NATIONAL CENTRAL UNIVERSITY
Graduate Institute of Applied Geology

Landform Behaviors in Kaffiøyra Under Climate Change Conditions Using Remote Sensing and GIS Approach

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Introduction

Climate change: long-term change in average weather patterns

Key indicators

Temperature increases;

Rising sea levels;

Ice loss at poles & in mountain glaciers;

Frequency & severity changes in extreme weather: hurricanes, heatwaves, wildfires, droughts, floods, precipitation;

Cloud & vegetation cover changes.

https://www.pinterest.com/pin/17944098493519189/

Introduction

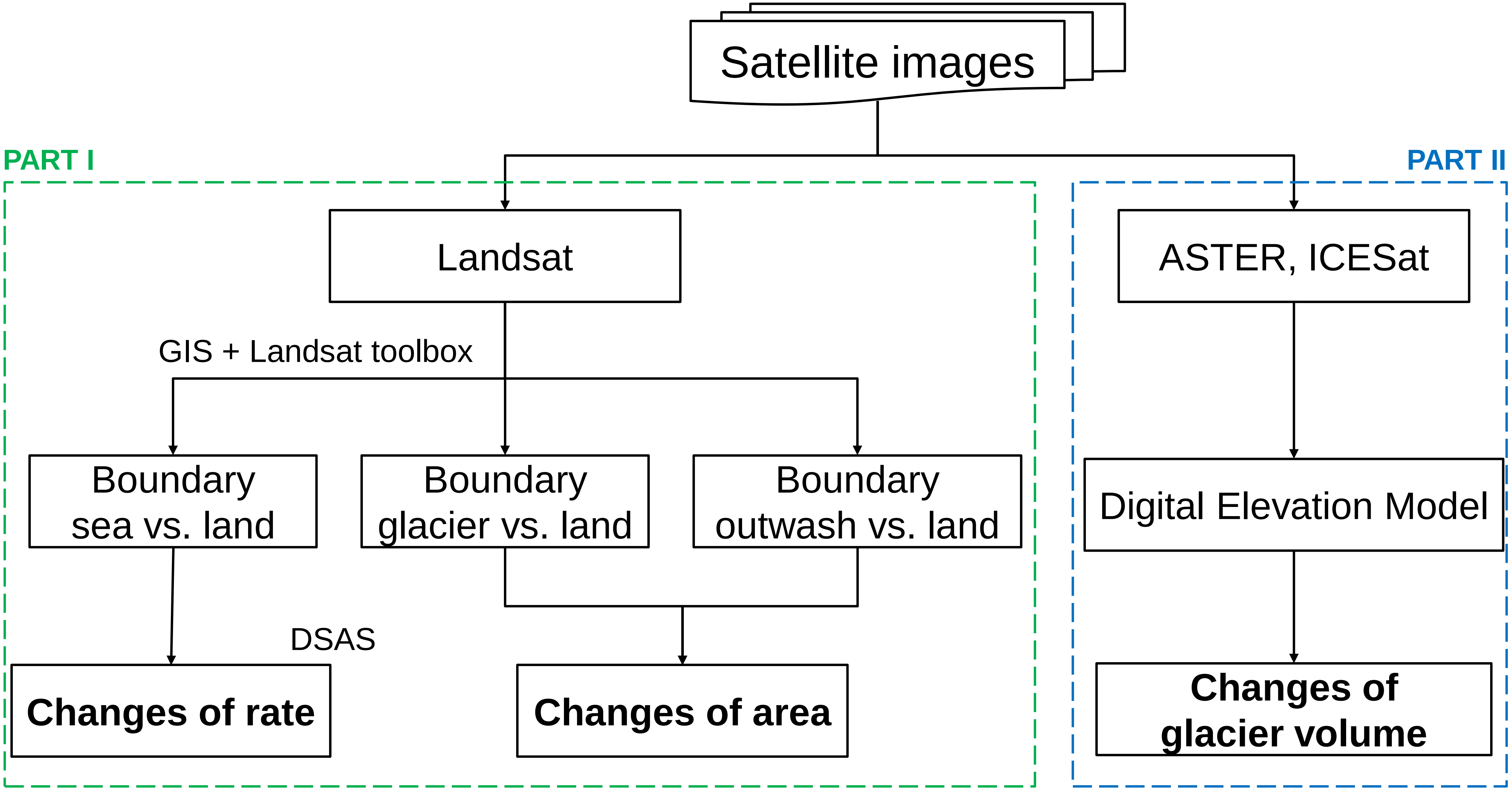
Objectives

- Quantifying the shoreline change rates from 1985 – 2023 by Landsat images
- Determining the changes of glacier and outwash area
- Estimating the glacier volume changes

Understanding the behaviors of Svalbard’s landform under climate change condition for almost 40 years

PART I

Shoreline, Glacier, Outwash Changes


Satellite images
PART I
PART II
Landsat
ASTER, ICESat
GIS + Landsat toolbox
Boundary
sea vs. land
Boundary
glacier vs. land
Boundary
outwash vs. land
Digital Elevation Model
DSAS
Changes of rate
Changes of area
Changes of
glacier volume

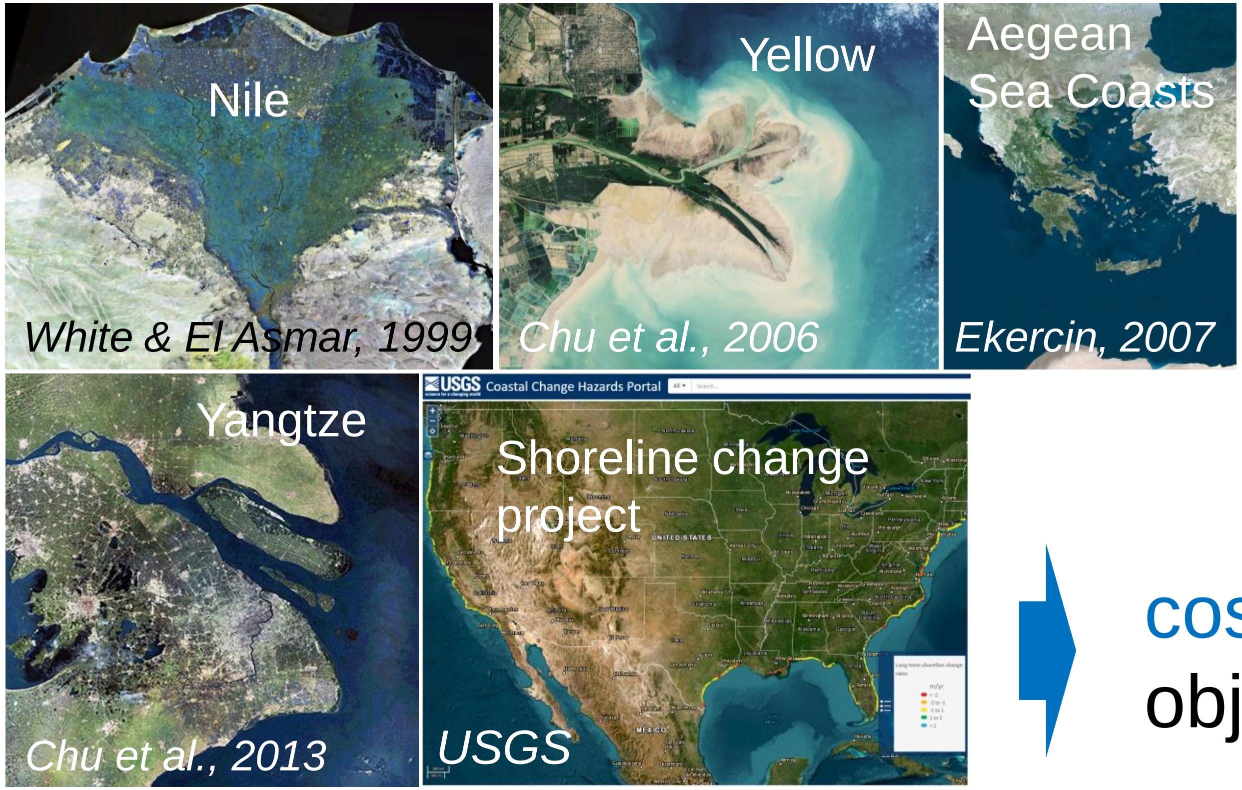
Methods

Monitoring long-term shoreline changes => Big problem

Integrating remote sensing + GIS technique

Landsat images

Digital Shoreline Analysis System (DSAS)



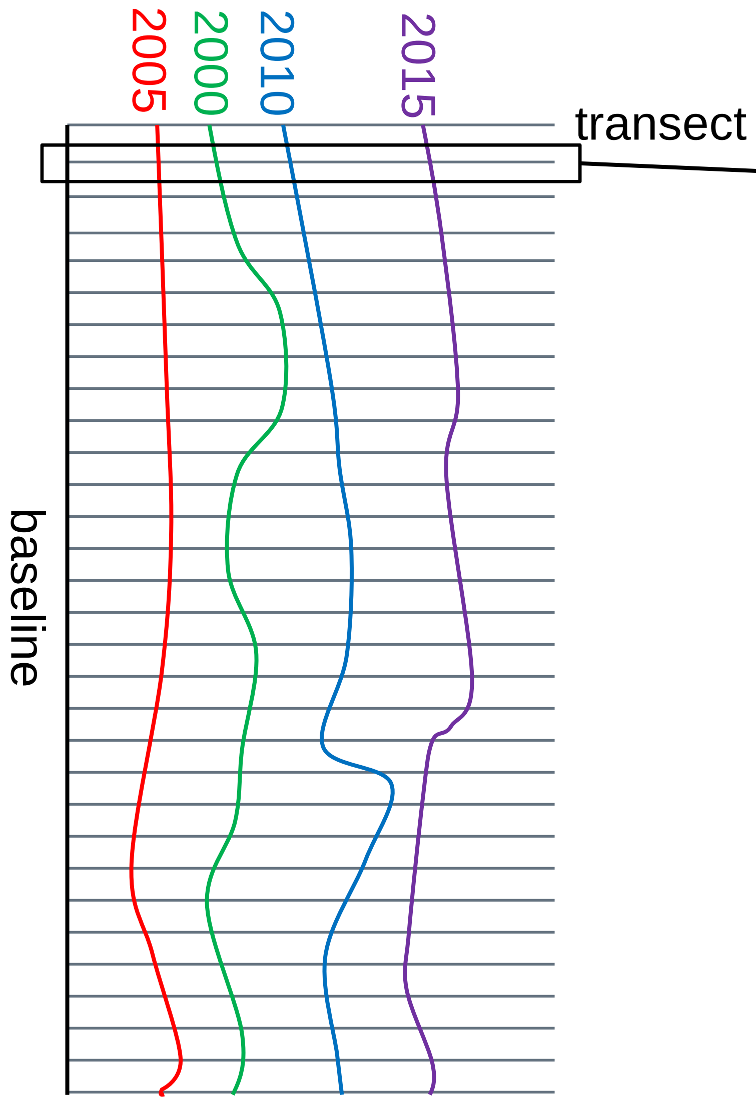
DSAS DIGITAL SHORELINE ANALYSIS SYSTEM

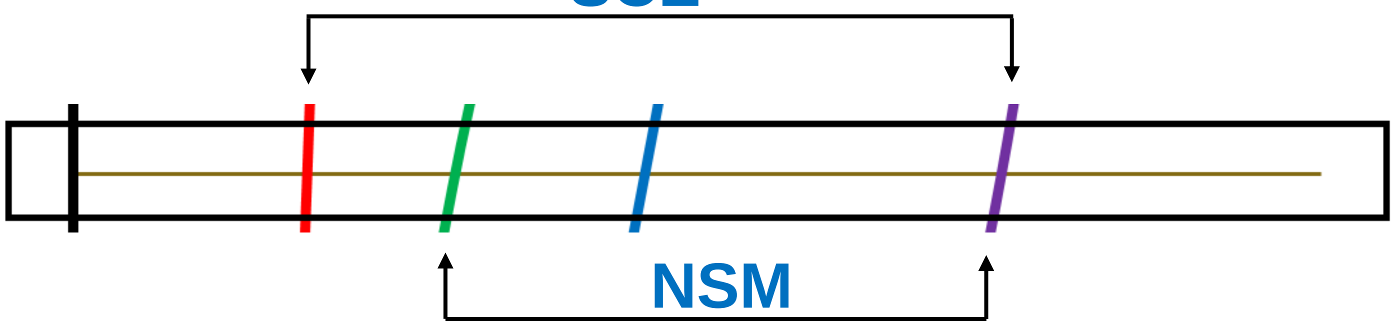
- Freely software work with ArcGIS
- Computing the rate-of-change statistics for a time series of shoreline (Himmelstoss et al., 2021)

cost-efficient tool for monitor long-term objects change

Methods

DSAS concept





EPR = NSM/time

NSM: net shoreline movement (m)
SCE: shoreline change envelope (m)
EPR: end point rate (m/yr)
LRR: linear regression rate (m/yr)

LRR: rate-of-change statistic by fitting a least square regression to all shorelines at each transect

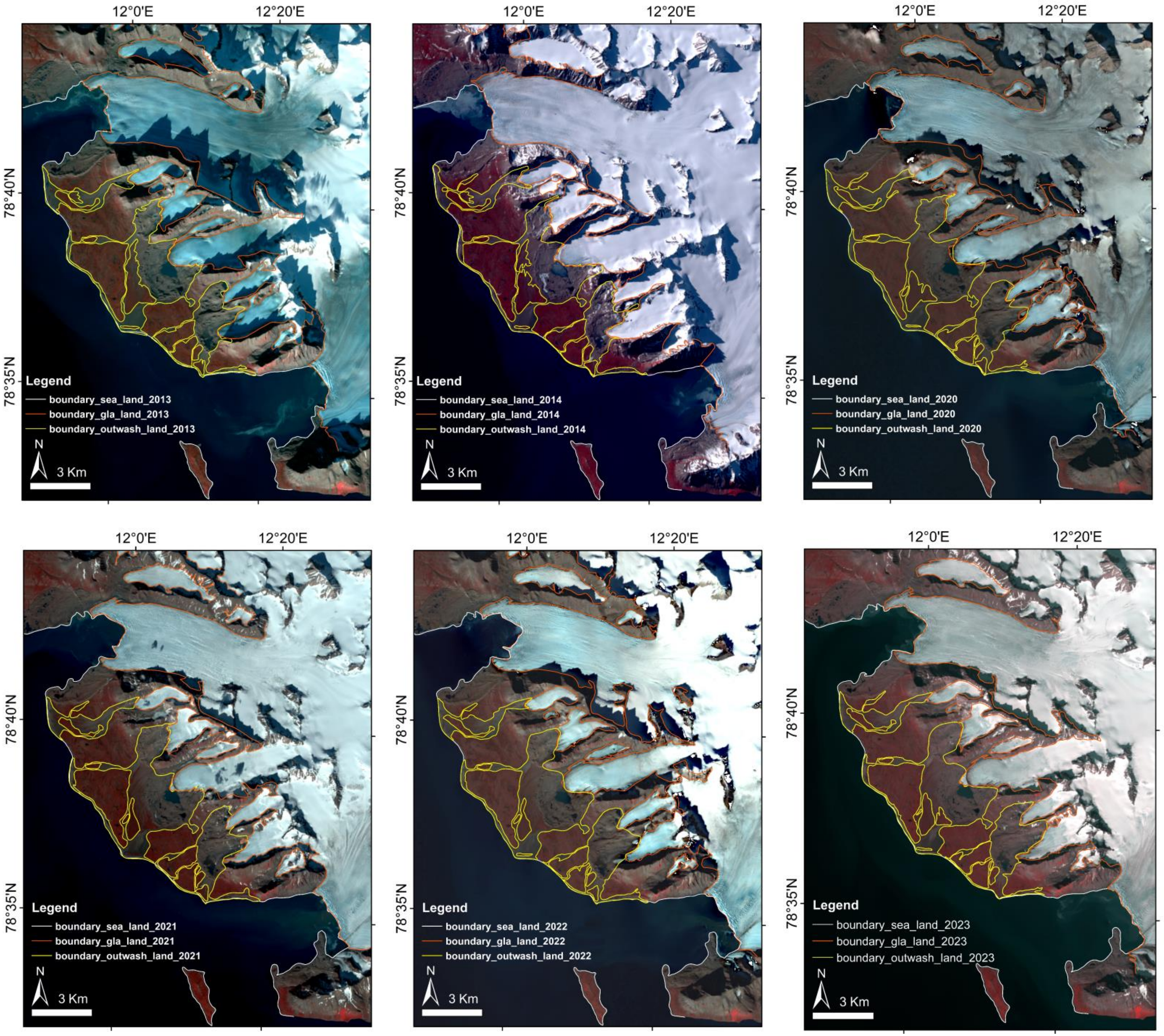
Transects **cast perpendicular** from reference **baseline** to **shorelines**

Landsat images collected

No.	Sensor	Frame	Acquisition date	Spatial resolution (m)	No.	Sensors	Frame	Acquisition date	Spatial resolution (m)
1	Landsat 4-5 TM	216/004	1985/08/30	30	21	Landsat 7 ETM+	220/003	2005/07/24	scan line error
2	Landsat 4-5 TM	217/004	1986/07/07	30	22	Landsat 4-5 TM	216/004	2006/07/23	30
3	Landsat 4-5 TM	217/004	1987/07/10	30	23	-			
4	Landsat 4-5 TM	216/004	1988/09/23	30	24	-			
5	Landsat 4-5 TM	217/004	1989/07/31	30	25	-			
6	Landsat 4-5 TM	221/003	1990/06/28	30	26	Landsat 7 ETM+	219/003	2010/07/31	scan line error
7	-				27	Landsat 7 ETM+	220/003	2011/07/25	scan line error
8	Landsat 4-5 TM	221/003	1992/07/03	30	28	-			
9	Landsat 4-5 TM	220/003	1993/07/15	30	29	Landsat 8 OLI/TIRS	217/004	2013/09/19	30
10	Landsat 4-5 TM	219/003	1994/08/28	30	30	Landsat 8 OLI/TIRS	029/240	2014/07/15	30
11	Landsat 4-5 TM	215/004	1995/08/19	30	31	Landsat 8 OLI/TIRS	216/004	2015/08/01	30
12	-				32	Landsat 8 OLI/TIRS	216/004	2016/07/02	30
13	-				33	Landsat 8 OLI/TIRS	220/003	2017/08/20	30
14	-				34	Landsat 8 OLI/TIRS	025/241	2018/07/30	30
15	Landsat 7 ETM+	218/003	1999/07/10	30	35	Landsat 8 OLI/TIRS	215/004	2019/08/21	30
16	Landsat 7 ETM+	214/004	2000/08/17	30	36	Landsat 8 OLI/TIRS	215/004	2020/08/23	30
17	Landsat 7 ETM+	214/004	2001/06/17	30	37	Landsat 8 OLI/TIRS	216/004	2021/08/10	30
18	Landsat 7 ETM+	221/003	2002/07/07	30	38	Landsat 8 OLI/TIRS	221/003	2022/08/23	30
19	-				39	Landsat 8 OLI/TIRS	218/003	2023/07/20	30
20	-								

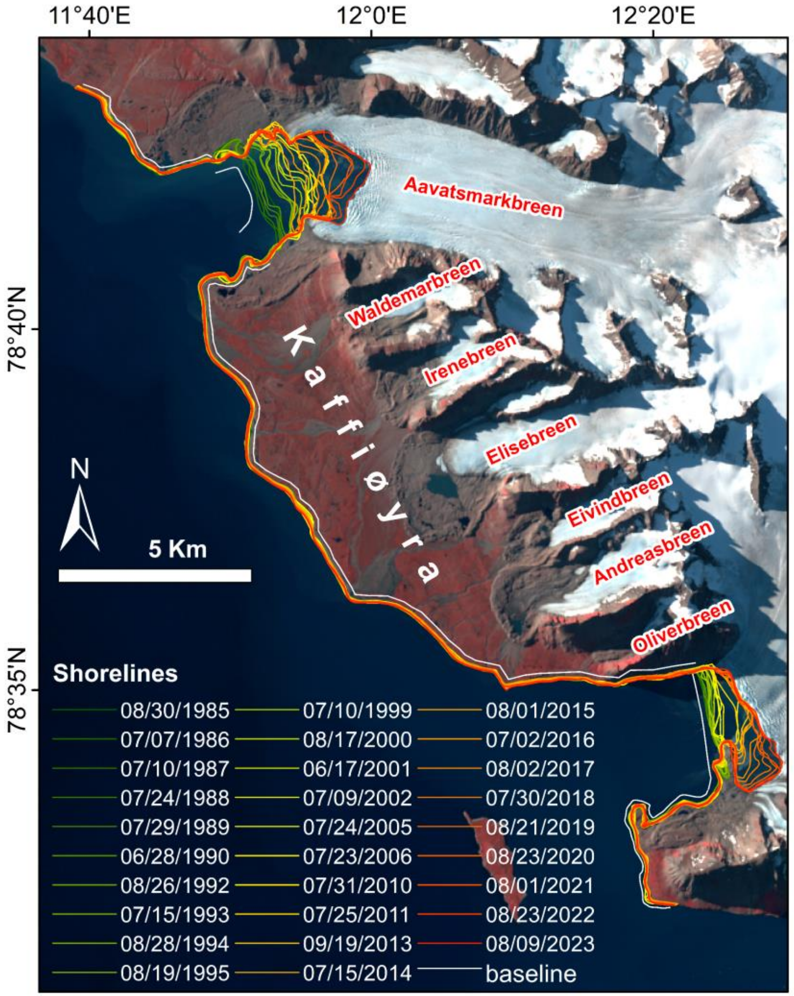
Jun., Jul., Aug., Sept. : **summer time**

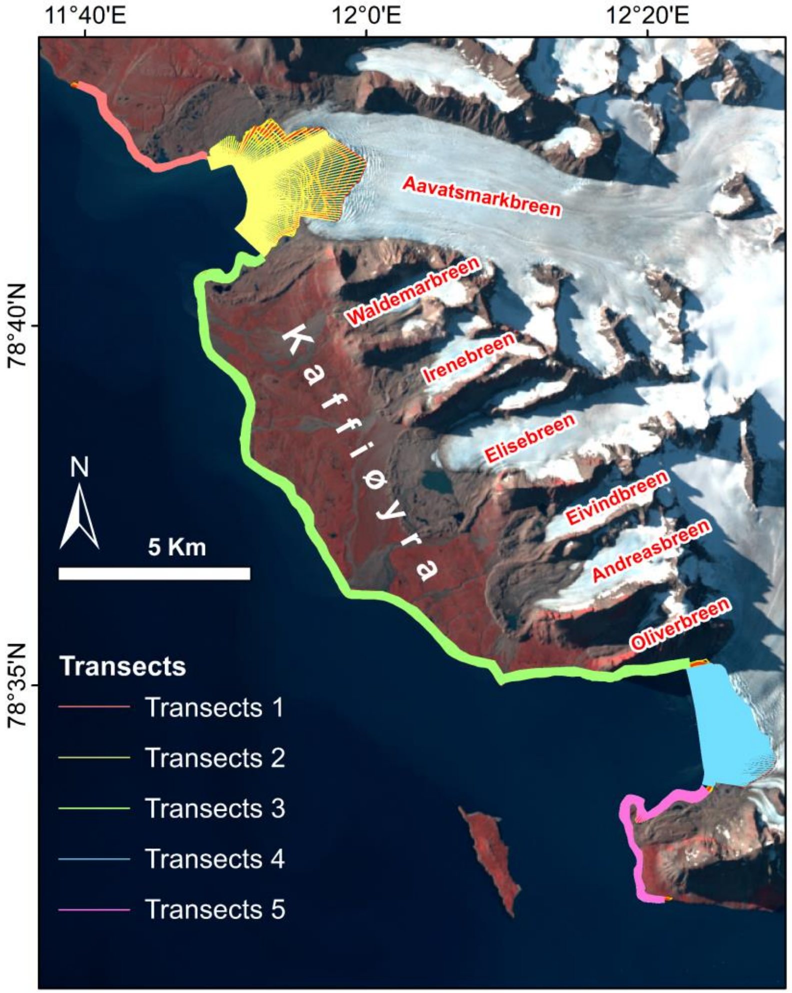
Shoreline, glacier, outwash extraction

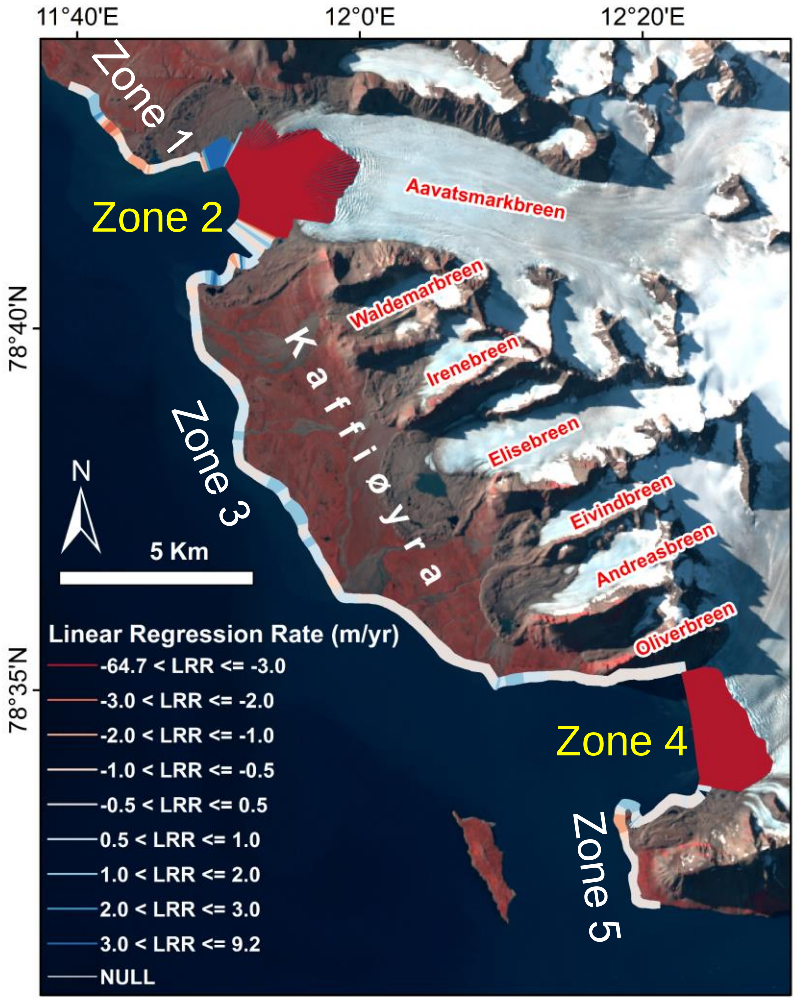


Results

① ② ③







Shorelines & baselines

Create transects

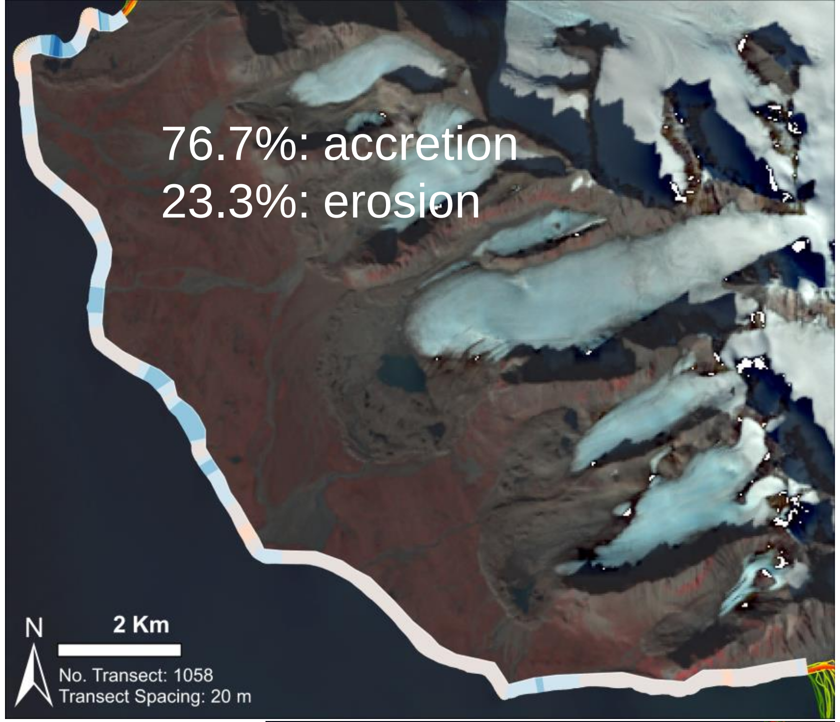
Calculate LRR

Results

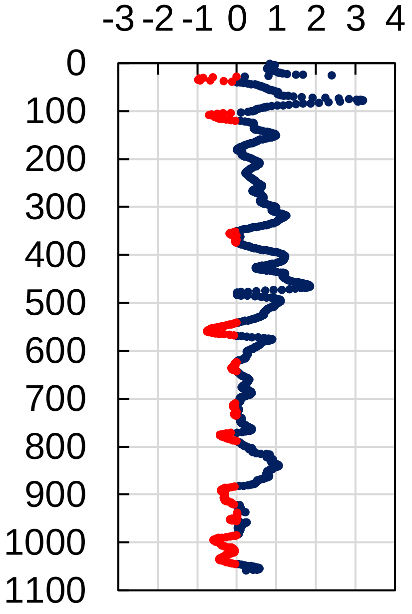
Zone 1, 3, 5: relatively stable shoreline

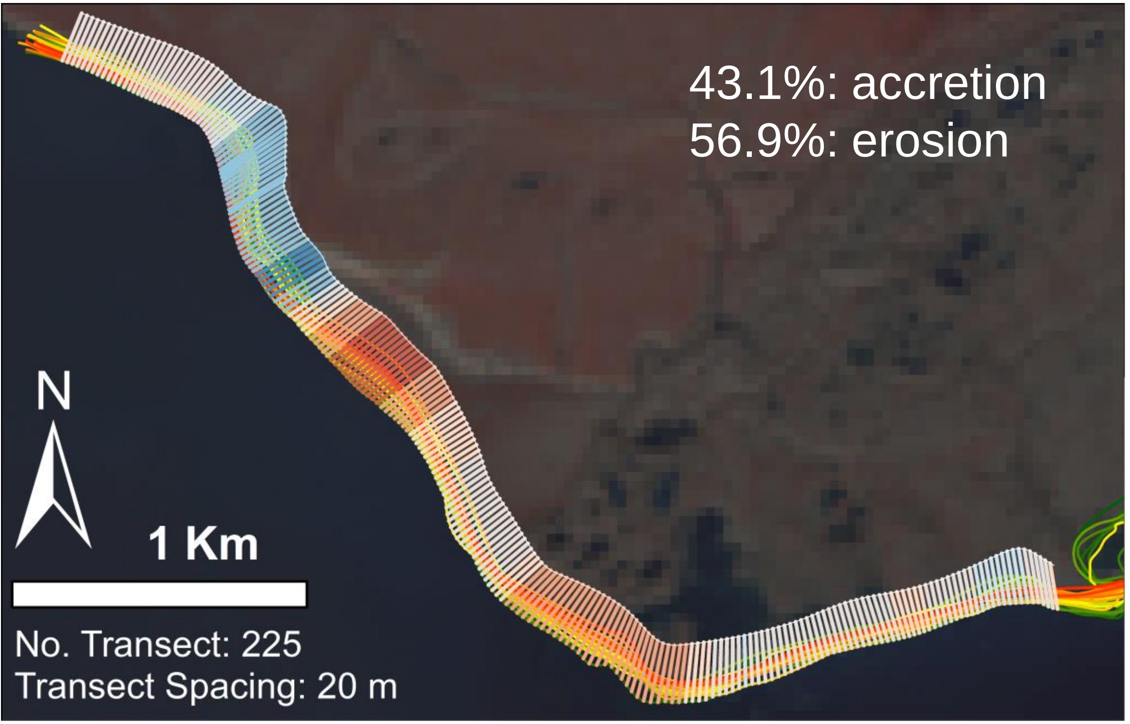
Rate vary: -2 to +3 m/yr

Accretion predominate

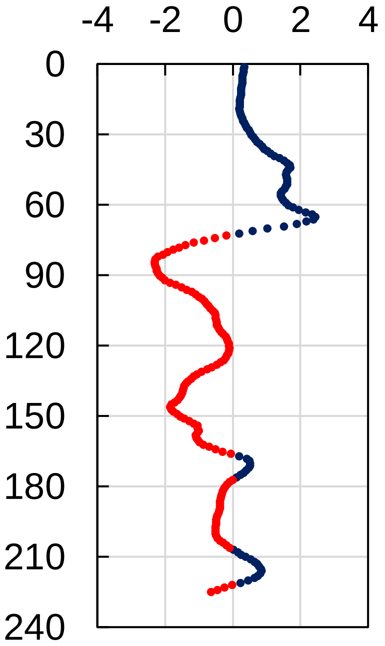


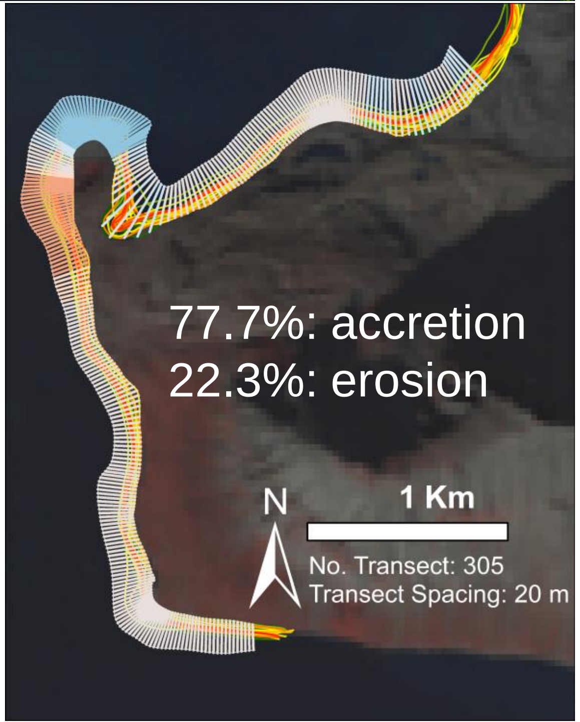
LRR 3



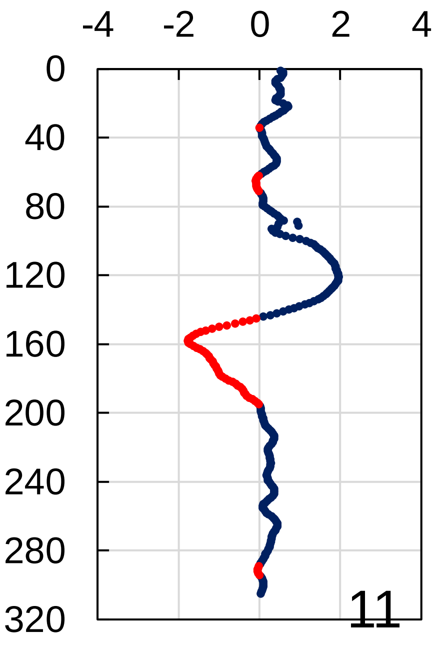


LRR 1





LRR 5

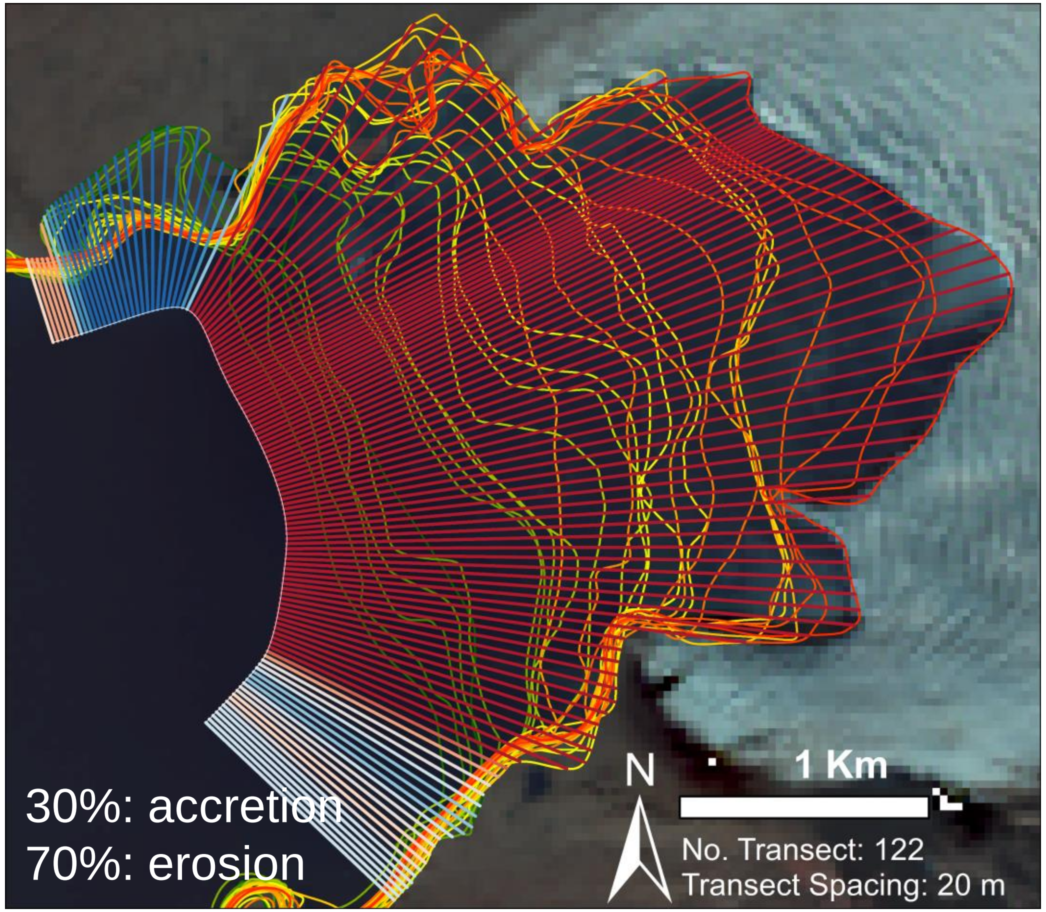


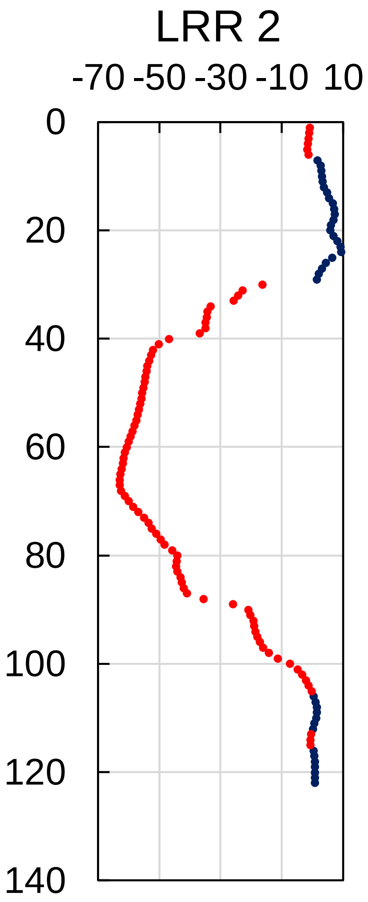
Results

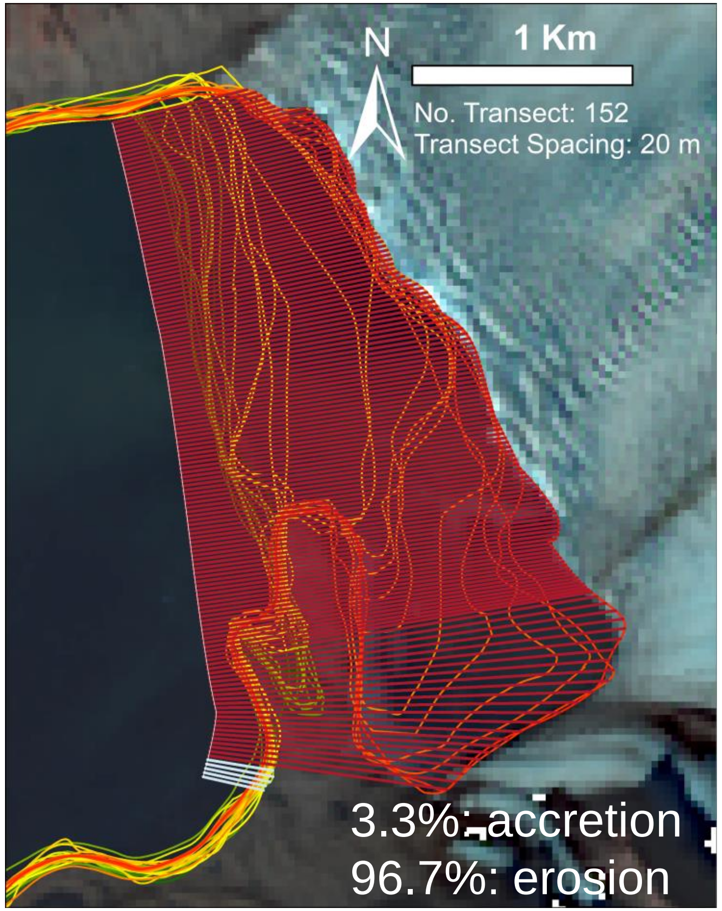
Zone 2, 4: extremely change shoreline

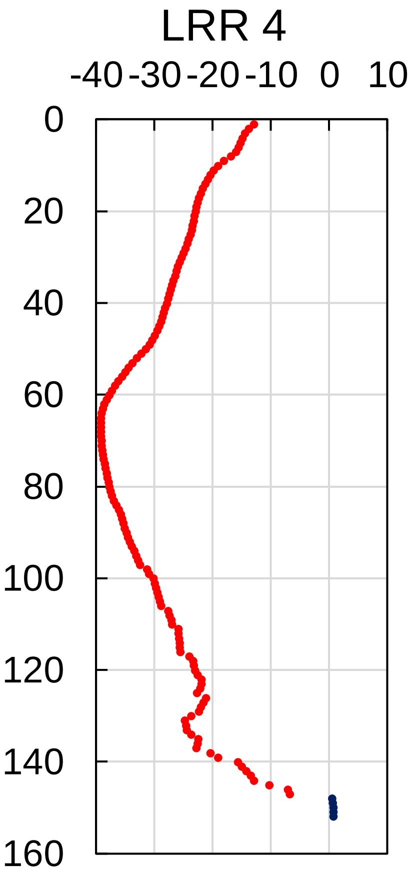
Rate vary: -64.7 to +10 m/yr

Erosion predominate



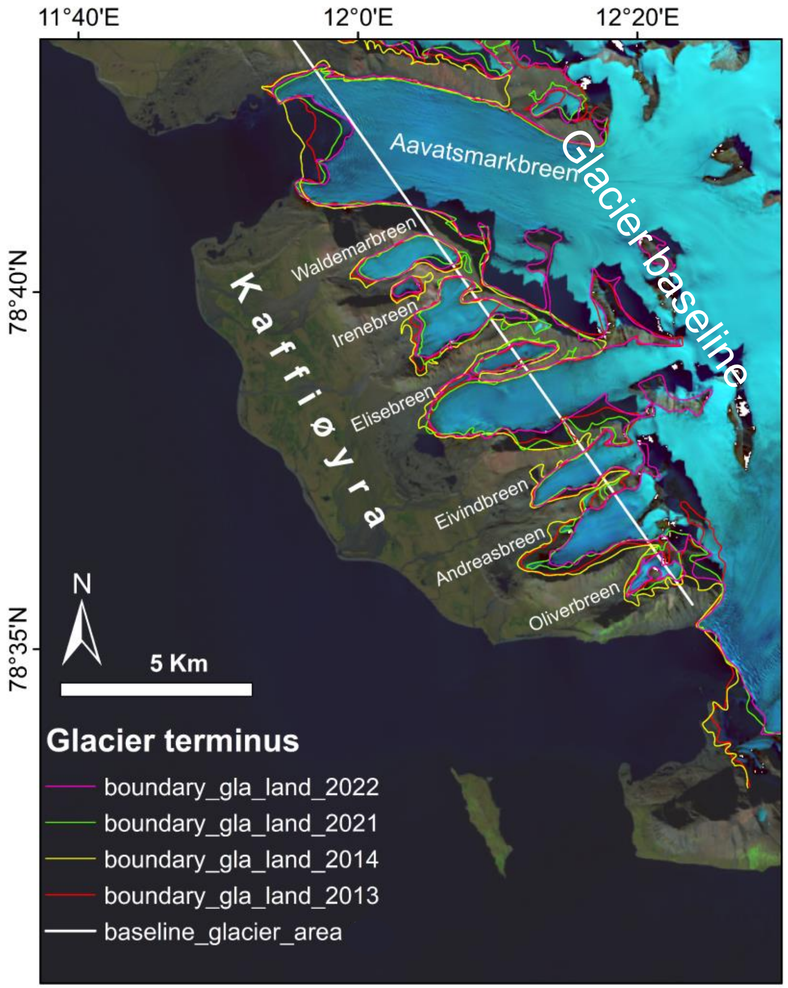


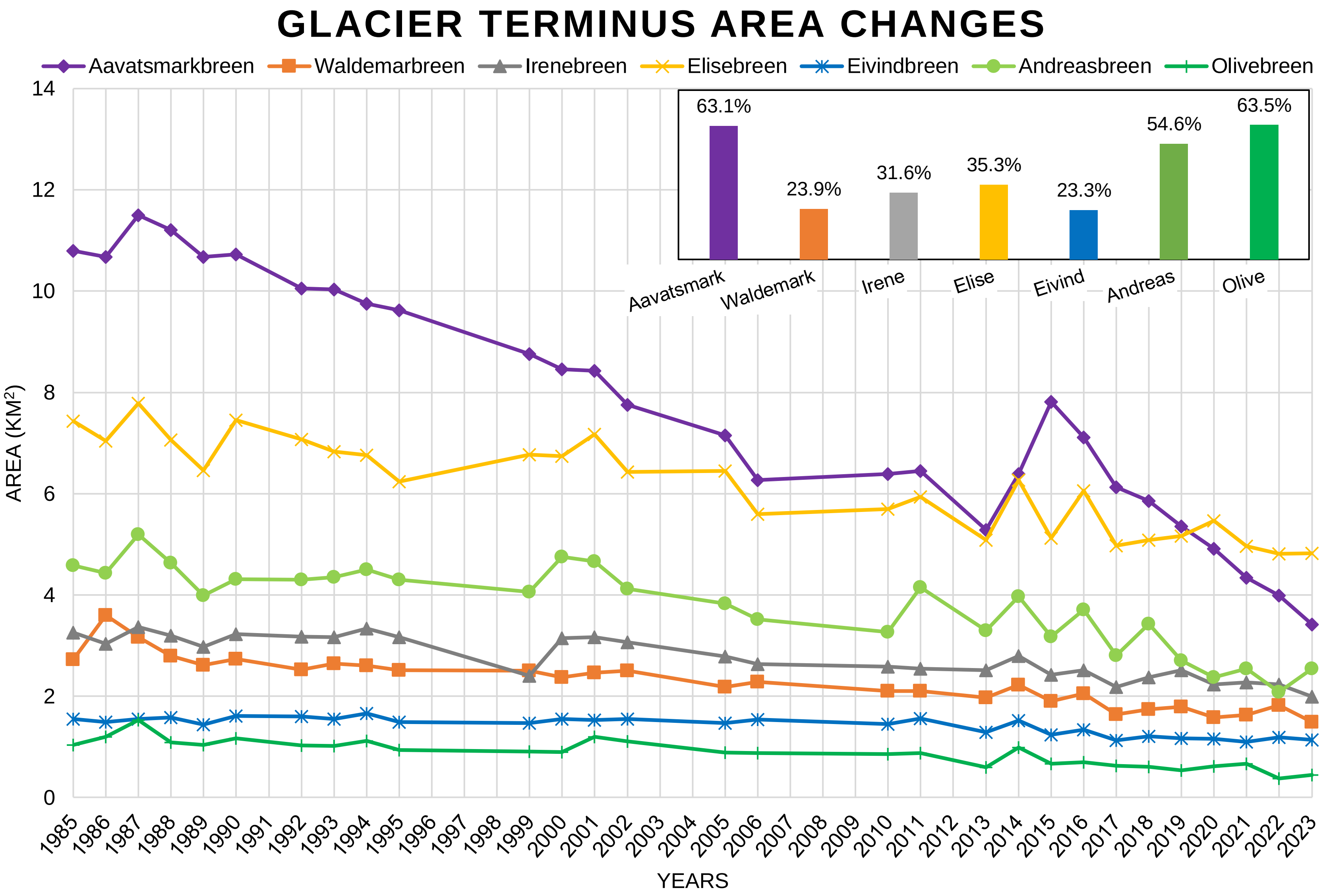




The land's shoreline is relatively stable, glacier's shoreline (terminus) is strongly eroded

Results

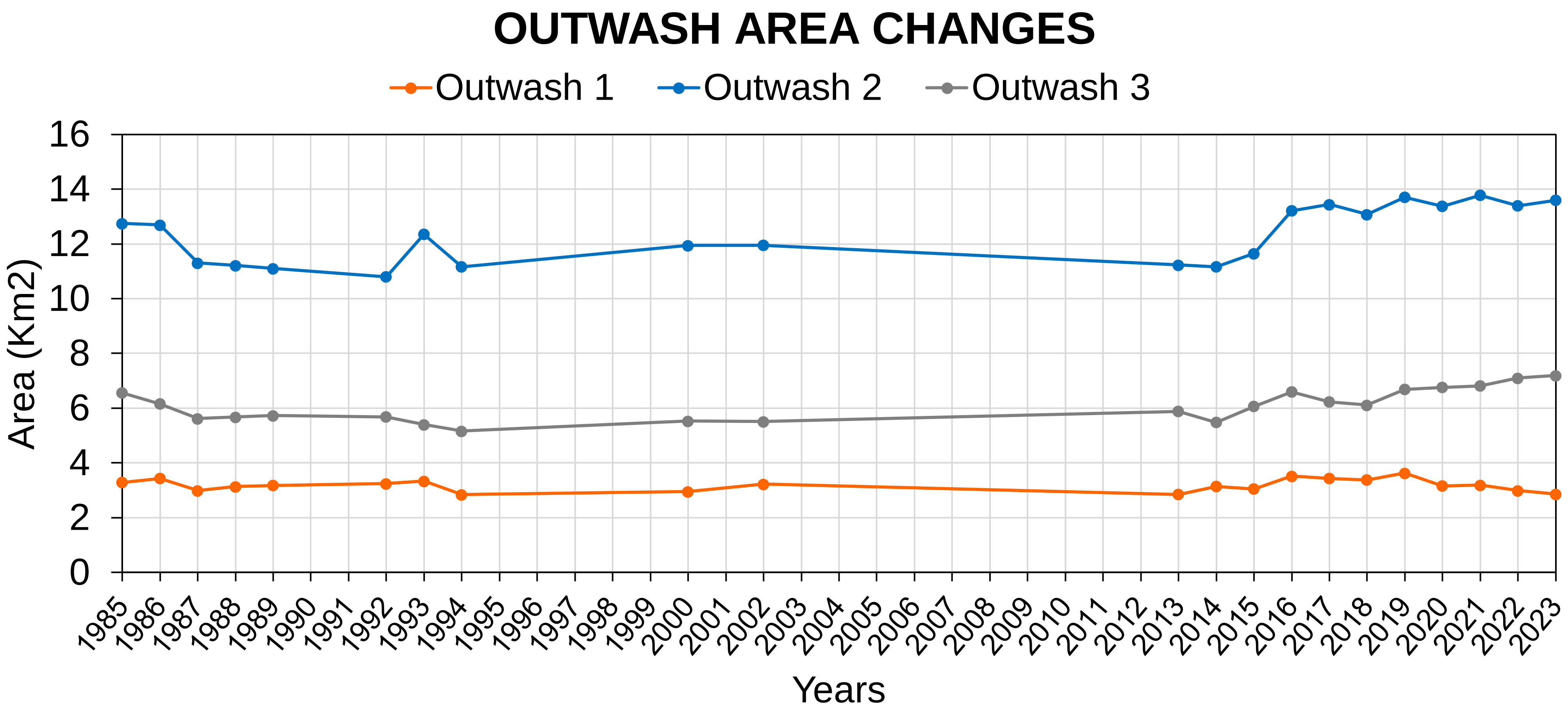




Glacier terminus area tends to decrease in 38 years

Aavatsmark, Andreas, Olive has lost more than 50% area

Results



Outwash area tends to increase, but not significantly

21/38 years are extracted, images unavailable or boundary difficult to determine

Conclusion

Remote Sensing + GIS Technique: suitable for monitoring long-term object changes (38 years)

The changes occur mainly at glacier terminus, whether on land or sea

(1) Shoreline change

Relatively stable in zone 1, 3, 5: LRR vary -2 to +3 m/yr, accretion predominate

Strongly eroded in zone 2, 4: LRR vary -64.7 to +10 m/yr, erosion predominate

Changes are mainly in glacier’s shoreline (terminus), land’s shoreline not significant

(2) Glacier terminus area tend to decrease

Top 3 largest glaciers area: Aavatsmark, Elise, Andreas lost 63.1%, 35.3%, 54.6%, respectively

(3) Outwash area tend to increase, but not significantly < 10%

PART II

Glacier Volume Loss in Vertical/Horizontal Direction

Glacier volume changes

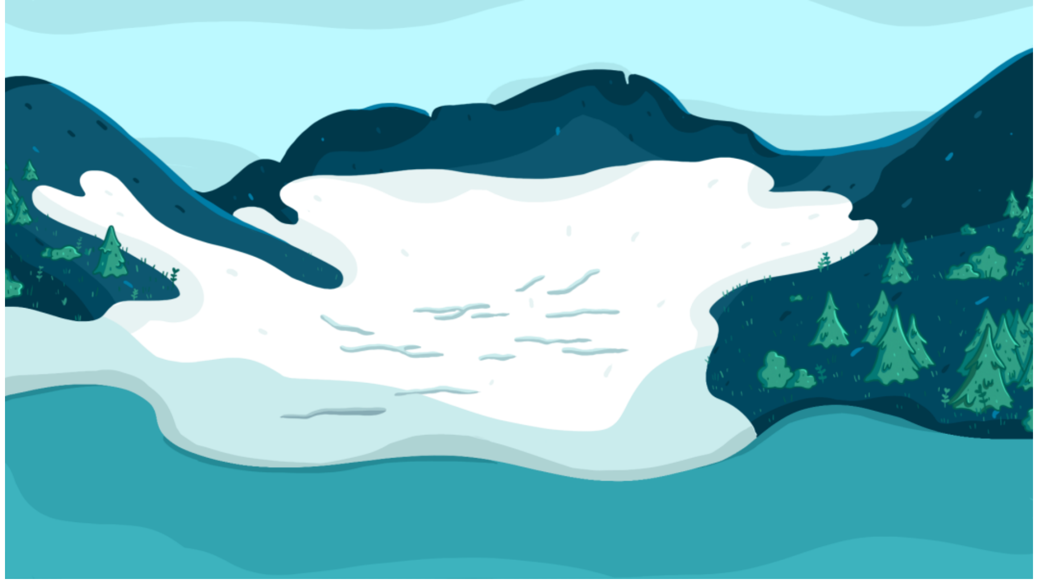
Late 2000s: 33 775 km^2 glaciers, cover 57% land of Svalbard

Climate change: glaciers - significant indicators

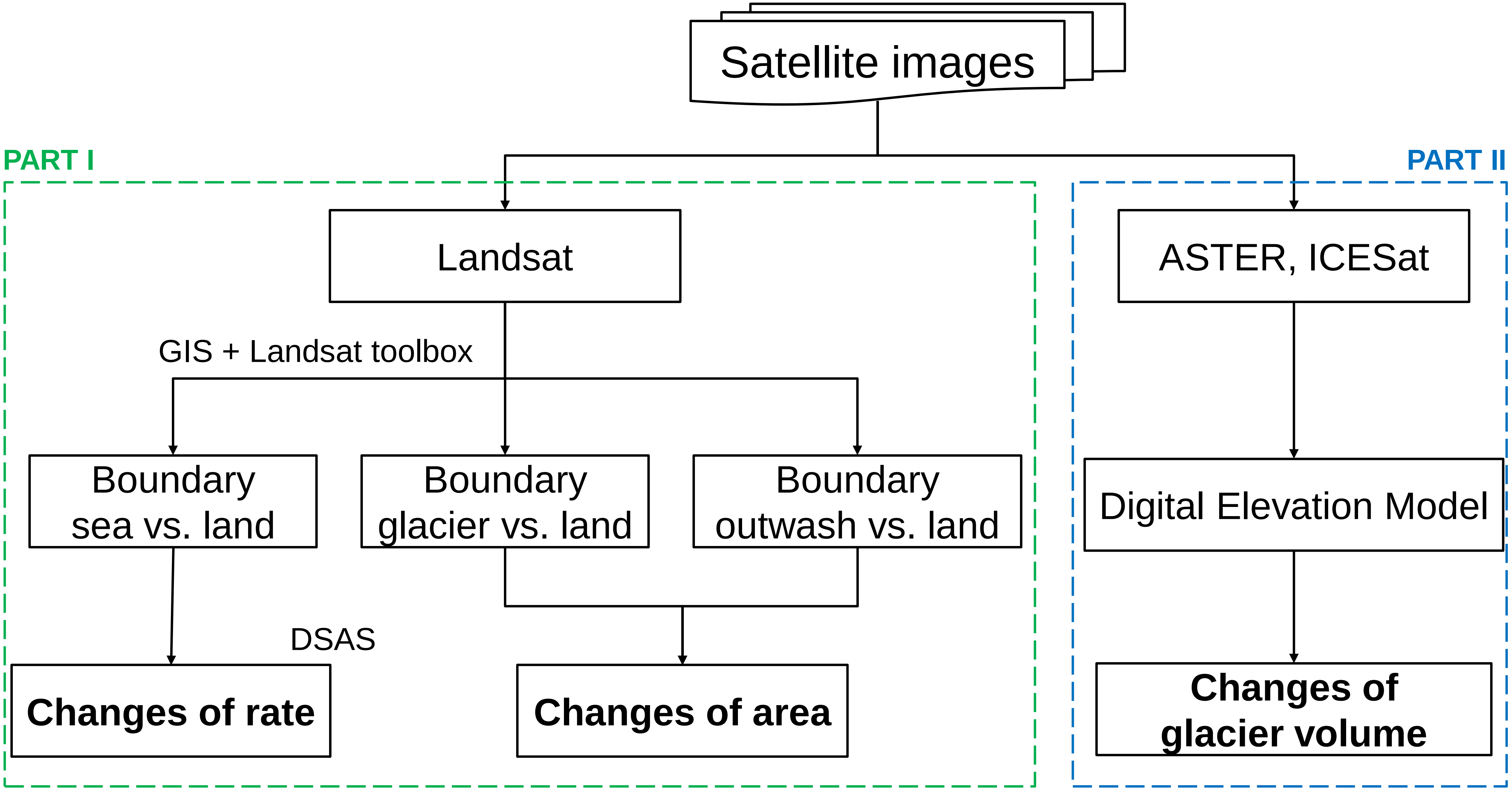
Changes in glacier thickness: key indicator reflect melting process

Glacier melting affect: regional water resources, hydrological cycles

➡ Estimating the glacier volume loss using multi-temporal DEMs



Glacier Survival – North Cascade Glacier Climate Project (nichols.edu)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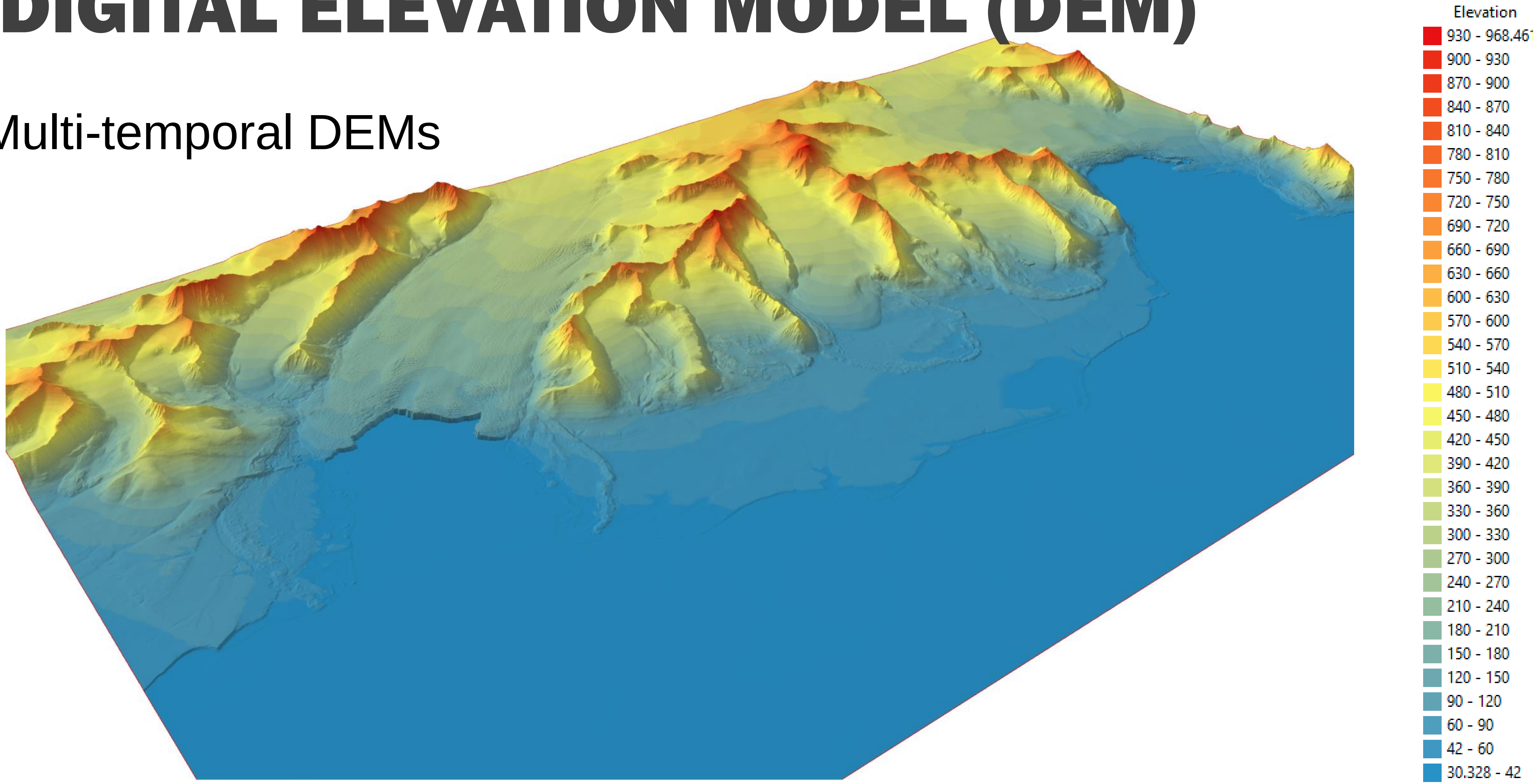
Changes of area
Changes of
glacier volume

DATA

	ASTER	ICESat	ICESat-2
Full name	The Advanced Spaceborne Thermal Emission and Reflection Radiometer	Ice, Cloud, land Elevation Satellite	Ice, Cloud, land Elevation Satellite-2
Resolution	15 – 90 m^2		
Objects	Land surface temp., emissivity, reflectance, elevation	Ice sheet mass balance, cloud, aerosol heights, land topography, vegetation	Retreating glaciers, shrinking sea ice, melting ice sheets, thickness sea ice, vegetation
Period	1999 - present	2003 – 2009	2018 - present

DIGITAL ELEVATION MODEL (DEM)

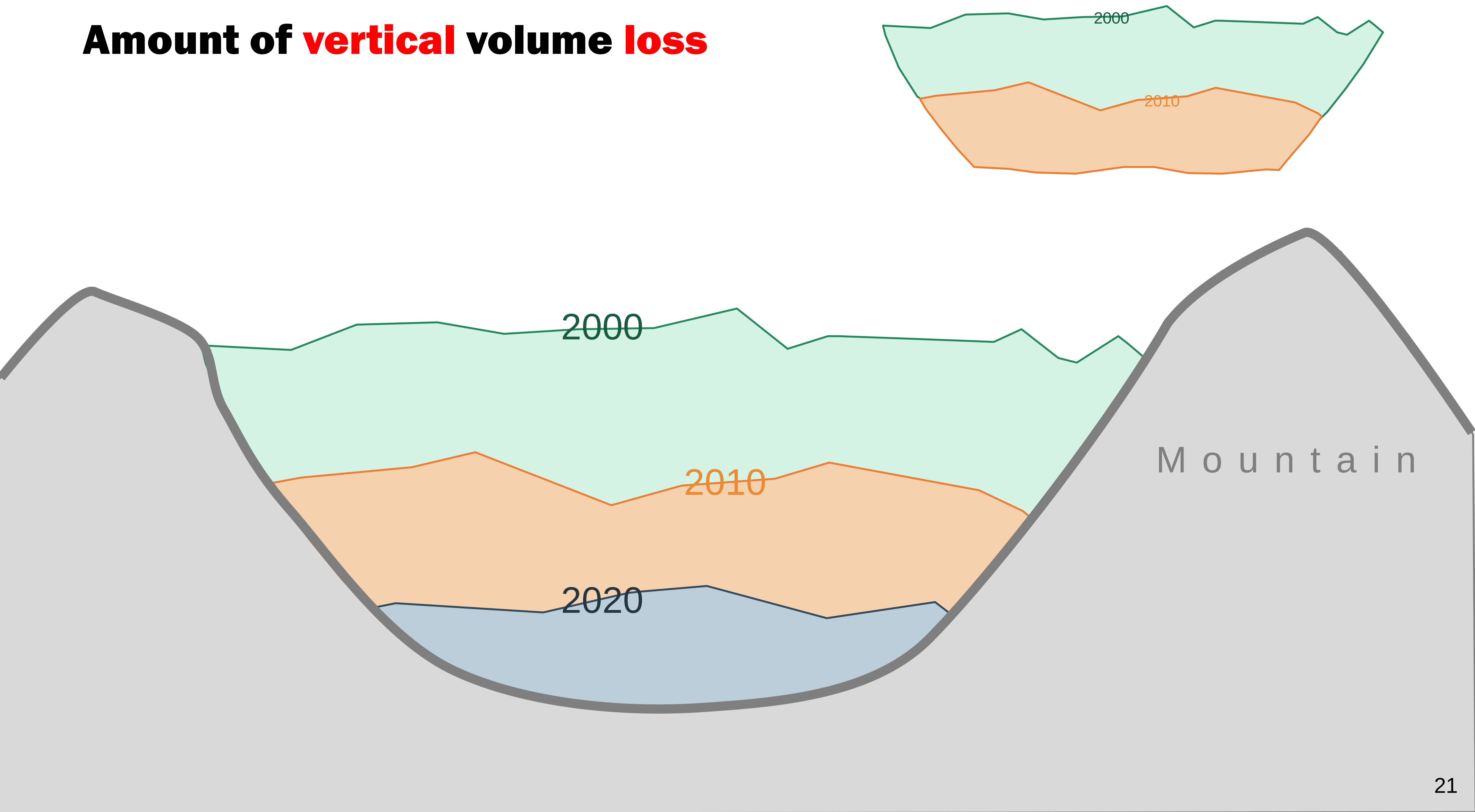
Multi-temporal DEMs

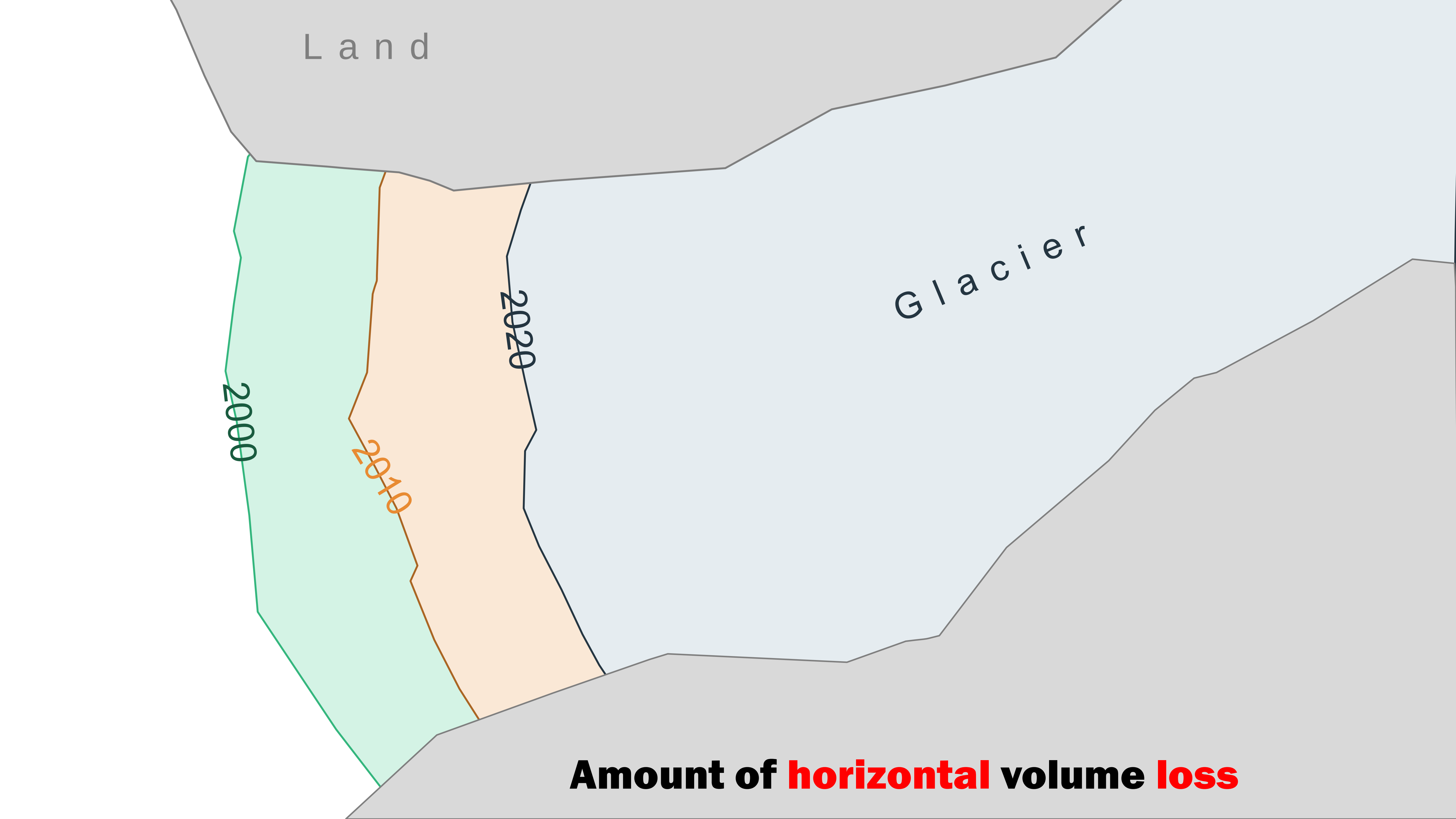


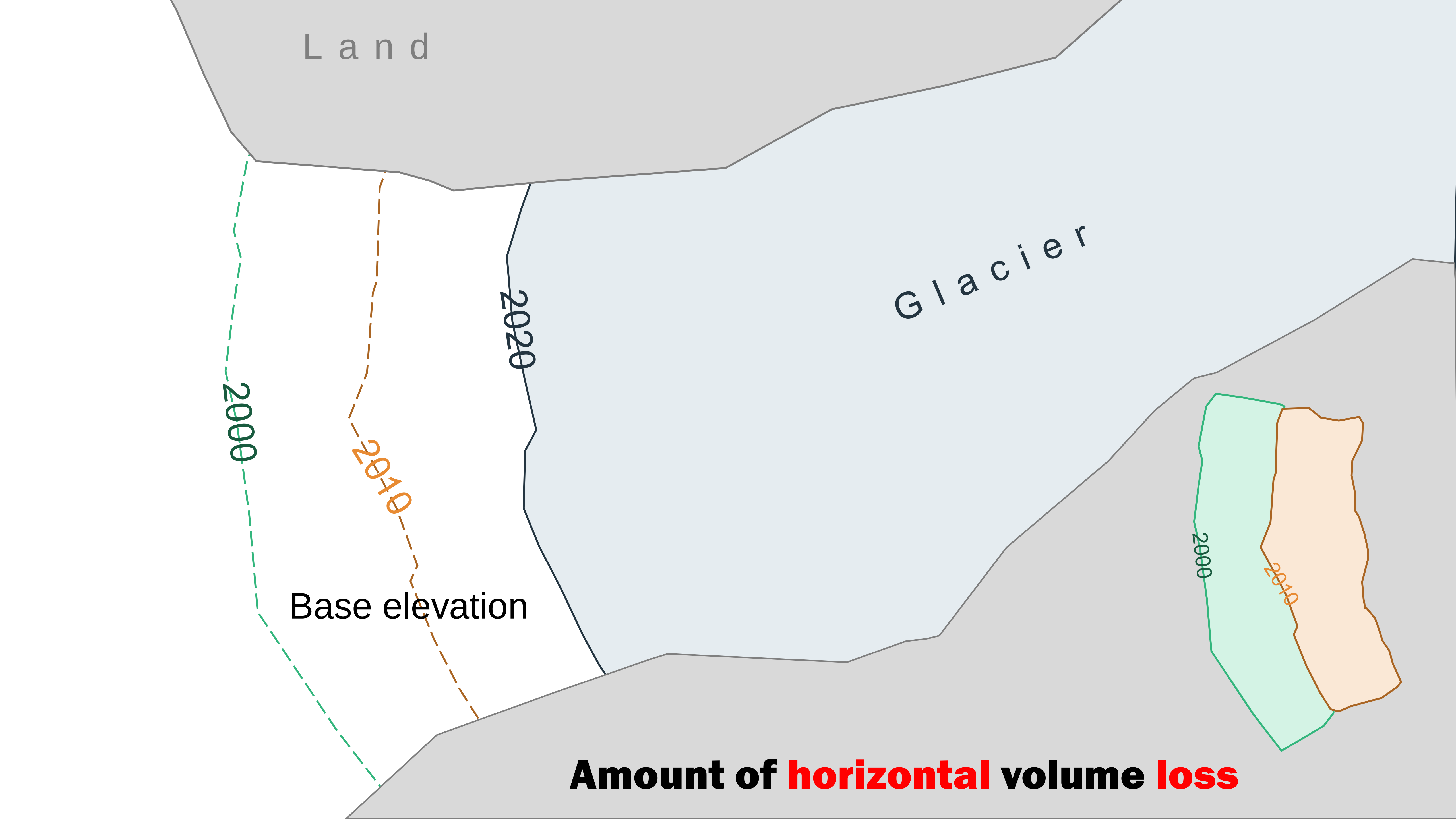
2m – Kaffiøyra's DEM

ArcticDEM – Polar Geospatial Center (umn.edu)

Amount of vertical volume loss




Land
Glacier
2000
2010
2020
Amount of horizontal volume loss

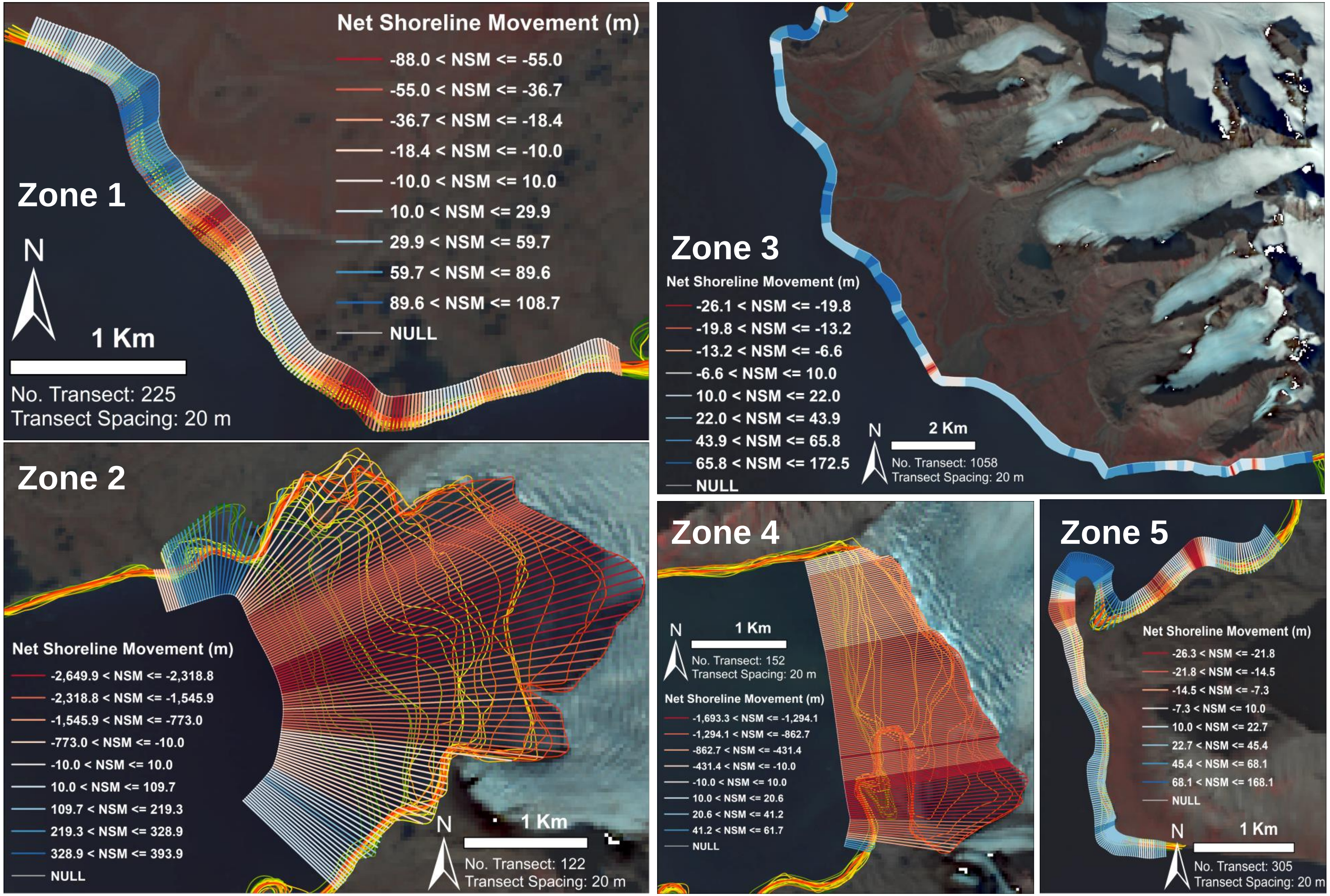


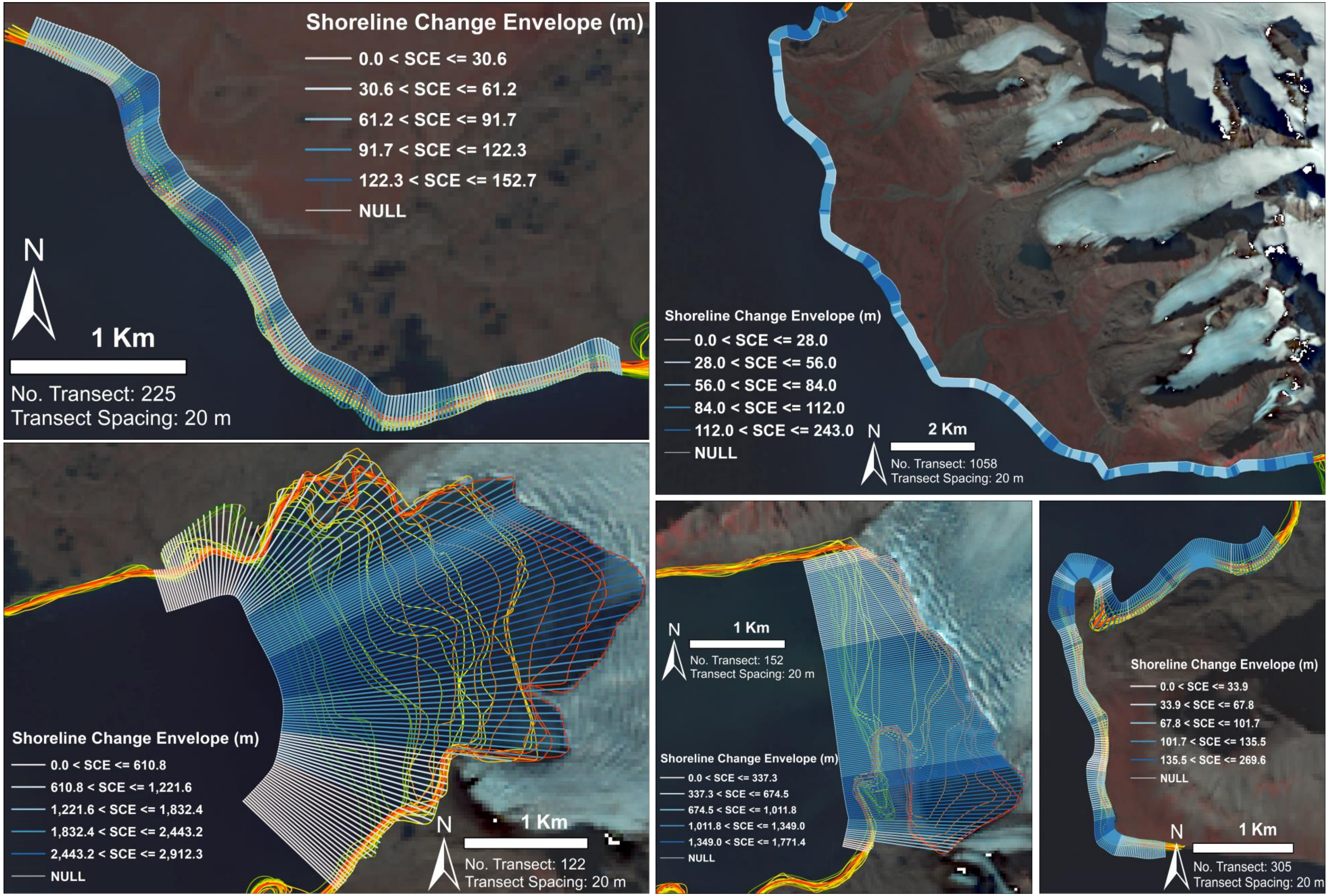
Land
Glacier
2020
2010
2000
Base elevation
2000
2010
Amount of horizontal volume loss

Future works

- Collect the satellite images data
- Process and generate DEMs
- Estimate the glacier volume loss in Kaffiøyra


THANK YOU!
Q & A


Zone 1
Net Shoreline Movement (m)
-88.0 < NSM <= -55.0
-55.0 < NSM <= -36.7
-36.7 < NSM <= -18.4
-18.4 < NSM <= -10.0
-10.0 < NSM <= 10.0
10.0 < NSM <= 29.9
29.9 < NSM <= 59.7
59.7 < NSM <= 89.6
89.6 < NSM <= 108.7
NULL
N
1 Km
No. Transect: 225
Transect Spacing: 20 m
Zone 2
Net Shoreline Movement (m)
-2,649.9 < NSM <= -2,318.8
-2,318.8 < NSM <= -1,545.9
-1,545.9 < NSM <= -773.0
-773.0 < NSM <= -10.0
-10.0 < NSM <= 10.0
10.0 < NSM <= 109.7
109.7 < NSM <= 219.3
219.3 < NSM <= 328.9
328.9 < NSM <= 393.9
NULL
N
1 Km
No. Transect: 122
Transect Spacing: 20 m
Zone 3
Net Shoreline Movement (m)
-26.1 < NSM <= -19.8
-19.8 < NSM <= -13.2
-13.2 < NSM <= -6.6
-6.6 < NSM <= 10.0
10.0 < NSM <= 22.0
22.0 < NSM <= 43.9
43.9 < NSM <= 65.8
65.8 < NSM <= 172.5
NULL
N
2 Km
No. Transect: 1058
Transect Spacing: 20 m
Zone 4
N
1 Km
No. Transect: 152
Transect Spacing: 20 m
Net Shoreline Movement (m)
-1,693.3 < NSM <= -1,294.1
-1,294.1 < NSM <= -862.7
-862.7 < NSM <= -431.4
-431.4 < NSM <= -10.0
-10.0 < NSM <= 10.0
10.0 < NSM <= 20.6
20.6 < NSM <= 41.2
41.2 < NSM <= 61.7
NULL
Zone 5
Net Shoreline Movement (m)
-26.3 < NSM <= -21.8
-21.8 < NSM <= -14.5
-14.5 < NSM <= -7.3
-7.3 < NSM <= 10.0
10.0 < NSM <= 22.7
22.7 < NSM <= 45.4
45.4 < NSM <= 68.1
68.1 < NSM <= 168.1
NULL
N
1 Km
No. Transect: 305
Transect Spacing: 20 m


Shoreline Change Envelope (m)
0.0 < SCE <= 30.6
30.6 < SCE <= 61.2
61.2 < SCE <= 91.7
91.7 < SCE <= 122.3
122.3 < SCE <= 152.7
NULL
N
1 Km
No. Transect: 225
Transect Spacing: 20 m
Shoreline Change Envelope (m)
0.0 < SCE <= 28.0
28.0 < SCE <= 56.0
56.0 < SCE <= 84.0
84.0 < SCE <= 112.0
112.0 < SCE <= 243.0
NULL
N
2 Km
No. Transect: 1058
Transect Spacing: 20 m
Shoreline Change Envelope (m)
0.0 < SCE <= 610.8
610.8 < SCE <= 1,221.6
1,221.6 < SCE <= 1,832.4
1,832.4 < SCE <= 2,443.2
2,443.2 < SCE <= 2,912.3
NULL
N
1 Km
No. Transect: 122
Transect Spacing: 20 m
N
1 Km
No. Transect: 152
Transect Spacing: 20 m
Shoreline Change Envelope (m)
0.0 < SCE <= 337.3
337.3 < SCE <= 674.5
674.5 < SCE <= 1,011.8
1,011.8 < SCE <= 1,349.0
1,349.0 < SCE <= 1,771.4
NULL
Shoreline Change Envelope (m)
0.0 < SCE <= 33.9
33.9 < SCE <= 67.8
67.8 < SCE <= 101.7
101.7 < SCE <= 135.5
135.5 < SCE <= 269.6
NULL
N
1 Km
No. Transect: 305
Transect Spacing: 20 m

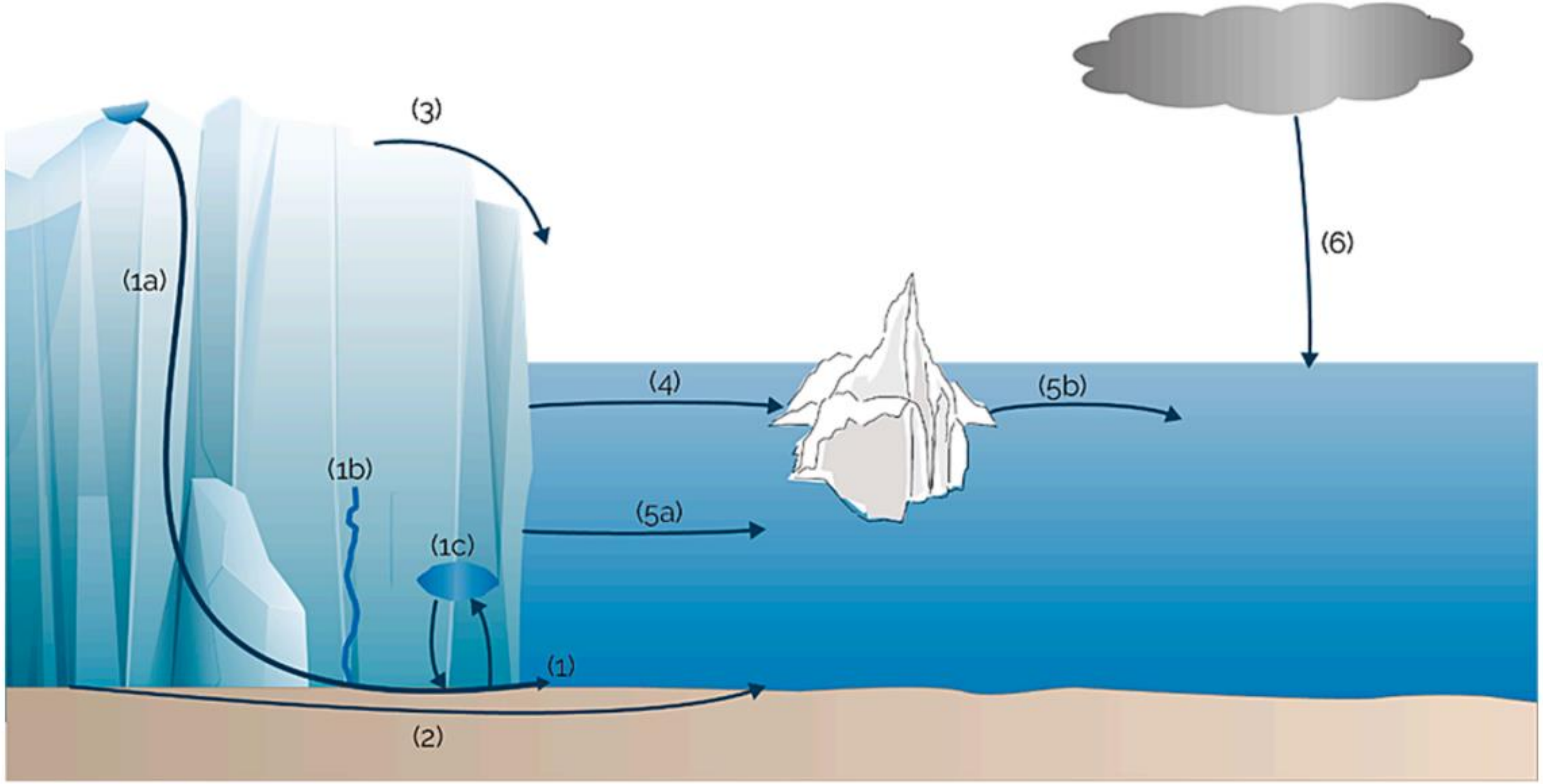


Fig. 3. Potential freshwater inputs in a fjord with a tidewater glacier. 1) subglacial discharge fed by surface melt in summer (1a), basal ice melt (1b) or delayed outflow of internally stored meltwater (1c). 2) Submarine groundwater discharge. 3) surface runoff in summer (glacial ice and snow- melt). 4) solid ice discharge. 5) submarine melt of (5a) the glacier terminus, or (5b) icebergs, including ice melange and potentially sea ice. 6) precipitation.