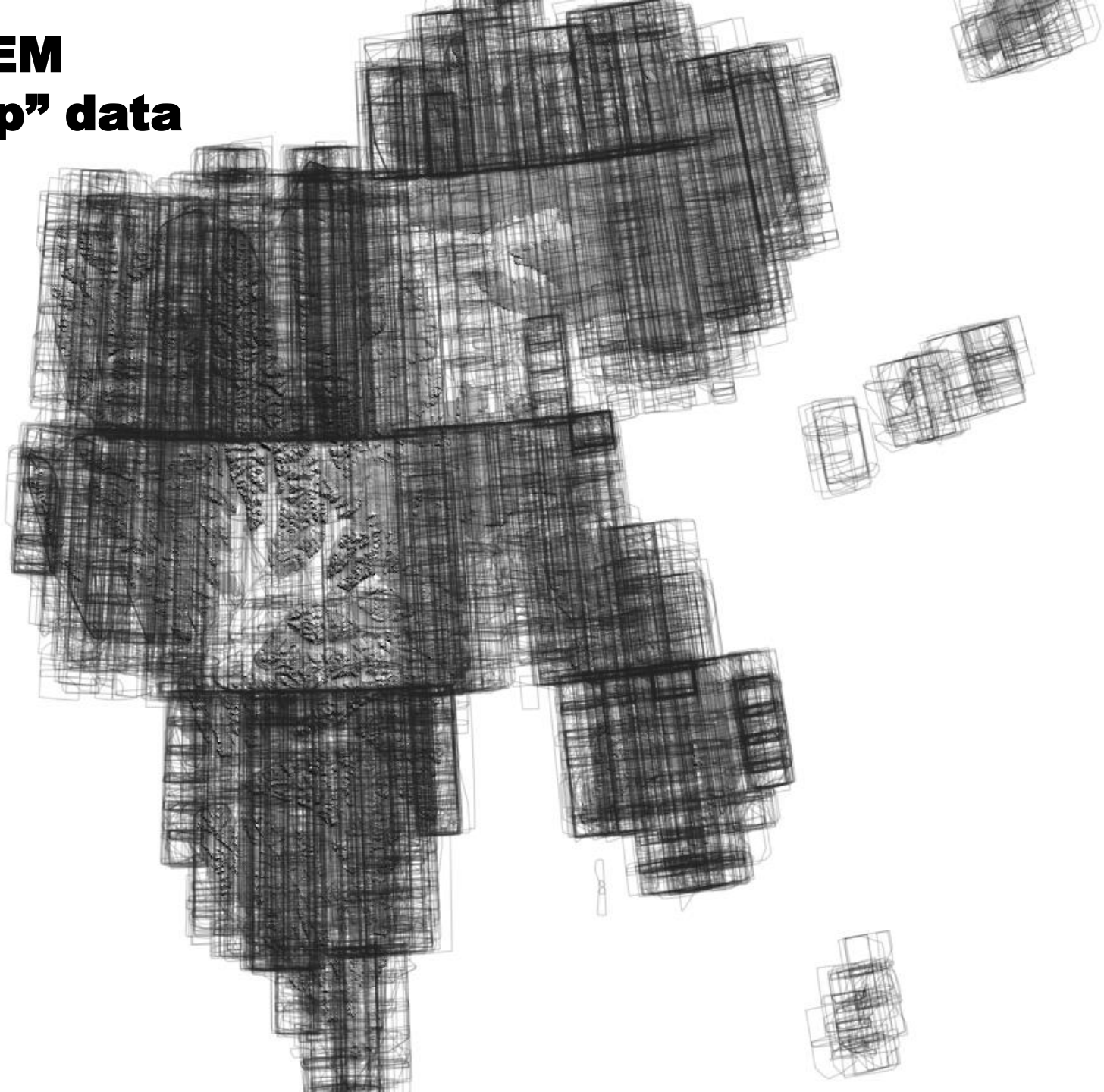
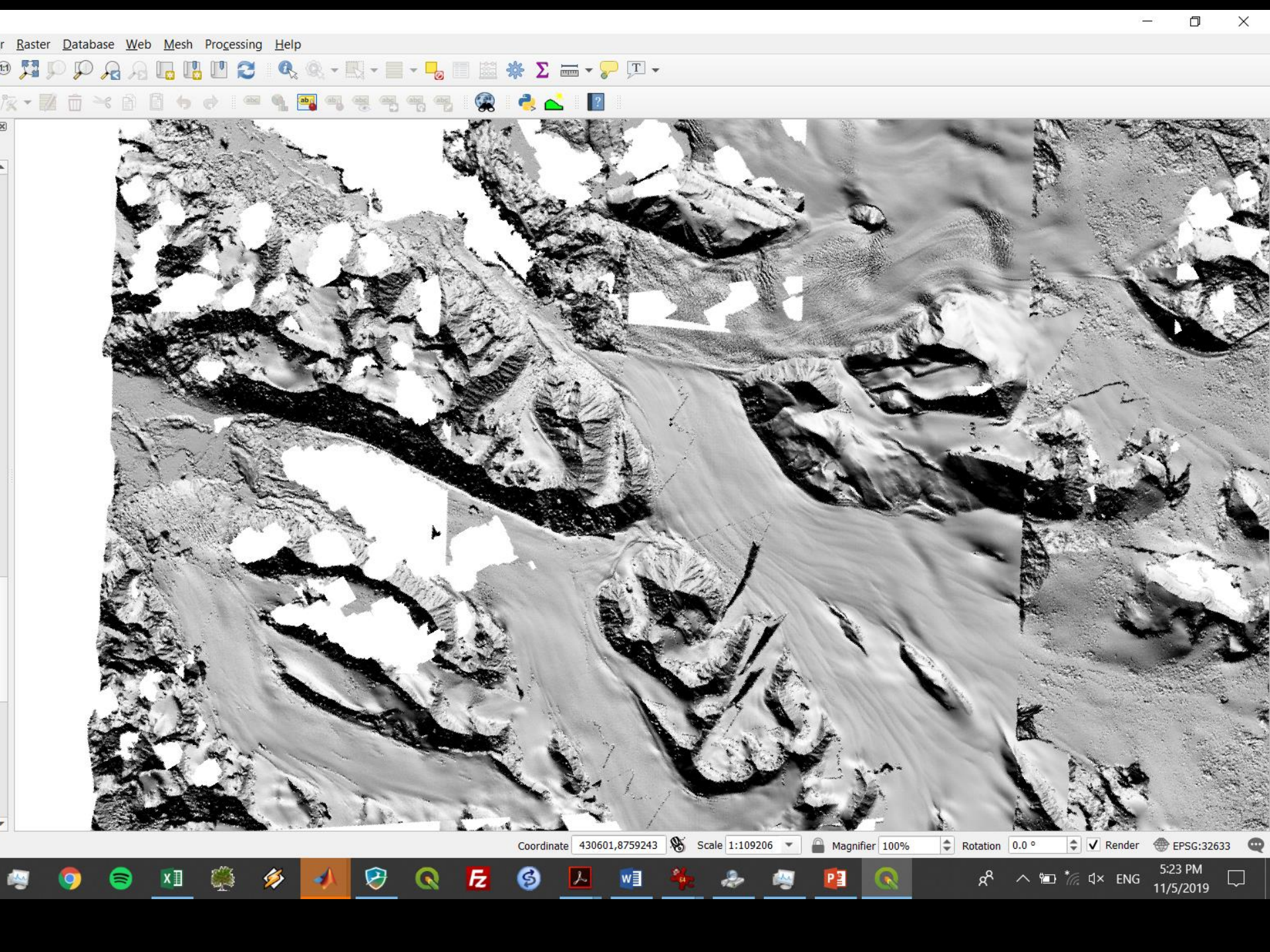

Arctic DEM
2-m “strip” data

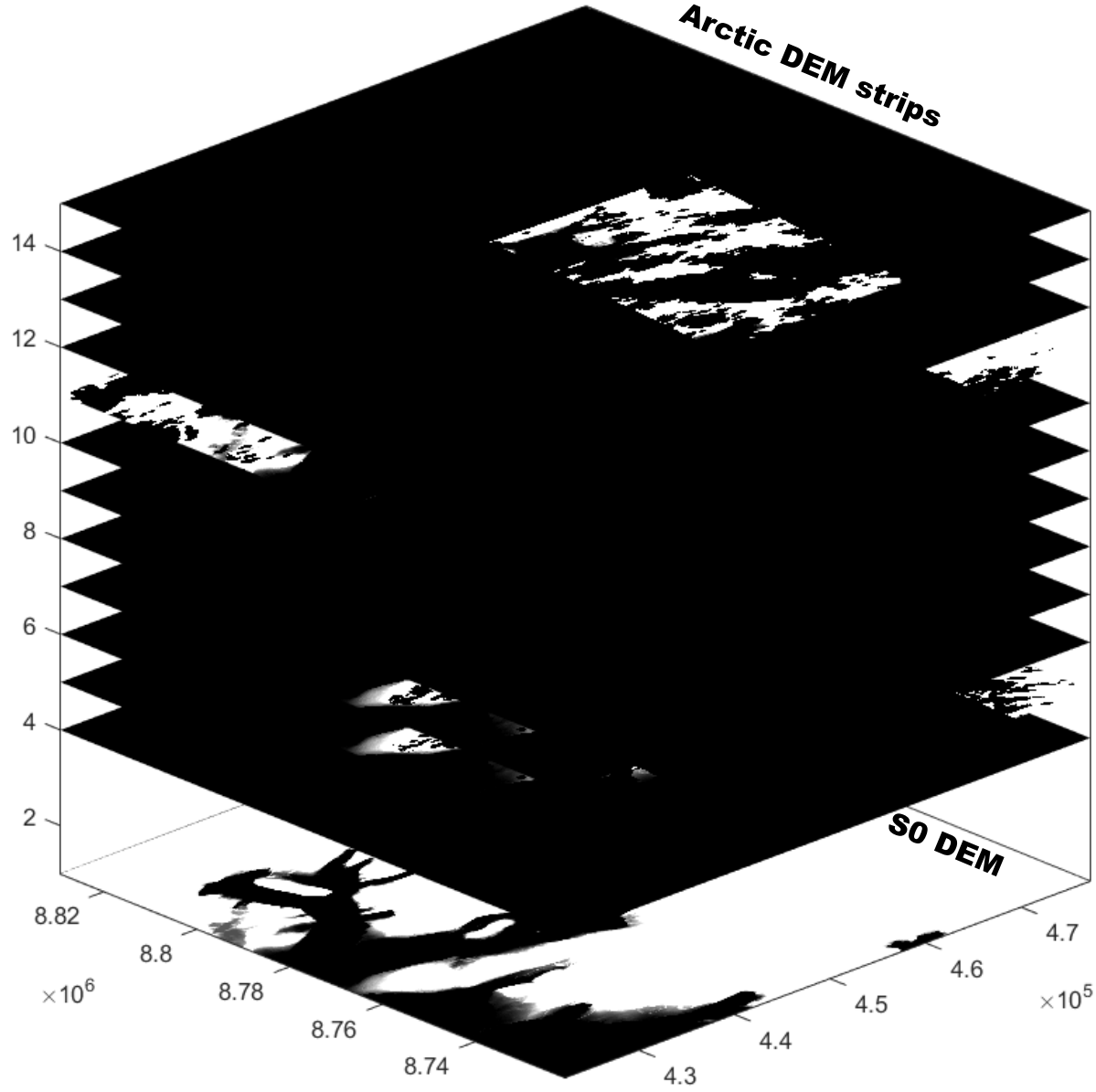


# DEM strips	
2012:	711
2013:	1,047
2014:	747
2015:	3,077
2016:	3,338
2017:	2,329

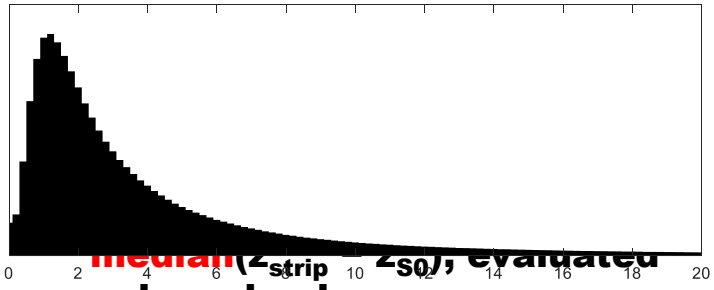
Total size:
2.3 TB


r Raster Database Web Mesh Processing Help
Coordinate 430601,8759243
Scale 1:109206
Magnifier 100%
Rotation 0.0 °
Render
EPSG:32633
ENG
5:23 PM
11/5/2019

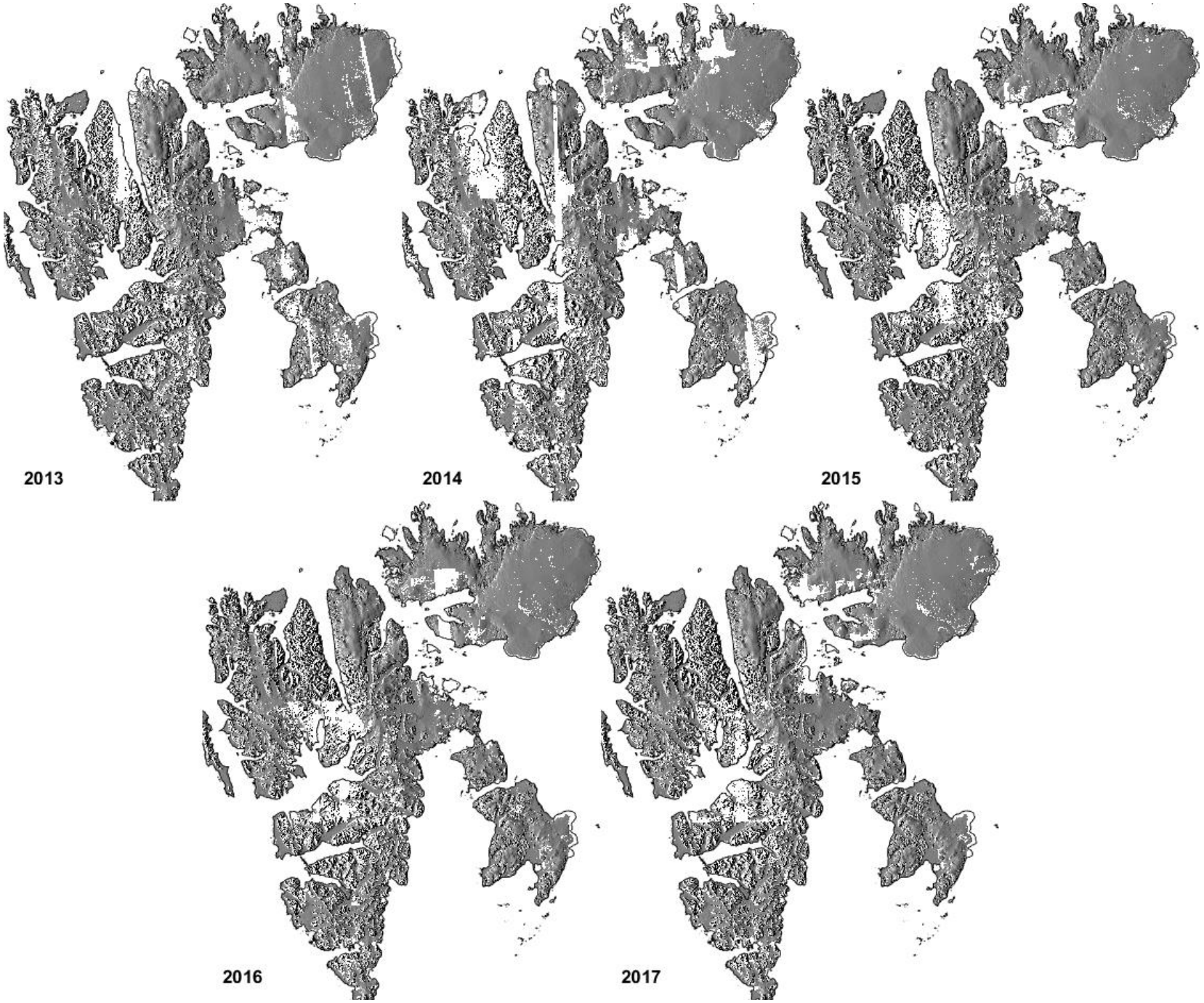
How to make your own annual ADEMs…

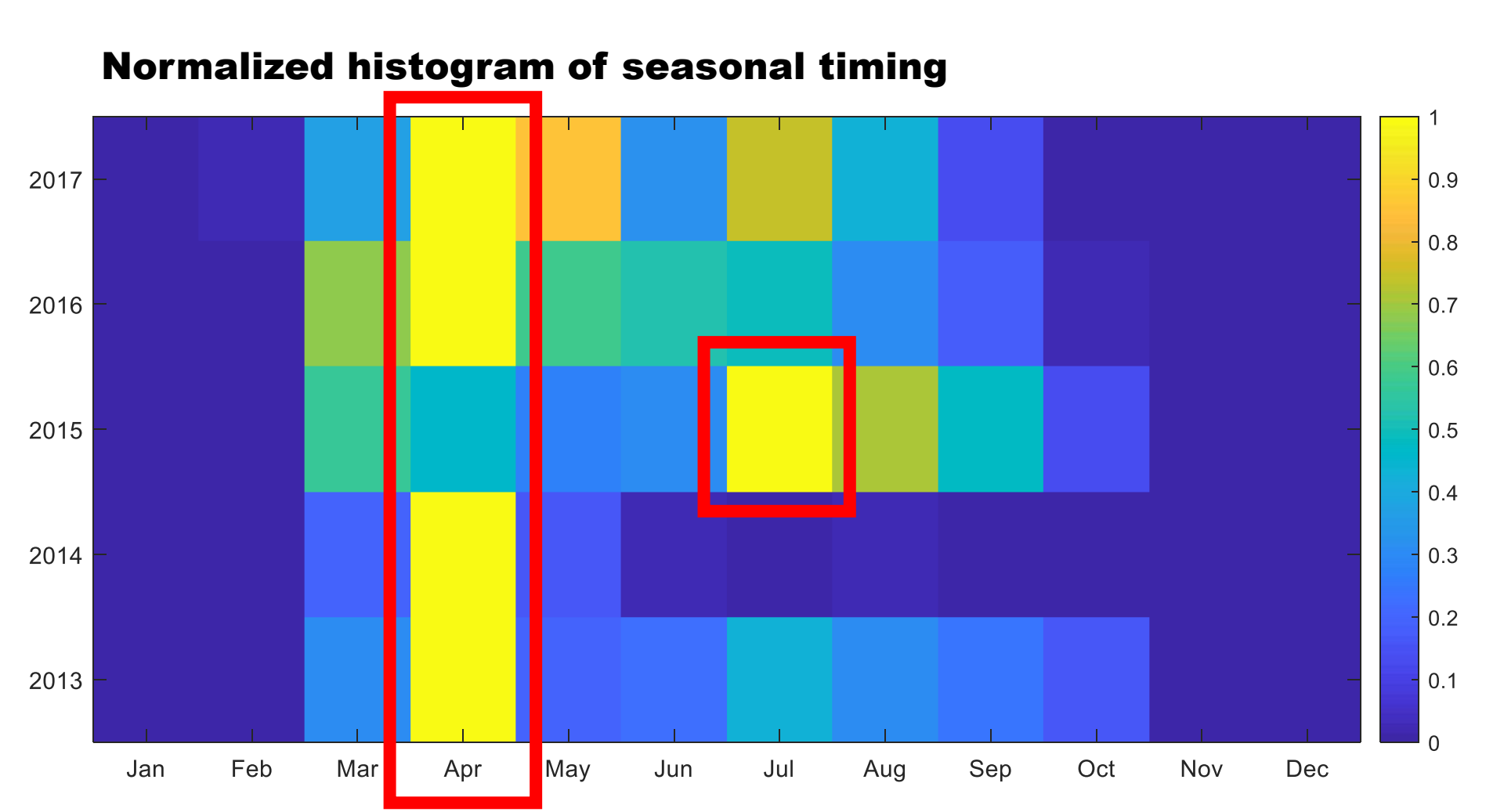


- **Assume ADEM strips have co-registration errors Δx, Δy, and Δz, but are otherwise planar.**
- **Neglect Δx and Δy.**

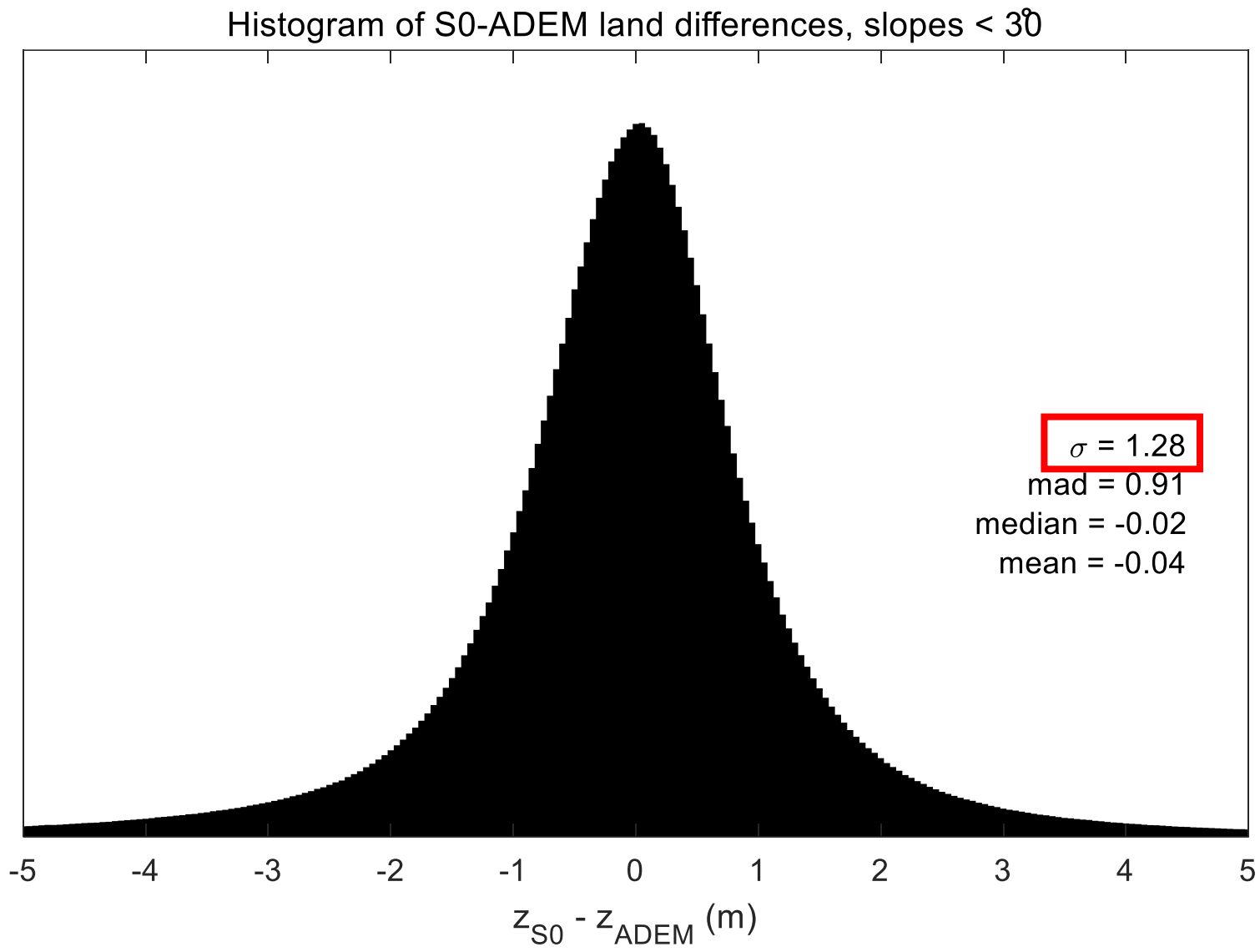


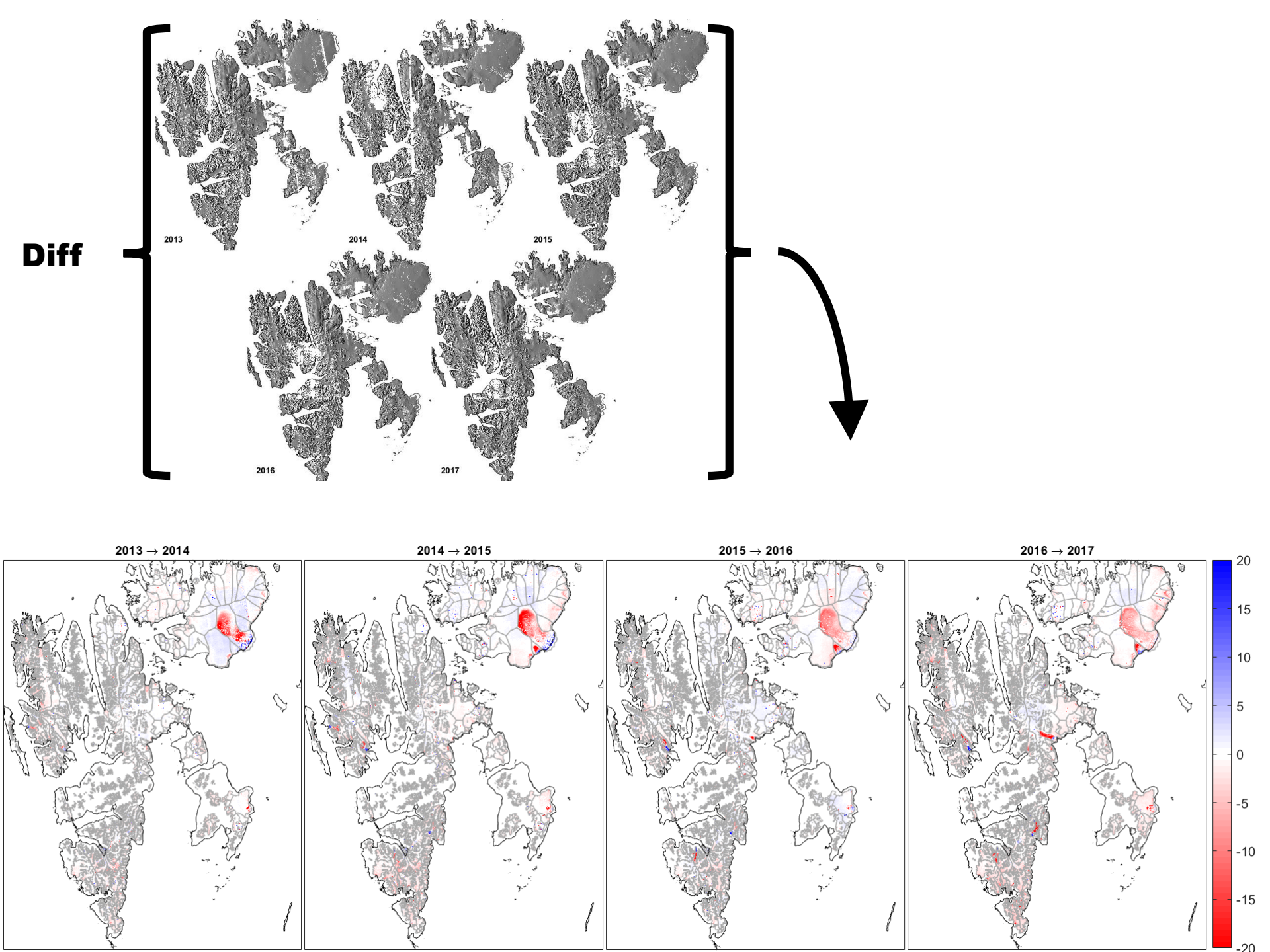
- **median(z_{strip} − z_{S0}), evaluated only on land areas.**
- **Take median of adjusted z_{strip} values to make a preliminary DEM.**
- **Then adjust each strip by subtracting**
  Δz = median(z_{strip} − $z_{prelimary}$)
- **Take median of adjusted strip data to make final DEM.**


2013
2014
2015
2016
2017

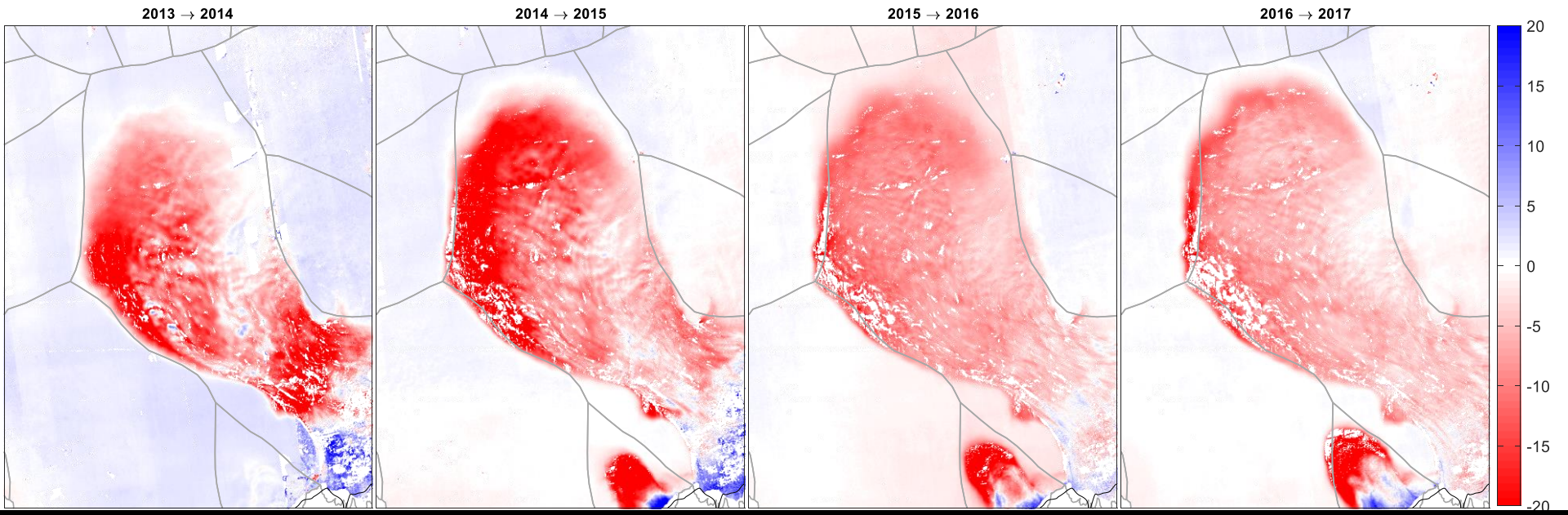

Normalized histogram of seasonal timing
2017
2016
2015
2014
2013
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0

Annual Arctic DEMs error

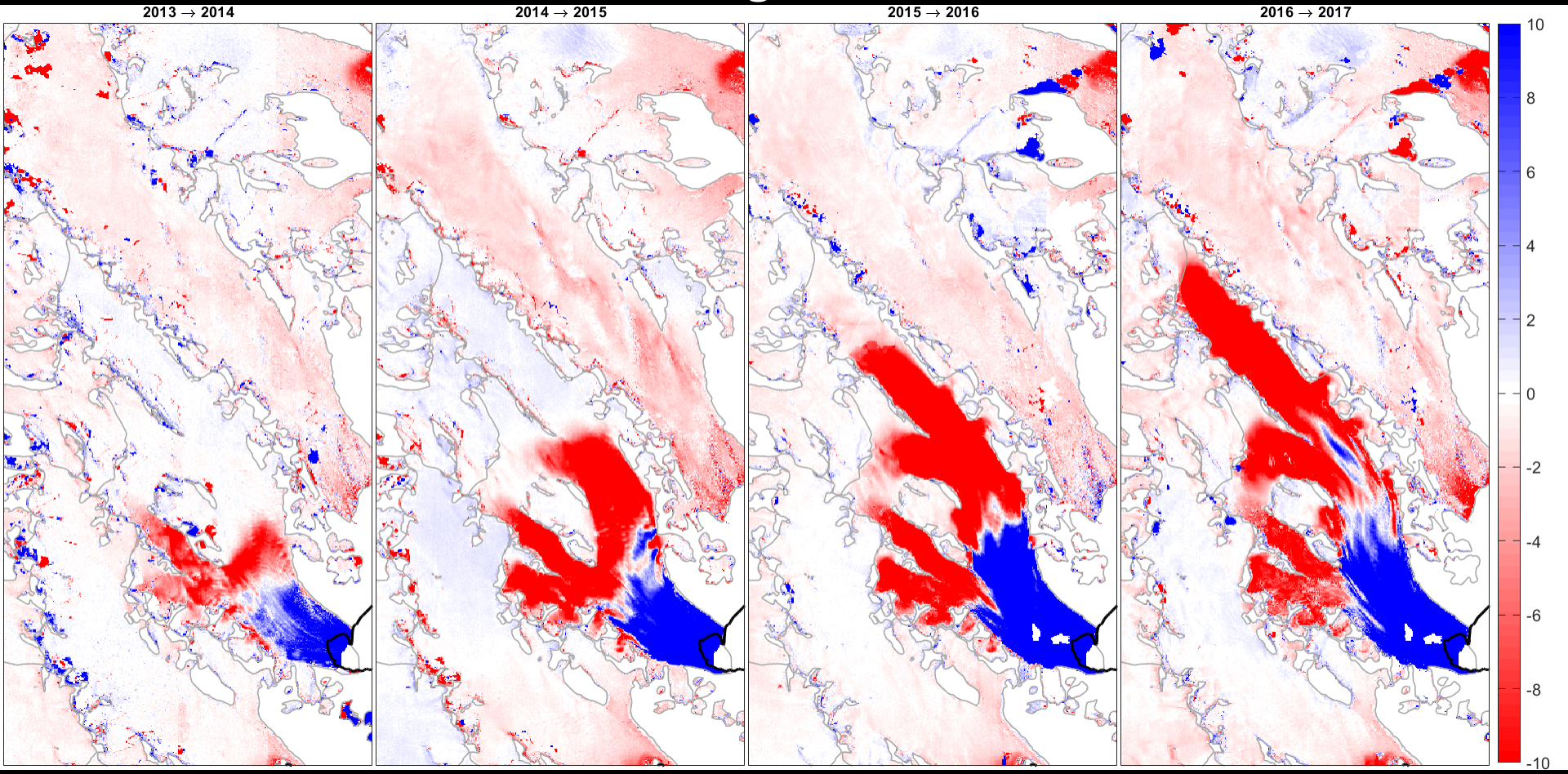



Diff
2013
2014
2015
2016
2017
2013 → 2014
2014 → 2015
2015 → 2016
2016 → 2017
20
15
10
5
0
-5
-10
-15
-20

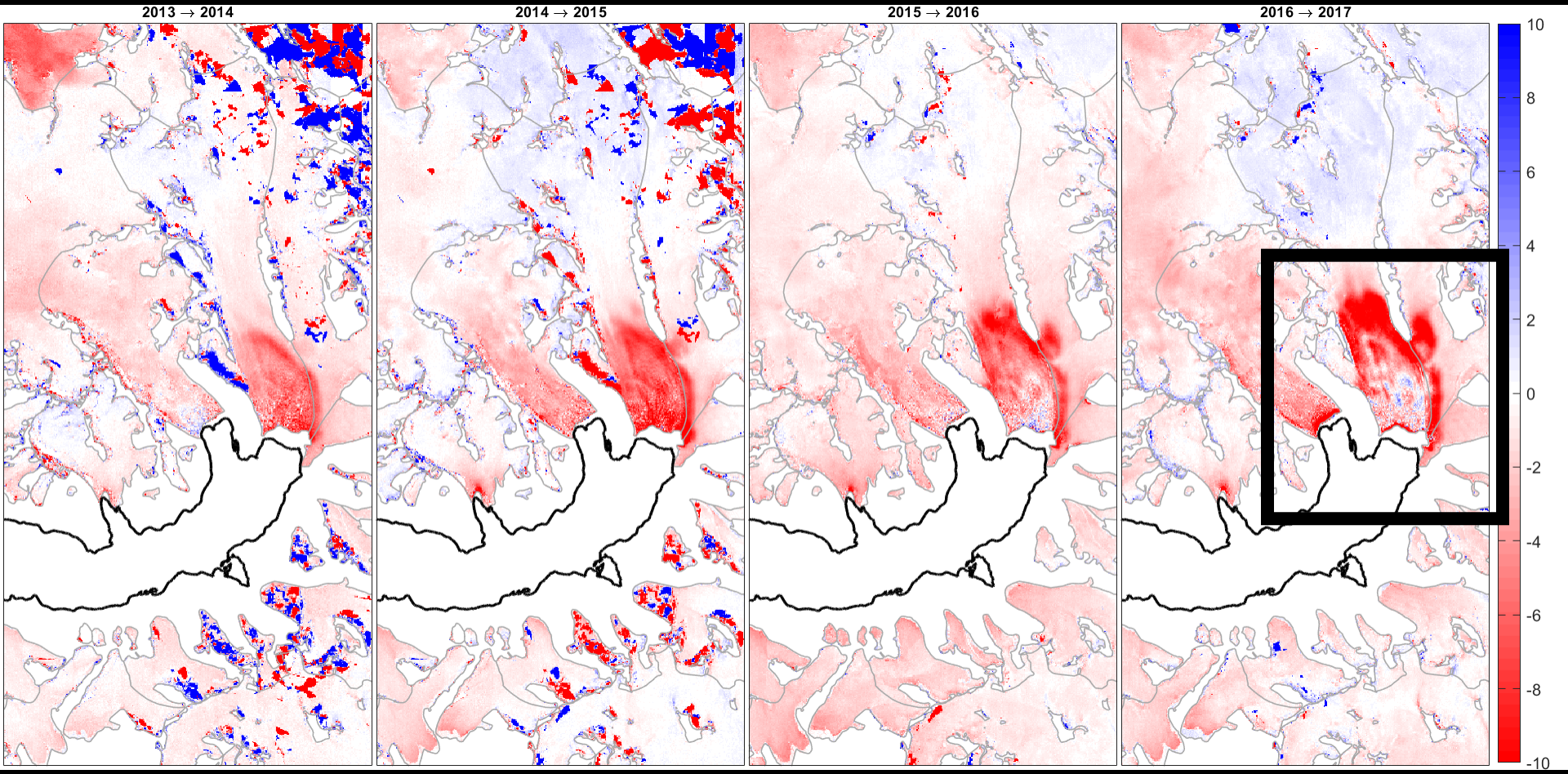
Basin-3 Austfonna



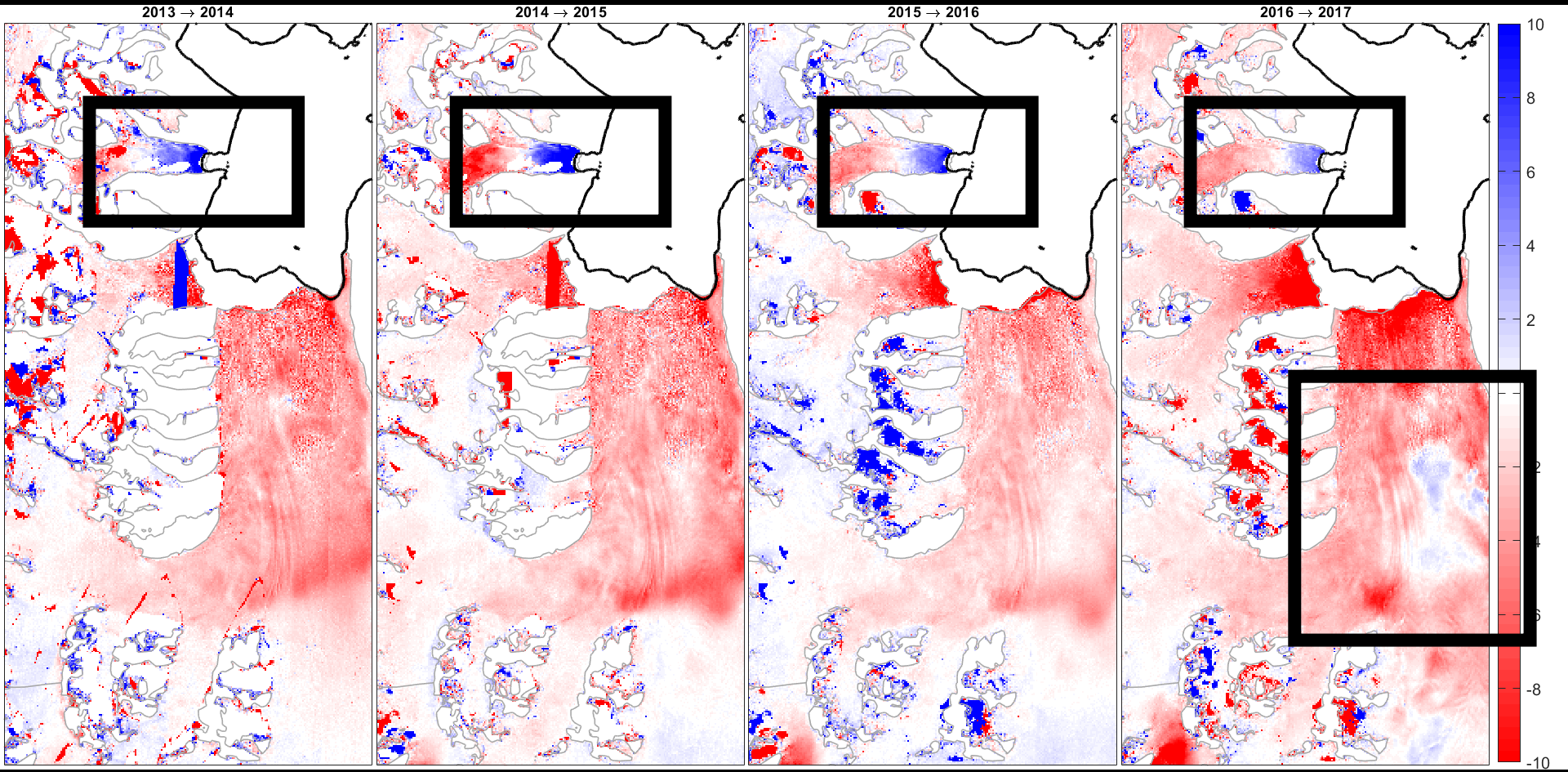
Wahlenbergbreen

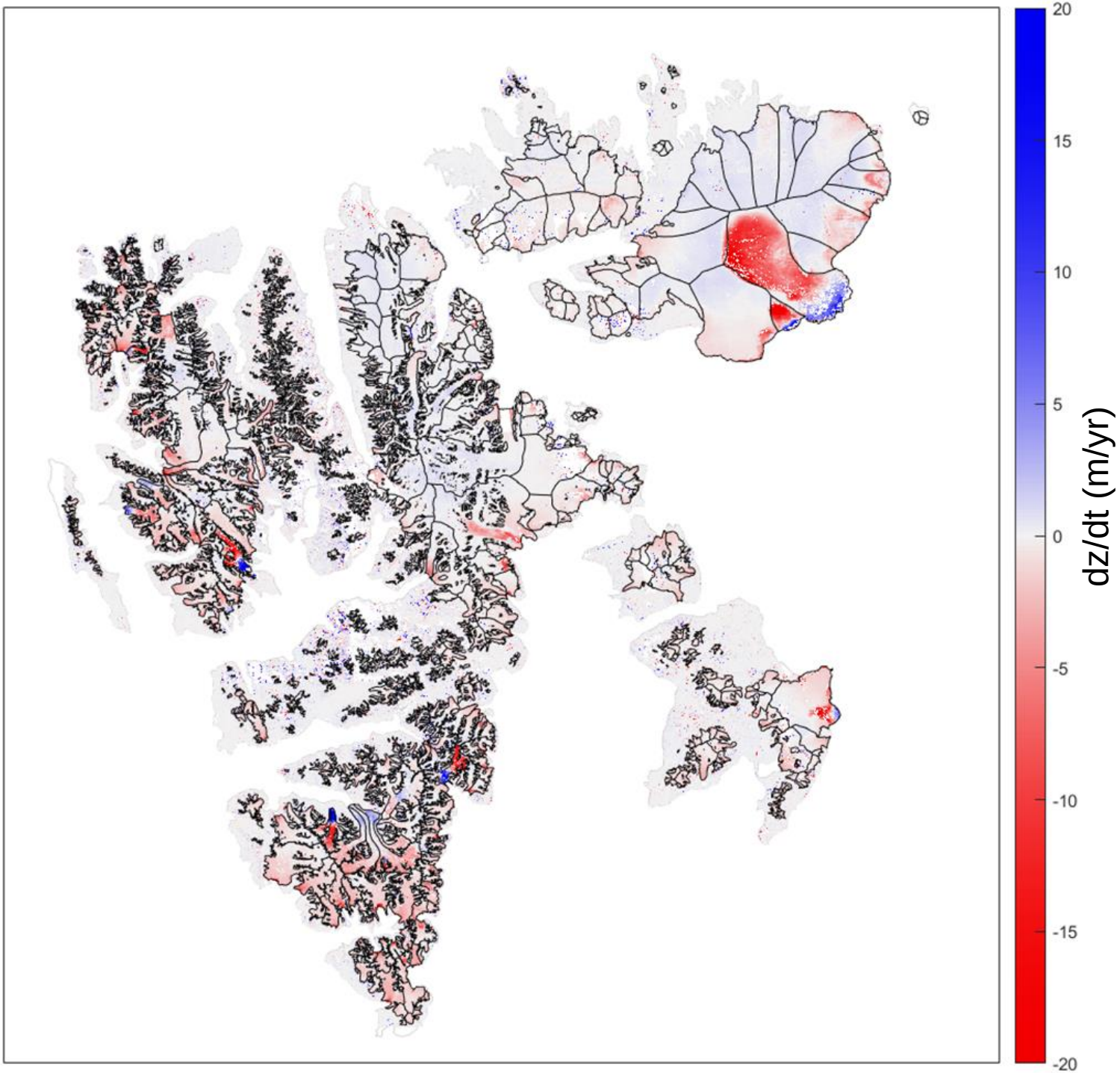


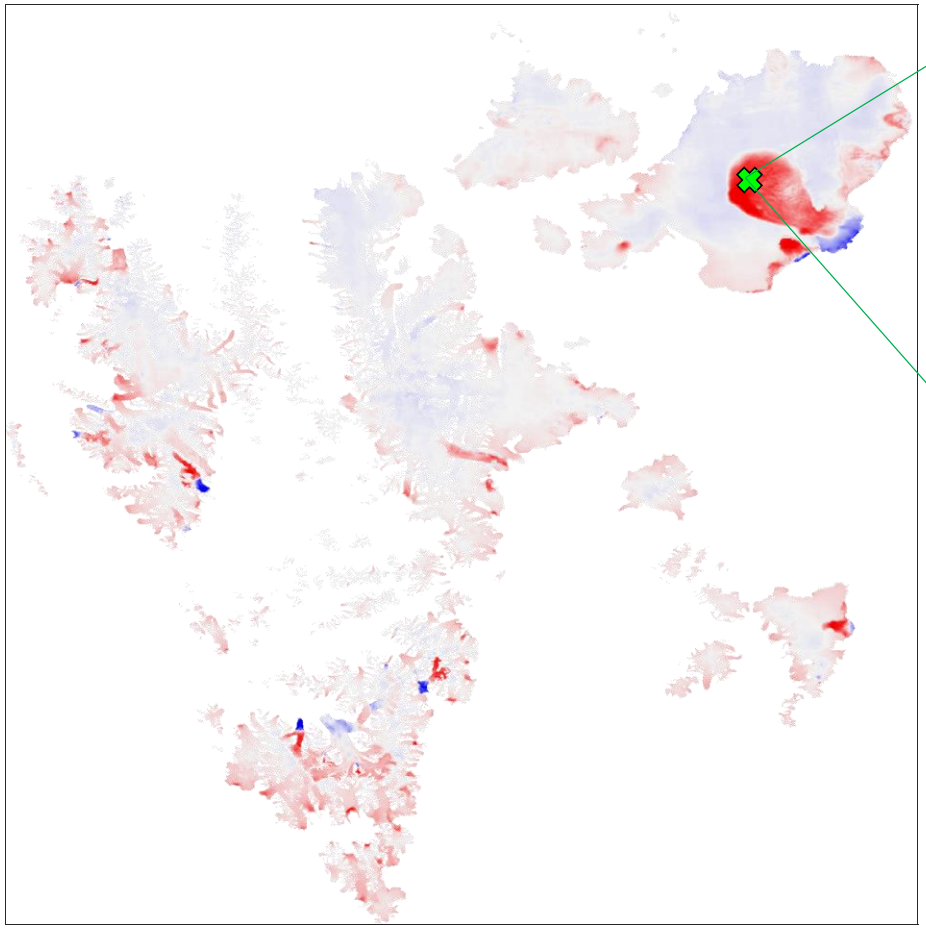
Osbornebreen

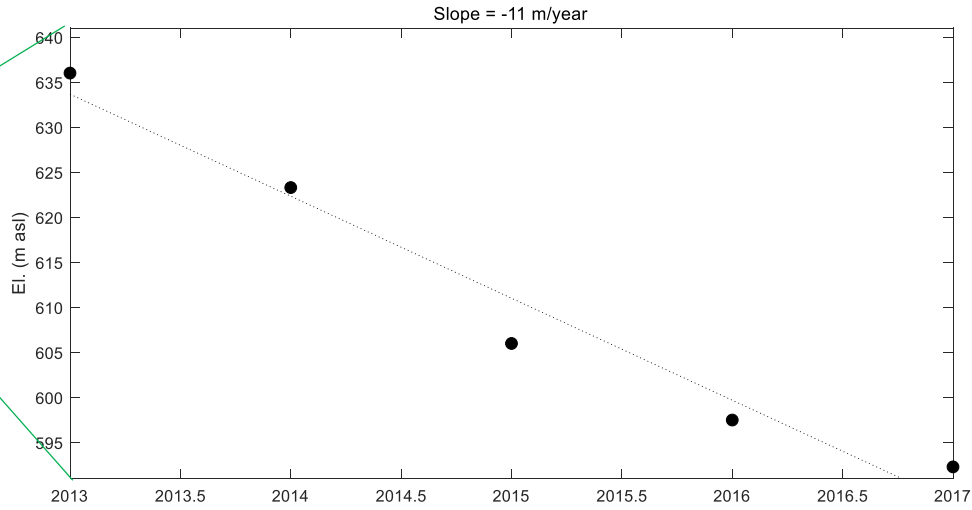


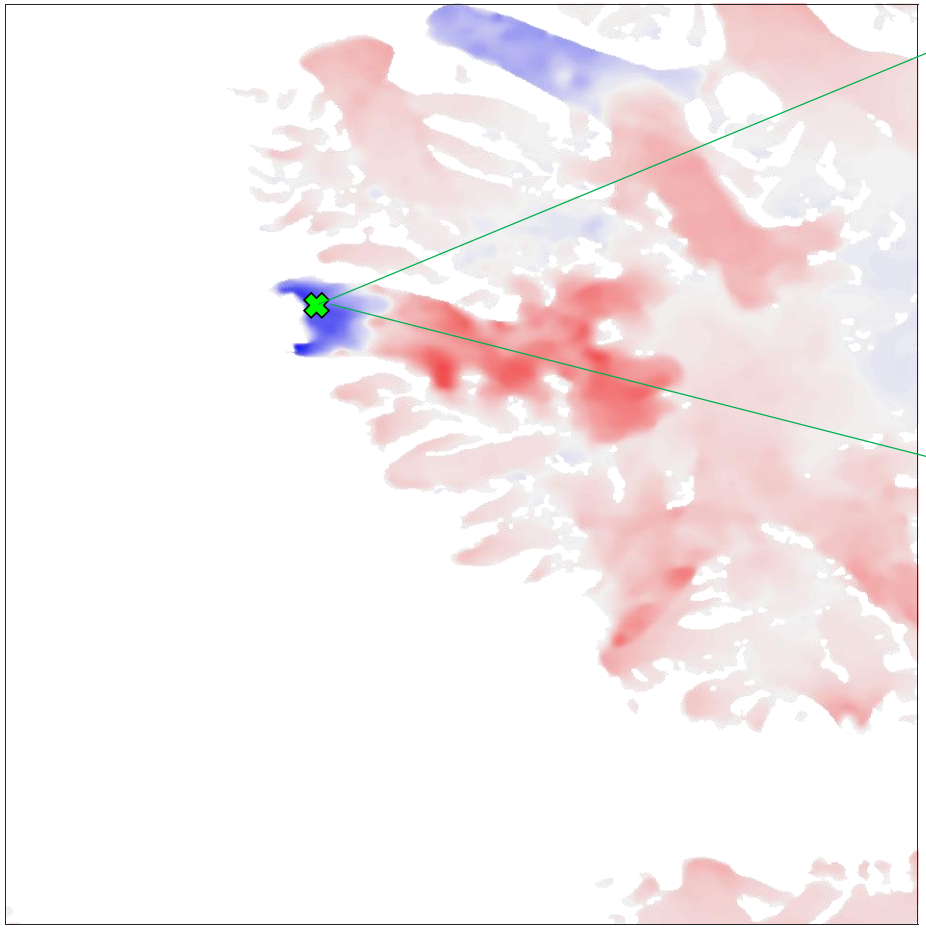
Monacobreen ...and Emmabreen

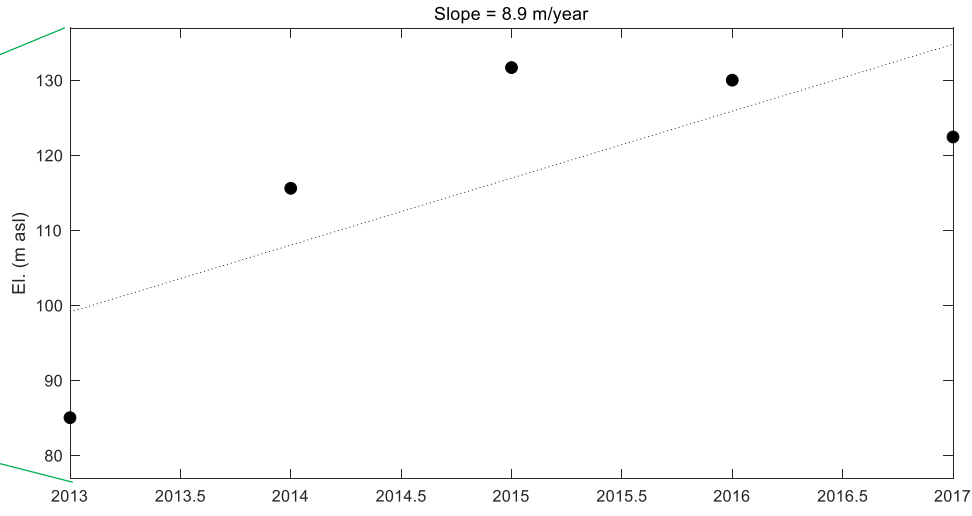


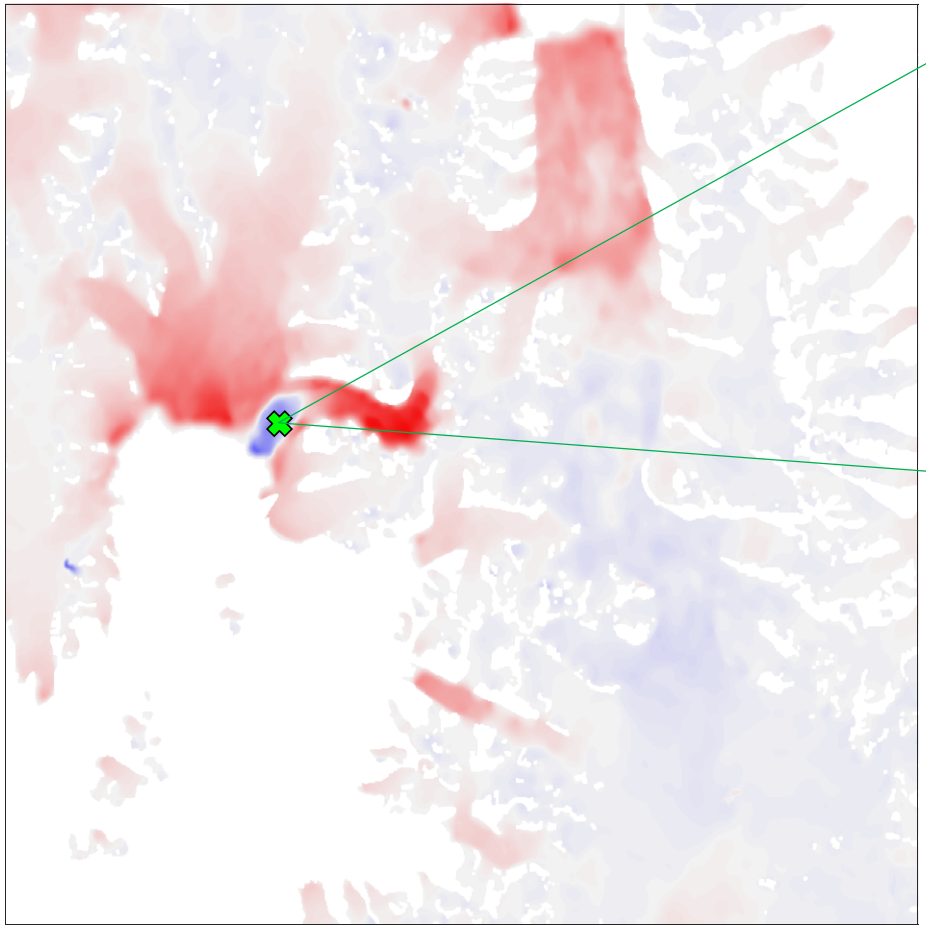

20
15
10
5
0
-5
-10
-15
-20
dz/dt (m/yr)

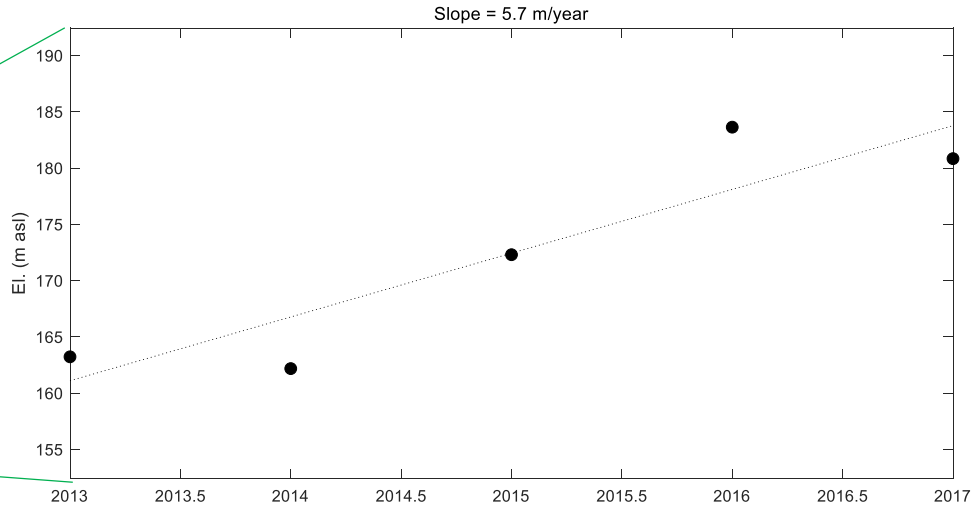


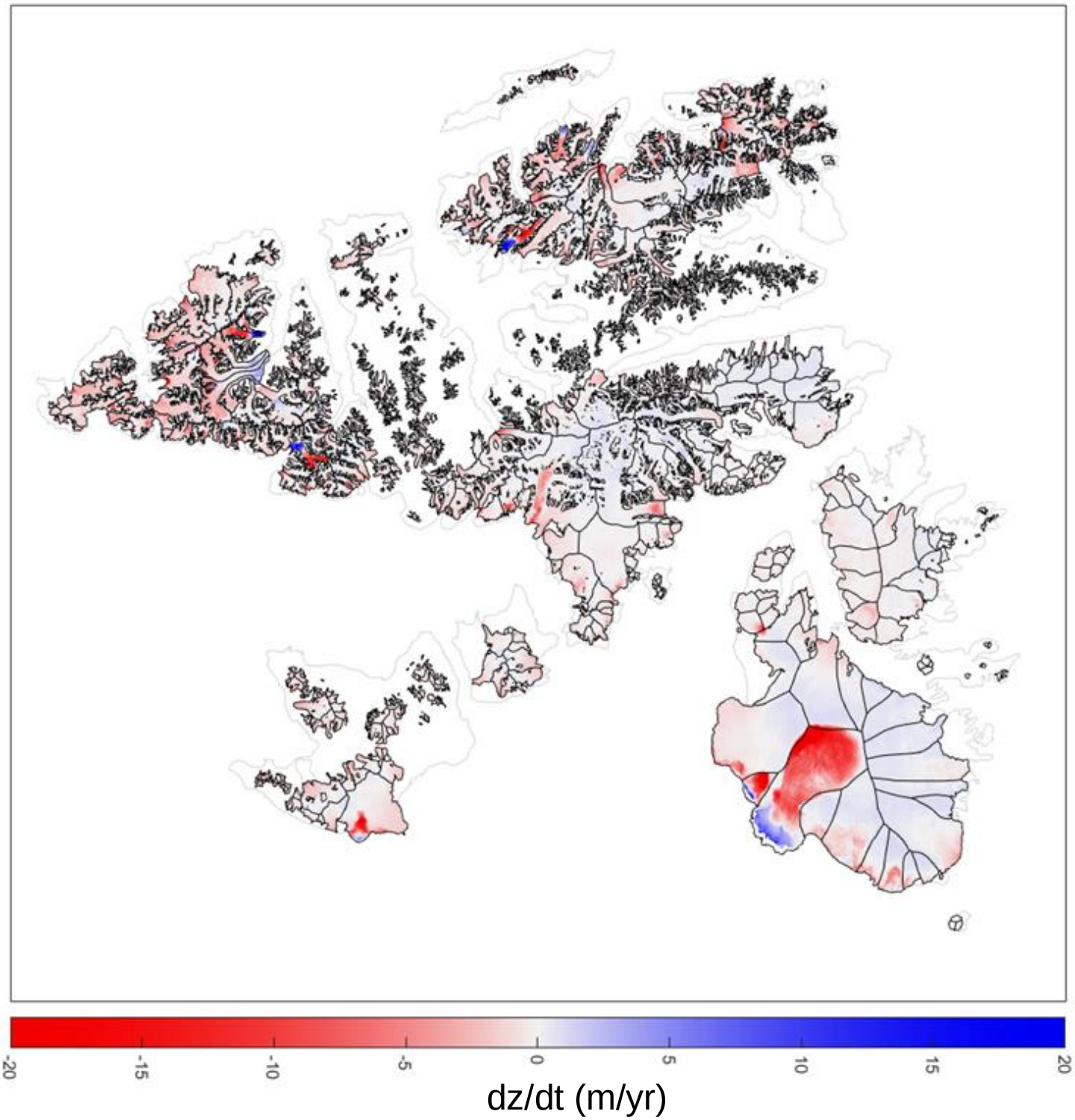

Slope = -11 m/year
El. (m asl)
640
635
630
625
620
615
610
605
600
595
2013
2013.5
2014
2014.5
2015
2015.5
2016
2016.5
2017

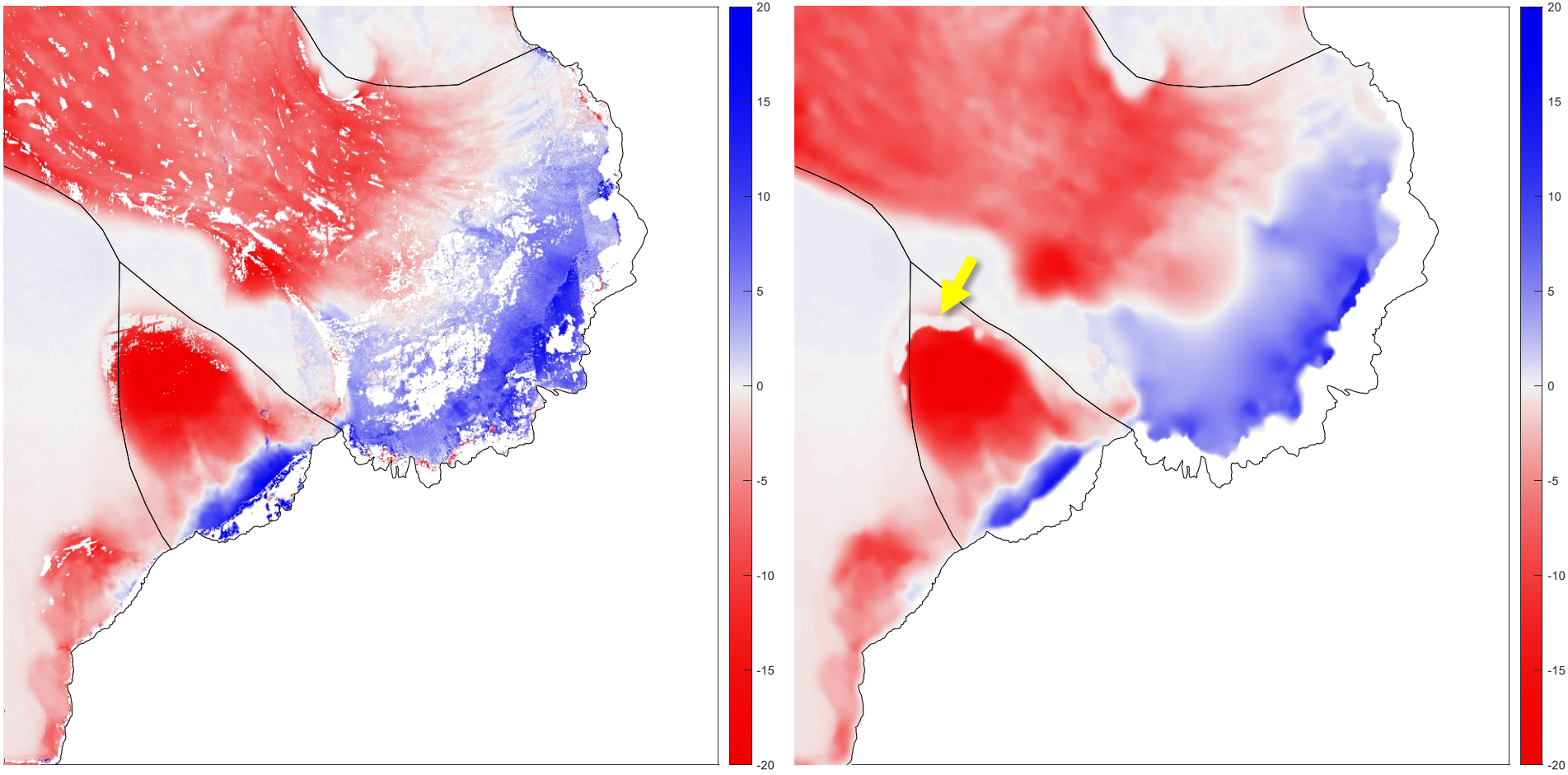


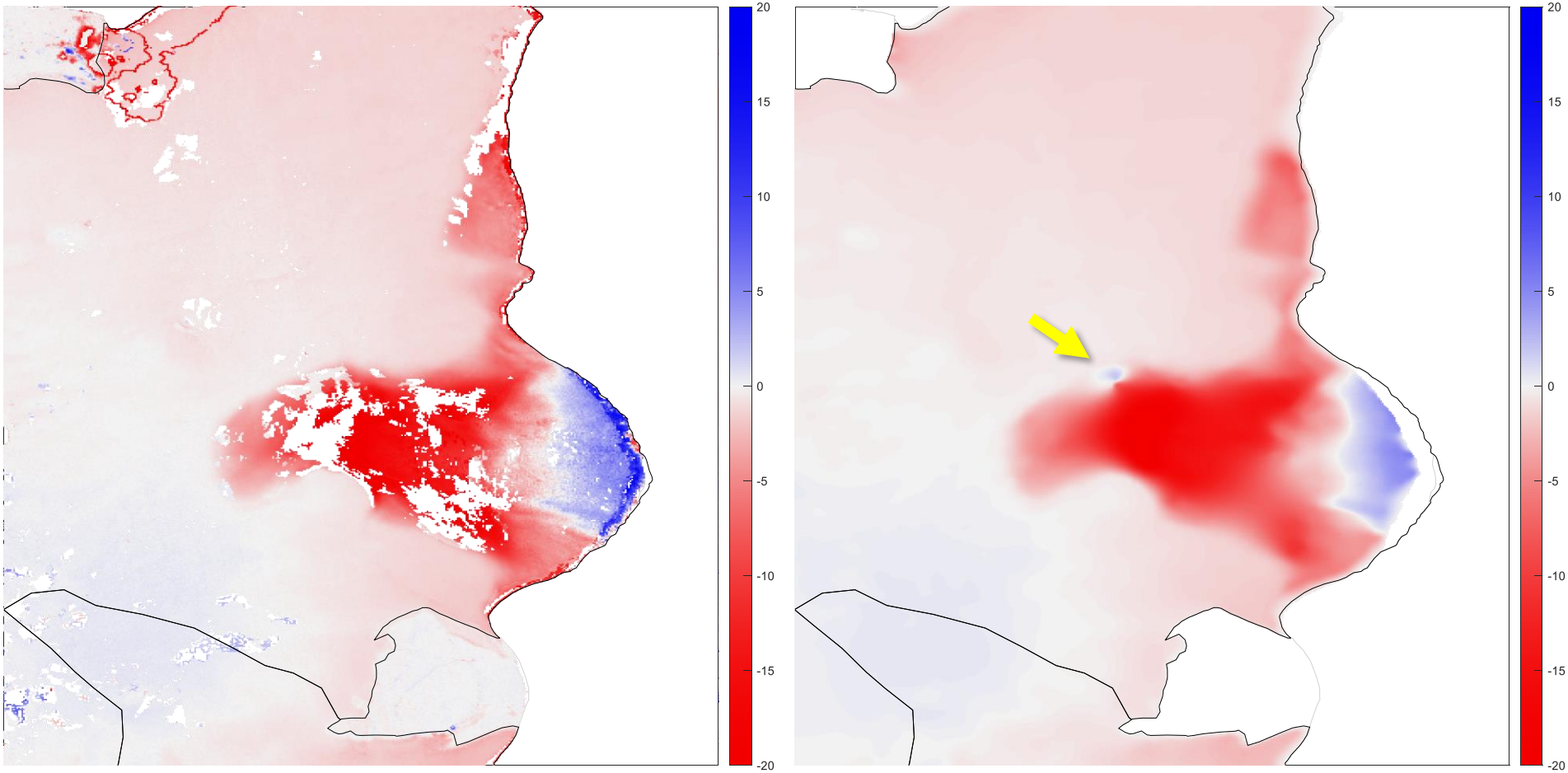

Slope = 8.9 m/year
El. (m asl)
130
120
110
100
90
80
2013
2013.5
2014
2014.5
2015
2015.5
2016
2016.5
2017

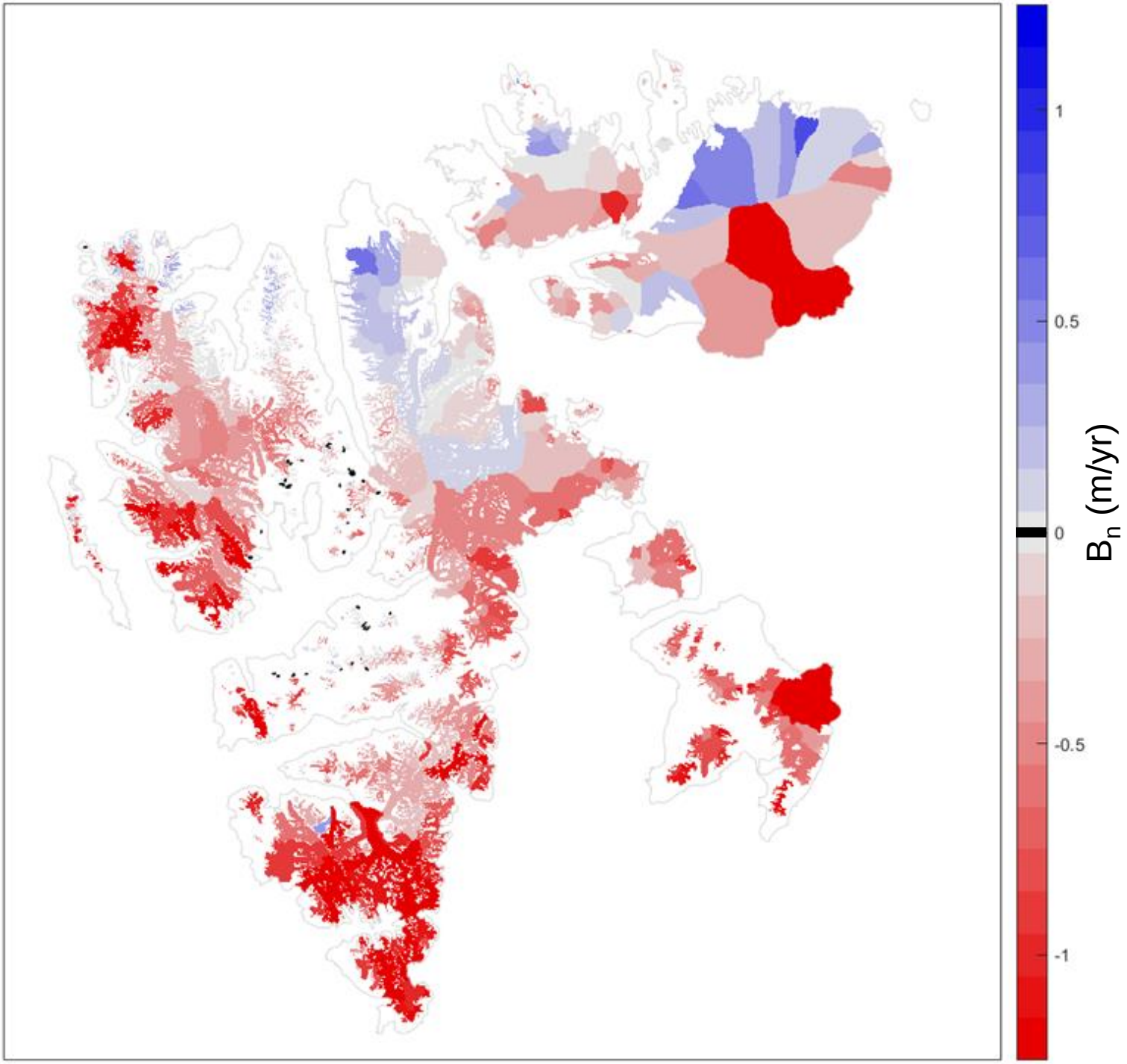


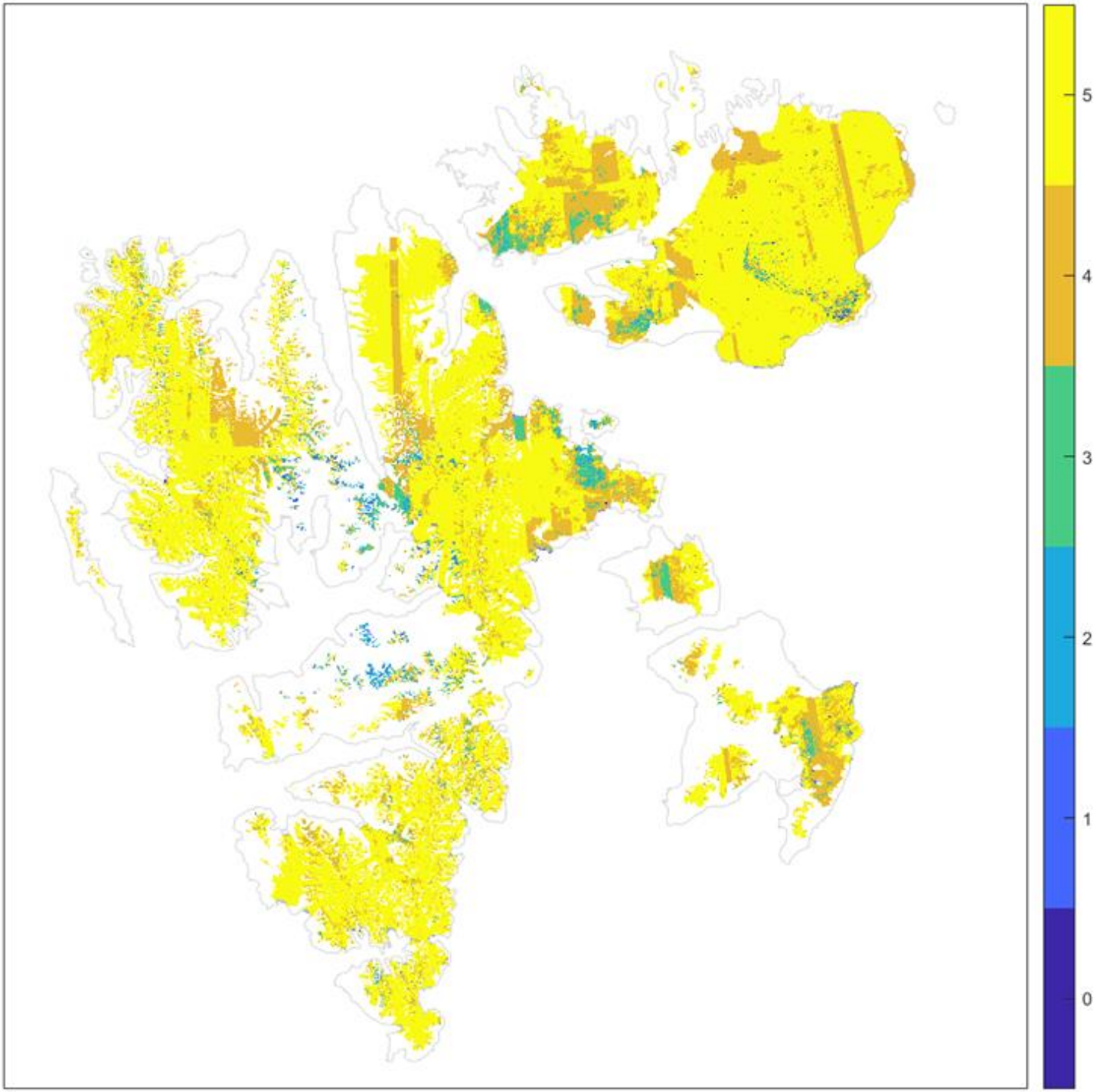

Slope = 5.7 m/year
El. (m asl)
190
185
180
175
170
165
160
155
2013
2013.5
2014
2014.5
2015
2015.5
2016
2016.5
2017

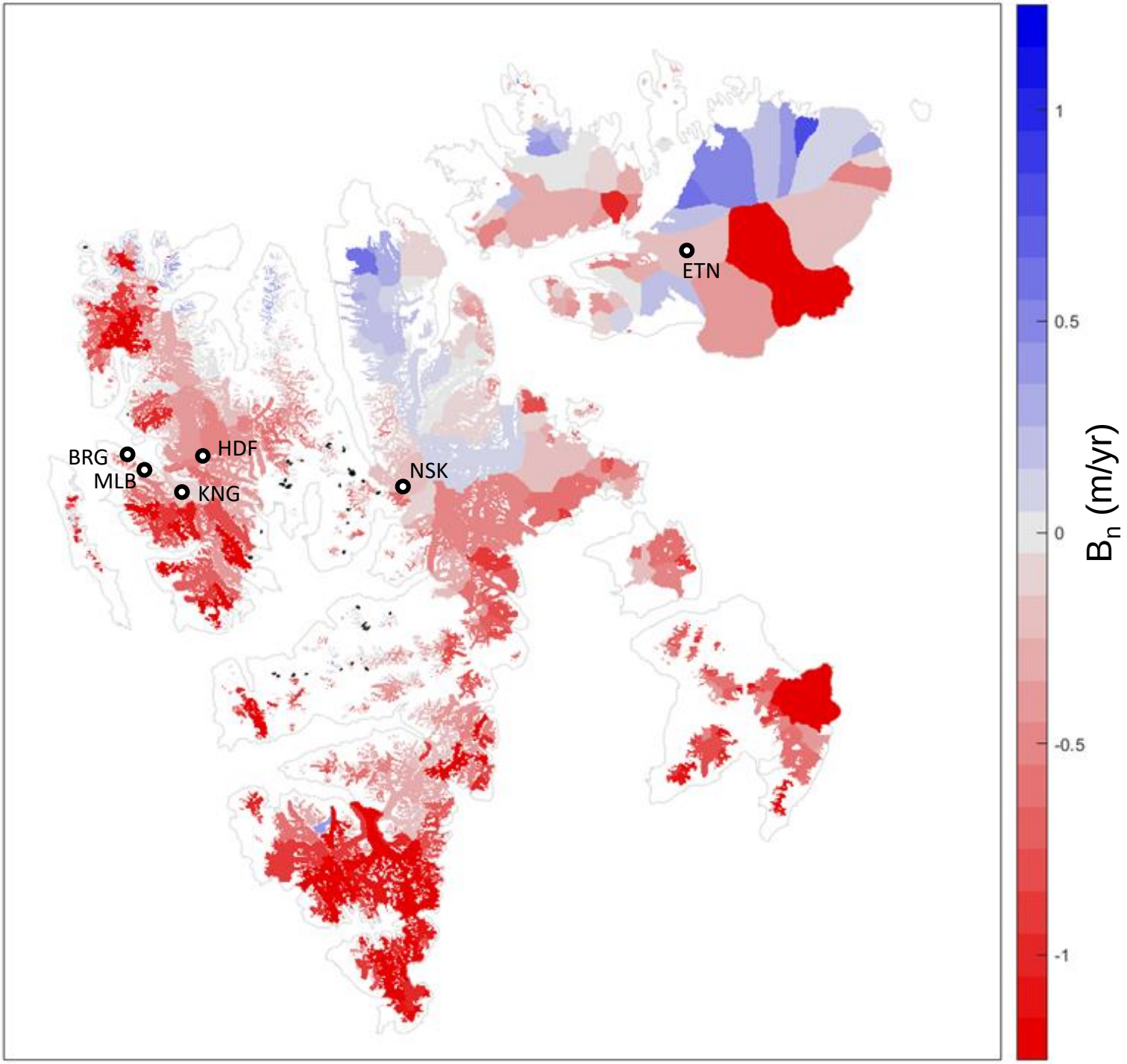

-20
-15
-10
-5
0
5
10
15
20
dz/dt (m/yr)

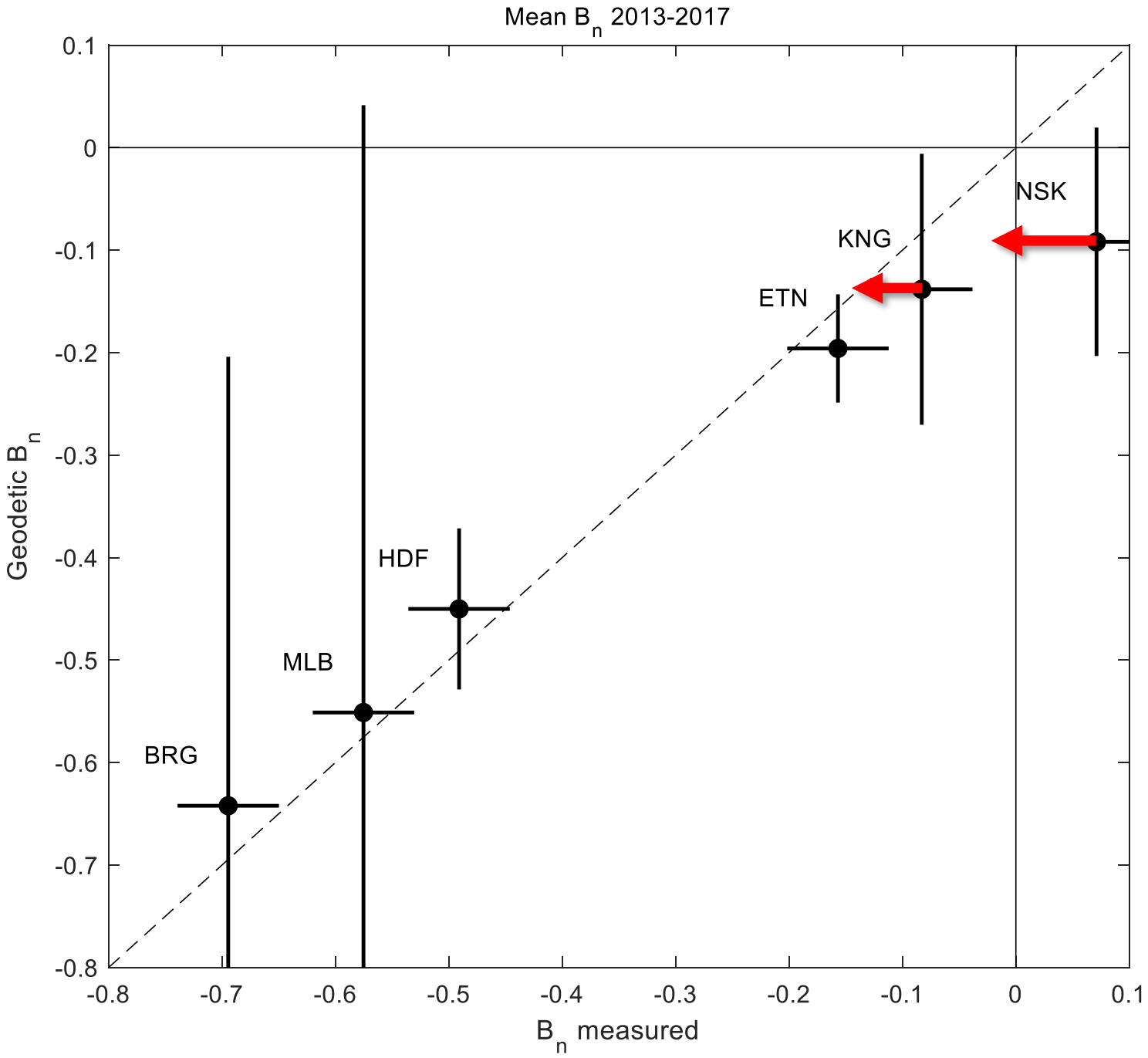

20
15
10
5
0
-5
-10
-15
-20
20
15
10
5
0
-5
-10
-15
-20


20
15
10
5
0
-5
-10
-15
-20
20
15
10
5
0
-5
-10
-15
-20

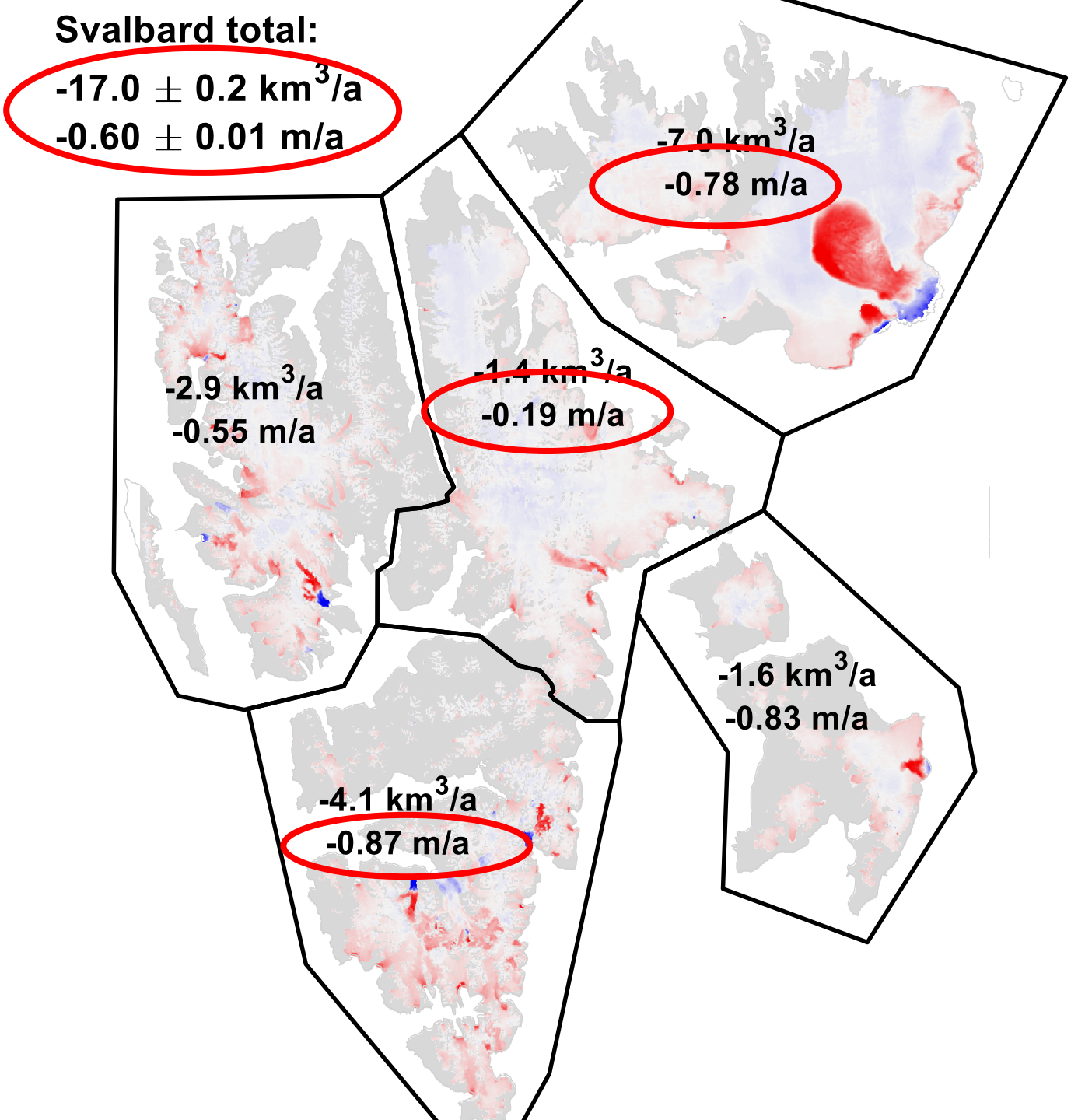

1
0.5
0
-0.5
-1
B_n (m/yr)


5
4
3
2
1
0

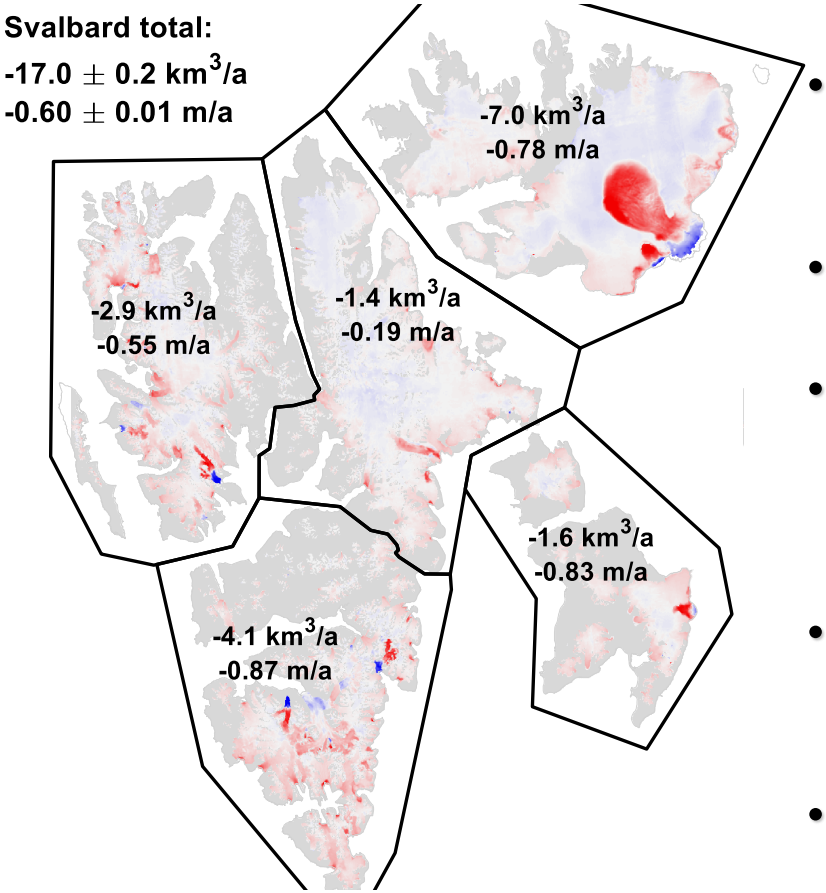

ETN
HDF
BRG
MLB
KNG
NSK
1
0.5
0
-0.5
-1
B_n (m/yr)


Mean B n 2013-2017
Geodetic B n
B n measured
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
-0.8
-0.8
-0.7
-0.6
-0.5
-0.4
-0.3
-0.2
-0.1
0
0.1
BRG
MLB
HDF
ETN
KNG
NSK

And so, finally...


Svalbard total:
-17.0 ± 0.2 km3/a
-0.60 ± 0.01 m/a
-7.0 km3/a
-0.78 m/a
-2.9 km3/a
-0.55 m/a
-1.4 km3/a
-0.19 m/a
-1.6 km3/a
-0.83 m/a
-4.1 km3/a
-0.87 m/a

Conclusions



- **Arctic DEM products not 100% perfect, but pretty dang good!**
- **Arctic DEM products well-suited for deriving dz/dt**
- **DEMs available only to 2017, so far**
- **Total Svalbard mass loss for 2013-2017 = 17 km³/yr, specific mass balance = 60 cm/yr**
- **Consistent with recent Cryosat-2 results (Morris et al, in review)**
- **S. Spitsbergen most negative, 87 cm/yr**
- **Austfonna mass loss comparable, 78 cm/yr, almost entirely due to surging along SE coast.**
- **NE Spitsbergen least negative**