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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Date: 2024/04/26

Introduction

Climate change: long-term change in average weather patterns

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

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.

Introduction

- What are long-term patterns & magnitudes of shoreline, glacier, outwash changes?
- What are long-term behavior between tidewater and land glacier in same climate conditions?
- Correlation between temperature variations & glacier retreat?
- Can develop a predictive model with existing data to predict future glacier changes?

Objectives

- Quantifying the landform changes 1985 – 2023 by remote sensing and GIS,
- Combining observation data to analyze the correlation temperature vs. area changes,
- Developing the predictive model base on the correlation.

Materials and Methods

Svalbard place in High Arctic

Glaciers cover ~ 60% of the land

Mean T vary -14ºC (winter) - +6ºC (summer)

Annual precipitation: 200 – 300 mm

Kaffiøyra: southwest of Svalbard

Shoreline: rate changes

Tidewater – Land glaciers: area – rate changes

Outwash: area changes

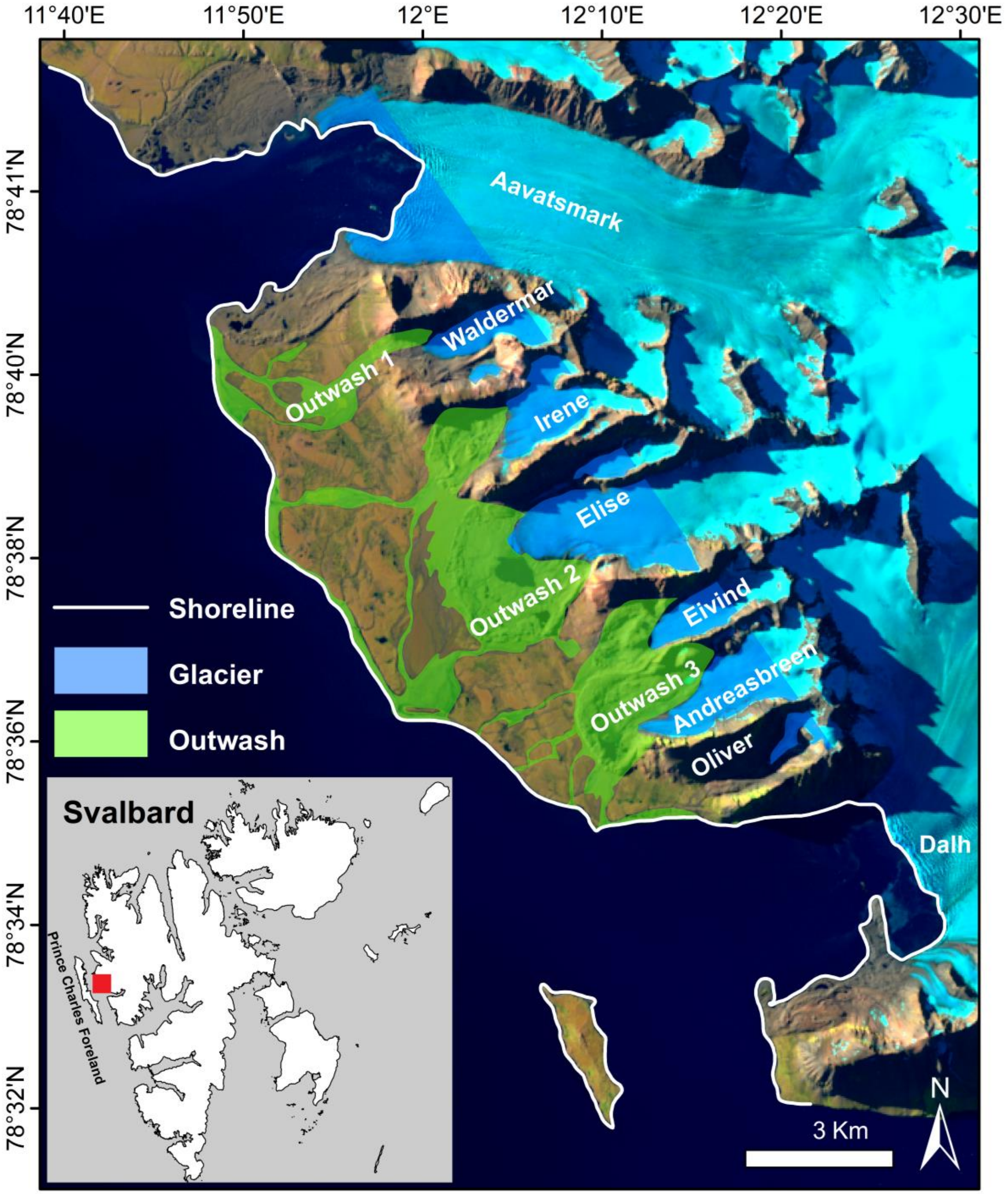
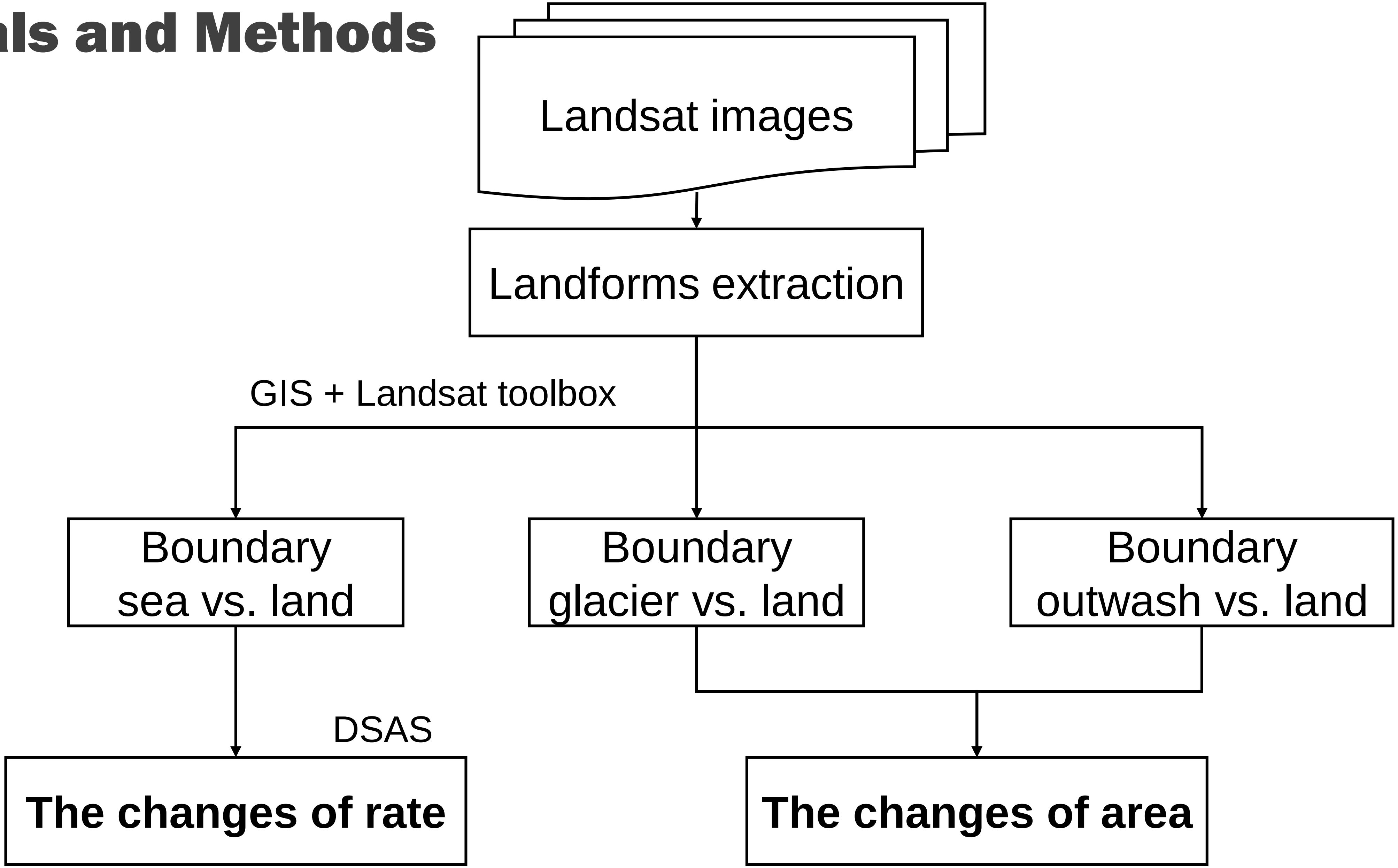


Figure 2. The study area is Kaffiøyra placed in southwest Svalbard

Materials and Methods



Digital Shoreline Analysis System

Landsat images 1985 - 2023

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	-								

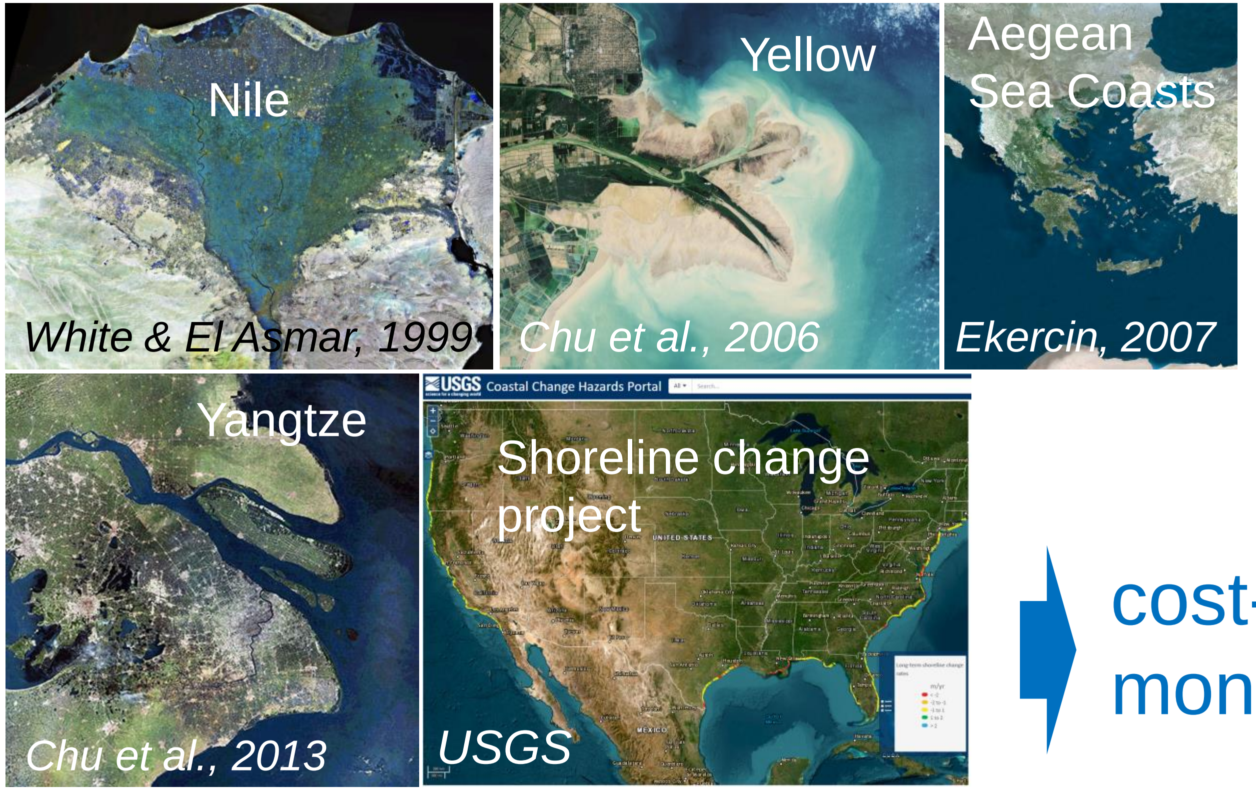
Jun., Jul., Aug., Sept. : **summer time**

Materials and Methods

Monitoring long-term shoreline changes => Big problem
Integrating remote sensing + GIS technique

Landsat images

Digital Shoreline Analysis System (DSAS)



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

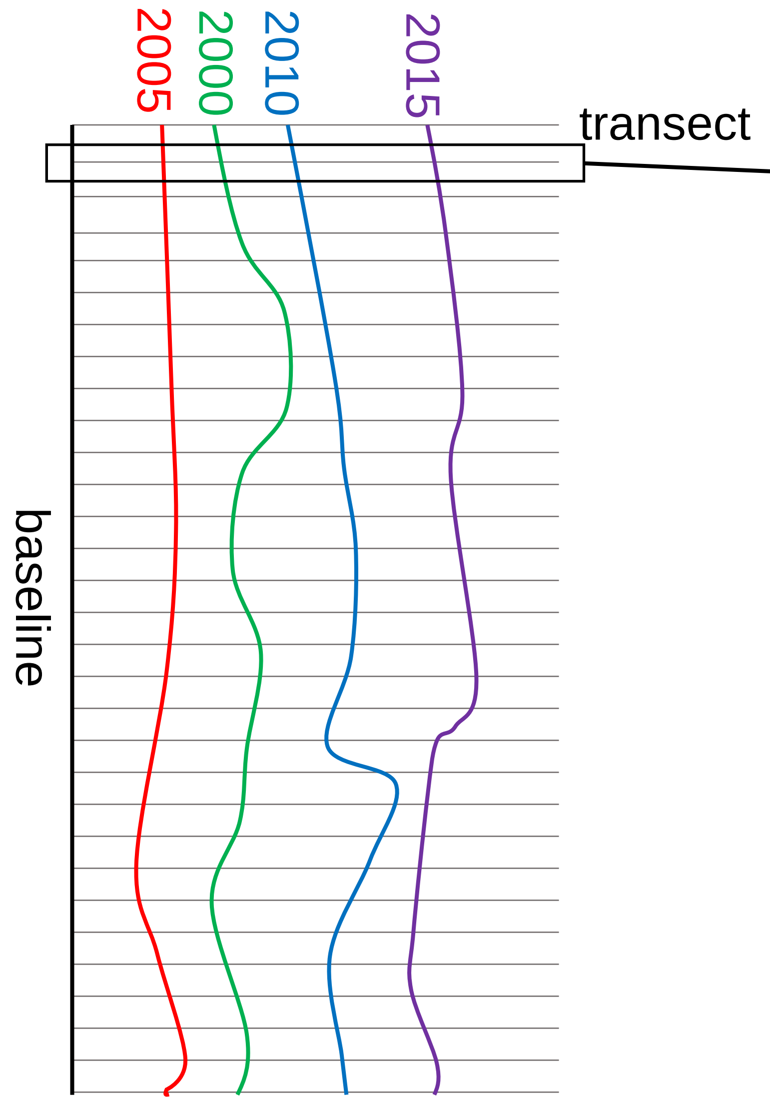
cost-efficient tool for monitor long-term changes

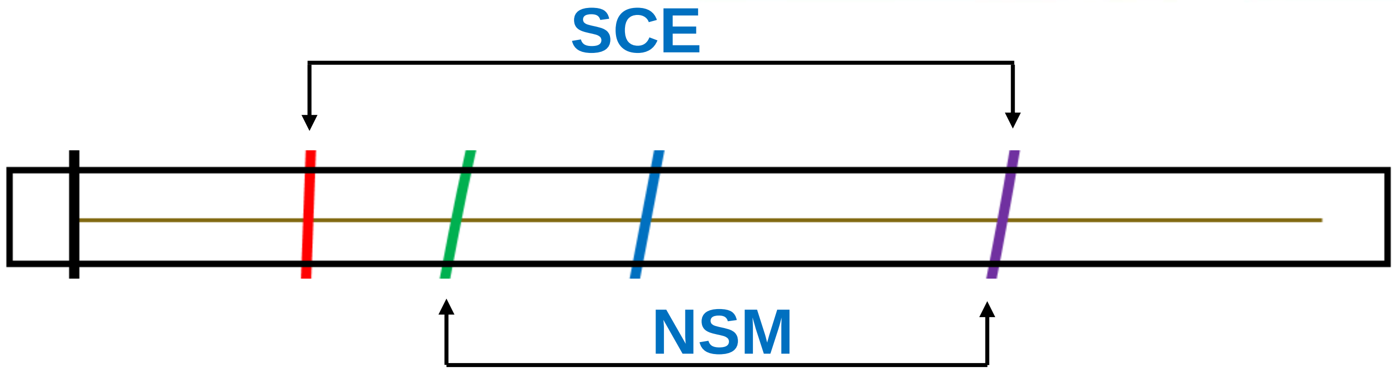
Materials and Methods

Landsat toolbox

No.	Processes	Descriptions
1	Download and Extract images	*https://eathexplorer.usgs.gov/*
2	Landsat Tasseled Cap	Calculate the Tasseled Cap brightness, greenness, and wetness transformations. Normalize the band values to 0-255.
3	NDMI/NDVI	Calculate the Normalize Difference Moisture Index (NDMI) and Normalized the band values to 0-255.
4	Category Creation for Land & Sea	Take Tasseled Cap and NDMI bands as input and create a 10-class land cover data set and dendrogram (note any band combination could be used).
5	Classify Land and Sea	Reclass the land cover data set from 10 to 2 classes.
6	Create Shore Boundary	Create a shoreline from the 2-class land cover data set using Majority filtering, Contour, and Smooth line commands.
7	Output shorelines	Correct for cloud/surf/beach.

Materials and Methods DSAS concept





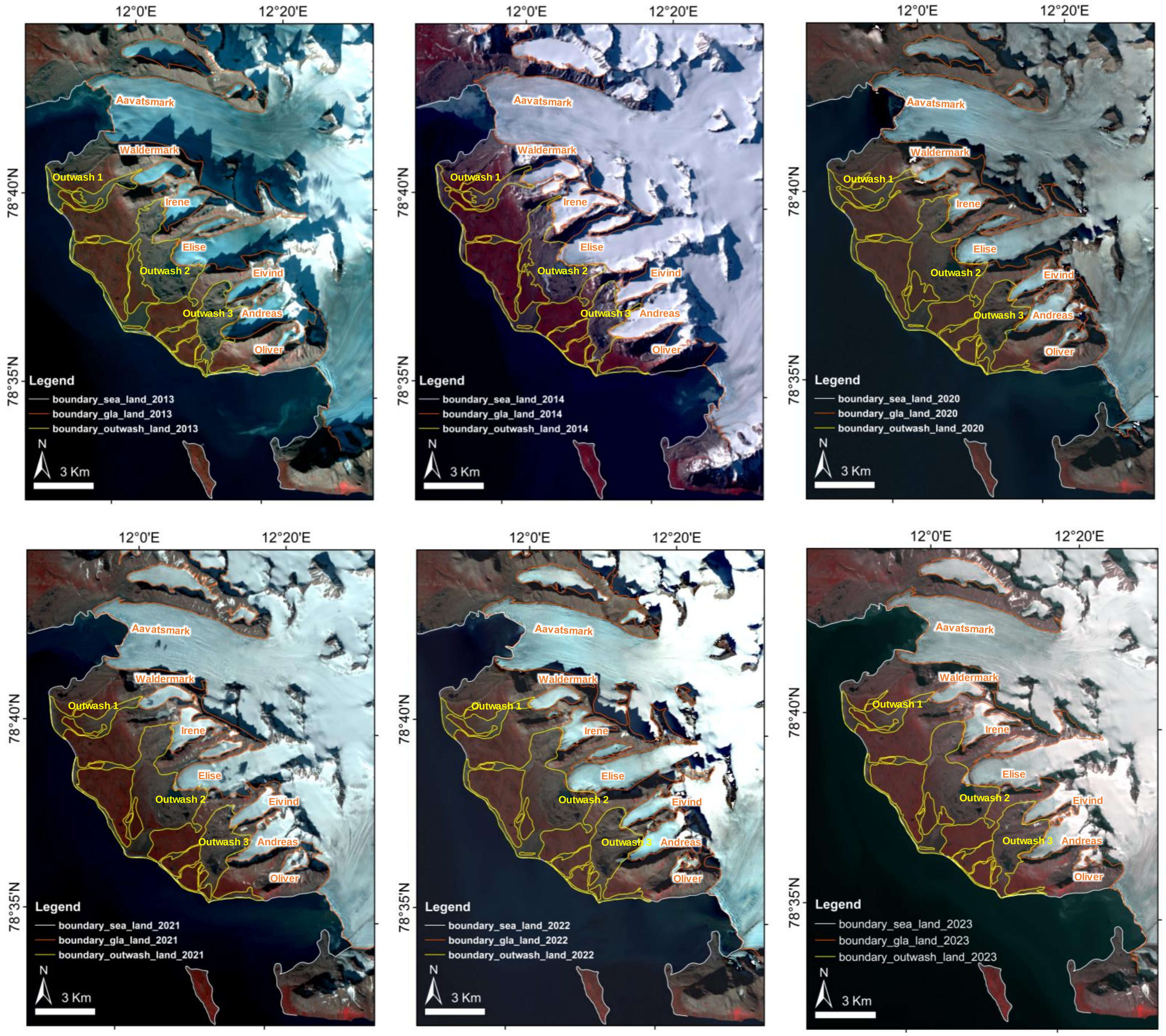
EPR = NSM/time

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**

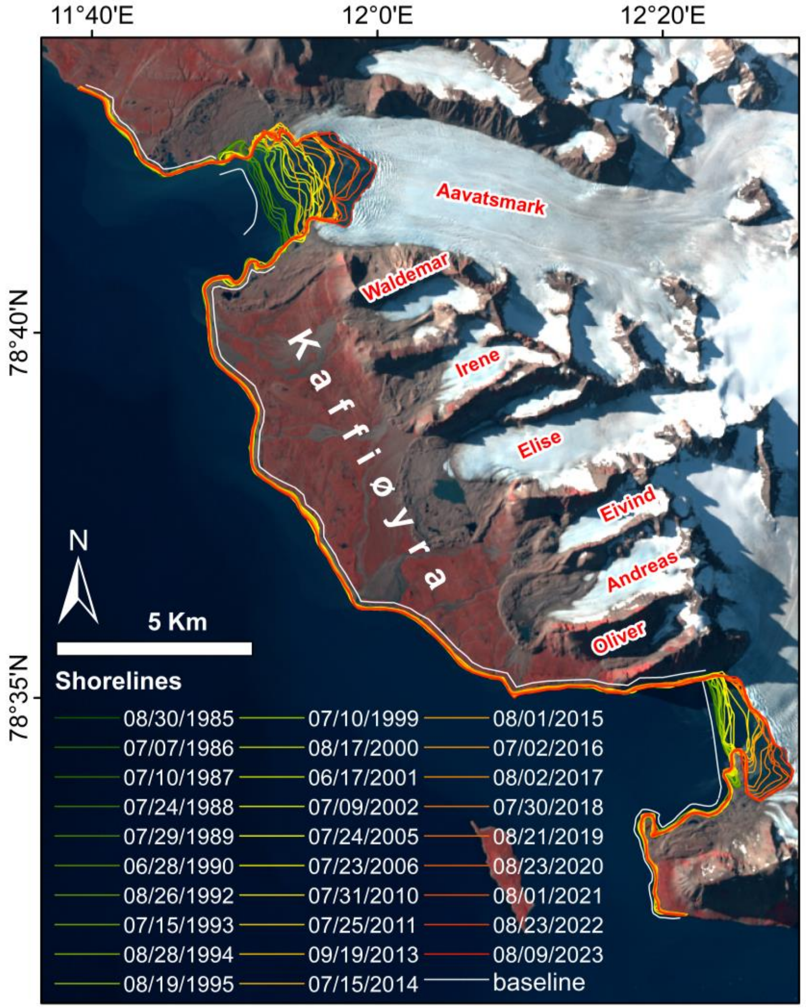
Shoreline, glacier, outwash extraction



Results & Discussion

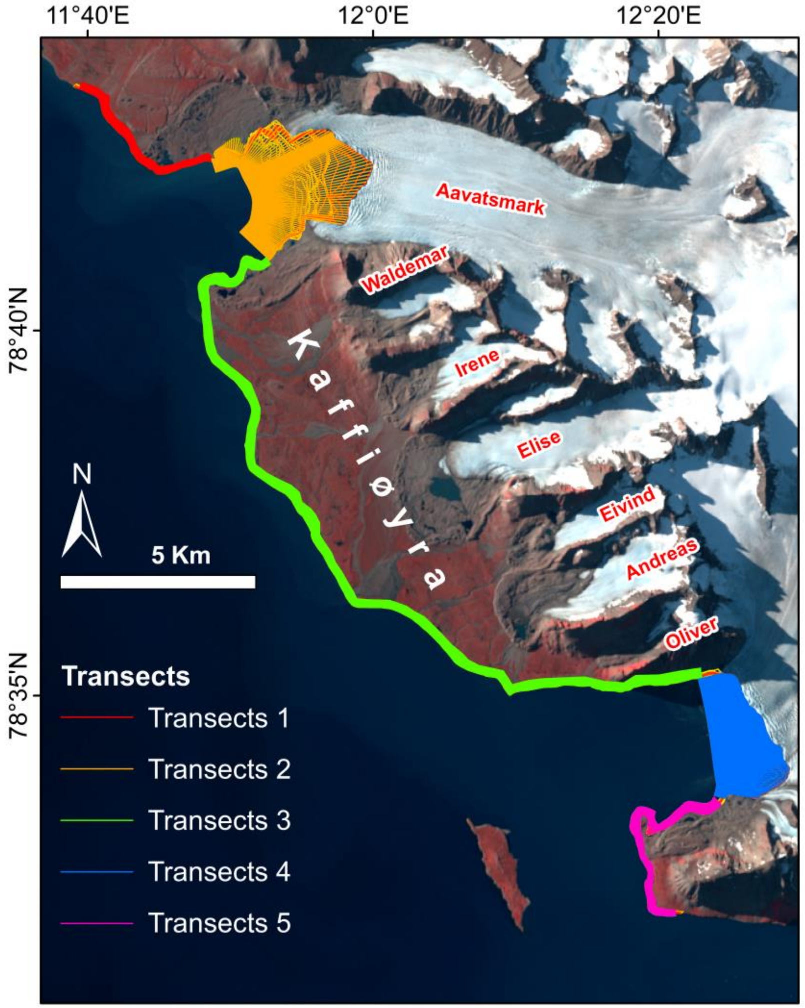
Shoreline

①



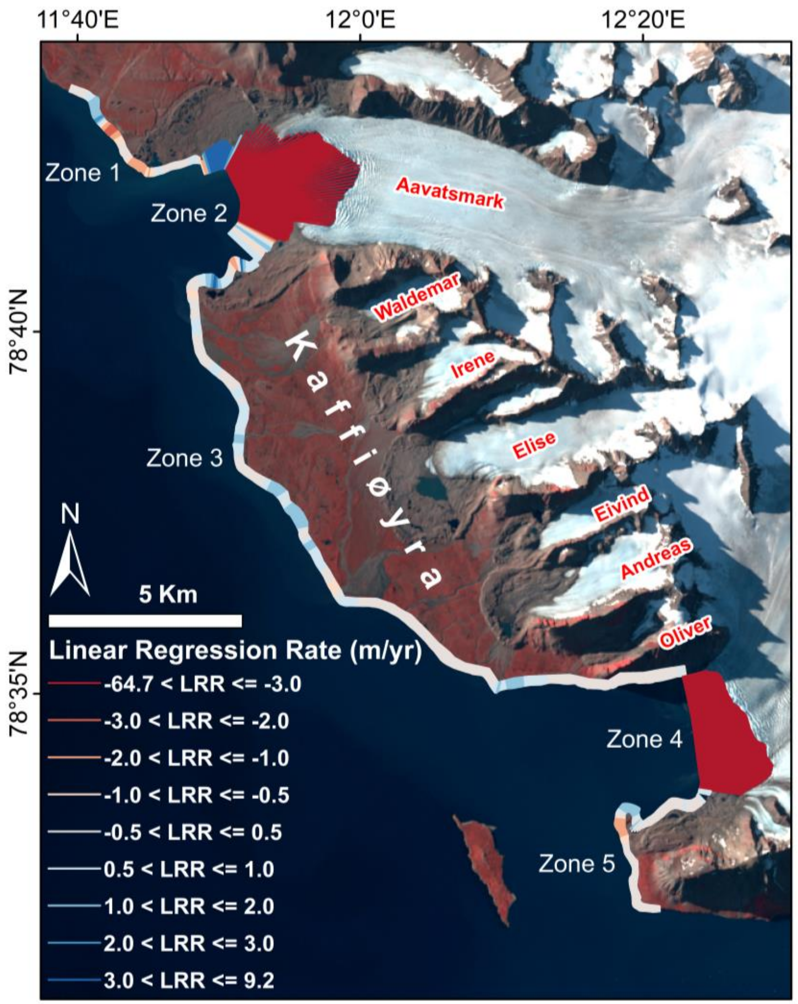
Shorelines & baselines

②



Create transects

③



Calculate LRR

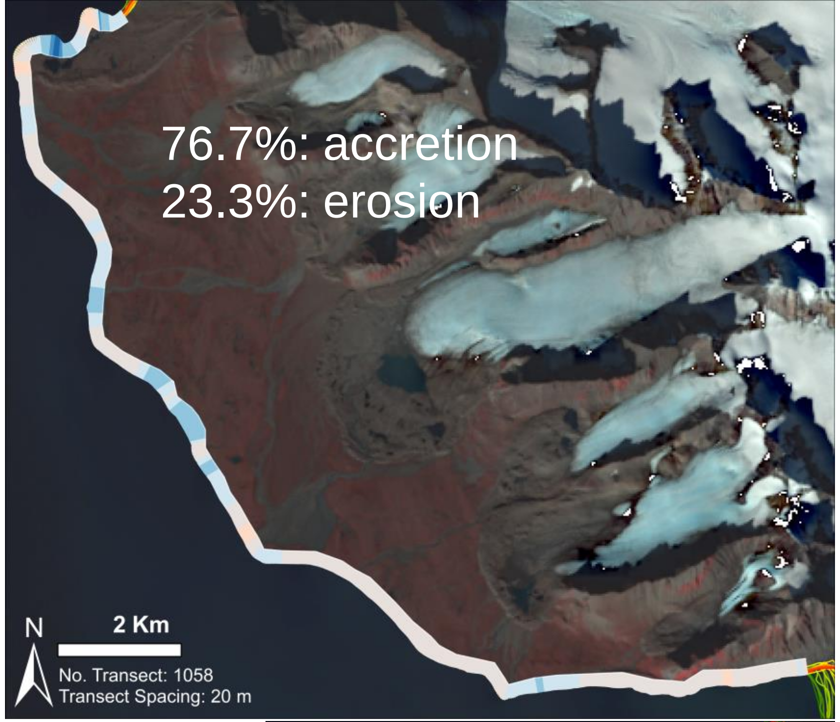
Results & Discussion

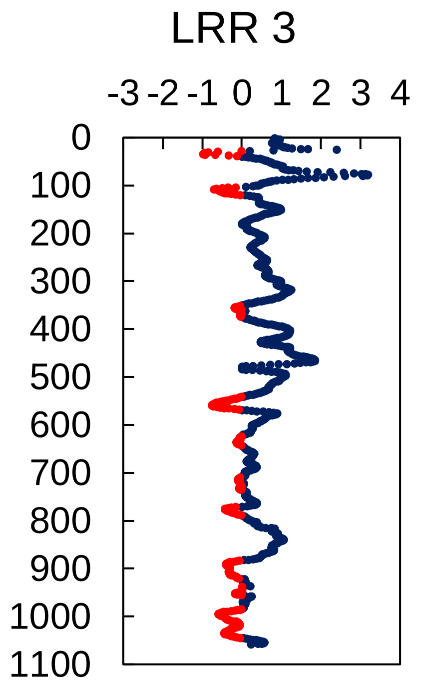
Shoreline

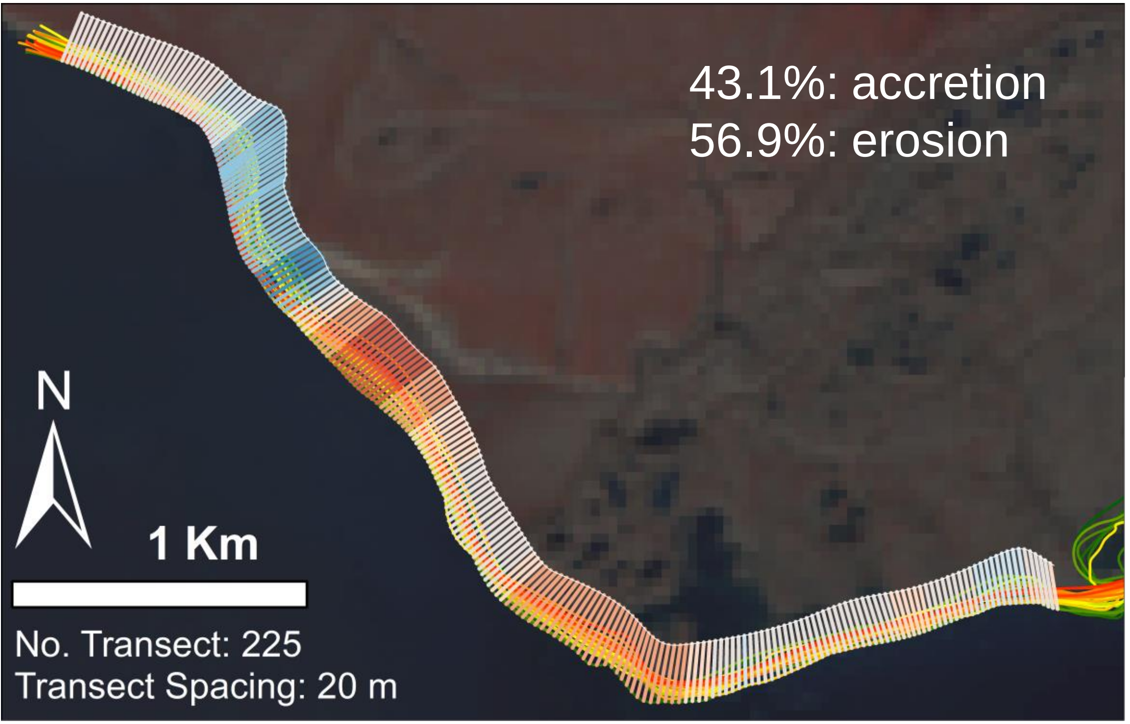
Zone 1, 3, 5: relatively stable shoreline

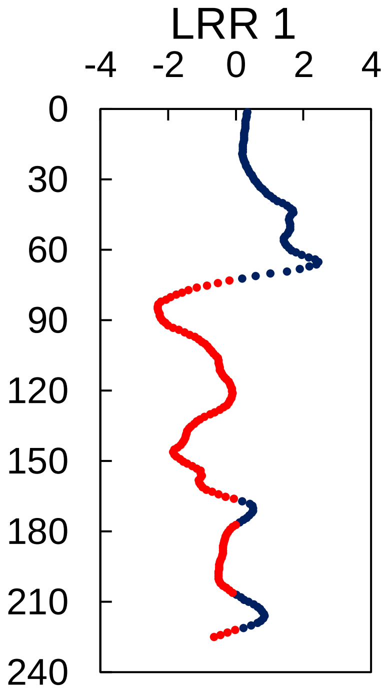
Rate vary: -2 to +3 m/yr

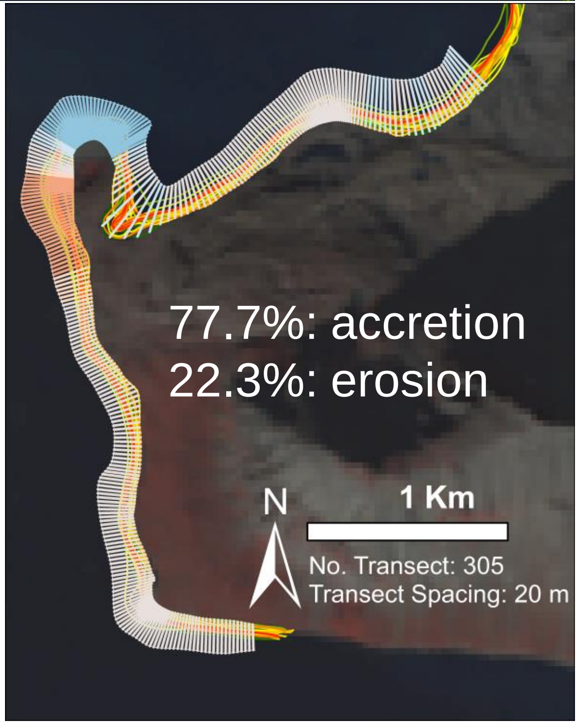
Accretion predominate

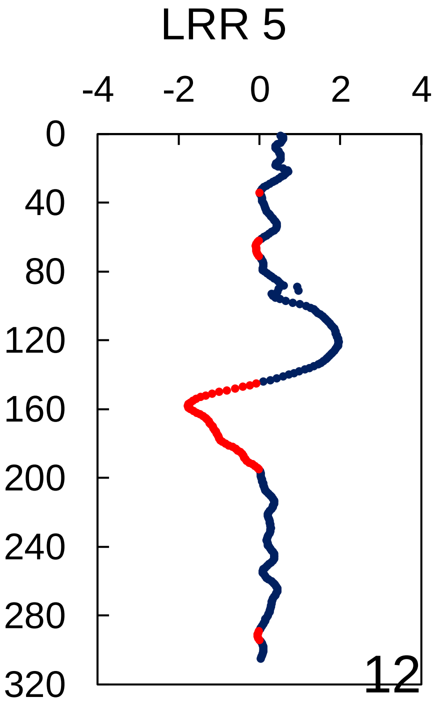












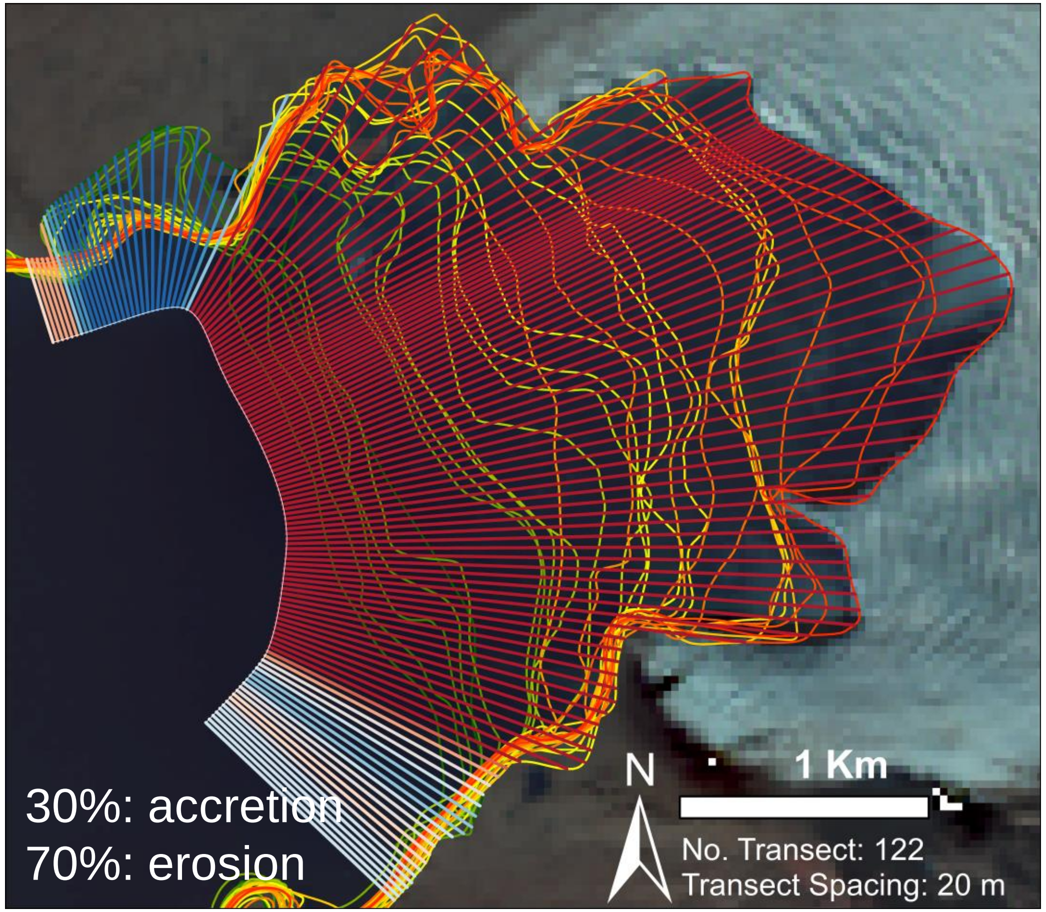
Results & Discussion

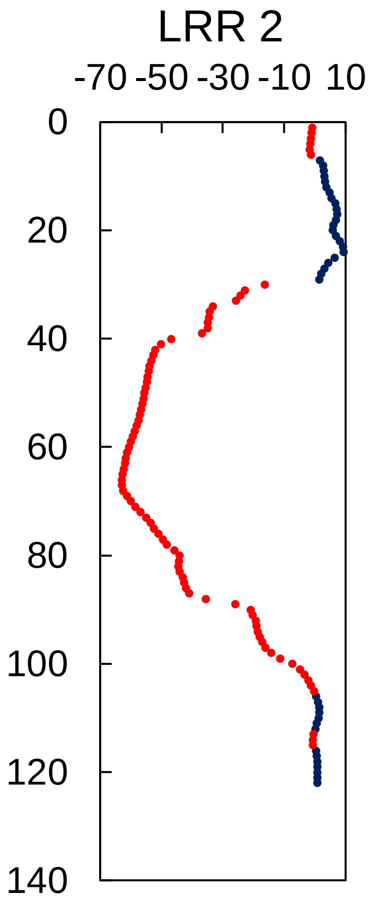
Shoreline

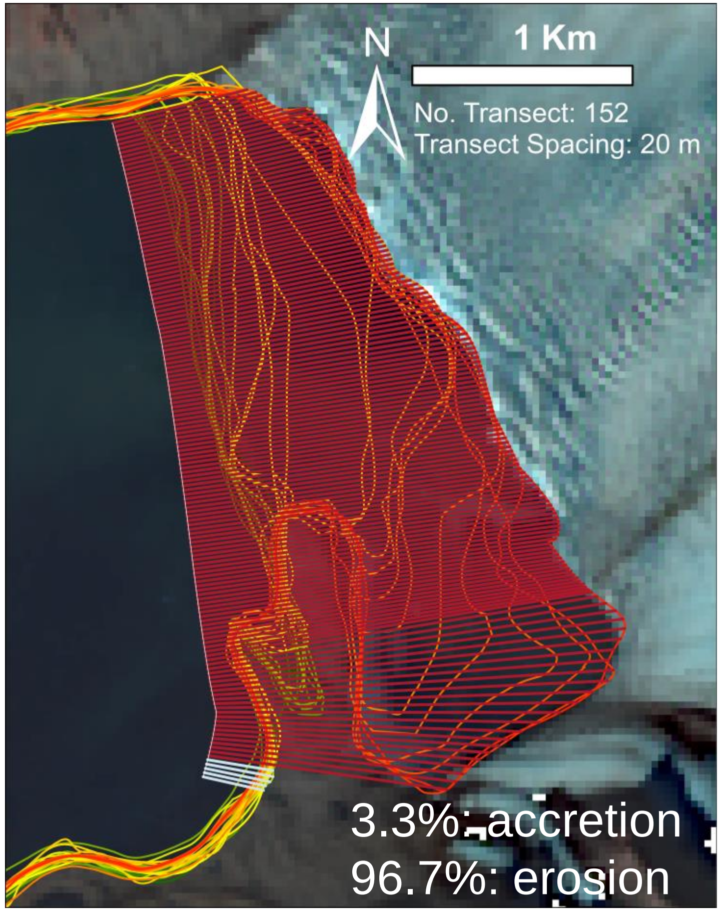
Zone 2, 4: extremely change shoreline

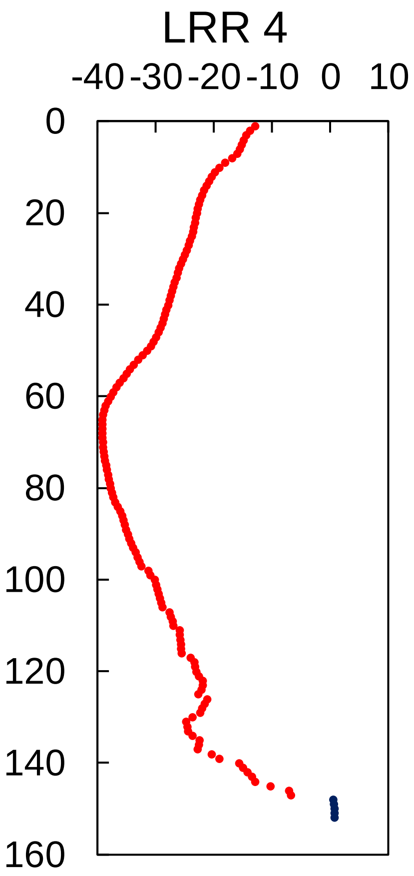
Rate vary: -64.7 to +10 m/yr

Erosion predominate







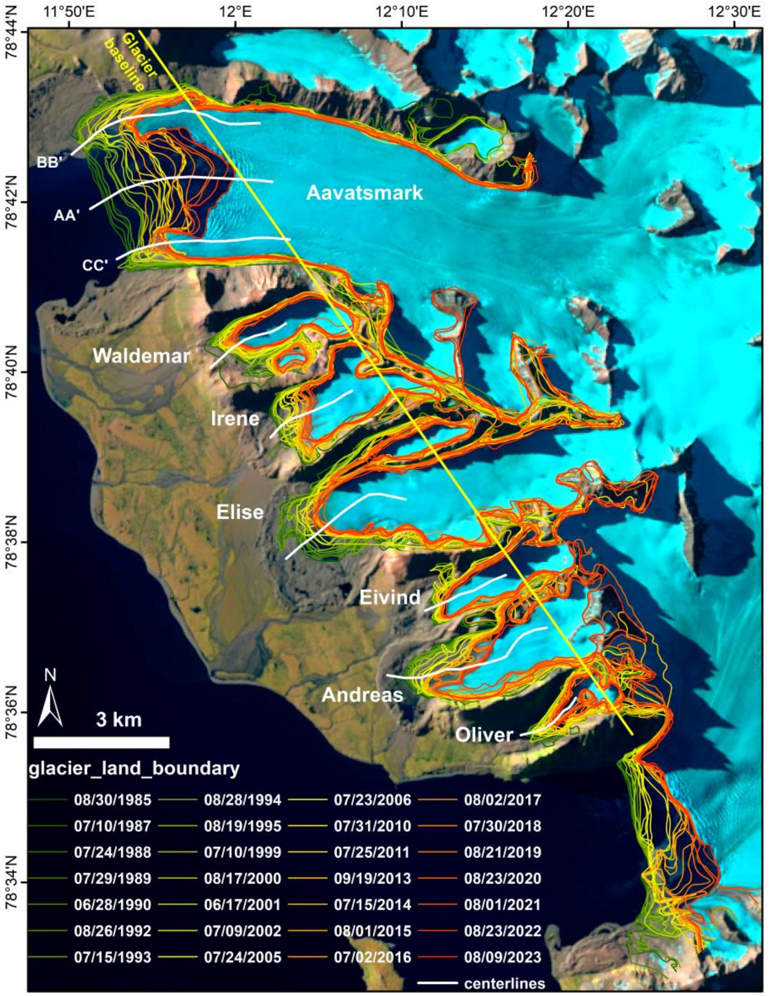


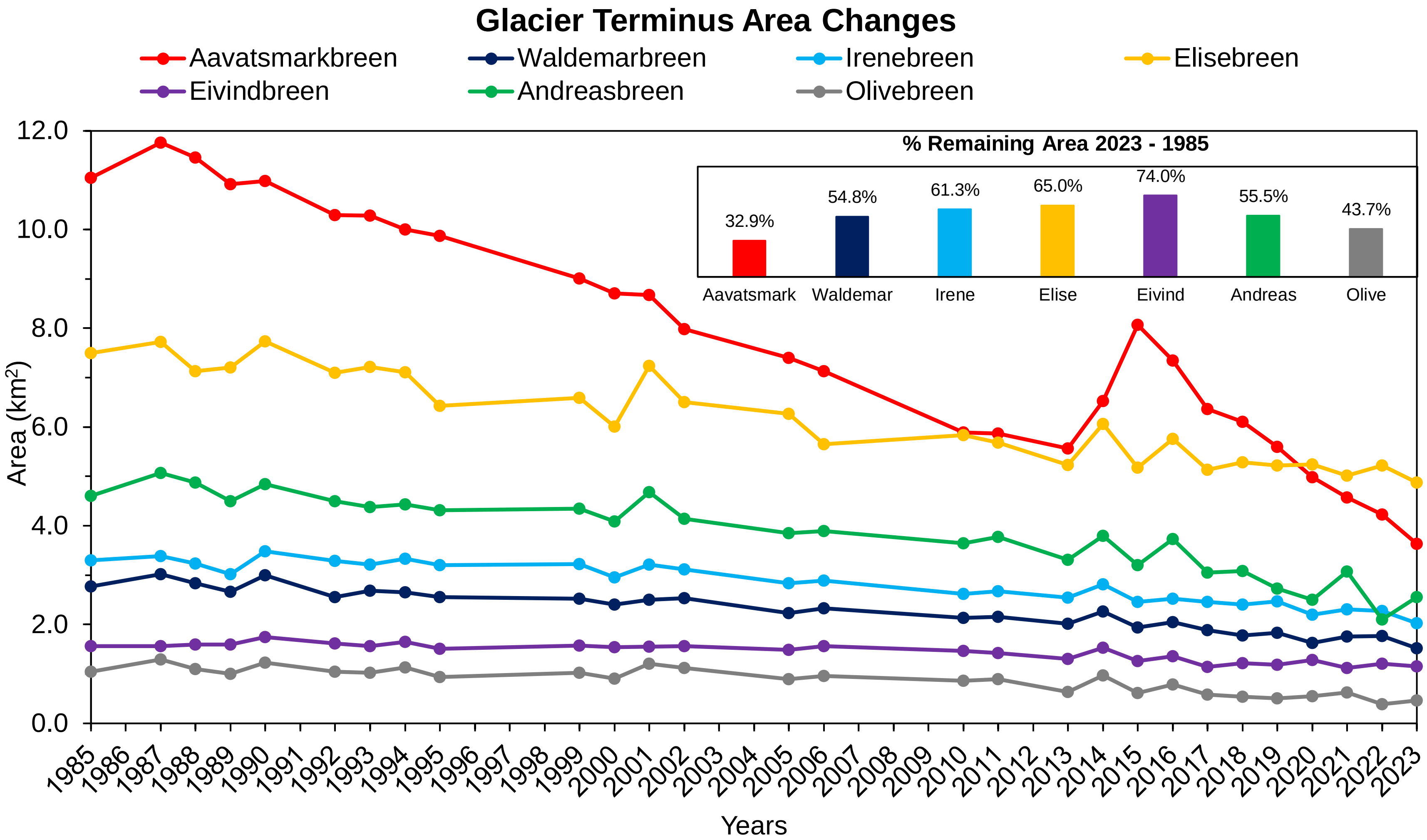
➡ The land's shoreline is relatively stable, glacier's shoreline (terminus) is strongly eroded

Results & Discussion

Glacier

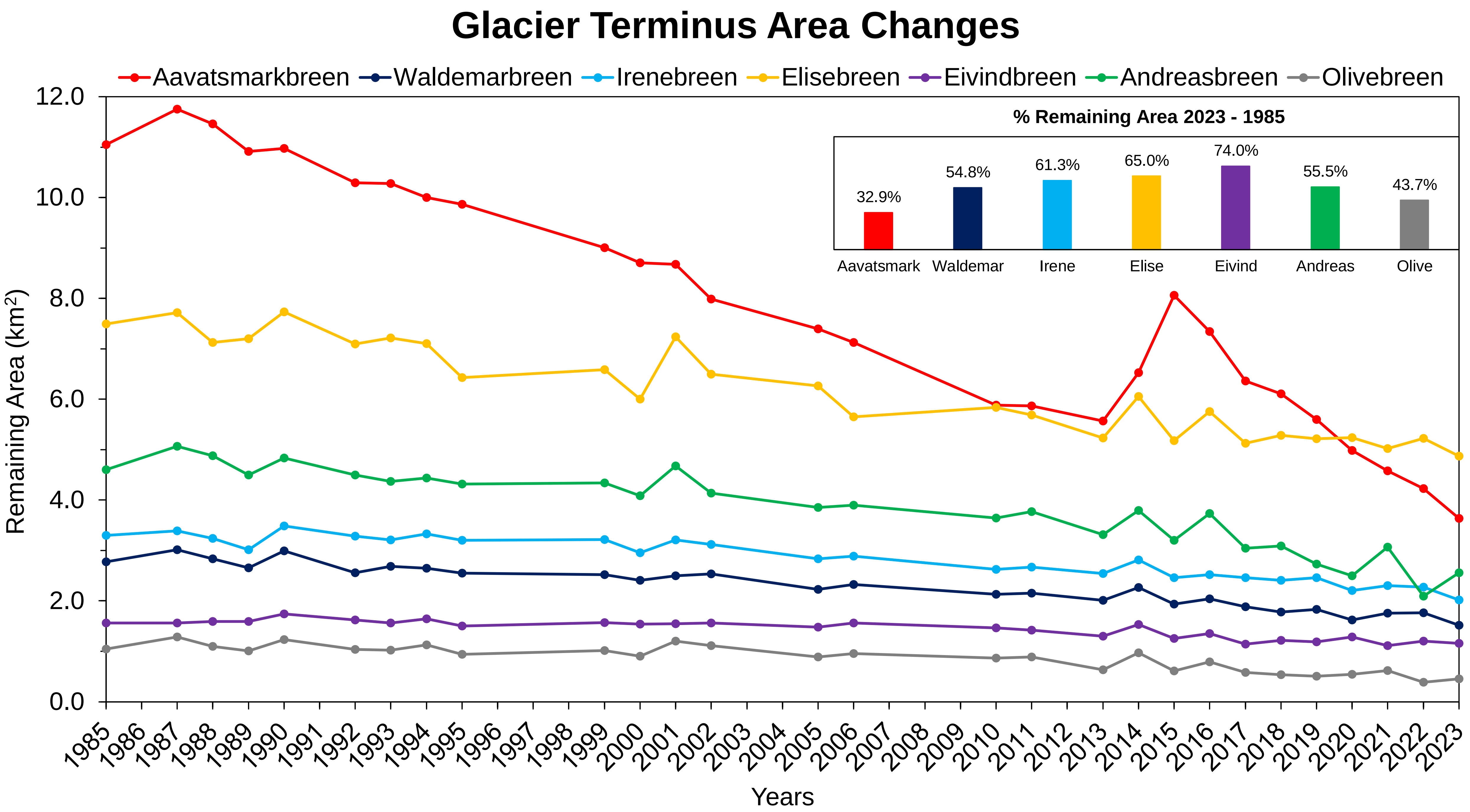
Glaciers area tends to decrease in 38 years





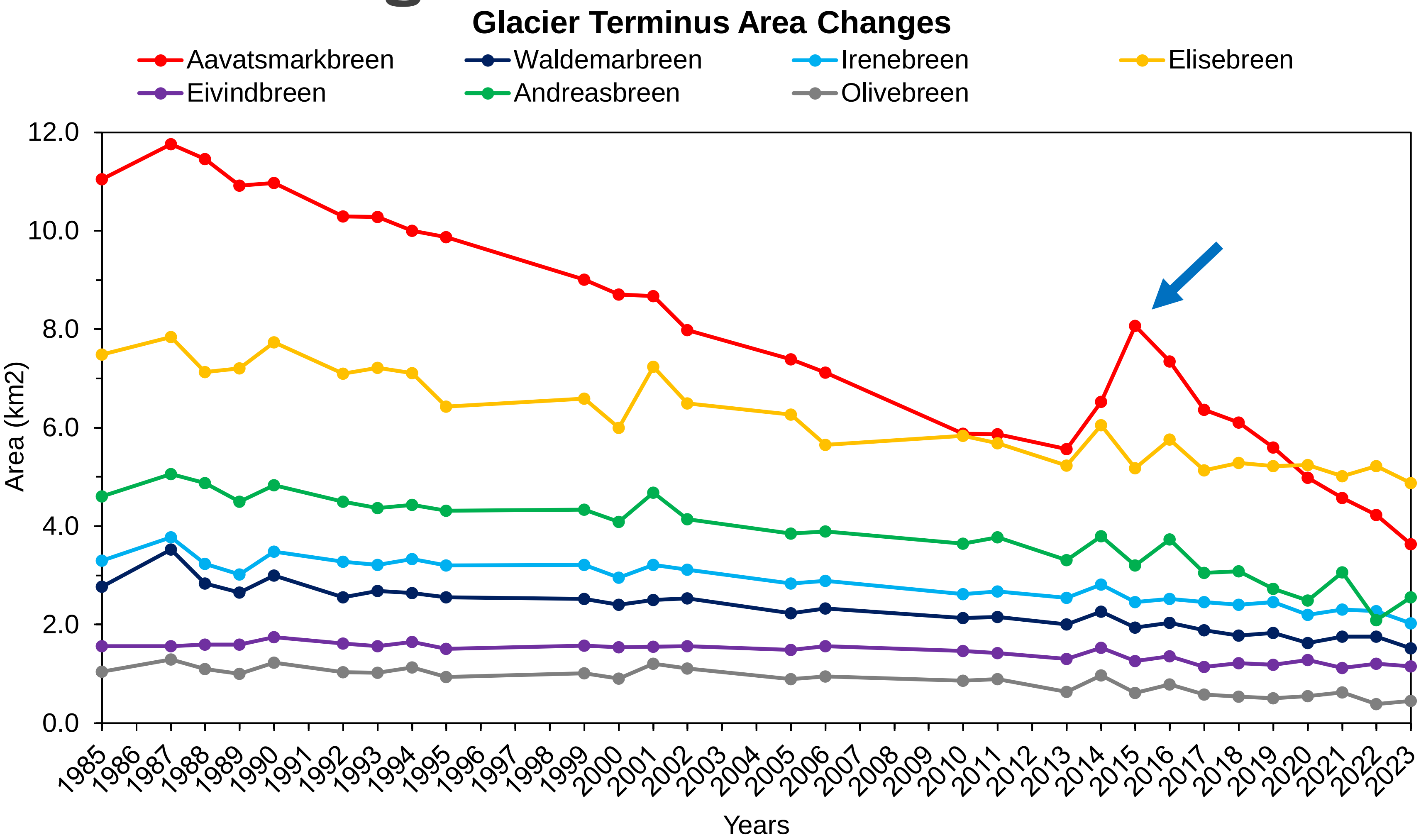
Tidewater glacier - Aavatsmark lost 67.1% area
Land glacier avg. 40.9% area

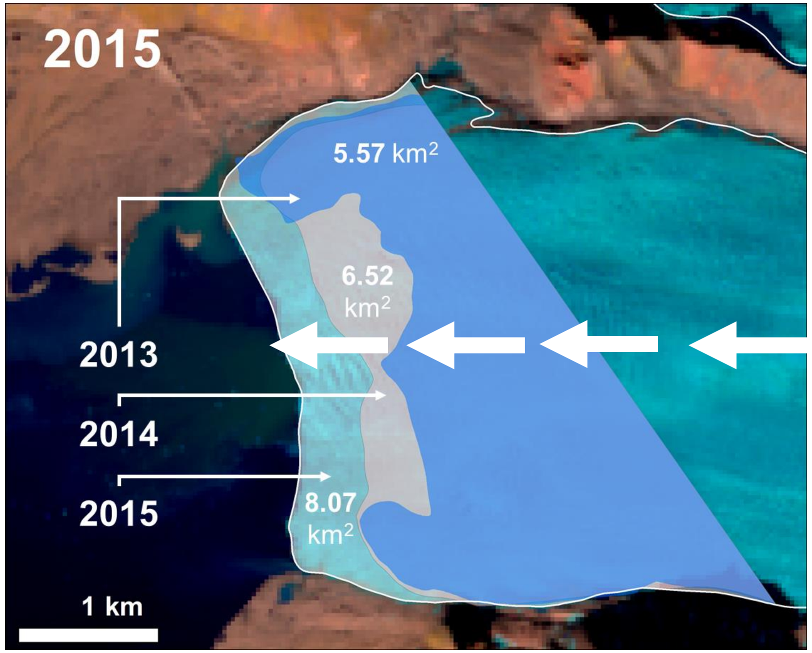
Same climate conditions
Tidewater glacier more vulnerable


Glacier Terminus Area Changes
Aavatsmarkbreen
Waldemarbreen
Irenebreen
Elisebreen
Eivindbreen
Andreasbreen
Olivebreen
Remaining Area (km²)
Years
12.0
10.0
8.0
6.0
4.0
2.0
0.0
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
% Remaining Area 2023 - 1985
32.9%
54.8%
61.3%
65.0%
74.0%
55.5%
43.7%
Aavatsmark
Waldemar
Irene
Elise
Eivind
Andreas
Olive

Results & Discussion

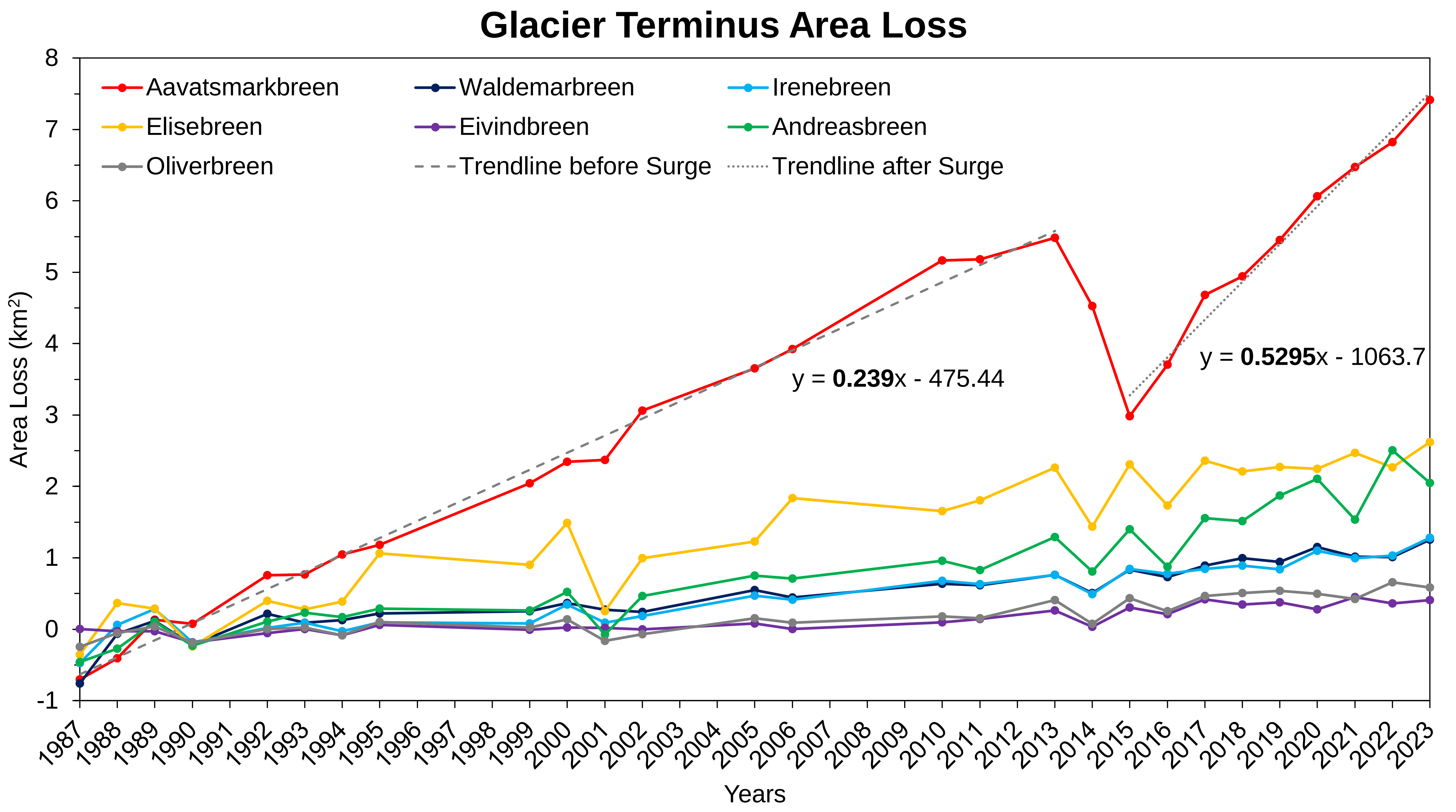
Glacier surge



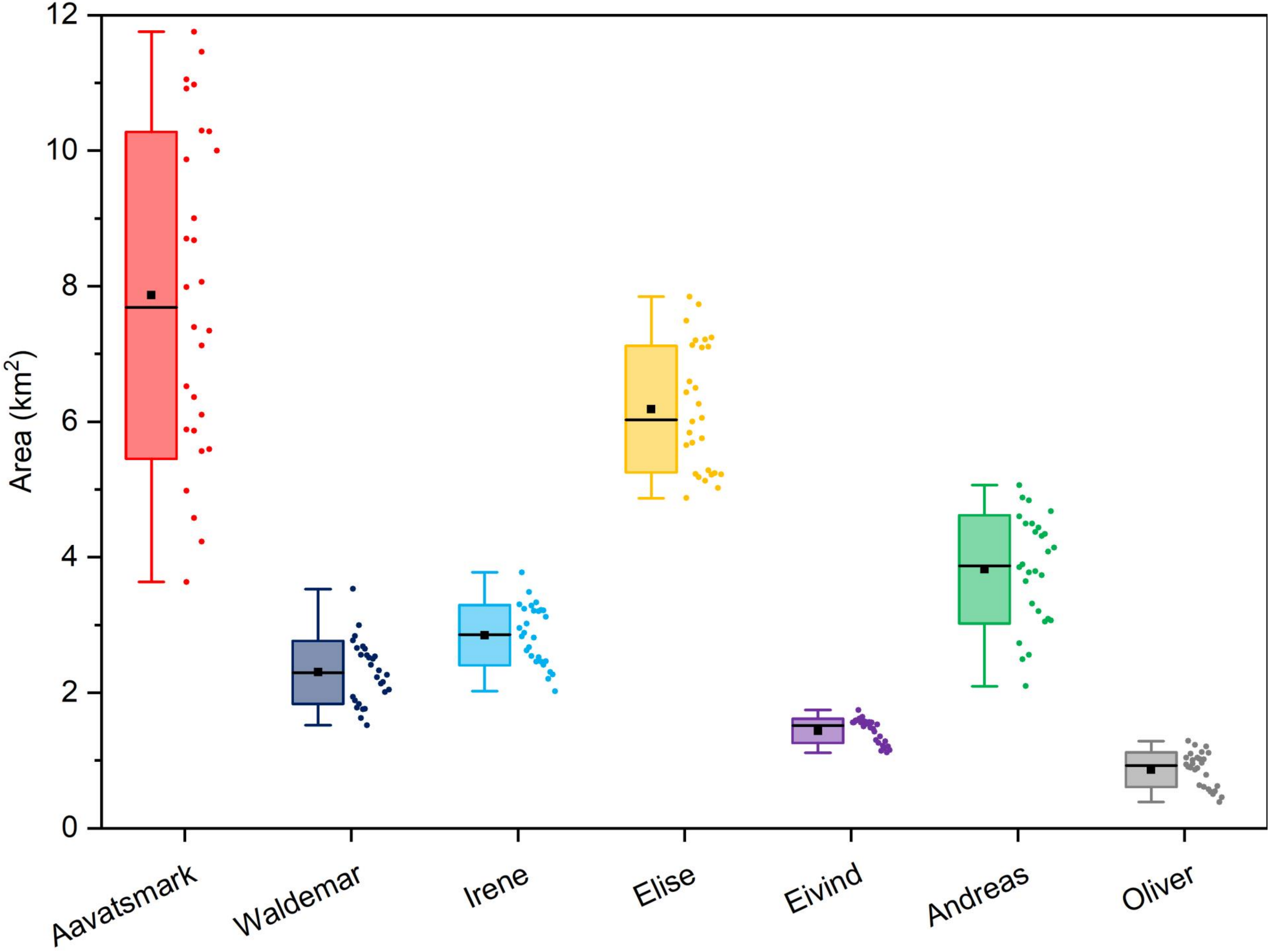


Glacier surge: mass advances rapidly due to accumulative water under glacier

Gain 2.5 km²

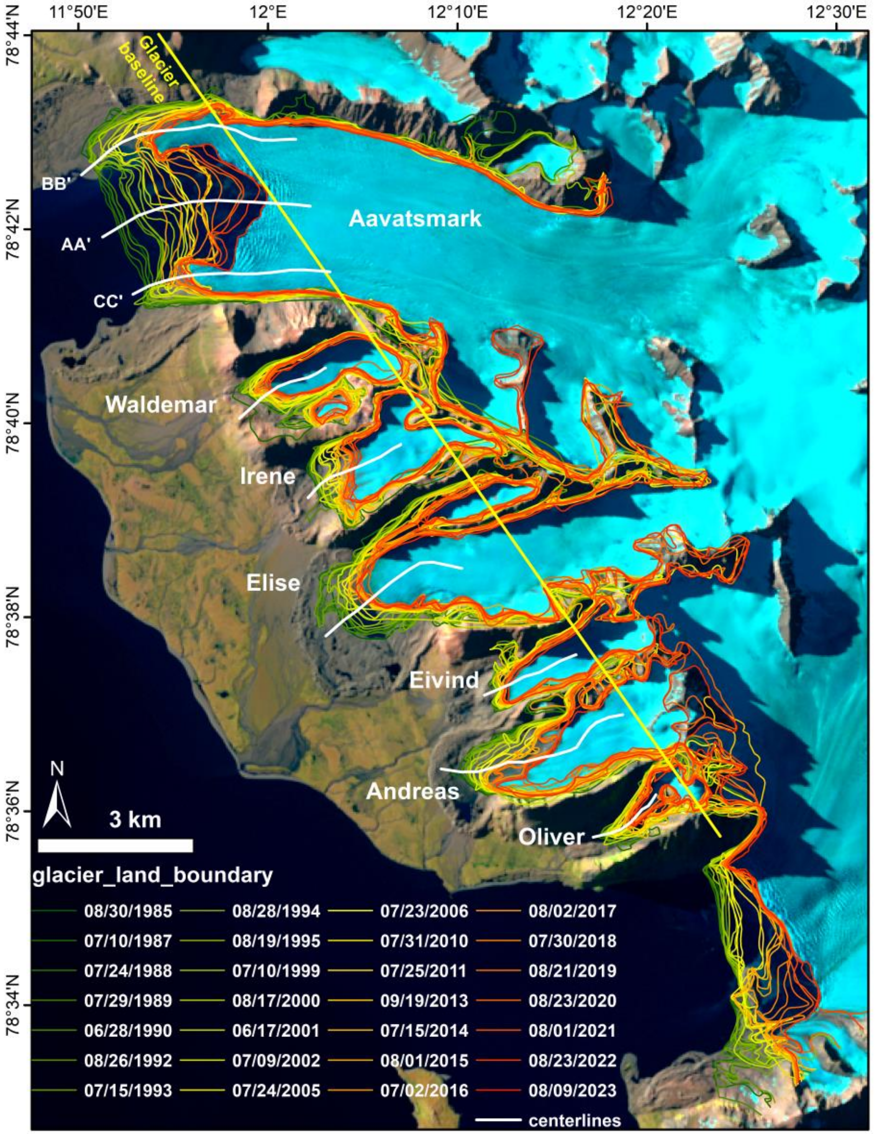


Glacier Terminus Area Loss
Aavatsmarkbreen
Waldemarbreen
Irenebreen
Elisebreen
Eivindbreen
Andreasbreen
Oliverbreen
Trendline before Surge
Trendline after Surge
y = 0.239x - 475.44
y = 0.5295x - 1063.7
Area Loss (km2)
Years
8
7
6
5
4
3
2
1
0
-1
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023

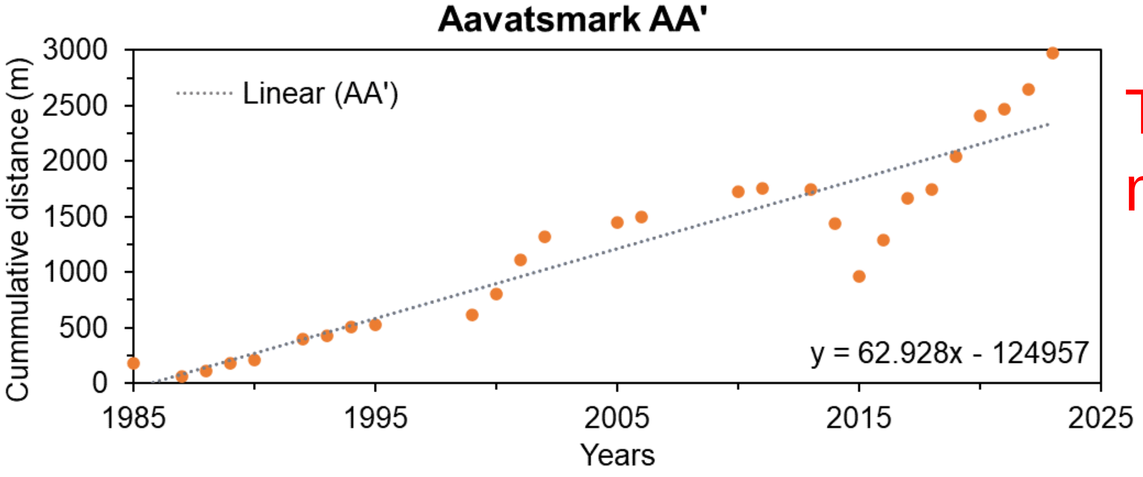

12
10
8
6
4
2
0
Area (km²)
Aavatsmark
Waldemar
Irene
Elise
Eivind
Andreas
Oliver

Results & Discussion

Glacier



No.	Glacier	Annual Regression Rate (m/yr)	Average Rate (m/yr)
1	Aavatsmarkbreen AA'	**62.93**	
2	Aavatsmarkbreen BB'	48.69	**43.74**
3	Aavatsmarkbreen CC’	19.62	
4	Waldemarbreen	9.24	
5	Elisebreen	19.48	
6	Irenebreen	22.96	**20.24**
7	Eivindbreen	7.03	
8	Andreasbreen	**43.74**	
9	Oliverbreen	18.99	

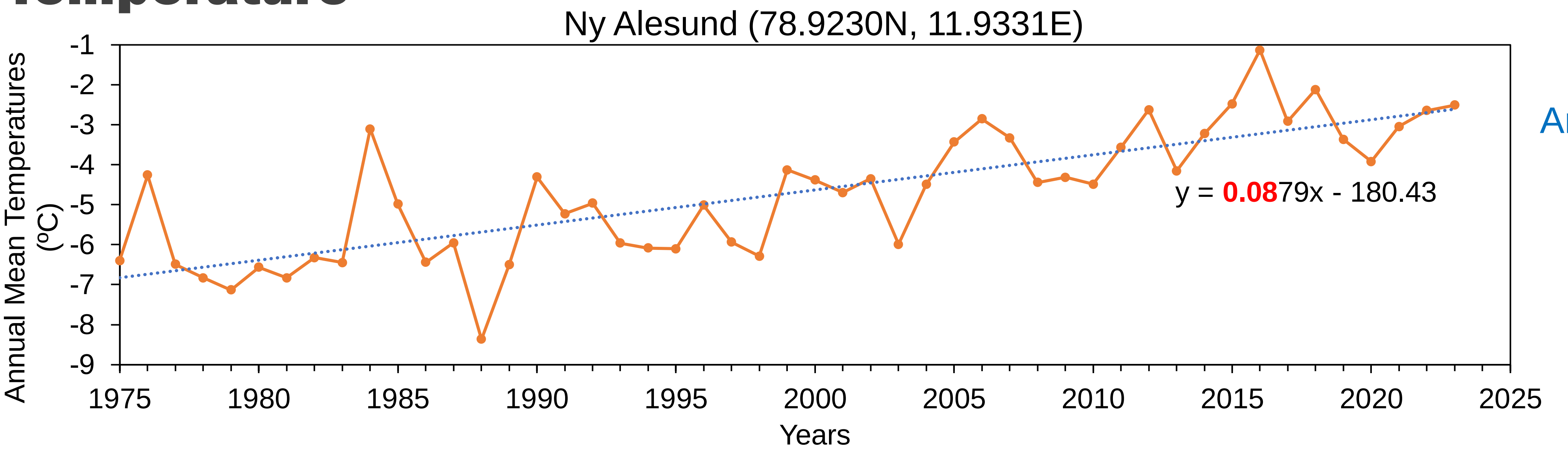


Tidewater glacier more vulnerable

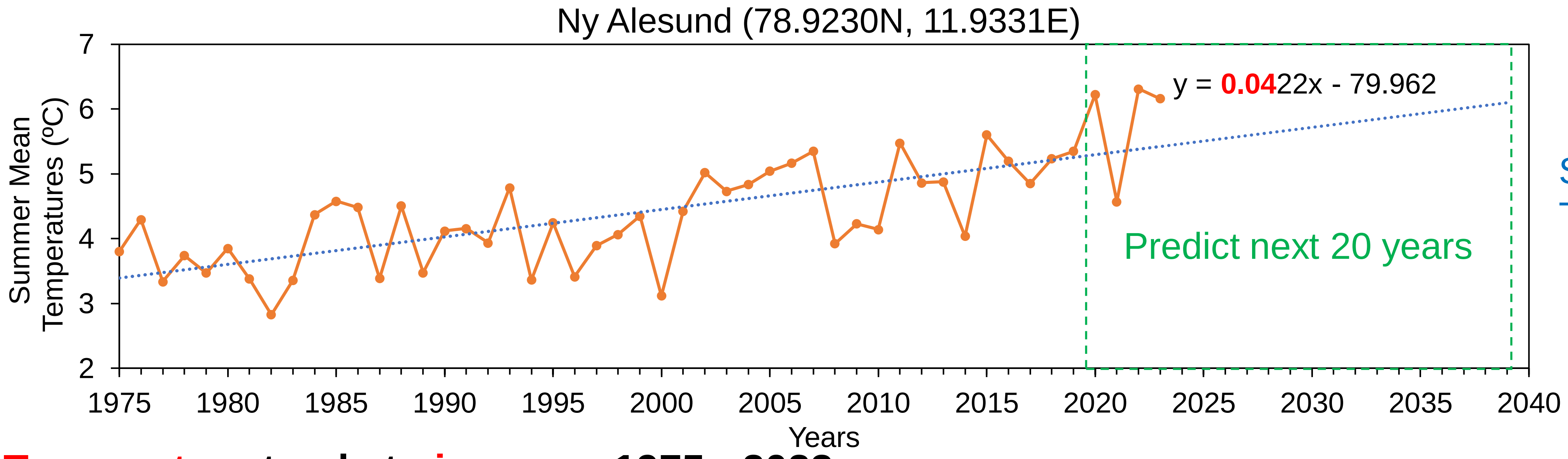
Results & Discussion

The station is **25km north** of Kaffiøyra

Temperature



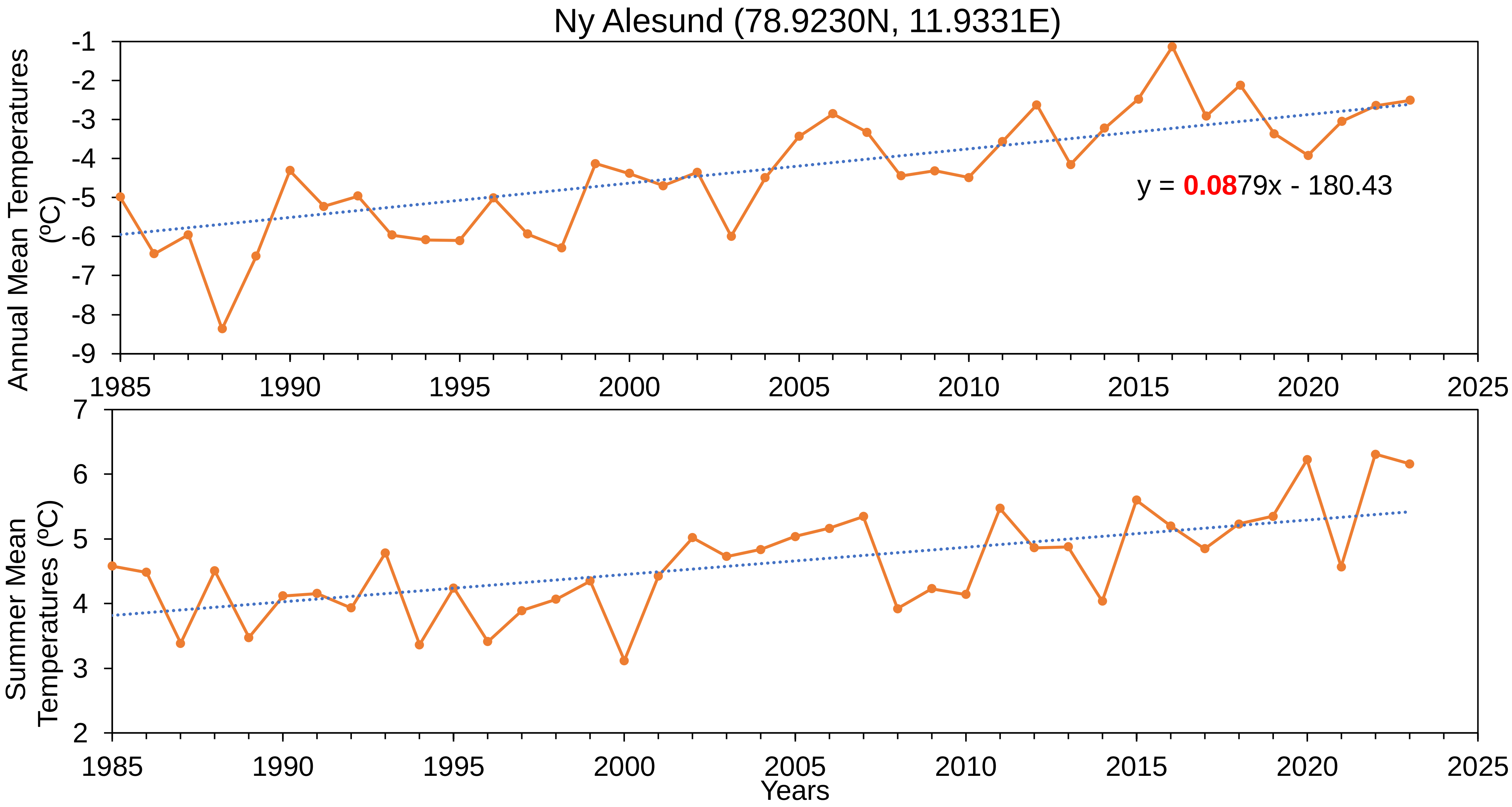
Annual Mean Temp.



Summertime Mean Temp. (Jun, Jul, Aug)

Temperature tends to increase 1975 - 2023

Data.GISS: GISS Surface Temperature Analysis (v4) (nasa.gov)


Ny Alesund (78.9230N, 11.9331E)
Annual Mean Temperatures (ºC)
y = 0.0879x - 180.43
Summer Mean Temperatures (ºC)
Years
-1
-2
-3
-4
-5
-6
-7
-8
-9
7
6
5
4
3
2
1985
1990
1995
2000
2005
2010
2015
2020
2025

Results & Discussion

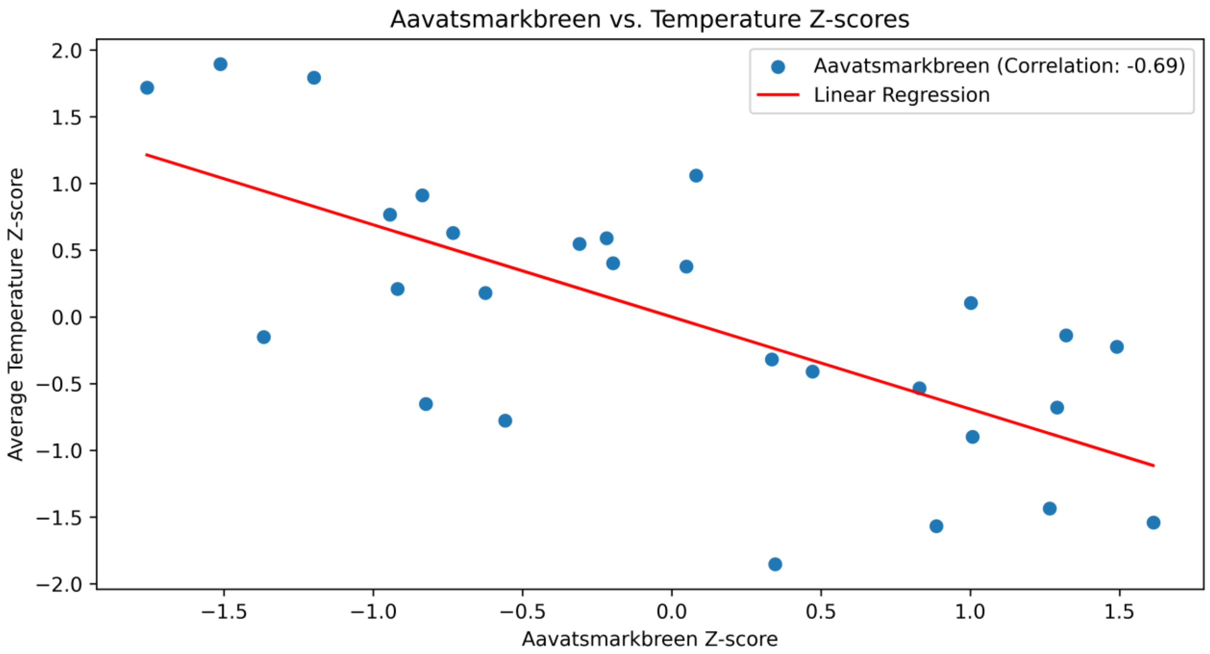
Correlation Temp. vs. Area

Z-score normalization 2 datasets

Negative correlation (-0.65 – -0.76)

avg. temperature in summertime vs. area

Higher Temp.=> lower glacier remaining Area



No.	Glaciers	Correlation coefficient (r)
1	Aavatsmarkbreen	-0.69
2	Waldemarbreen	-0.71
3	Irenebreen	-0.73
4	Elisebreen	-0.65
5	Eivindbreen	-0.67
6	Andreasbreen	-0.76
7	Oliverbreen	-0.72

Results & Discussion

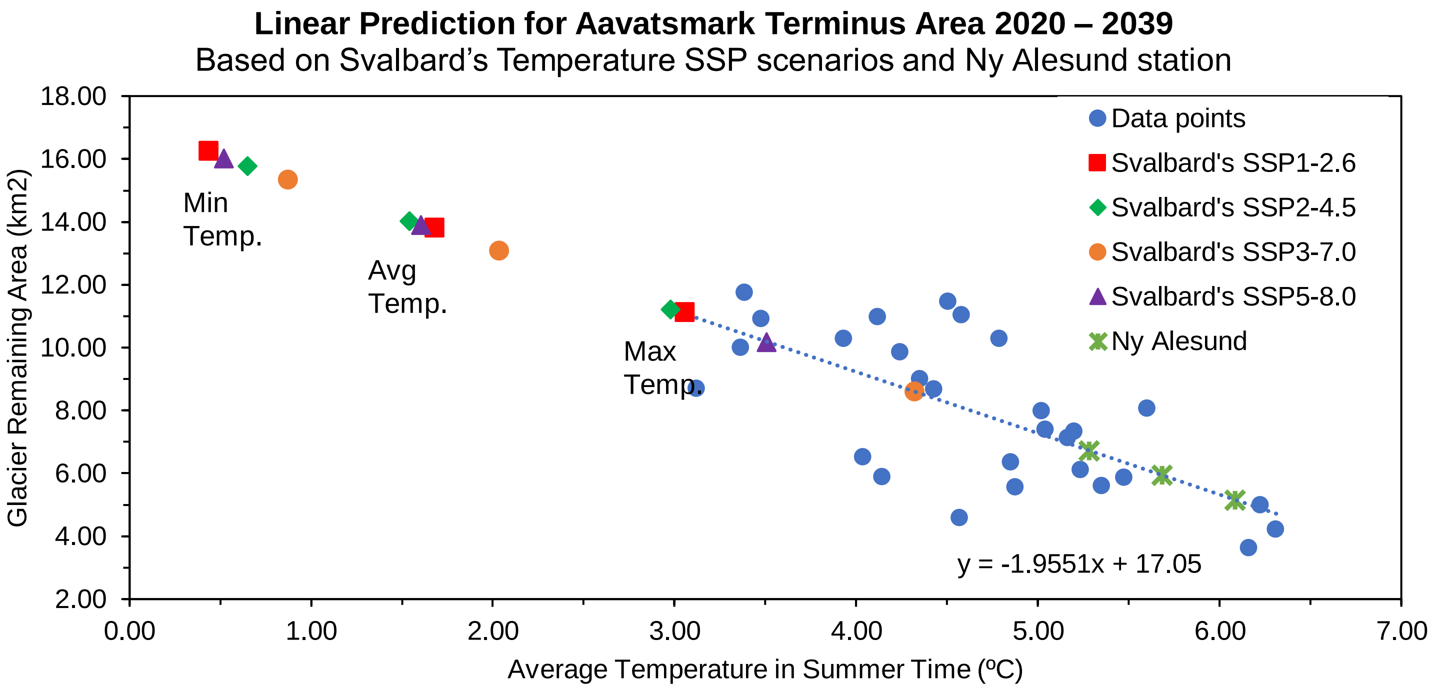
Predict future area changes

Temperature input:

SSP scenarios of Svalbard, 2020 – 2039

Ny Alesund's linear avg. summer, 2020 - 2039

SSPs: Shared Socioeconomic Pathways



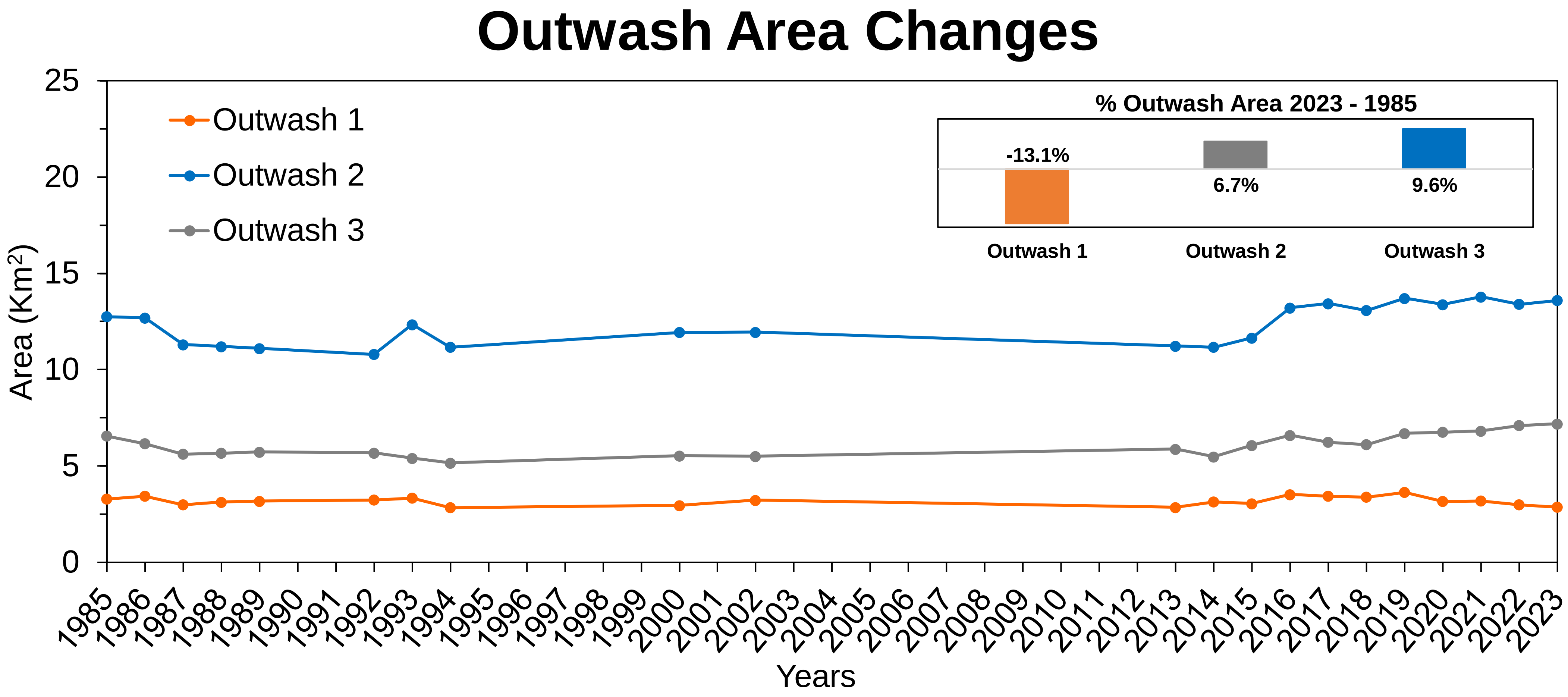
Source	Summertime Mean Temperature (ºC)			Remaining Area (km²)			Different percentage compared with 2023 (3.63 km²)(%)		
	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.
SSP1-2.6	0.44	1.68	3.06	16.25	13.81	11.13	77.66	73.71	67.39
SSP2-4.5	0.65	1.54	2.98	15.78	14.04	11.23	77.00	74.15	67.68
SSP3-7.0	0.87	2.04	4.32	15.34	13.07	8.60	76.34	72.23	57.79
SSP5-8.0	0.52	1.60	3.51	16.03	13.91	10.19	77.35	73.90	64.38
Ny Alesund	5.28	5.68	6.08	6.72	5.94	5.16	45.98	38.89	29.65

SSPs cannot capture the current changes

Ny Alesund data closely to current status

Results & Discussion

Outwash



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 changes vary in different zones

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

Strongly eroded in zone 2, 4: LRR vary - 65 to +10 m/yr, erosion predominate

Changes are mainly in tidewater glacier, land's shoreline not significant

(2) Glacier terminus area and rate tend to decrease

Aavatsmark area lost: 63.1%; avg. rate retreat 43.74 m/yr

Avg. land glacier area lost: 40.9%; avg. rate retreat 20.24 m/yr

→ Tidewater glacier more vulnerable under same climate conditions.

Negative correlation (-0.65 to -0.76) between temp. and glacier area

Conclusion

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

(4) Using regional climate change scenarios temperature cannot capture current status

Highlighted the crucial of monitoring systems to design suitable strategies for climate change