EGU2022

Little Ice Age glacier mapping from web map services

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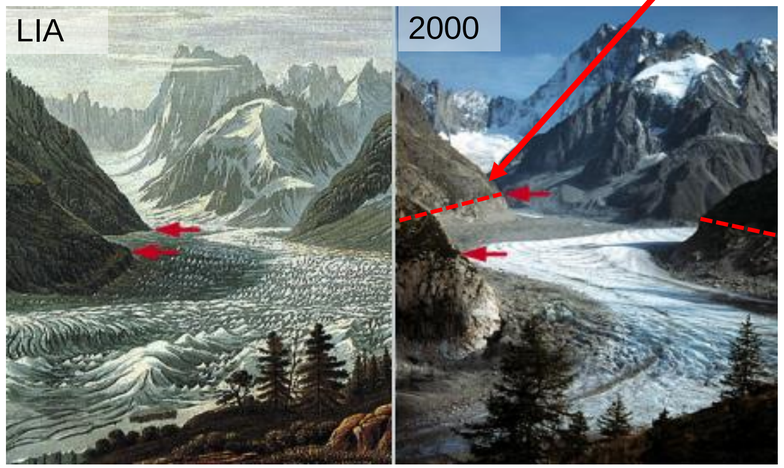
How can the Little Ice Age (LIA) glacier extent be mapped?

Old images and paintings; Field mapping

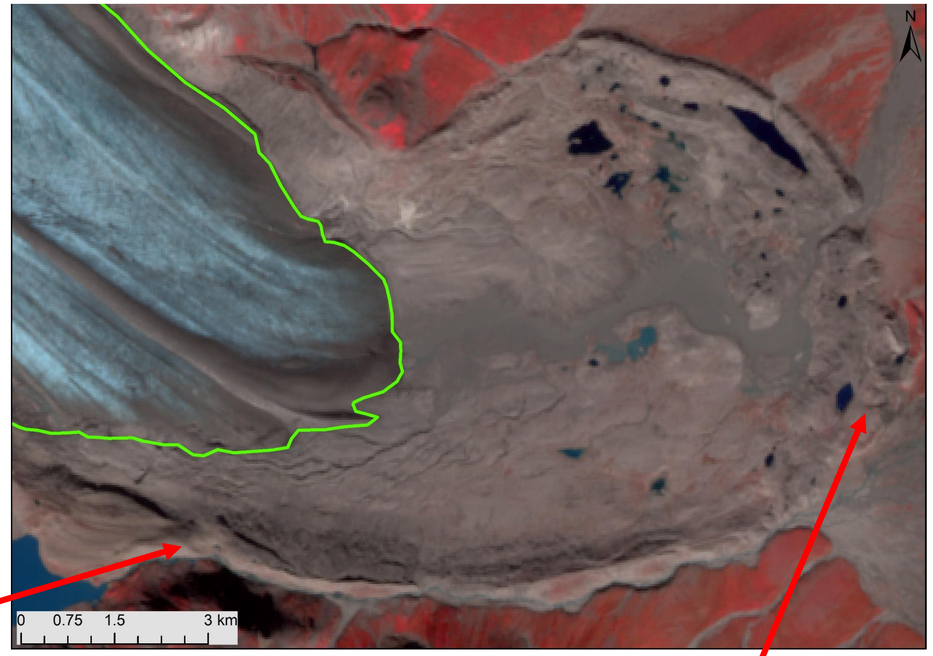
Pasterze, Österreich https://kurier.at/wissen/oesterreichs-gletscher-bilder-eines-niedergangs/400318197

Trim lines

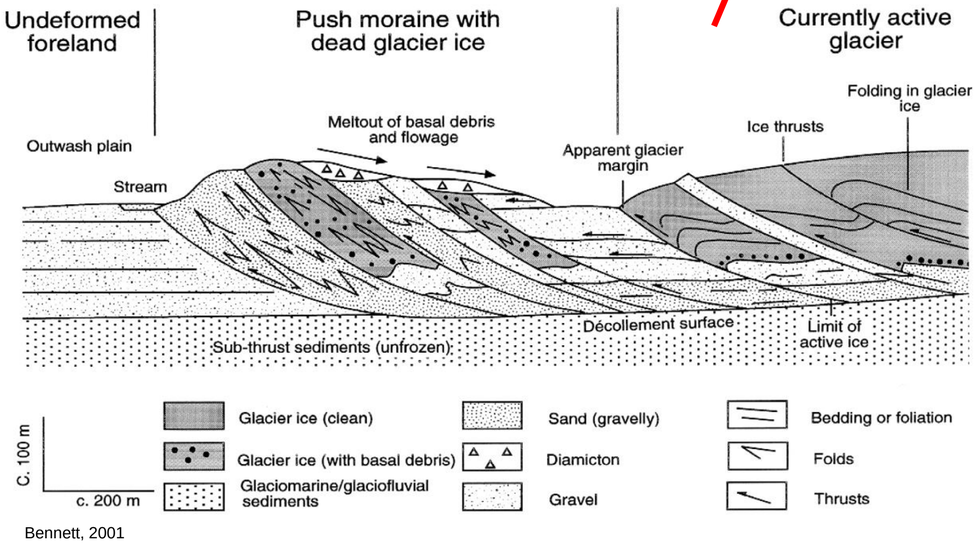


Mer de Glace - https://www.swisseduc.ch/glaciers/glossary/little-ice-age-two-en.html

Satellite images up to 10 m resolution (Sentinel 2)

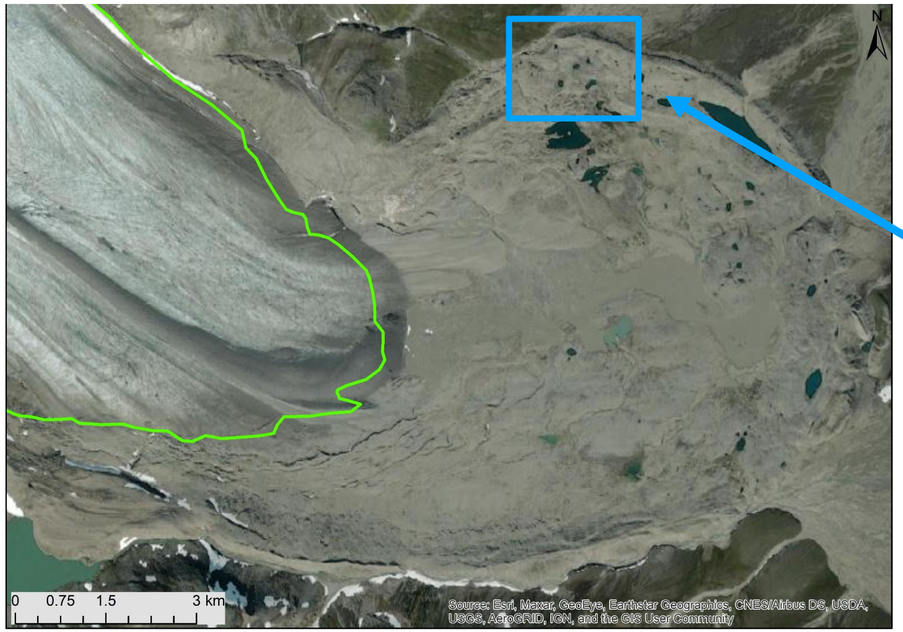


End/push moraines

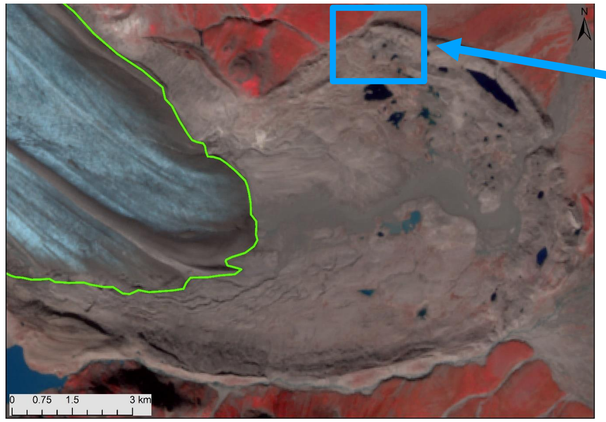


Bennett, 2001

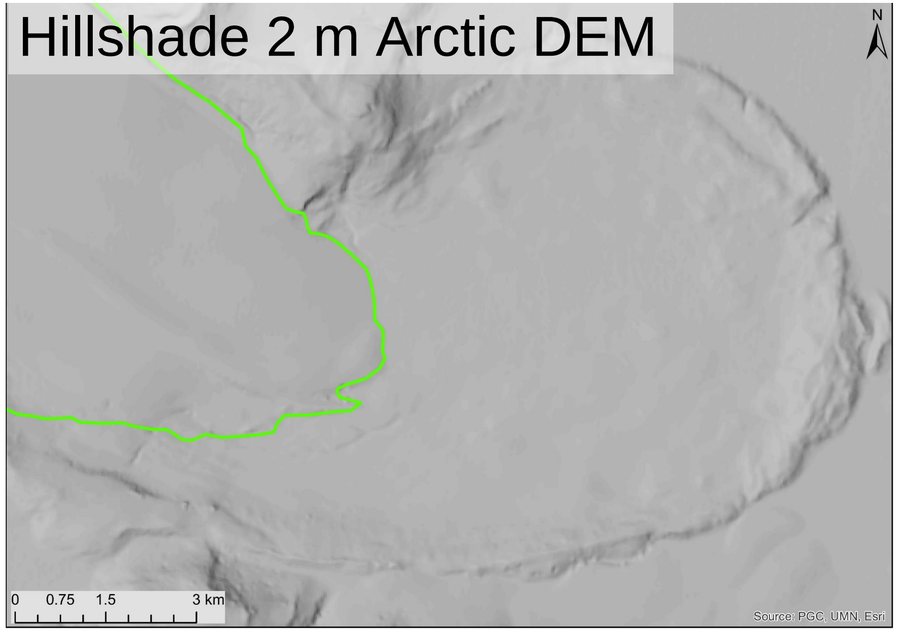
High-resolution web map services (wms)

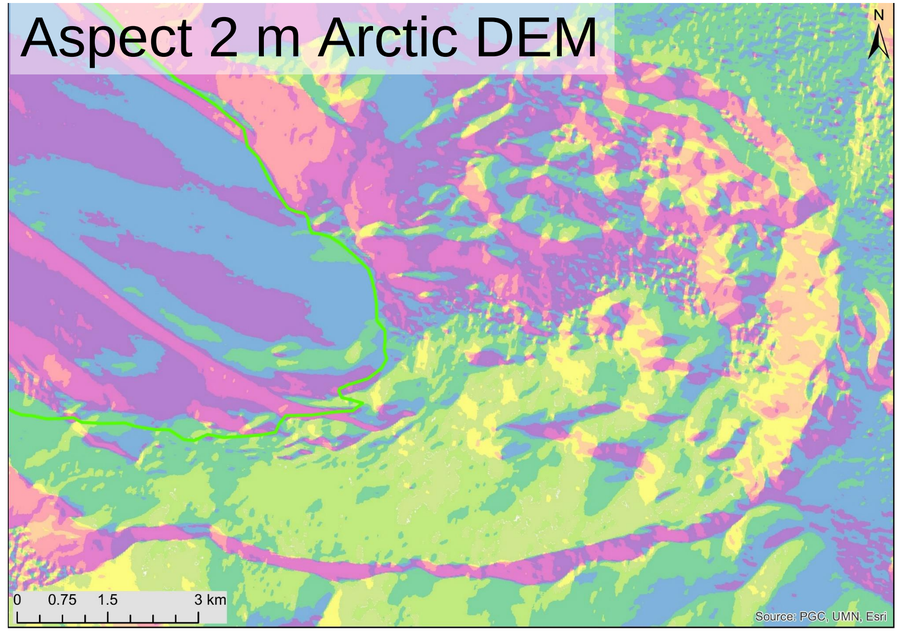


High resolution ESRI basemap (0.5 m)



10 m Sentinel 2





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Study regions

General approach

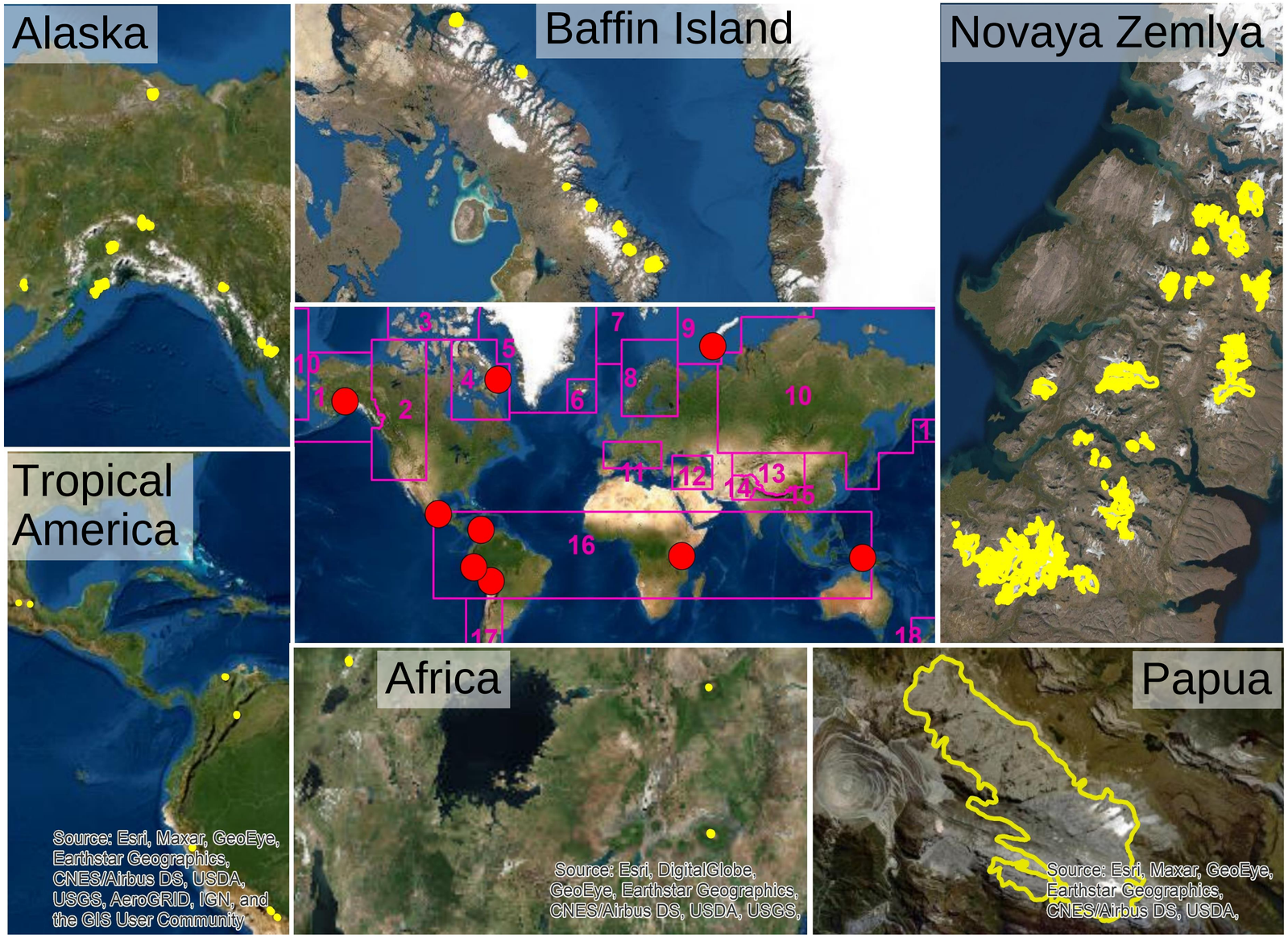
- LIA glacier mapping for selected regions
- ~ 100 glaciers per region
- Glacier from different size classes and climate regimes

Focus on Arctic regions due to:

- the significance in SLR contribution
- Few datasets available
- Inaccessible, thus great for remote sensing

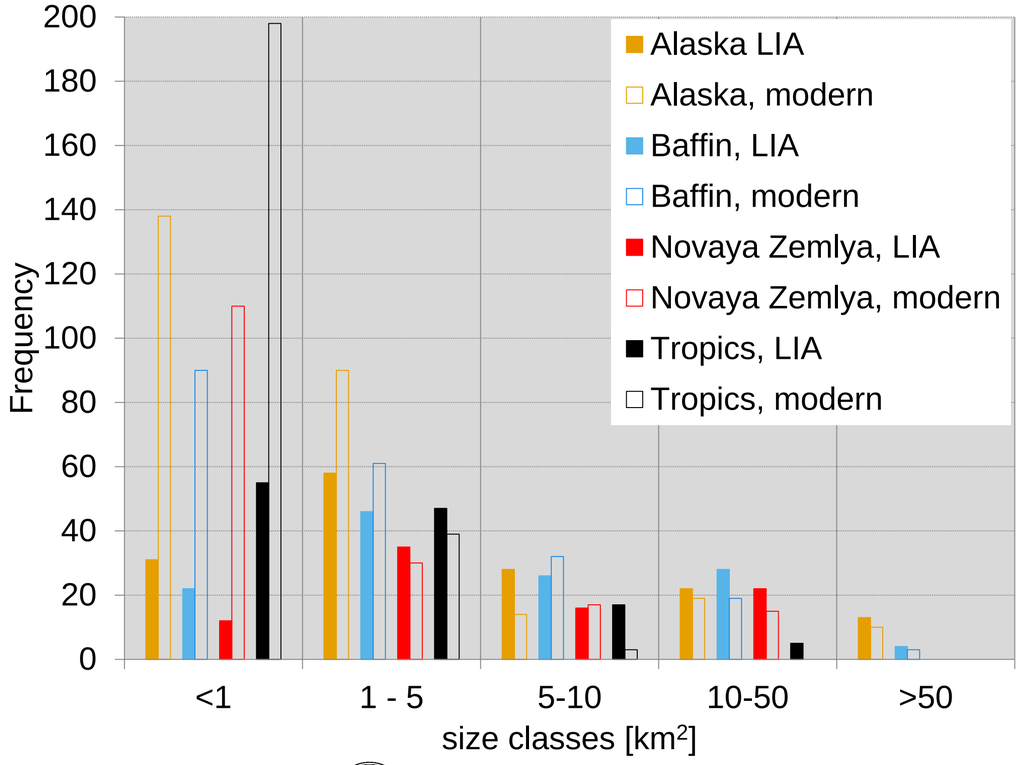
Tropical regions also included due to:

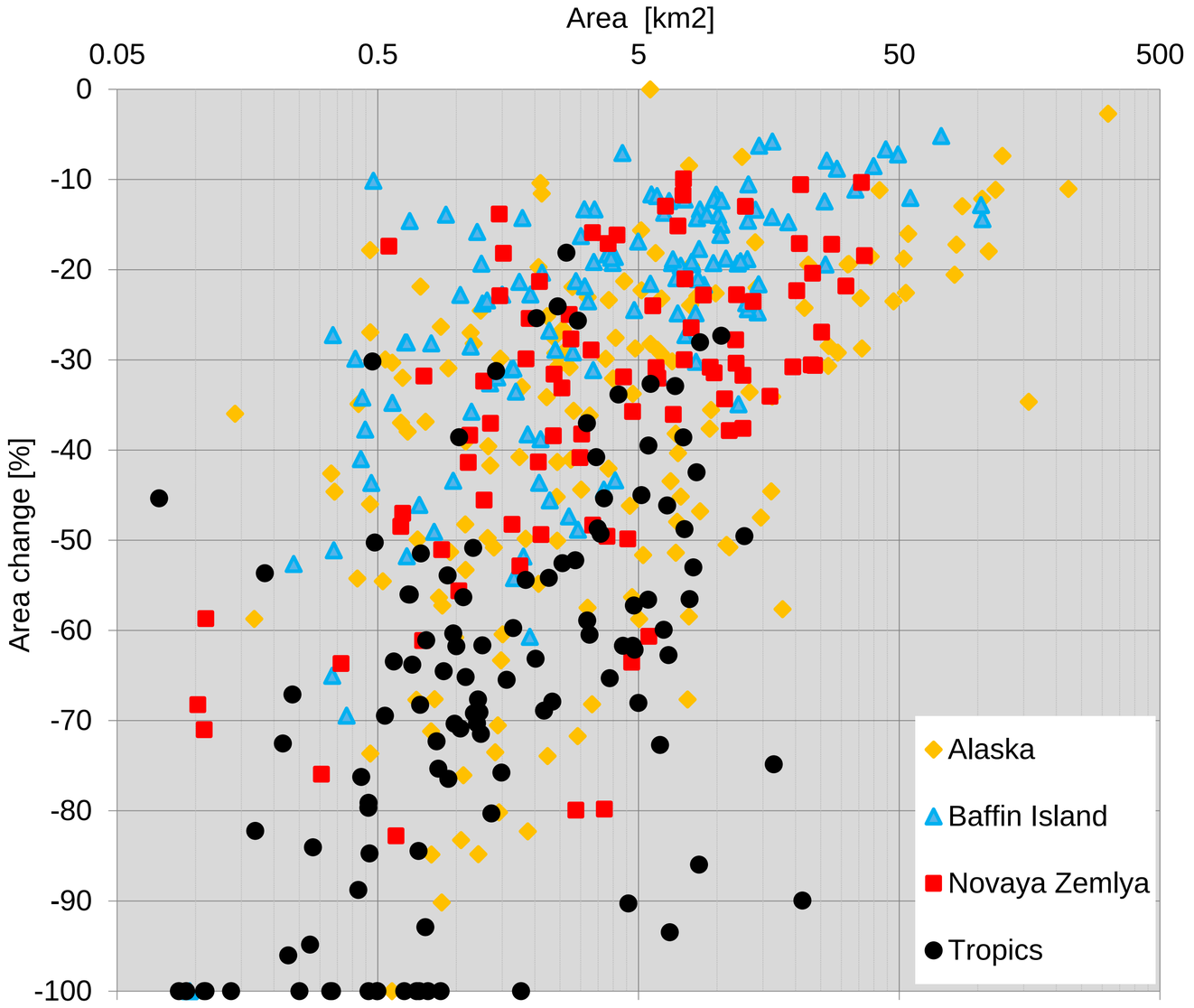
- Importance of glaciers as water resource
- Only few datasets



Results

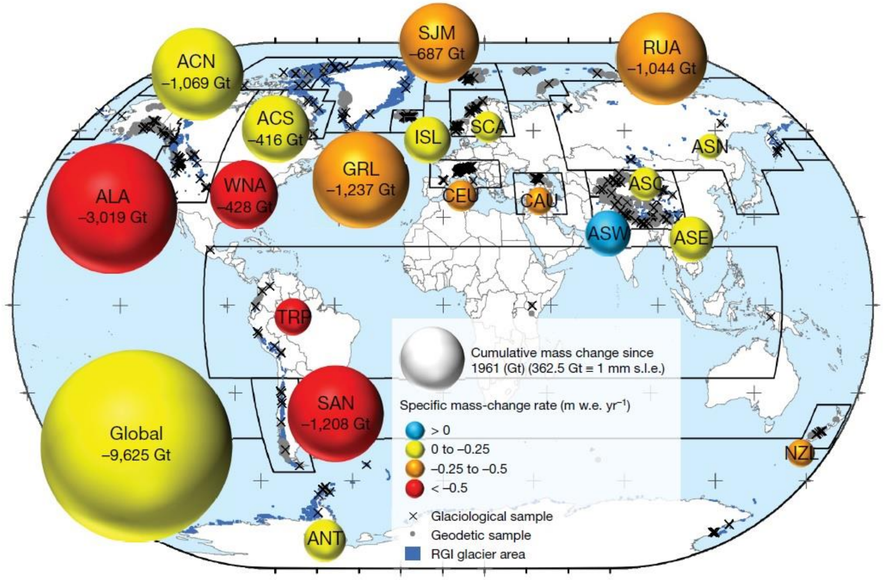
- 489 analysed LIA glaciers => 888 ice bodies today
- Min. 25 melted completely
- Area change: -20% (Alaska), -15.2% Baffin Island), -26% Novaya Zemlya), -60.7% (Tropics)



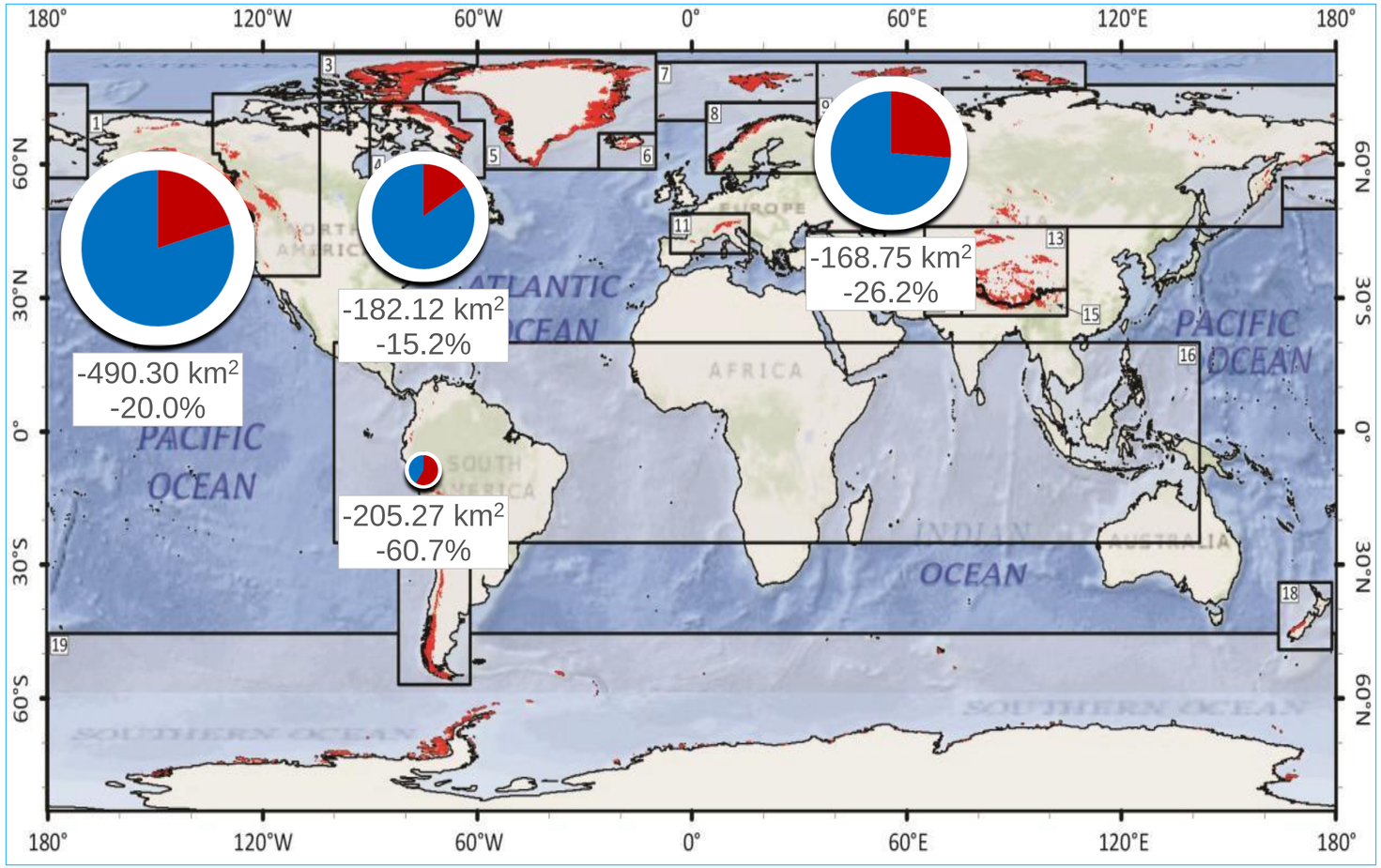


Glacier change per region

- Largest relative change in tropics
- But Arctic regions hold much more total glacier area (potential SLR)



Zemp et al. 2019

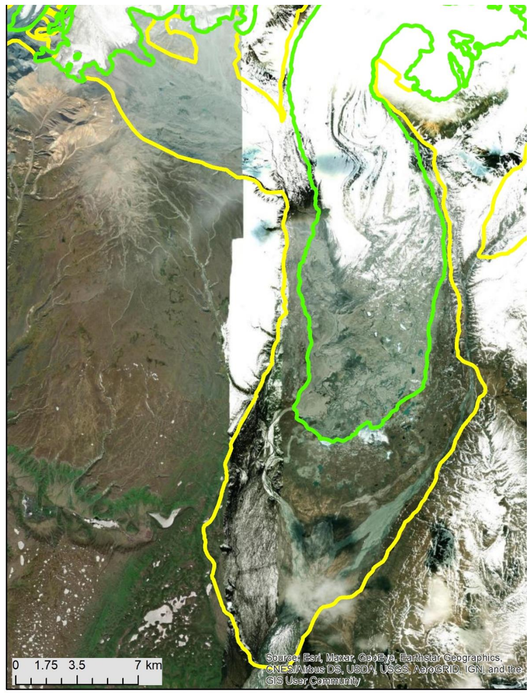


Alaska

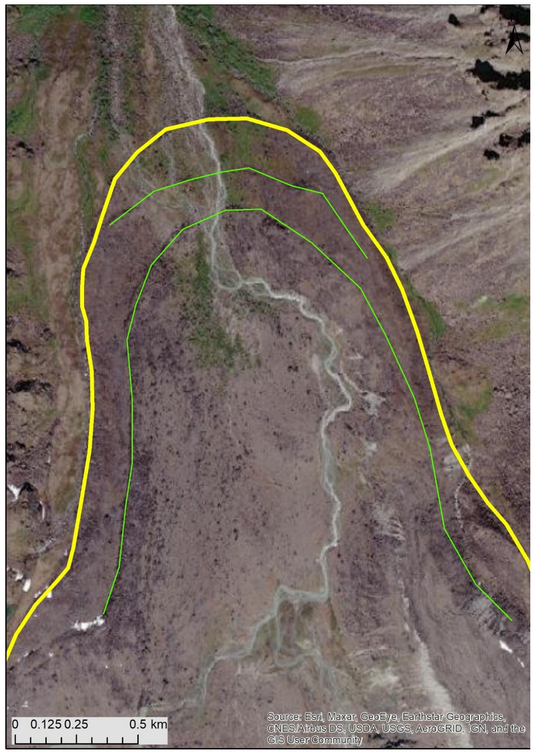
- Number of glaciers LIA: 152, 2008: 271
- Area LIA: 2449 km^2 , 2008: 1959 km^2
- Area change: -20% (-490 km^2)

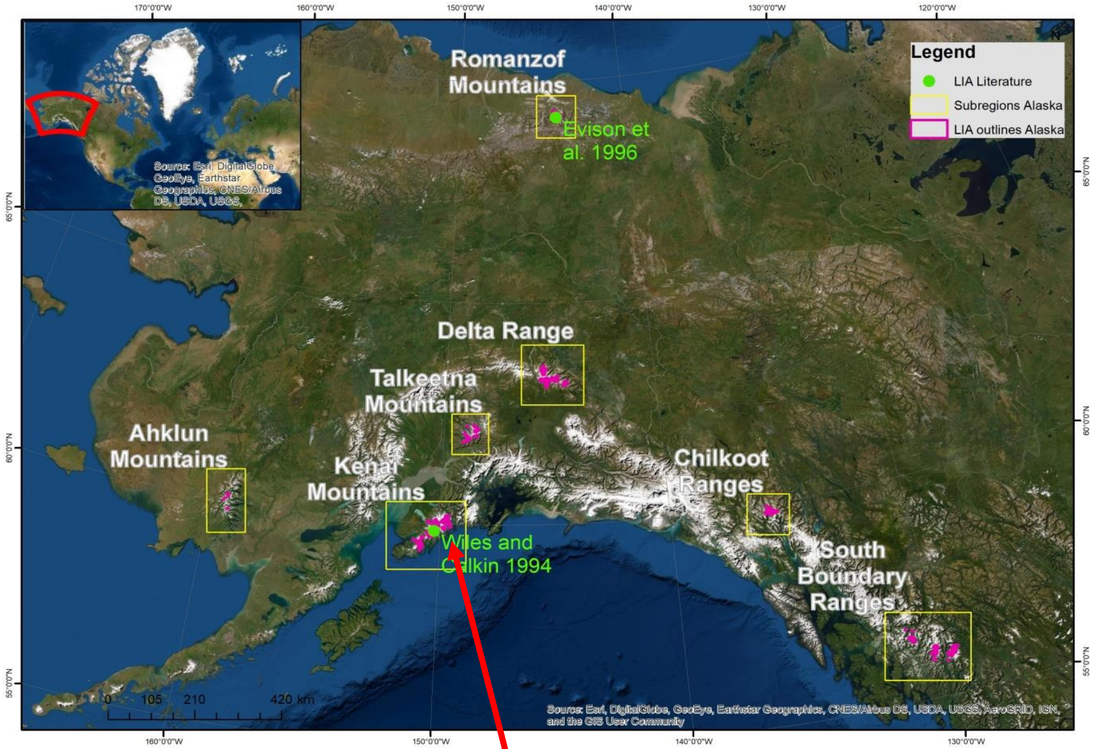
Difficulties:

Snow cover, quality of Esri basemap

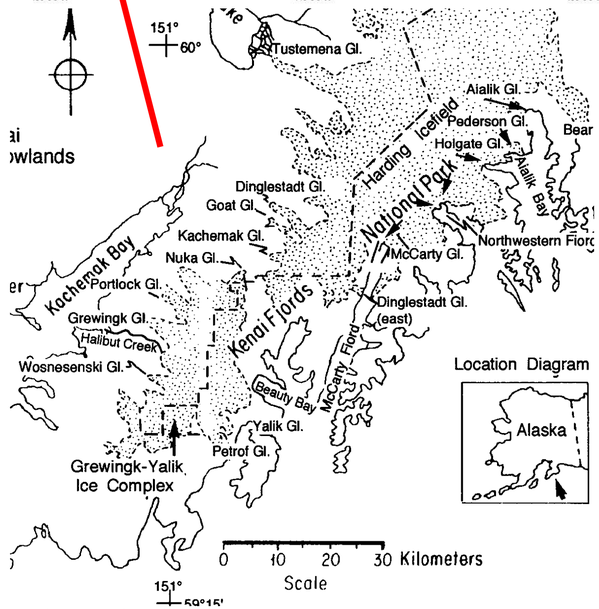


Multiple moraines





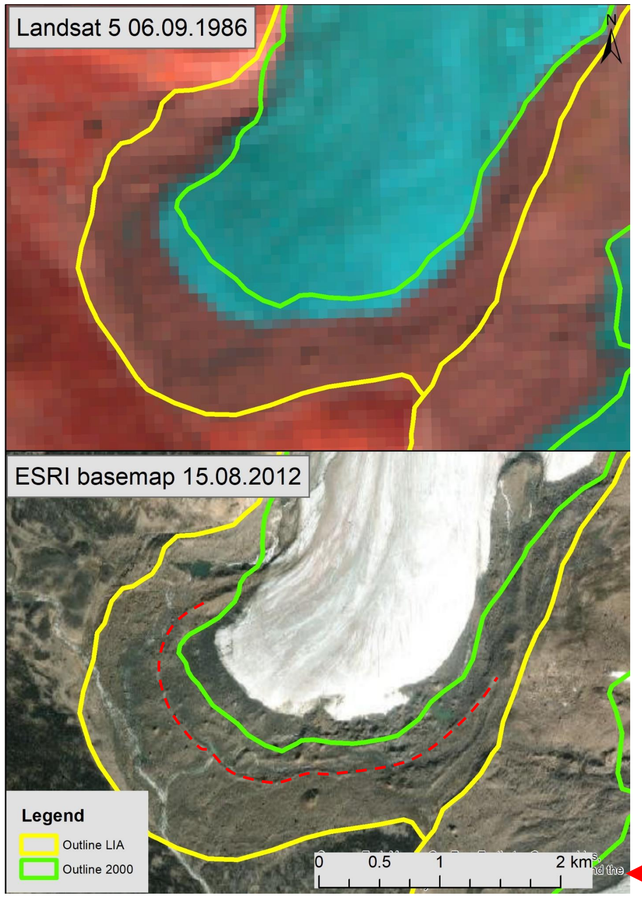
9 glaciers with dating source (1724-1904)

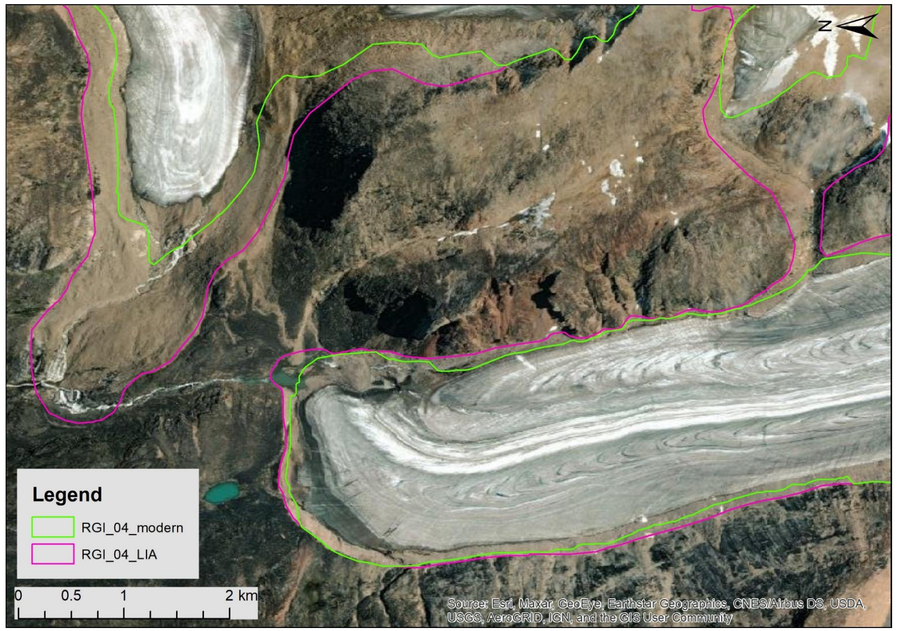


Wiles and Calkin 1994

Baffin Island

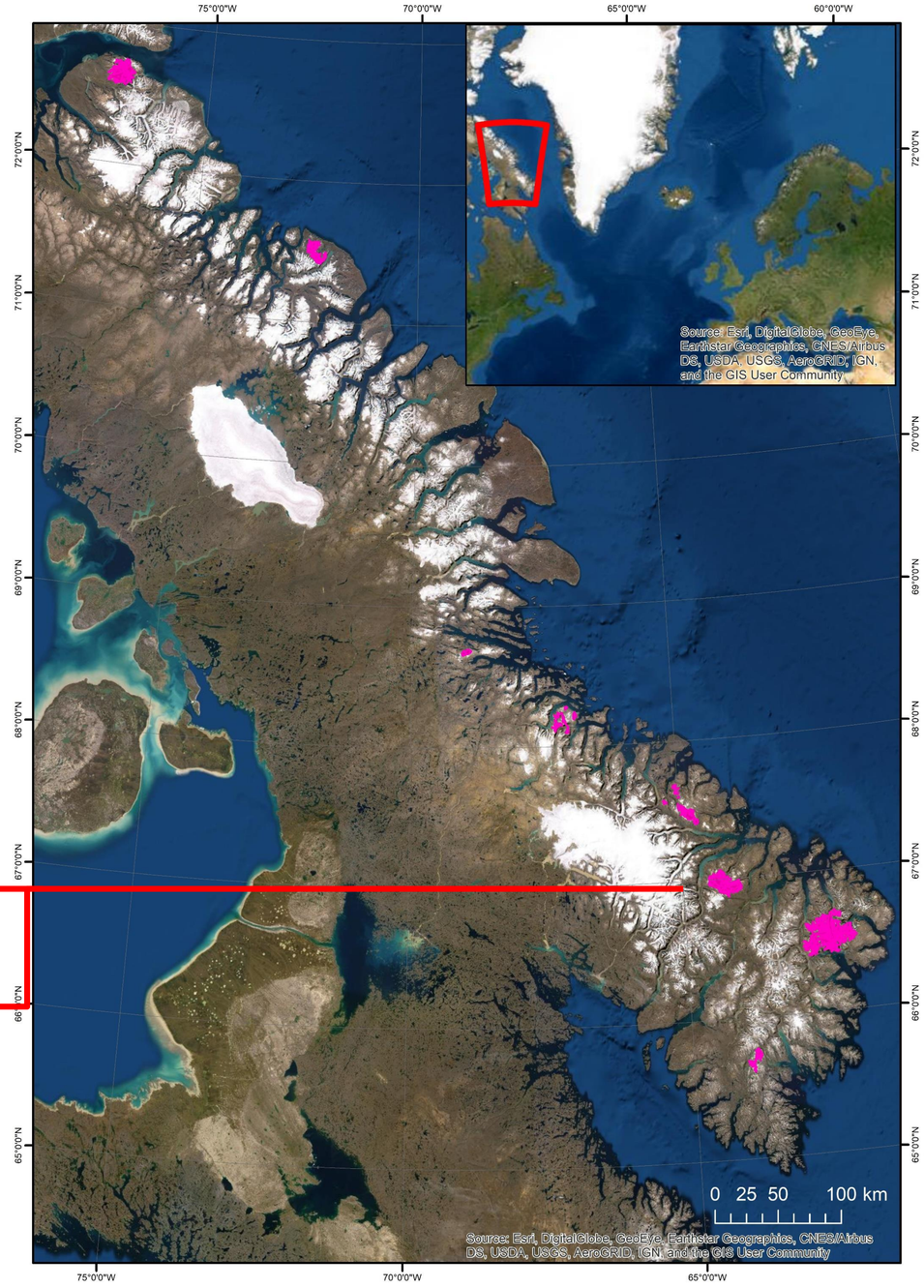
- Number of glaciers LIA: 126, 2000: 205
- Area LIA: 1198 km^2 , 2000: 1016 km^2
- Area change: -15% (-182 km^2)
- -12.5 % from Paul & Svoboda (2009)





Small moraine from the 1980s

Not much change since LIA

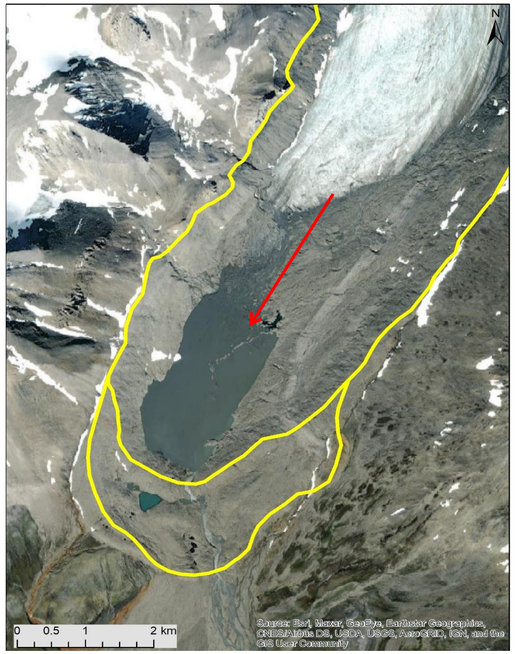


Novaya Zemlya

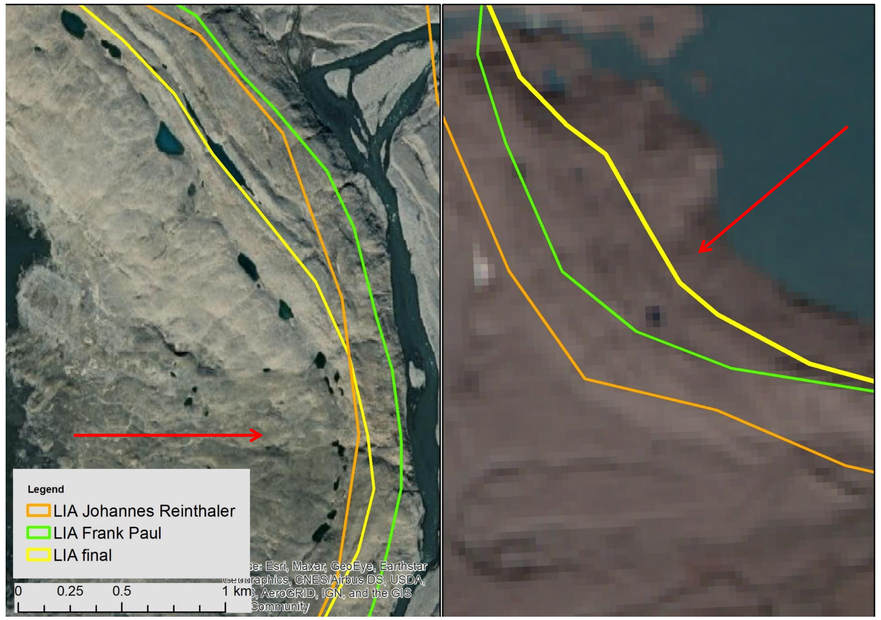
- Number of glaciers LIA: 85, 2016 172
- Area LIA: 644 km^2 , 2016: 475 km^2
- Area change: -26% (-169 km^2)

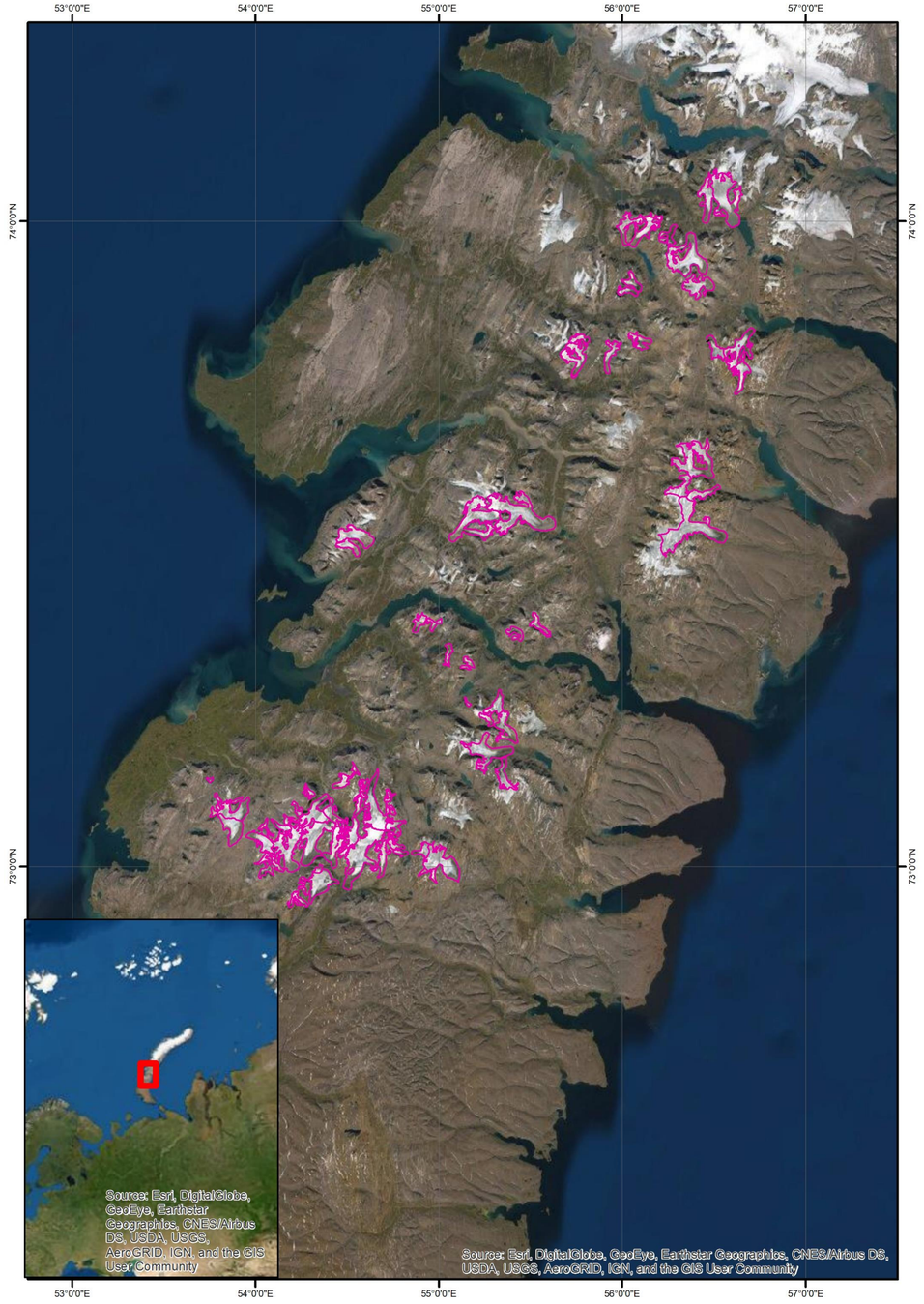
Difficulties:

multiple moraine belts



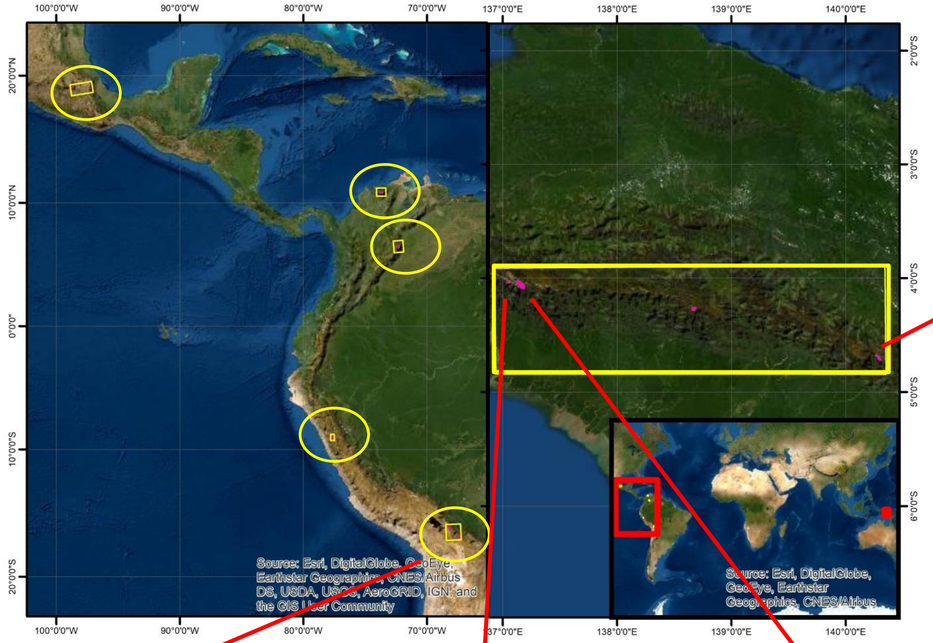
interpretation of push moraines

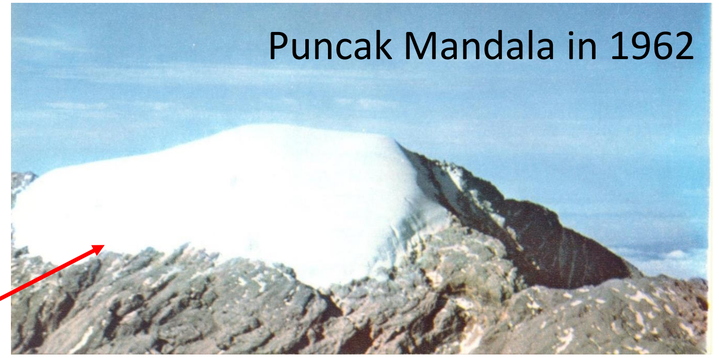




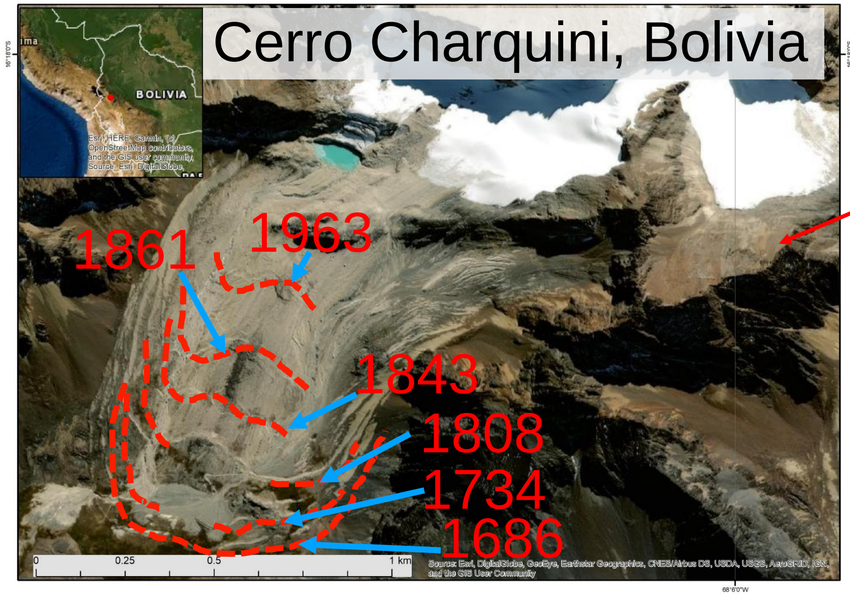
Tropics

- Number of glaciers LIA: 126, modern 240
- Area LIA: 310.5 km^2 , 2010 129 km^2
- Area change: -58% (-181.5 km^2)





Published in “To The Mountains of the Stars” 1962

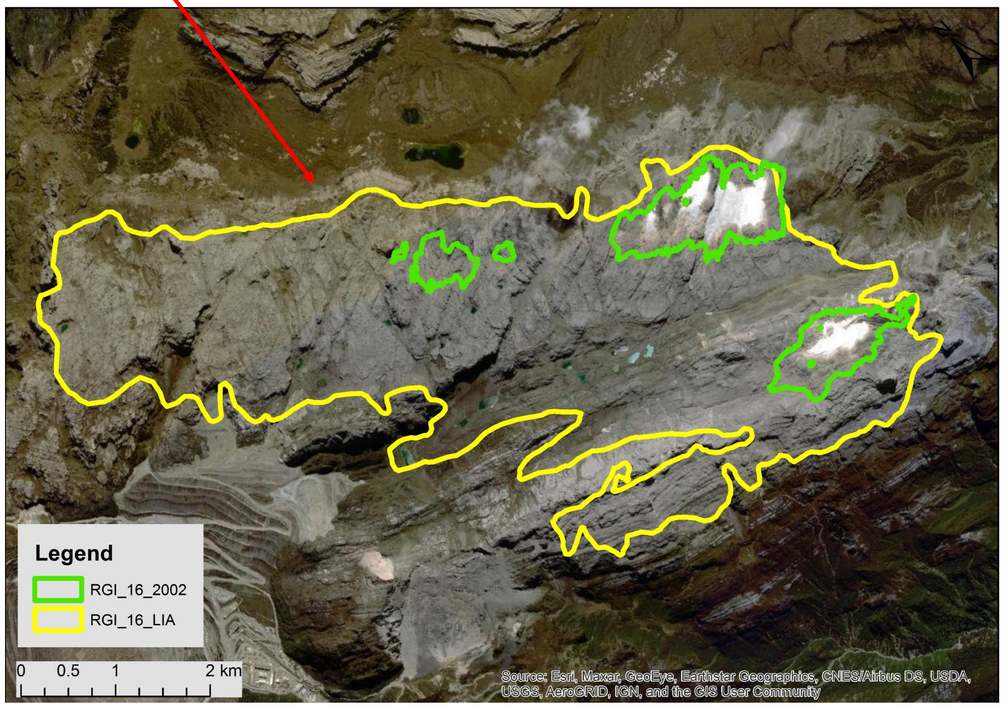


11 glaciers with dates (Rabatel et al. 2006, 2008)

Ngga Pilimsit 1972

Photo acquired during the Carstensz Glacier Expeditions

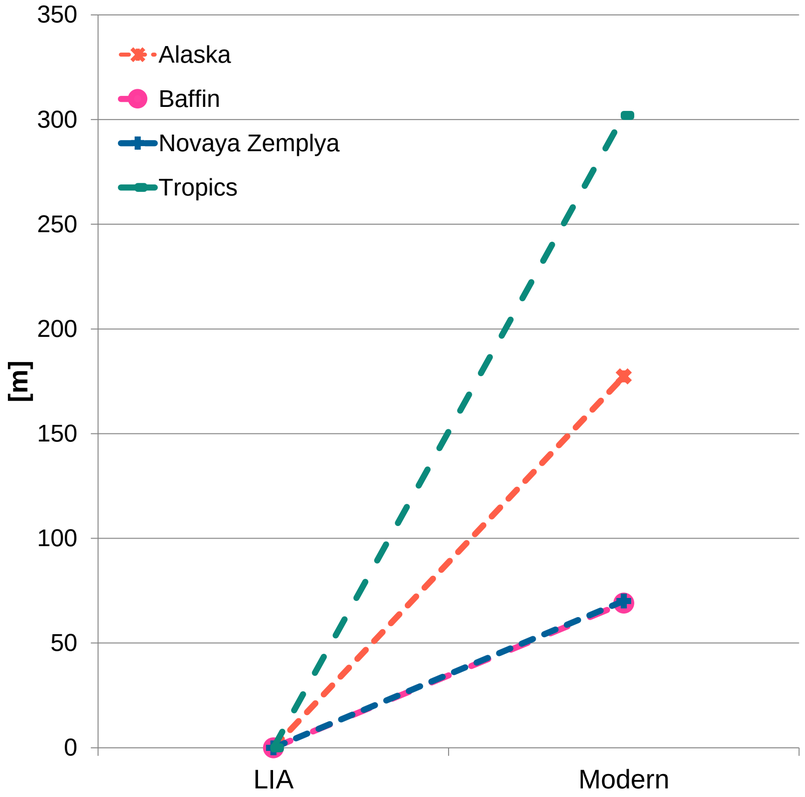
Puncak Jaya



Change in topographic parameters

	Nr. of glaciers	Average quality	Area (LIA)	Area (modern)	Relative change [%]	Chantge rate [% a^{-1}] (Time period)	Change in min elevation
Alaska	152	2.9	2449.27	1958.97	-20.0	-0.14 (1864-2008)	177±130
Baffin Island	126	2.5	1198.41	1016.28	-15.2	-0.10 (1850-2000)	70±89
Novaya Zemlya	85	3.1	644.01	475.26	-26.2	-0.16 (1850-2016)	70±58
Tropical South America	110	2.4	275.23	125.38	-54.4	-0.15 (1647-2003)	297±186
Mexico	2	2.0	15.13	0.73	-89.2	-0.60 (1850-1999)	596±6
Africa	13	2.1	27.52	3.68	-86.6	-0.76 (1888-2002)	227±176
Papua	1	2.0	21.26	2.14	-89.9	-0.71 (1875-2002)	186

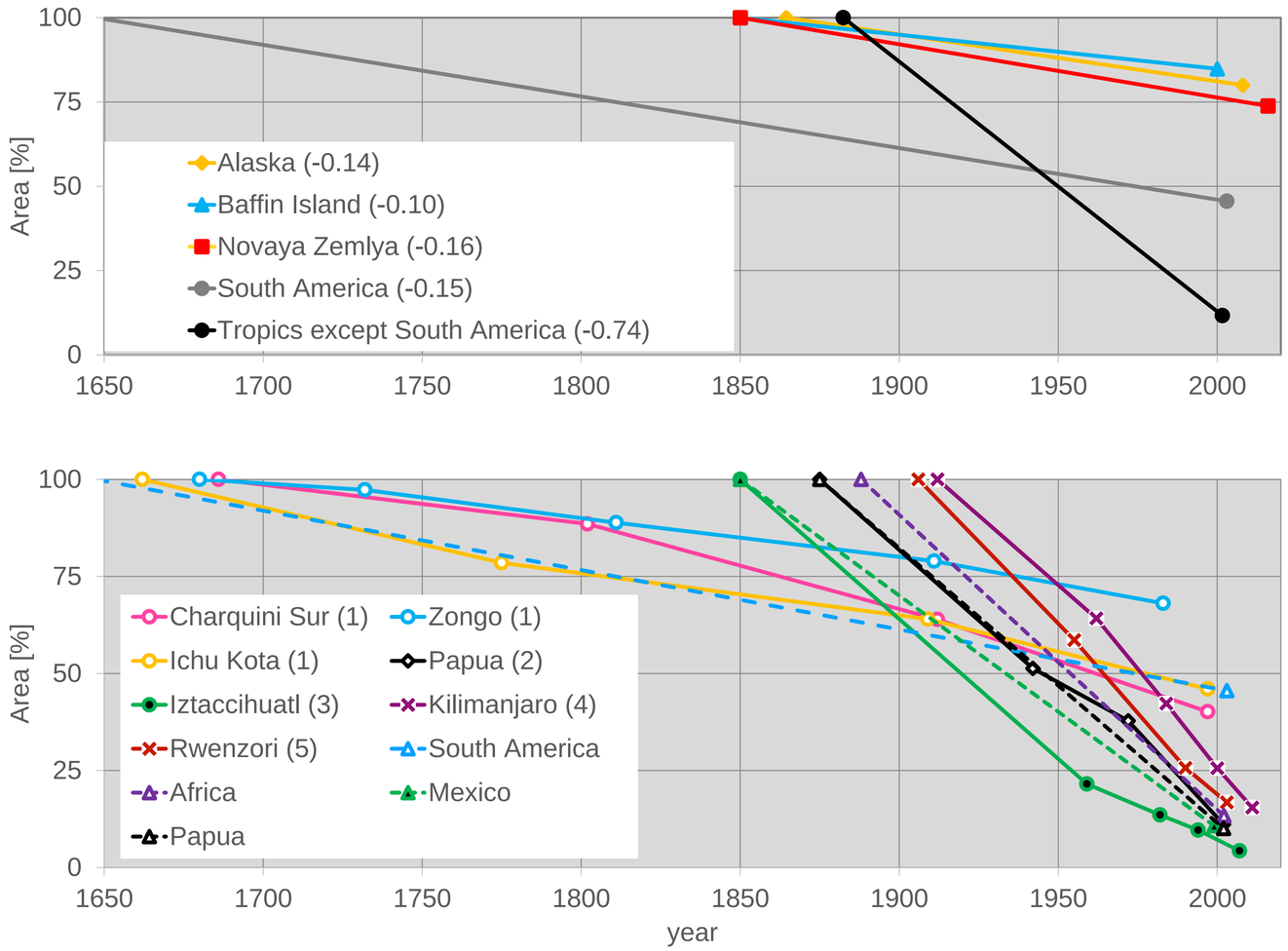
Change of min. elevation



Largest elevation change in tropics and Alaska

Change rates

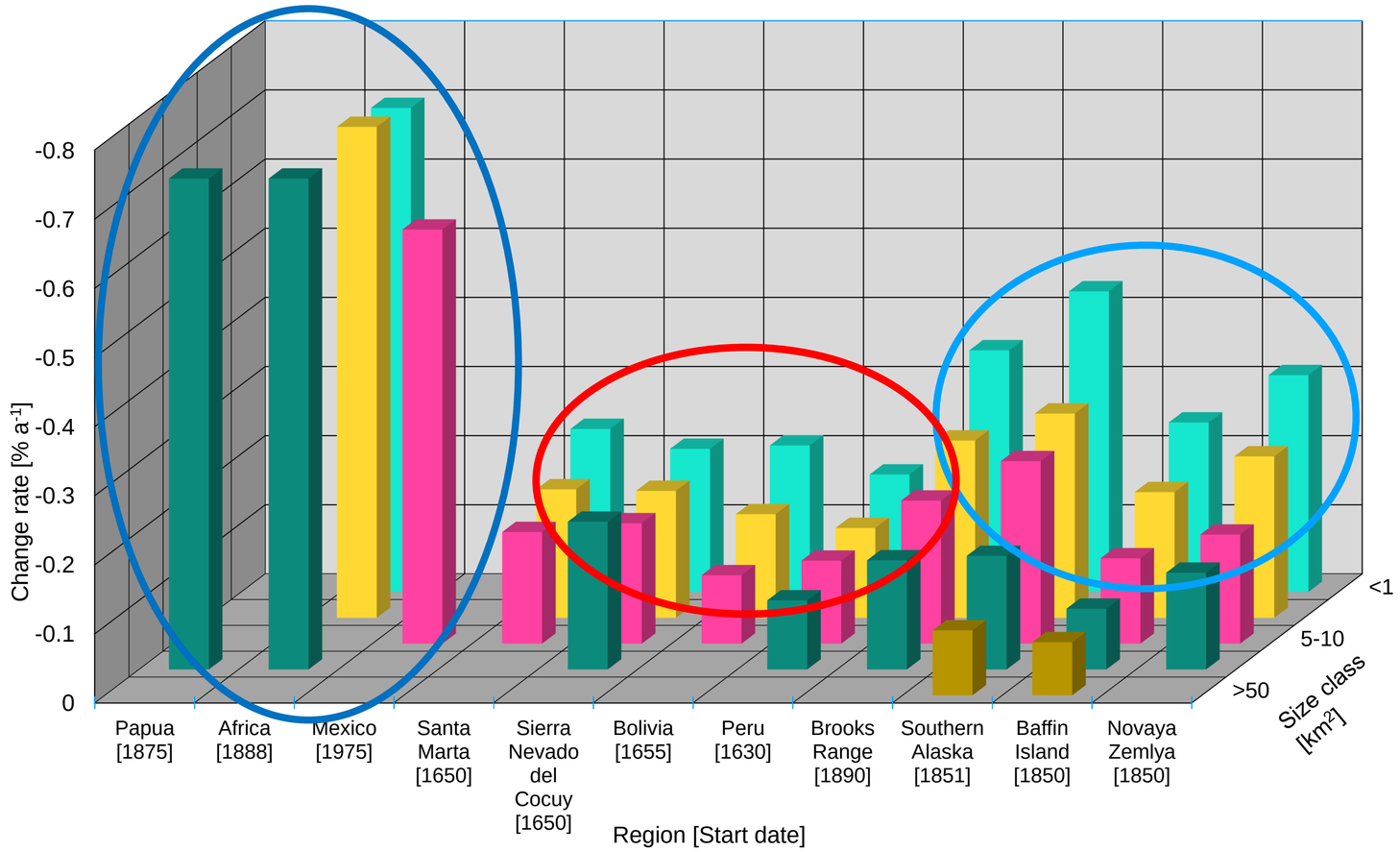
- Change rates largely dependent on LIA max date
- In the Arctic glaciers were near LIA max position until 1900 (Dowdeswell, 1995)
- In South America, “constant” retreat since the 17th century (with intermediate advances) and accelerated shrinkage after 1890 (Rabatel et al. 2006, Kinzl 1969)
- In other tropical regions rapid and constant retreat since the end of the 19th century



(1) Rabatel and others, 2008; (2) Allison and Peterson, 1976; Klein and Kincaid, 2006; (3) Schneider and others, 2008; (4) Cullen and others, 2013; (5) Kaser and Osmaston, 2002; Taylor and others, 2006;

Area change rates per size class

- Higher change rates for small glaciers
- Interregional variability decreases with increasing size
- Highest in Mexico, Papua and Africa (~1850)
- Peru and Bolivia lowest rates in tropics (~1650)
- Rates of small glaciers higher in the Artic than in South America
- Southern Alaska highest rate of Arctic regions -> response time?



Quality classification

4 quality classes:

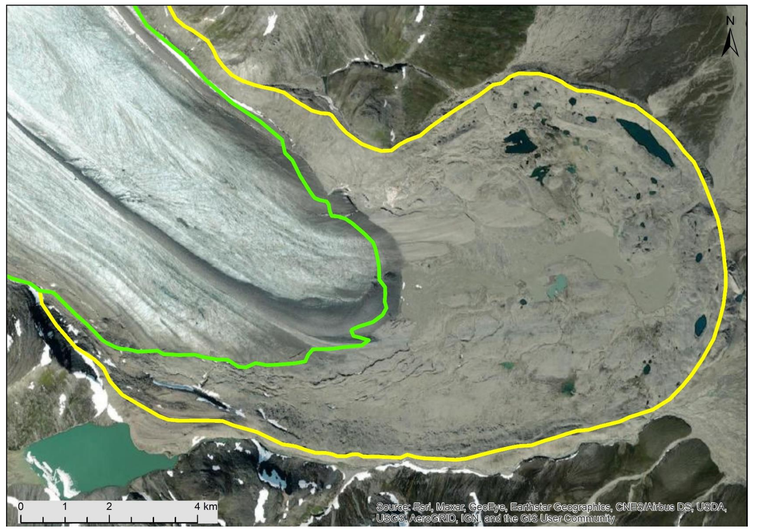
4. Very good
- Very well preserved moraines and trim lines

3. good
- Generally well preserved moraines / trim lines
- Minor parts of moraines missing

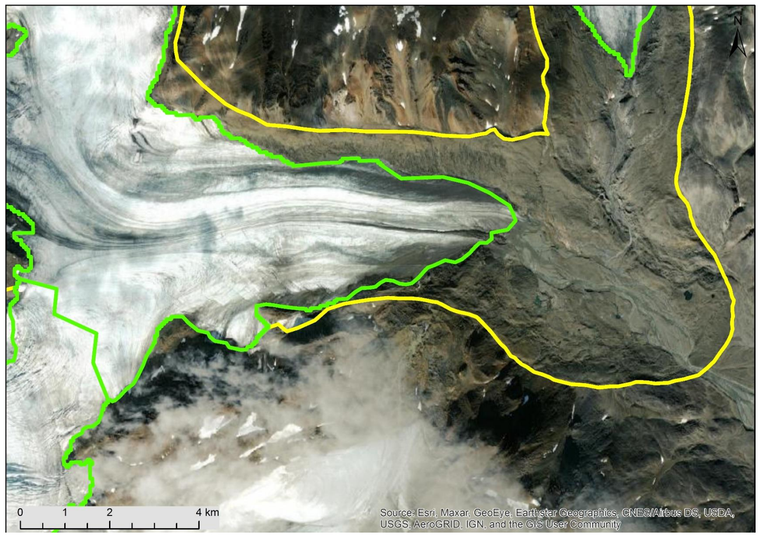
2. usable
- General outline can be estimated with some parts interpolated
- Low image quality of Esri basemap
- Shift in the modern outline

1. unusable
- Low quality of modern outline
- Front position can not be determined

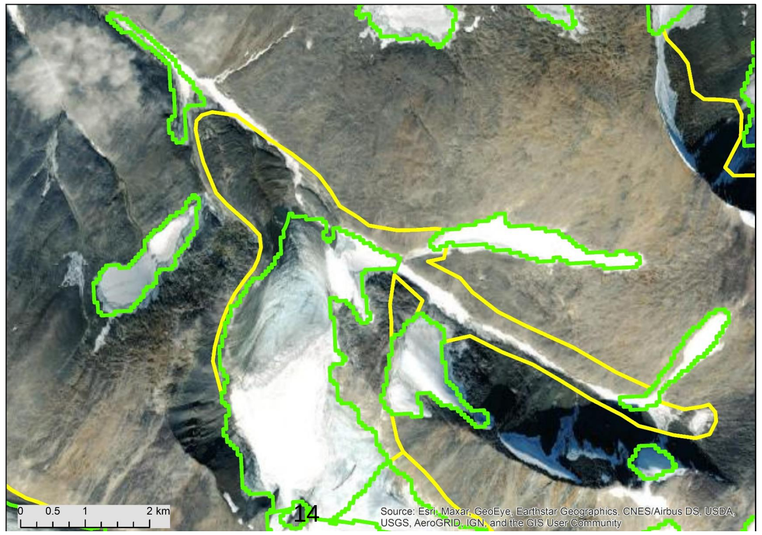
4: very good



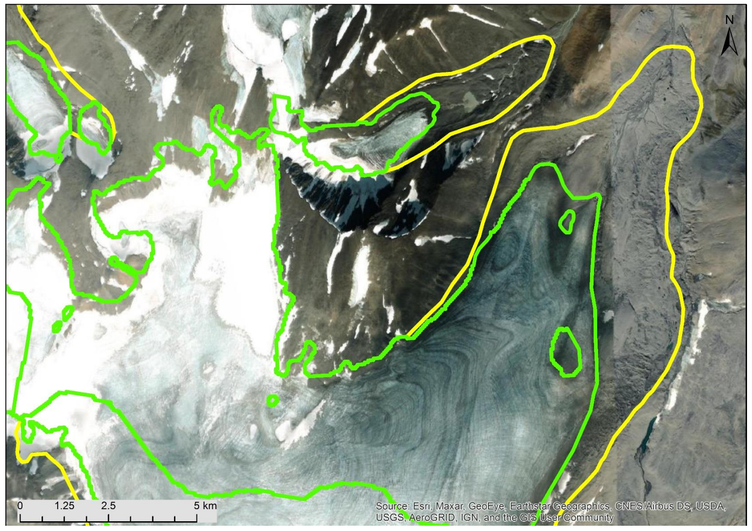
3: good



1 unusable



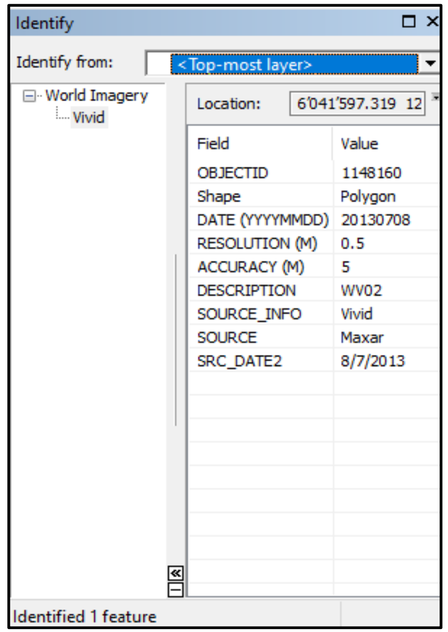
2 usable



Uncertainties

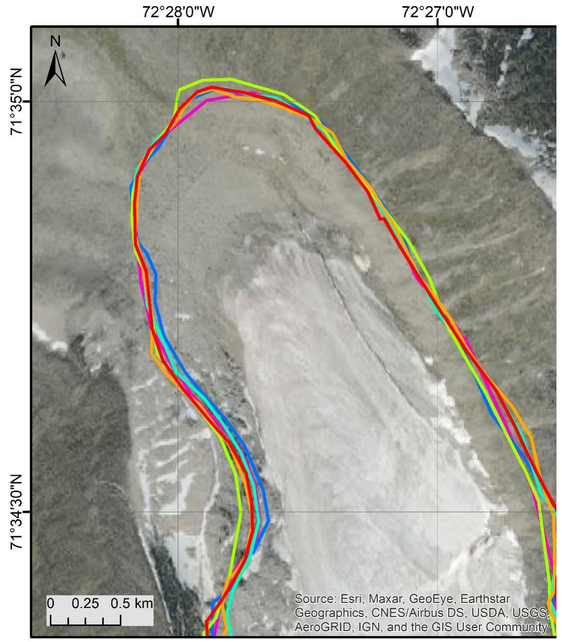
Input uncertainty

For ESRI Basemap 5-10 m, probably more in steep areas
Can be checked for each location



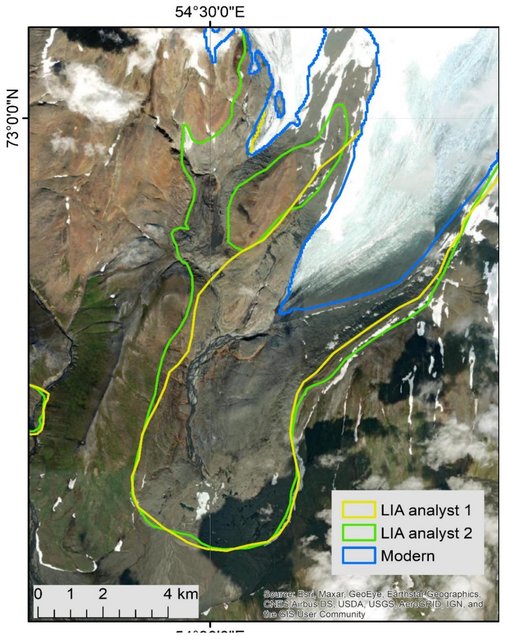
Reproduction accuracy

How well can we reproduce LIA outlines?
Multiple digitising experiment with High res. and Sentinel-2
1.4% ± 1.3%



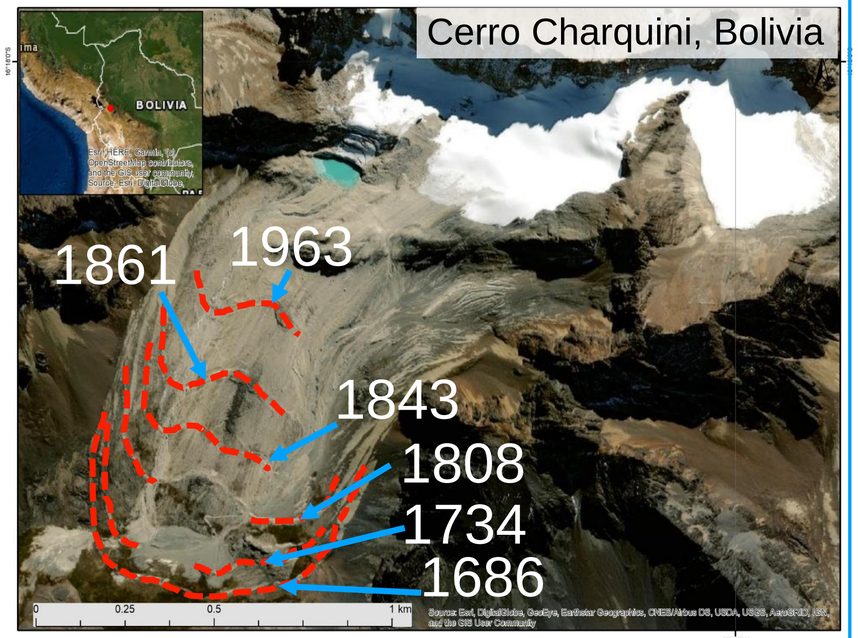
Interpretation accuracy

How well can we interpret LIA moraines and trim lines?
Digitising experiment between the two analyst's
1.9% ± 10%



Other sources of uncertainties

Multiple moraines => outermost mapped
Calving glacier and ice caps
Dating uncertainty?
Dating records only for a few glaciers
=> Regional LIA max date assigned



Dates from Rabatel et al. 2006

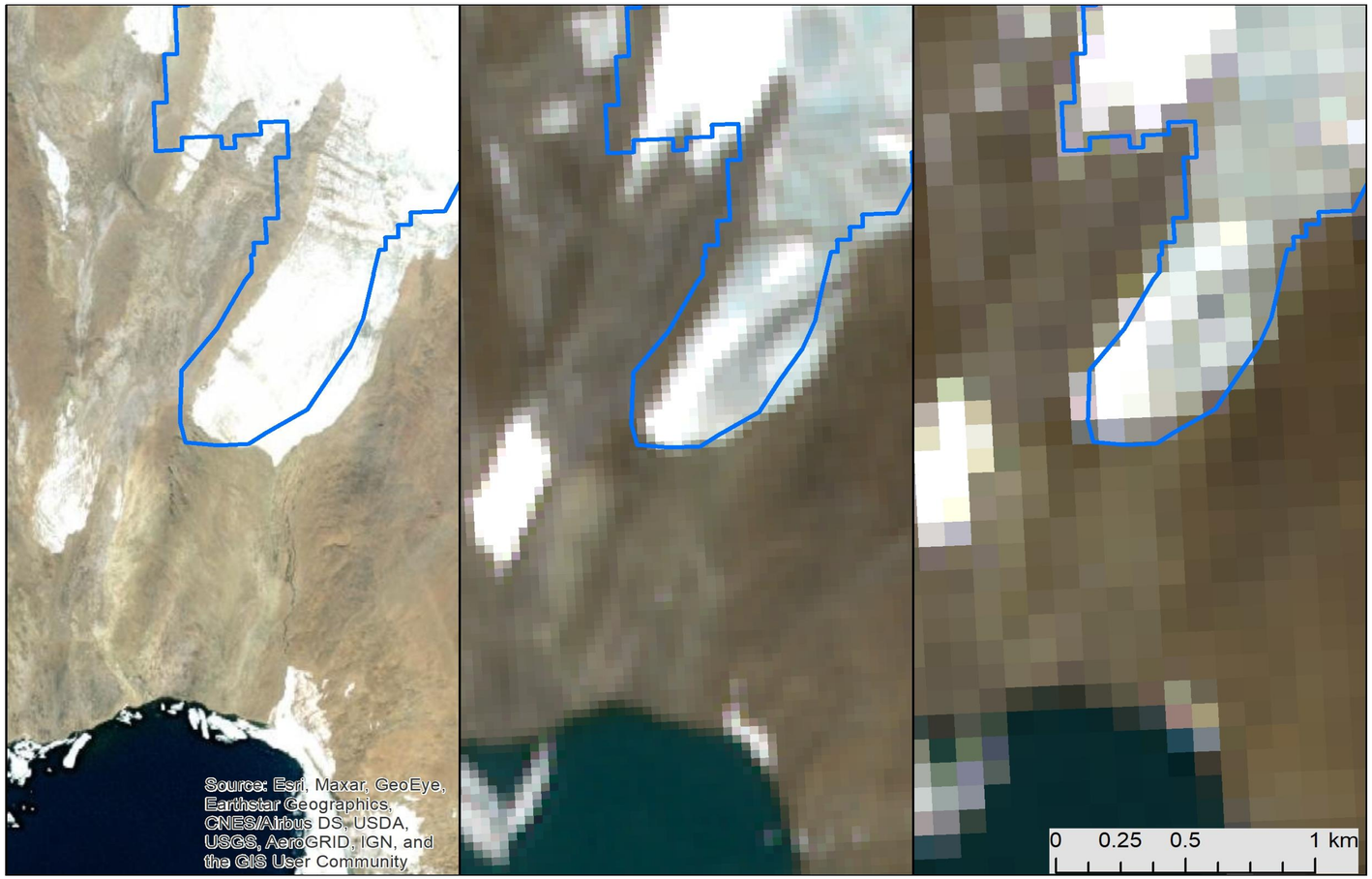
Total mapping uncertainty: 10.1%

Uncertainties

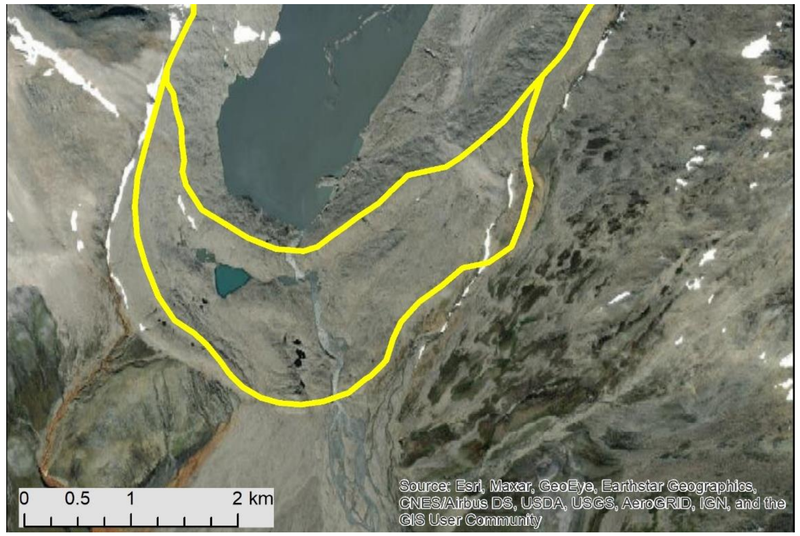
ESRI basemap
accuracy 5-10 m

Sentinel 2

Landsat 8
shift towards Sentinel-2



Multiple moraines

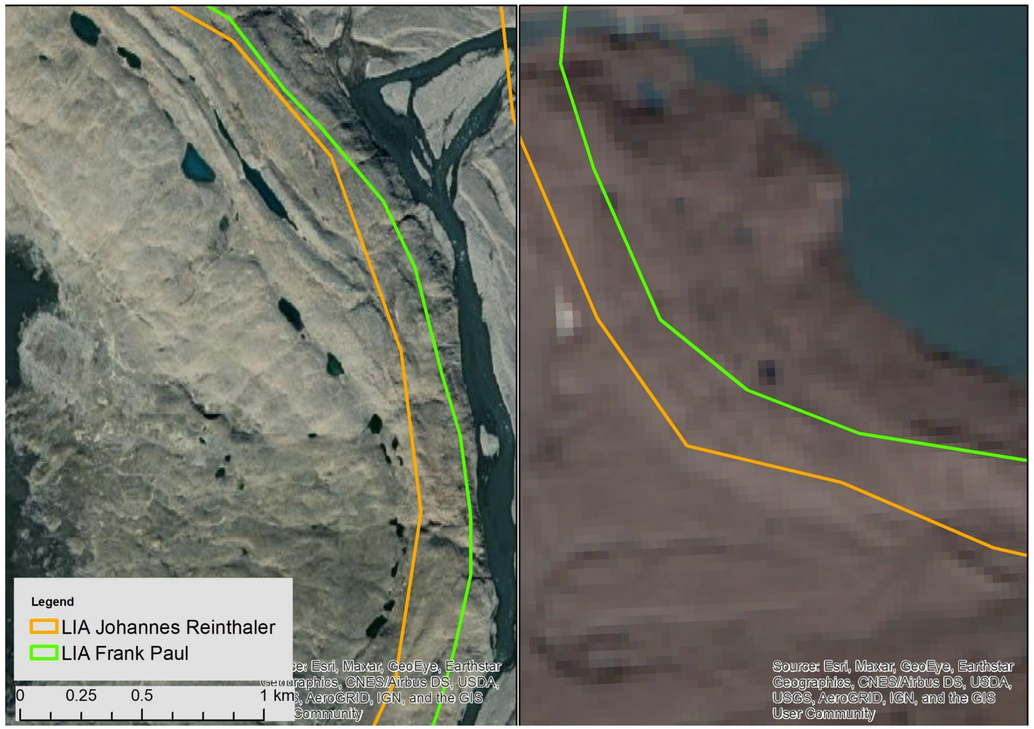


Timing of LIA max?

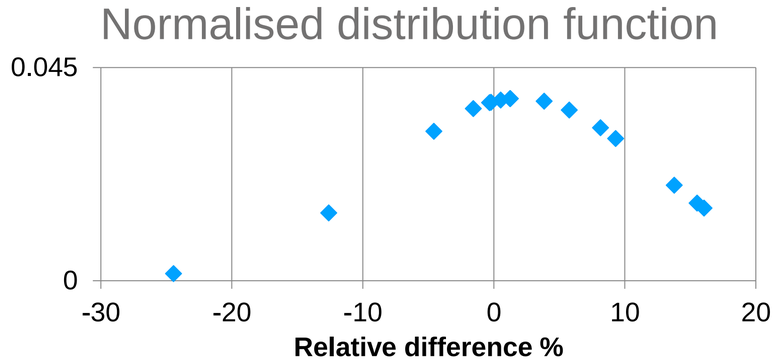
- Still much work to do
- Timing of max extent highly variable
- Some regions are missing dating's (e.g. Subantarctica)

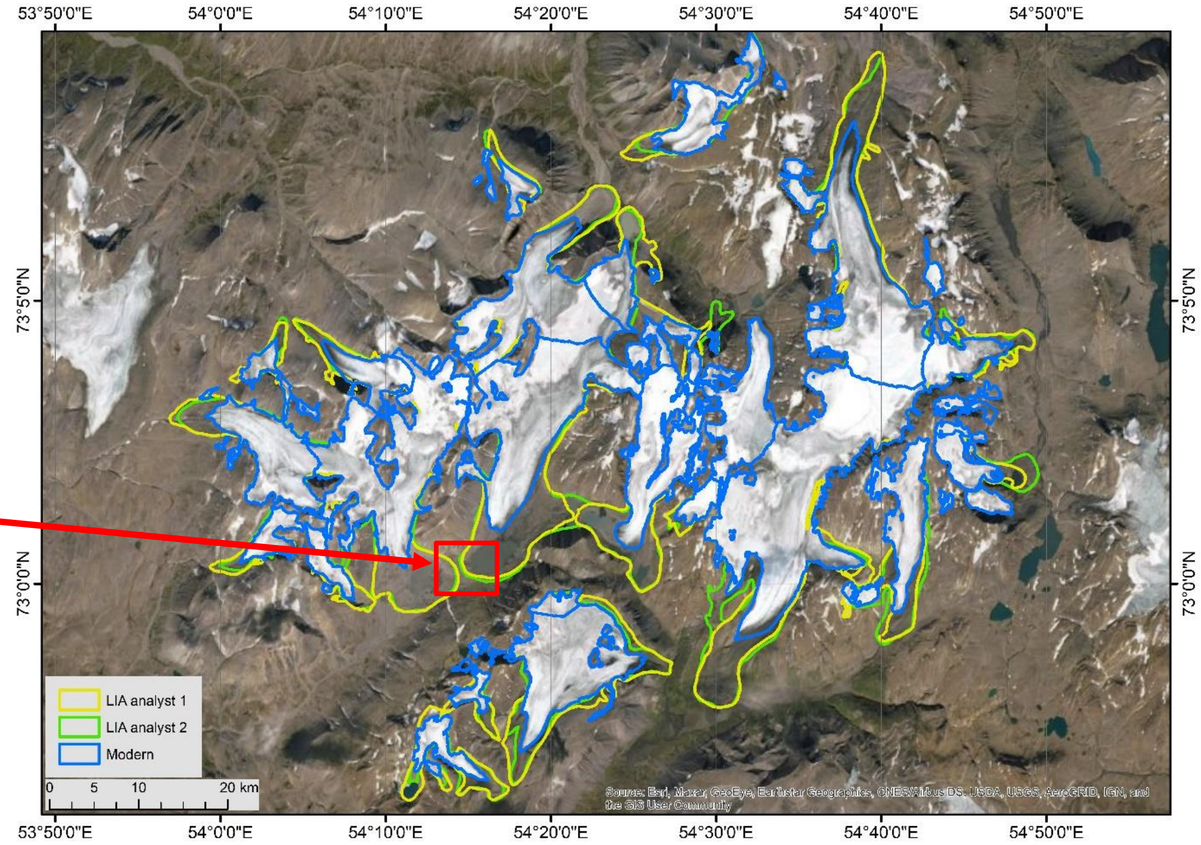
Interpretation accuracy

- 18 glaciers, 141.9 km^2 in 2016
- Area LIA: Analyst 1: 186.0 km^2, Analyst 2: 185.3 km^2
- Average difference of differences: 1.9% (Std.: 10%)

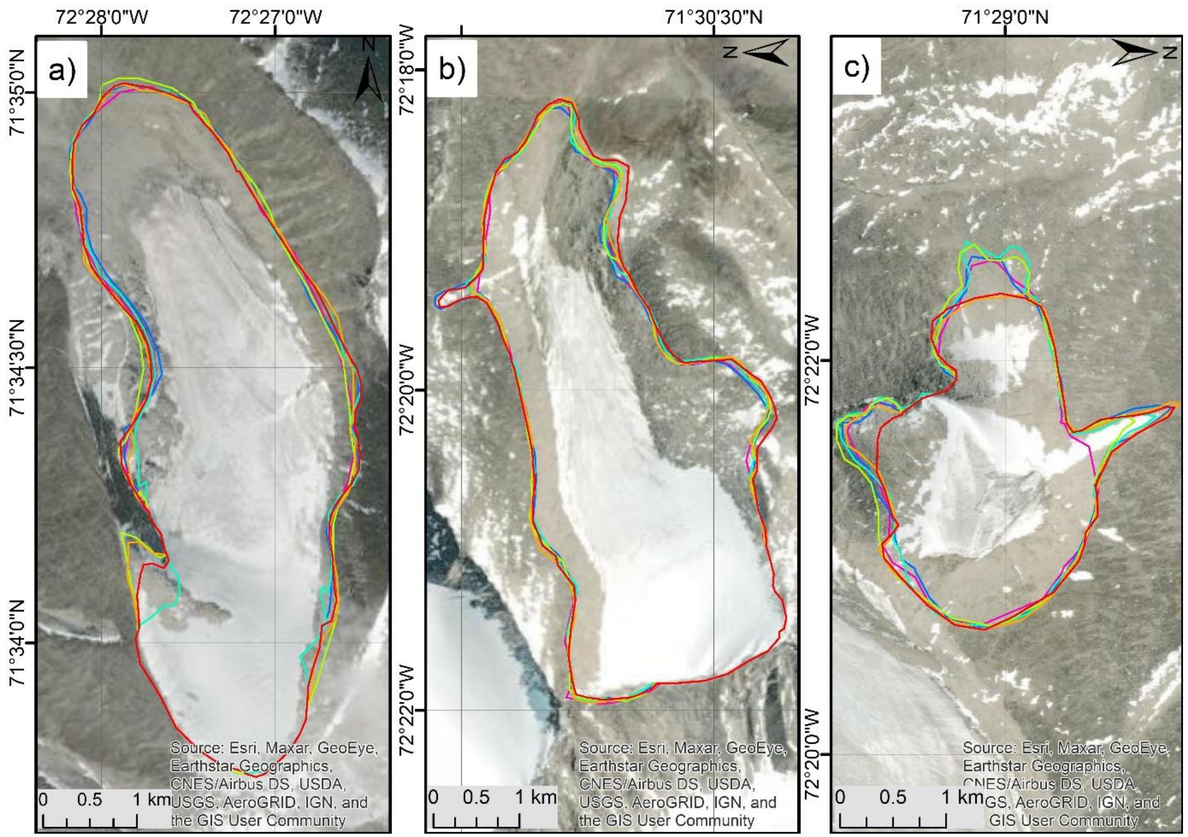


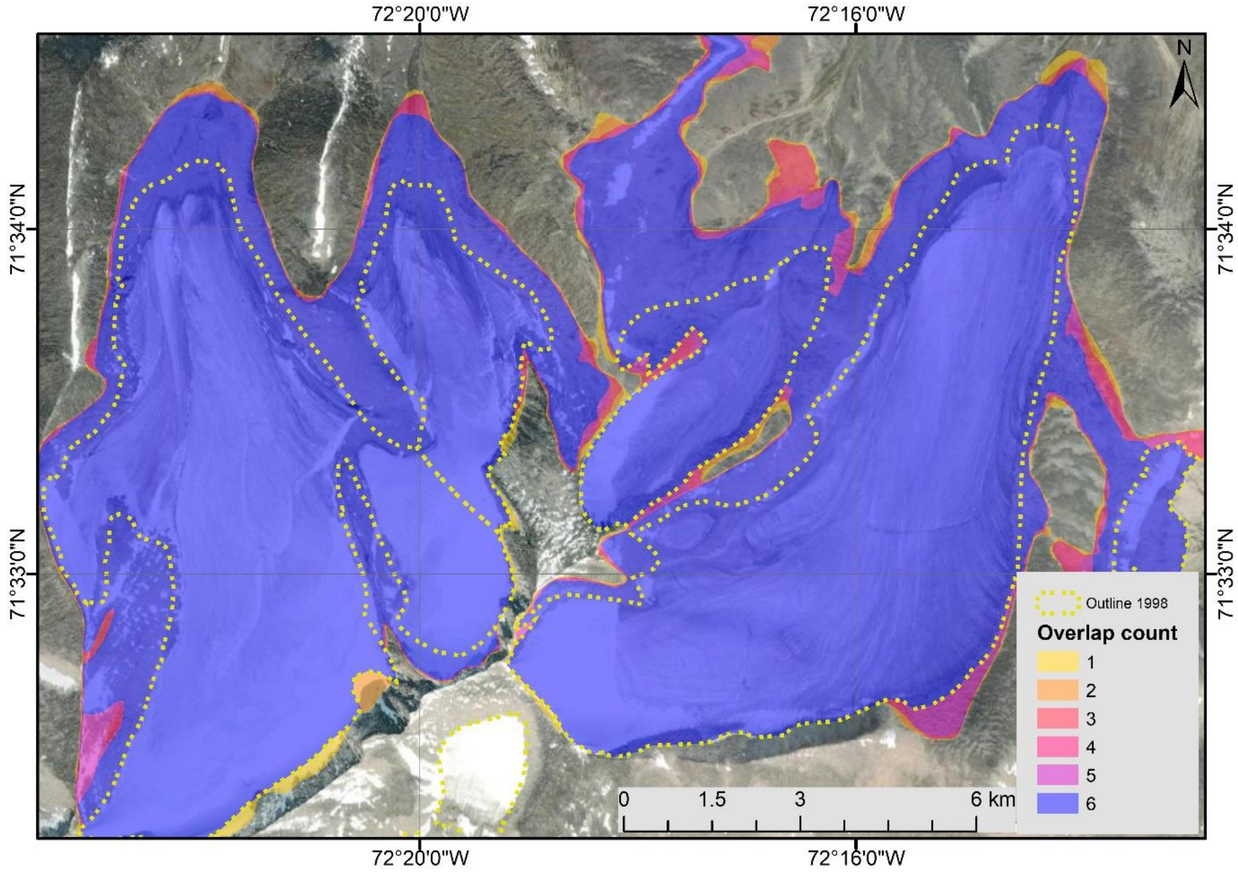
Esri Basemap vs. Sentinel-2





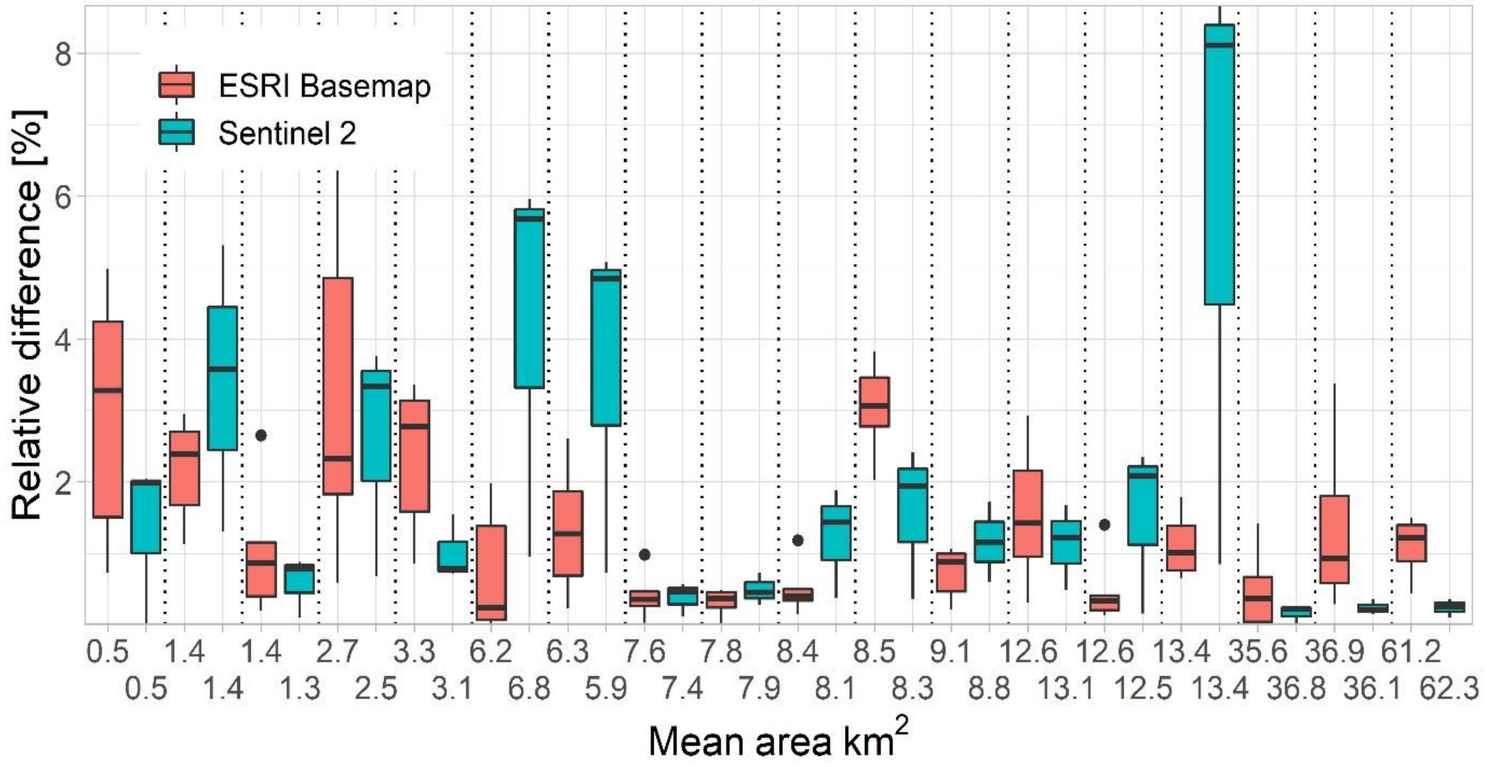
Reproduction accuracy





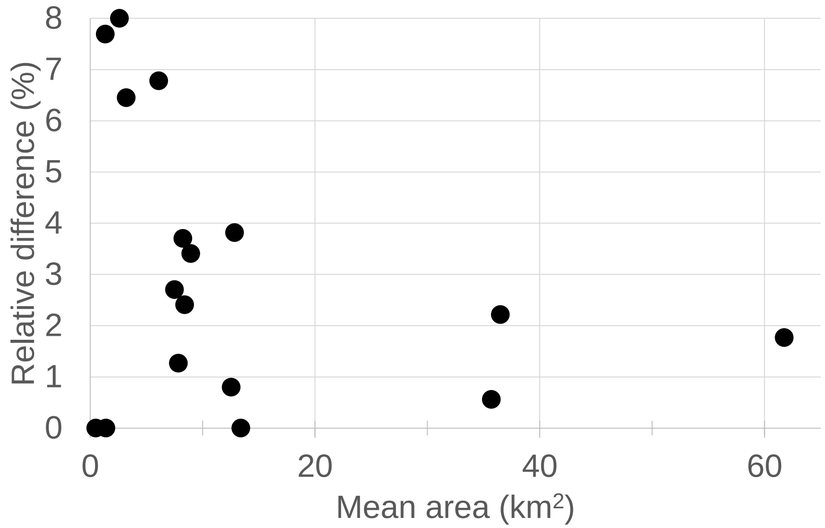
- 18 glaciers digitised six times each
- Glaciers from different size and quality classes

High resolution vs. Sentinel 2



- Average difference to mean:
  - ESRI basemap: 1.4% (Std.: 1.3%)
  - Sentinel 2: 1.7 (Std.: 2.0%)

Difference between ESRI basemap and Sentinel 2:
- Mean: 3.4% ± 3.0



Thank you very much for your attention

Happy to answer questions

1. Now (if there is time)
2. After the session
3. write me an email:

johannes.reinthaler@geo.uzh.ch

Find further information on the uploaded material and a paper will be published soon!

References

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