Michele Citterio
GEUS Glaciology and Climate Dept.

Caution, glacier terminus ahead: jökulhlaups, surges and large calving events

GEUS
Geological Survey of Denmark and Greenland

ice as a geological material

photo: John Sylvester

ice as a geological material

- solid phase lighter than liquid phase

- often close to or at the pressure melting point

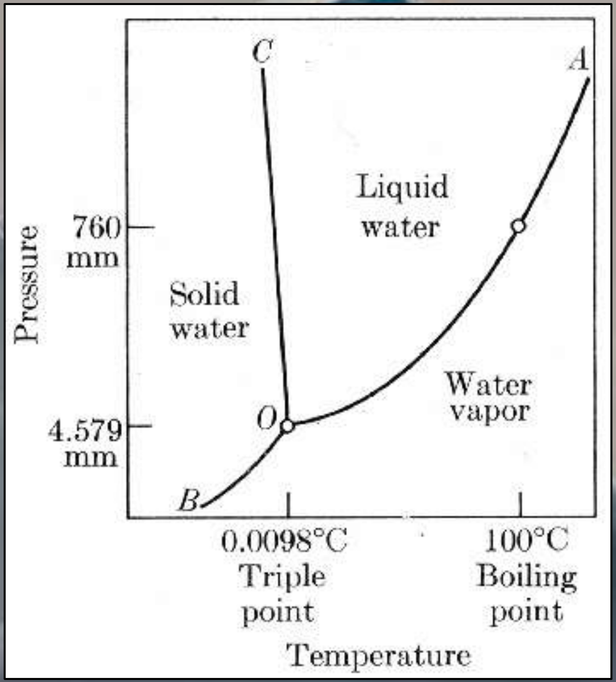
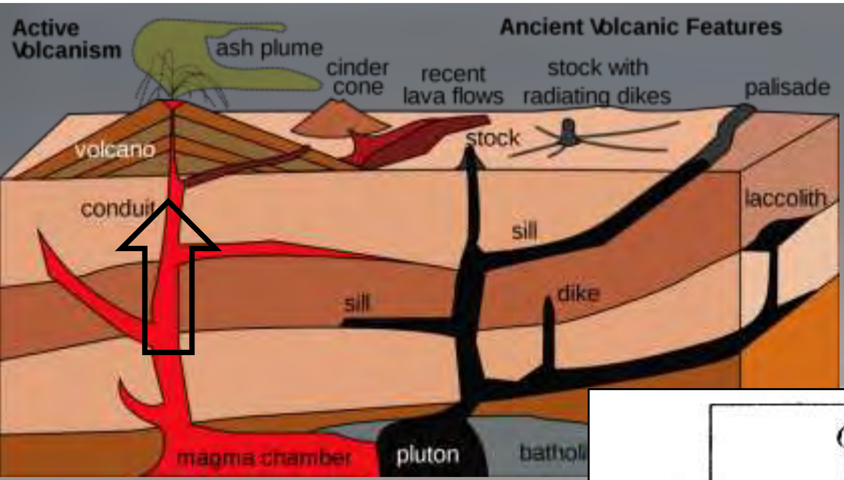
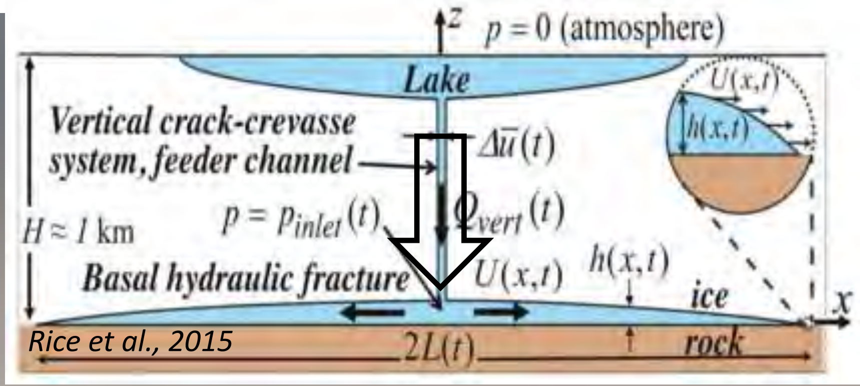
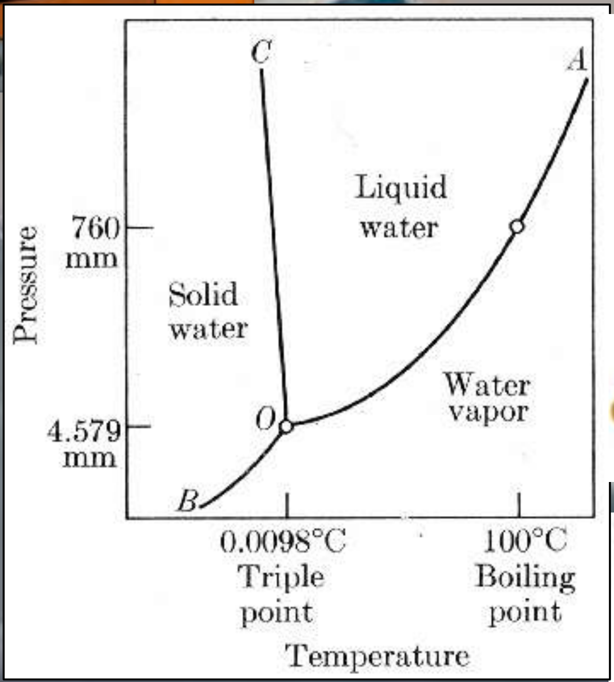


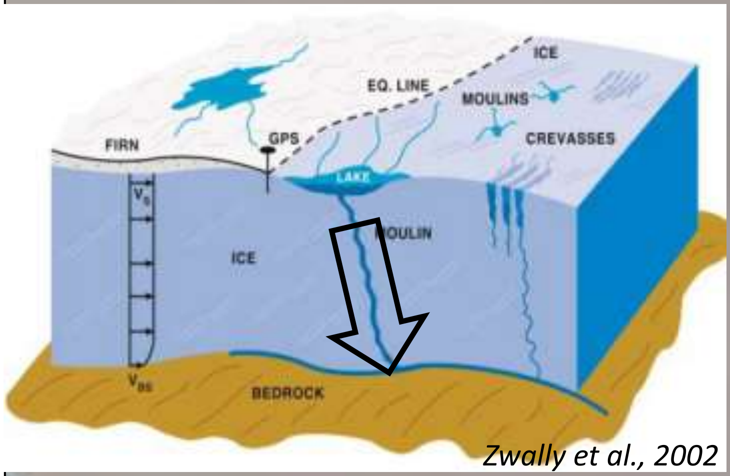
photo: John Sylvester

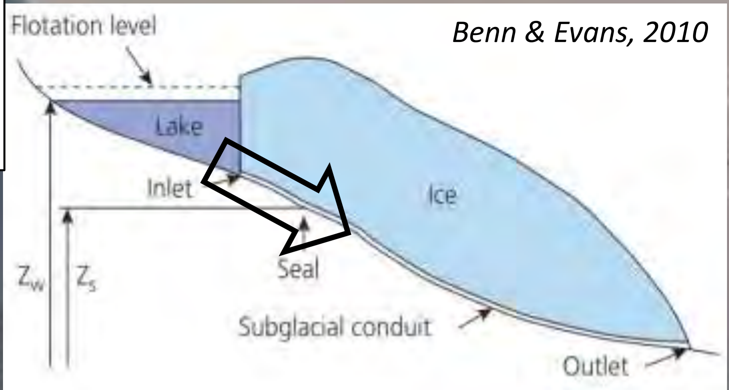
ice as a geological material









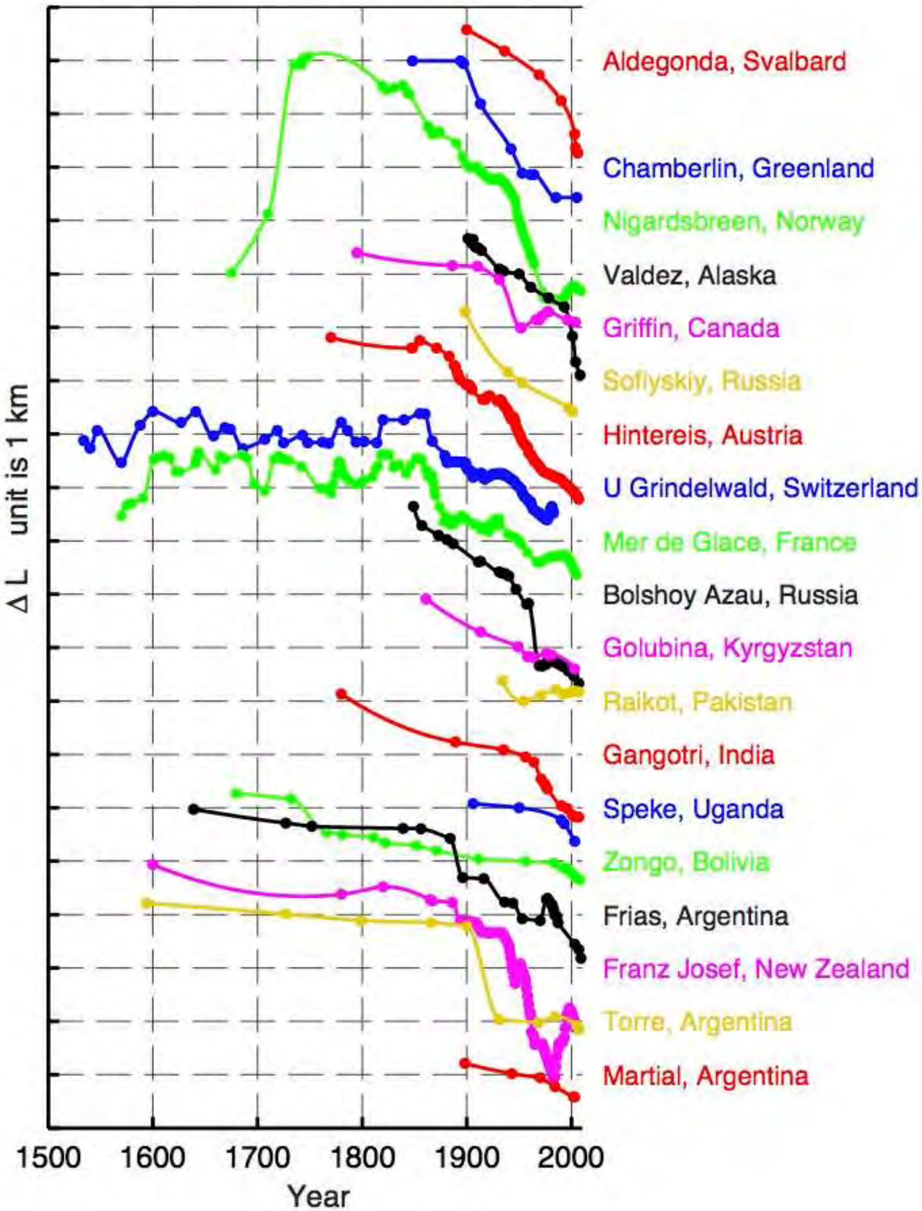


- solid phase lighter than liquid phase

- often close to or at the pressure melting point

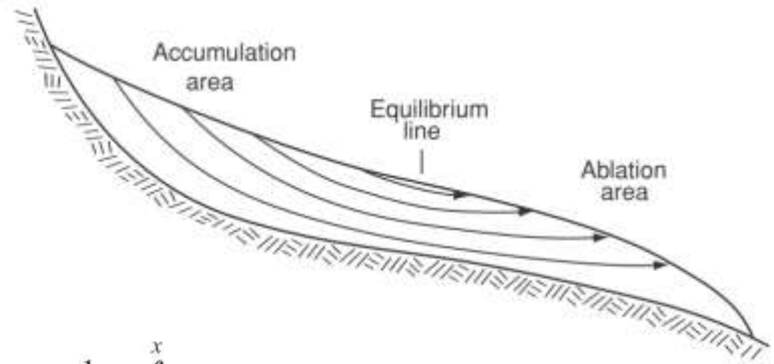
photo: John Sylvester

ice as a geological material

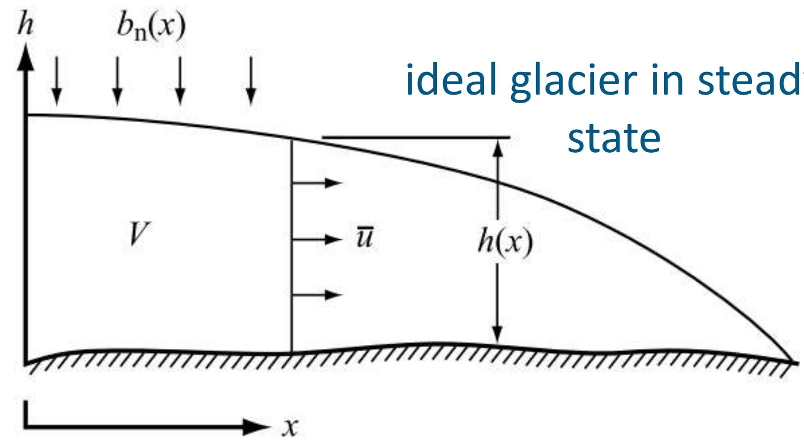


Leclercq & Oerlemans, 2012

Terminus fluctuations respond to climate forcing



$$\bar{u} = \frac{1}{h(x)} \int_0^x b_n(x)\, dx$$

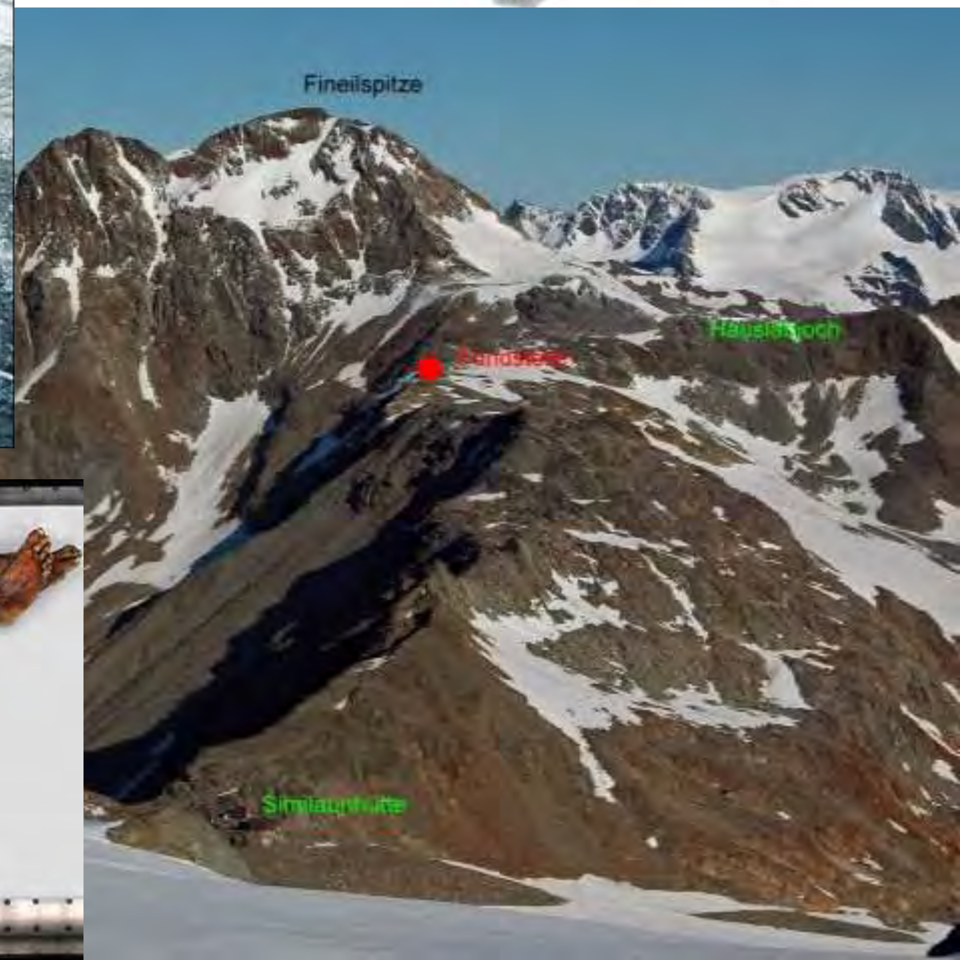


ideal glacier in steady state

Hooke, 2005

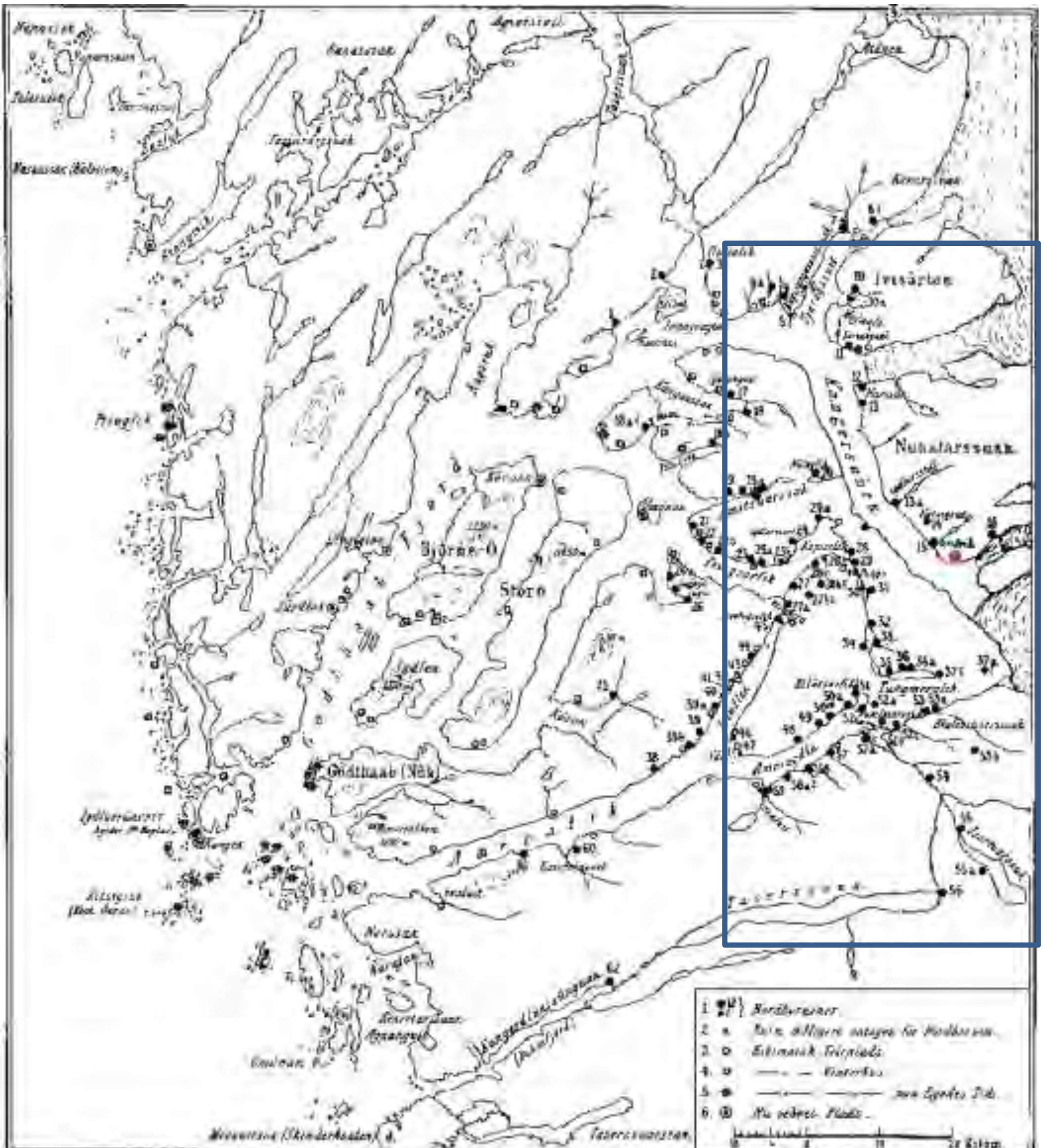
people and glaciers

'Ice Man' (5300 BP) found in 1991 at 3210 m



people and glaciers

Norse and Eskimo traces in close proximity to west Greenland glaciers

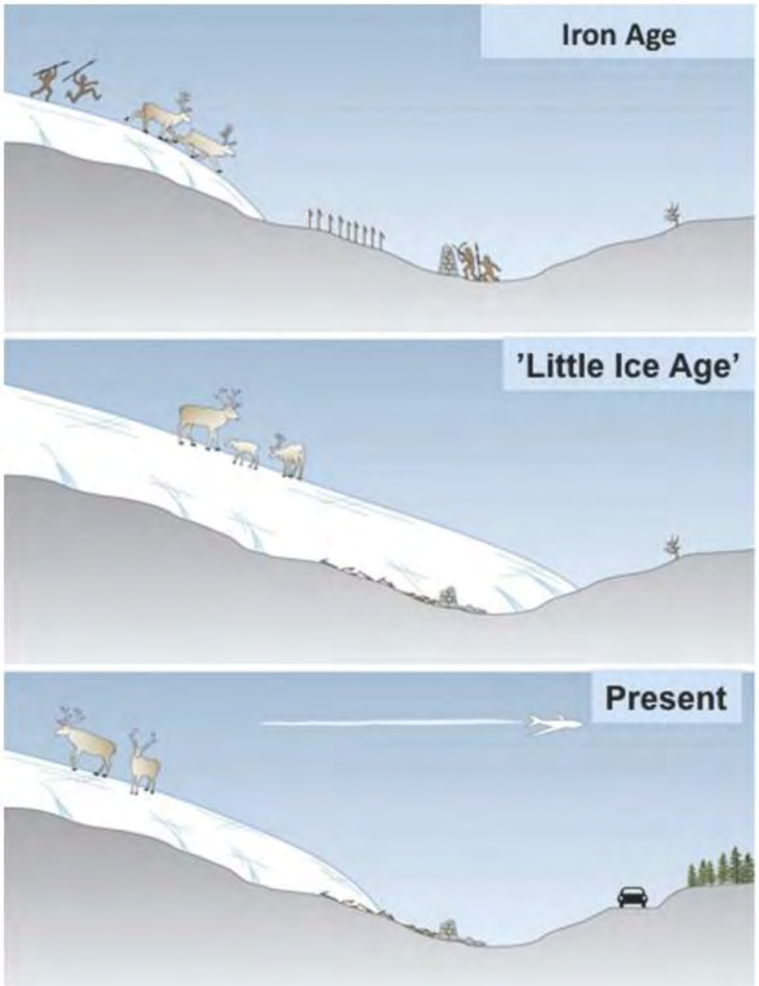


Bruun, 1917 in Weidick et al., 2012

Weidick et al., 2012

people and glaciers

Objects from reindeer hunting (3900-900 BP) found at melting ice patches in Norway



Nesje et al., 2011

people and glaciers

Rhone glacier (CH)

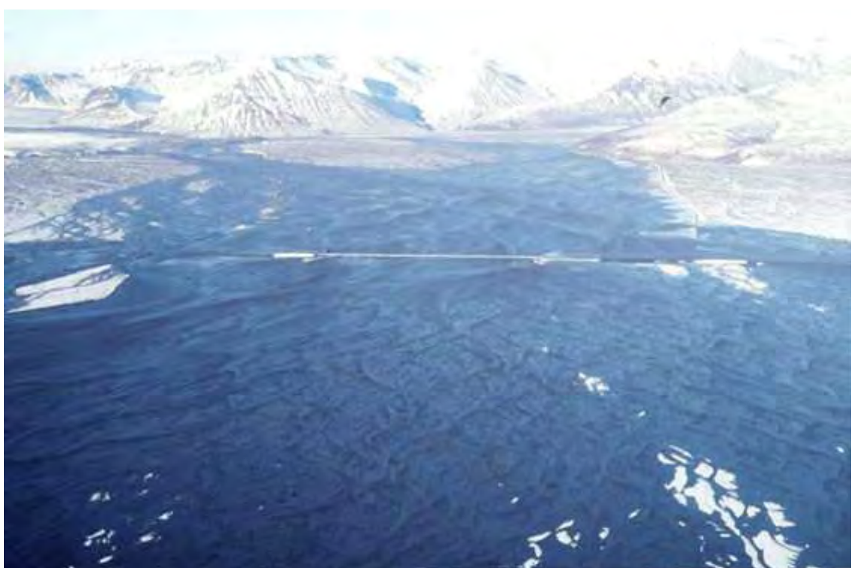
people and glaciers

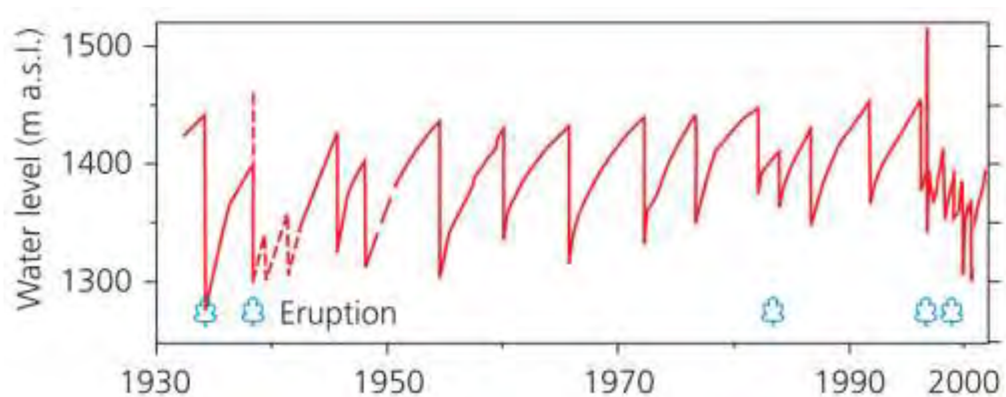
Argentière glacier, Chamonix (F) exorcised by the Bishop of Geneva in the 17th century

jökulhlaups, surges and calving

jökulhlaups

Volcanigenic subglacial lakes

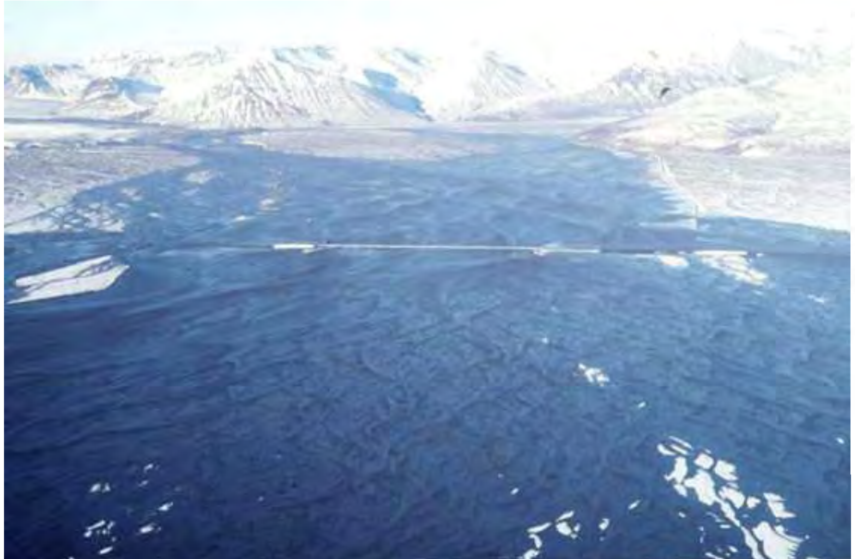


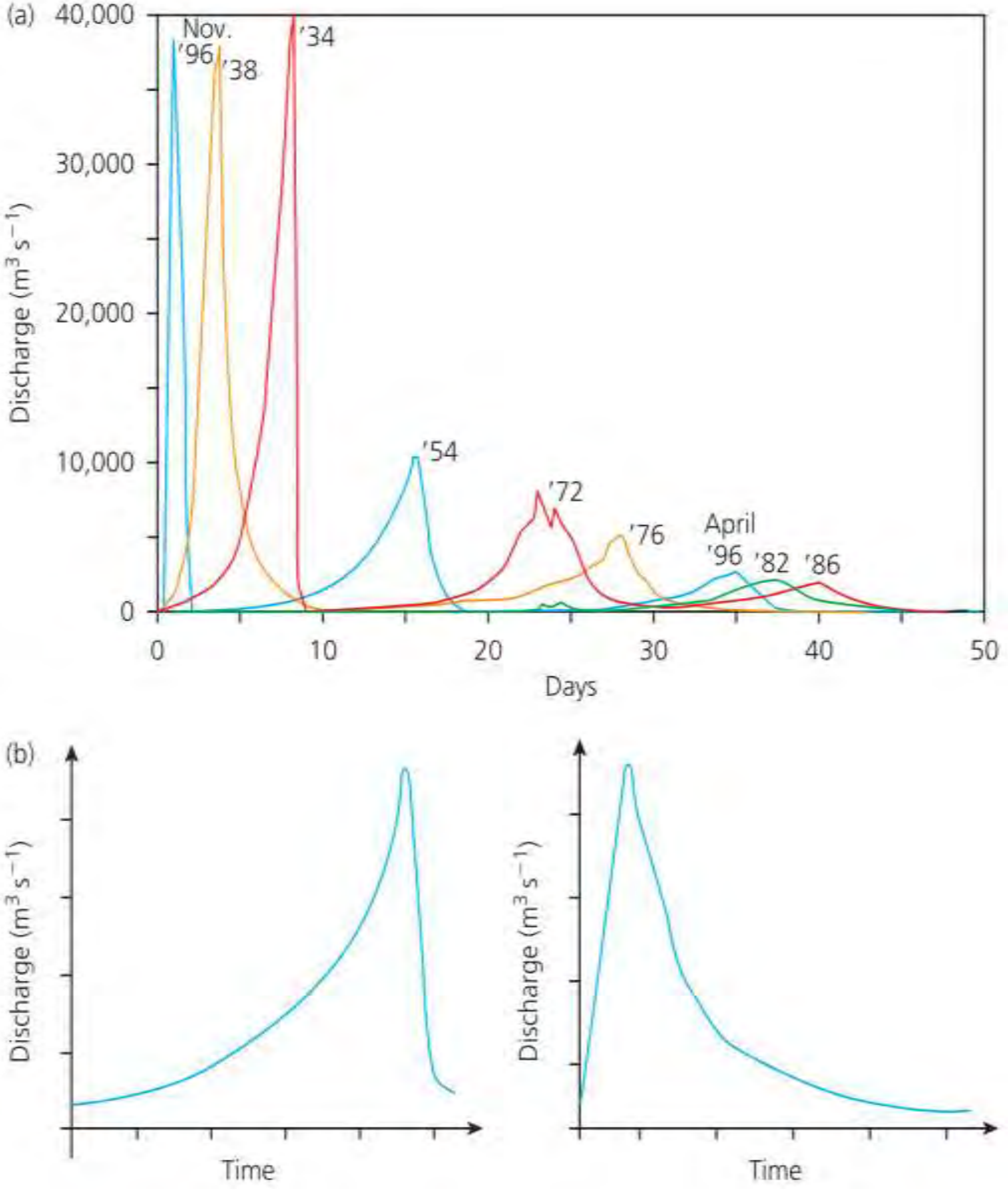


Björnsson, 2002

jökulhlaups

Volcanigenic subglacial lakes



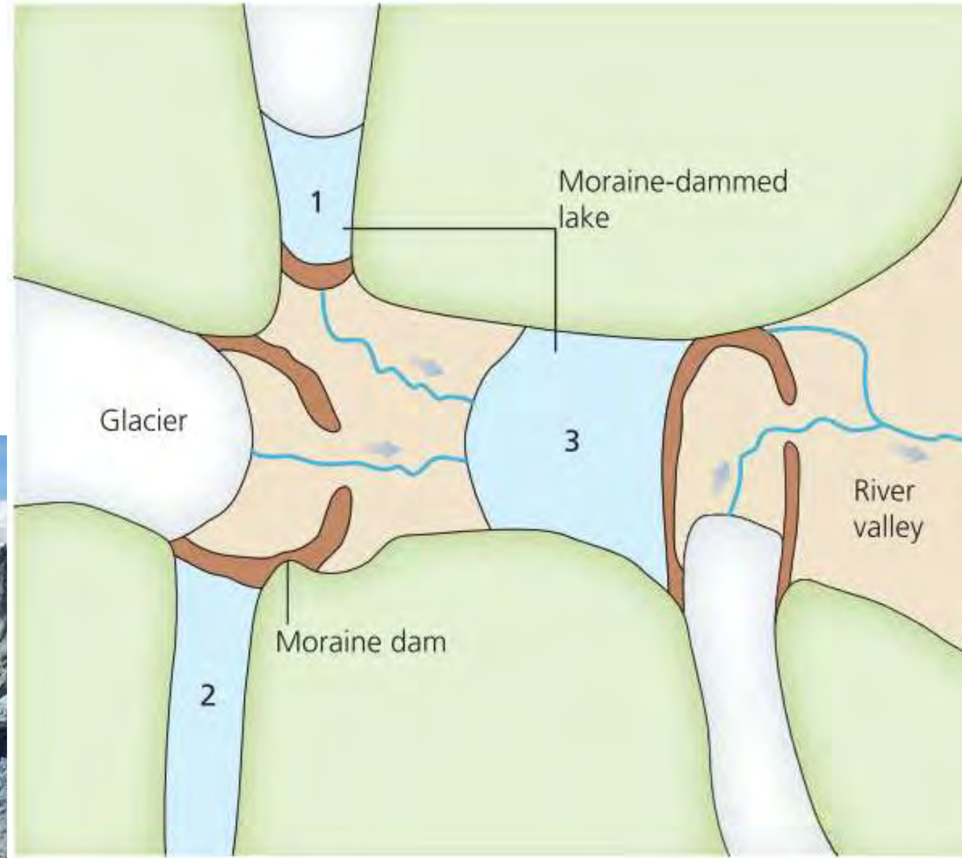


Björnsson, 2002

jökulhlaups

Moraine-dammed lakes

→ higher risk when glaciers retreat



Clague & Evans, 2000

Laguna Paron, Cordillera Blanca, Peru. Photo J. Alean, 1980

jökulhlaups

Moraine-dammed lakes

→ higher risk when glaciers retreat
→ especially common at debris covered glaciers

Lago del Miage, Italy. Photo J. Alean, 1982

jökulhlaups

Moraine-dammed lakes

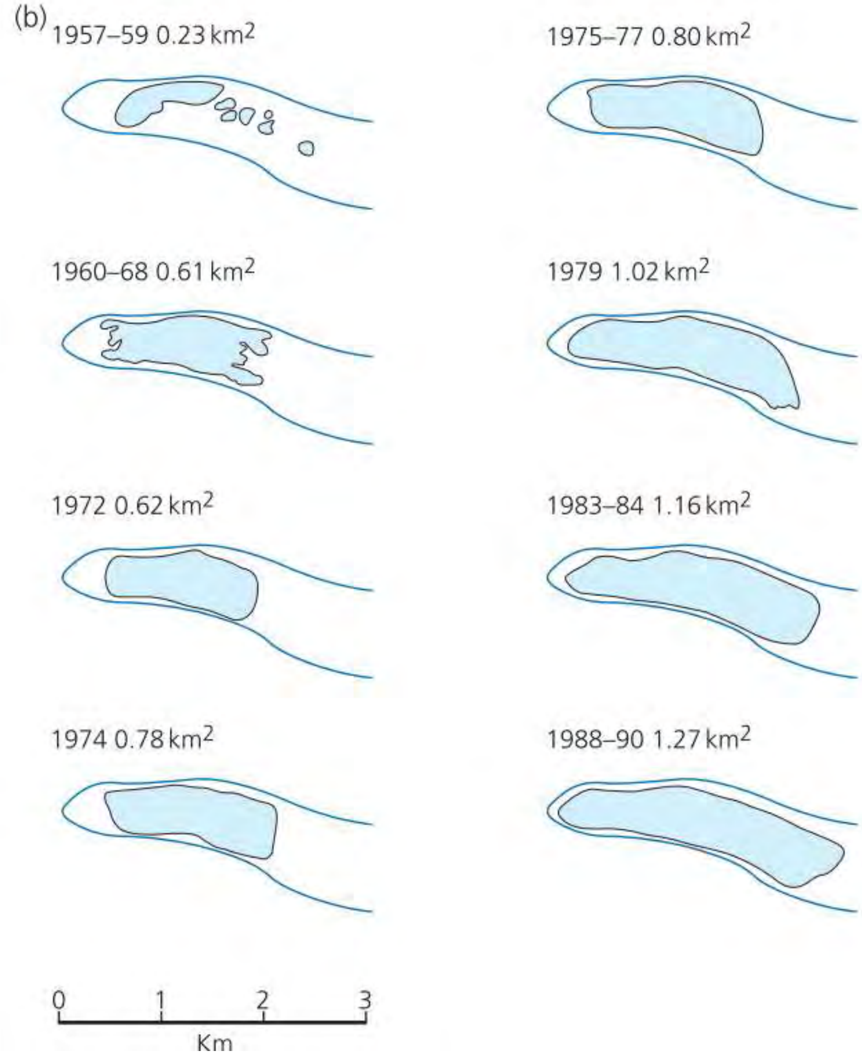
may be moraine- AND ice-dammed

Lago del Miage, Italy, 2005

jökulhlaups

Moraine-dammed lakes

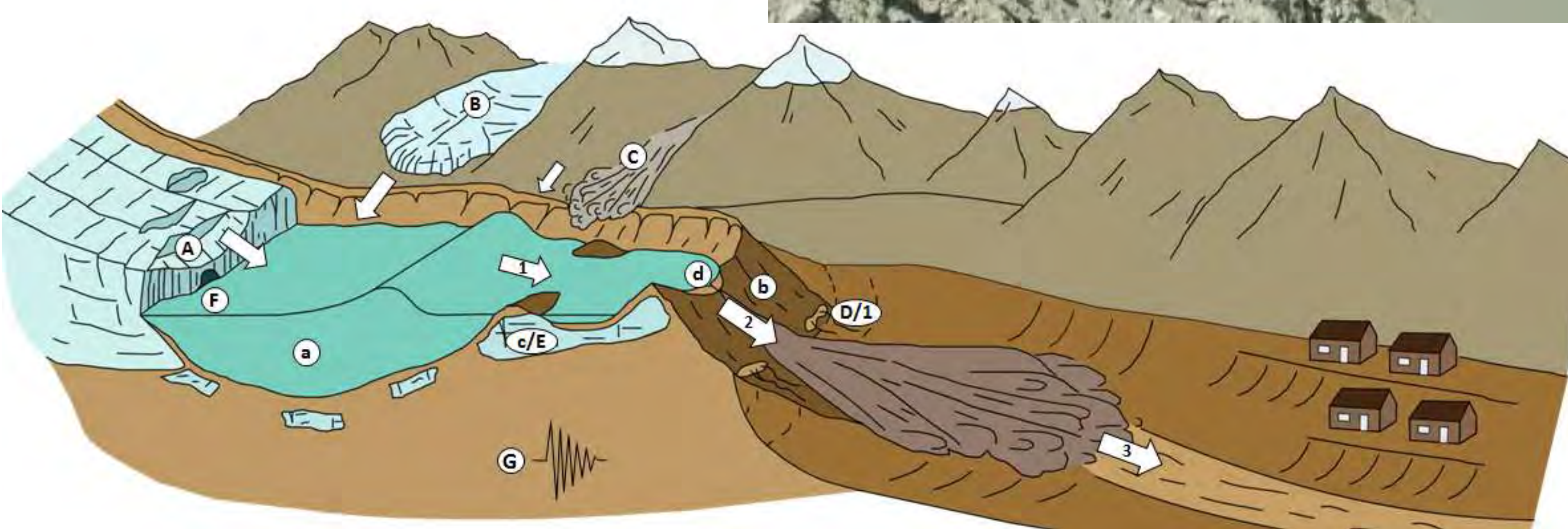
Can start as supraglacial lakes, e.g. Tsho Rolpa and Imja (Nepal)



jökulhlaups

Moraine-dammed lakes

may be ice-cored moraines slowly melting and lowering



jökulhlaups

Moraine-dammed lakes

Sometimes mitigation in feasible:
- artificial gate and level lowering

Tsho Rolpa Lake, Nepal, 2000 (Photo ?)

jökulhlaups

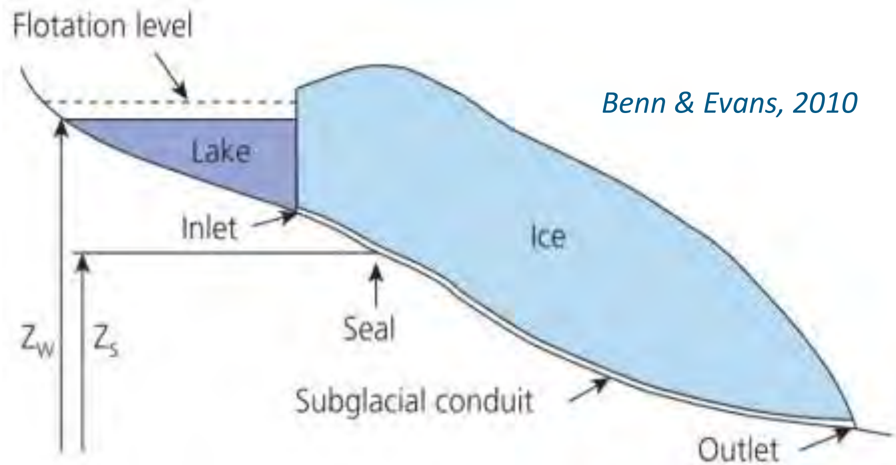
Moraine-dammed lakes

Sometimes mitigation in feasible:
- artificial gate and level lowering
- pumping (ephemeral lakes)

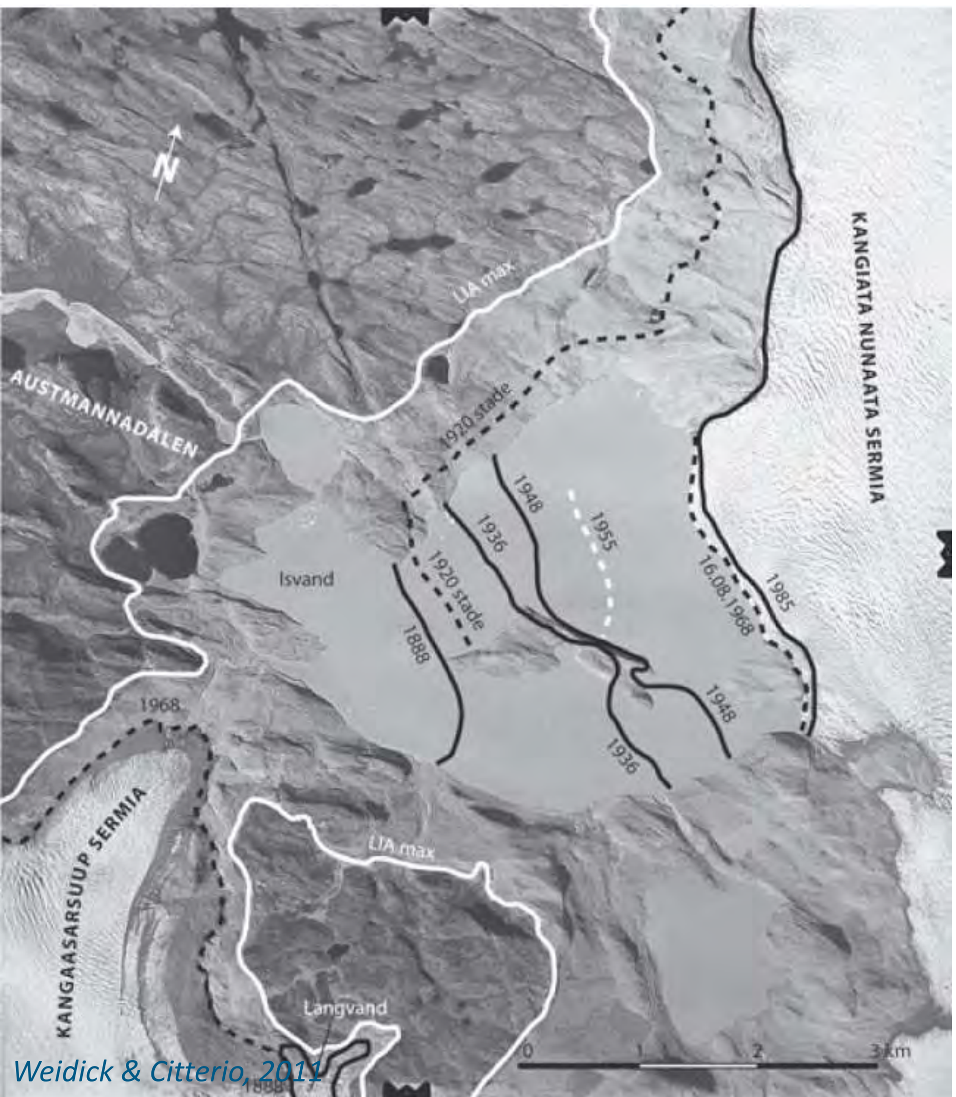
Belvedere glacier, Italy, 2002 (SMI/LM)

jökulhlaups

Ice-dammed lakes
→ higher risk when glaciers advance

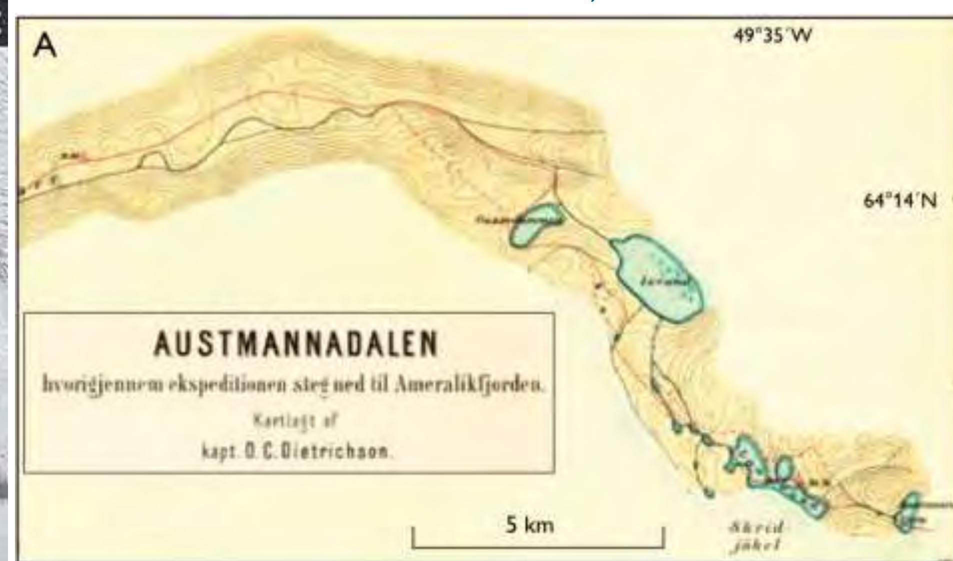


Benn & Evans, 2010



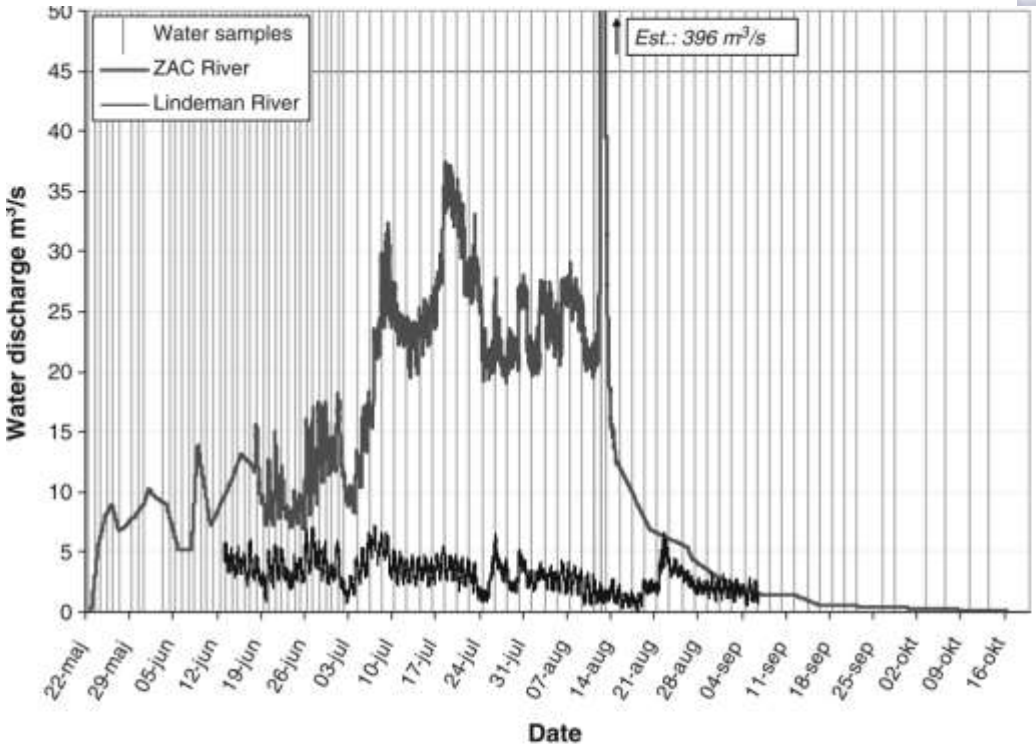
Weidick & Citterio, 2011

Nansen, 1890 in Weidick et al. 2012



jökulhlaups

Ice-dammed lakes
→ higher risk when glaciers advance

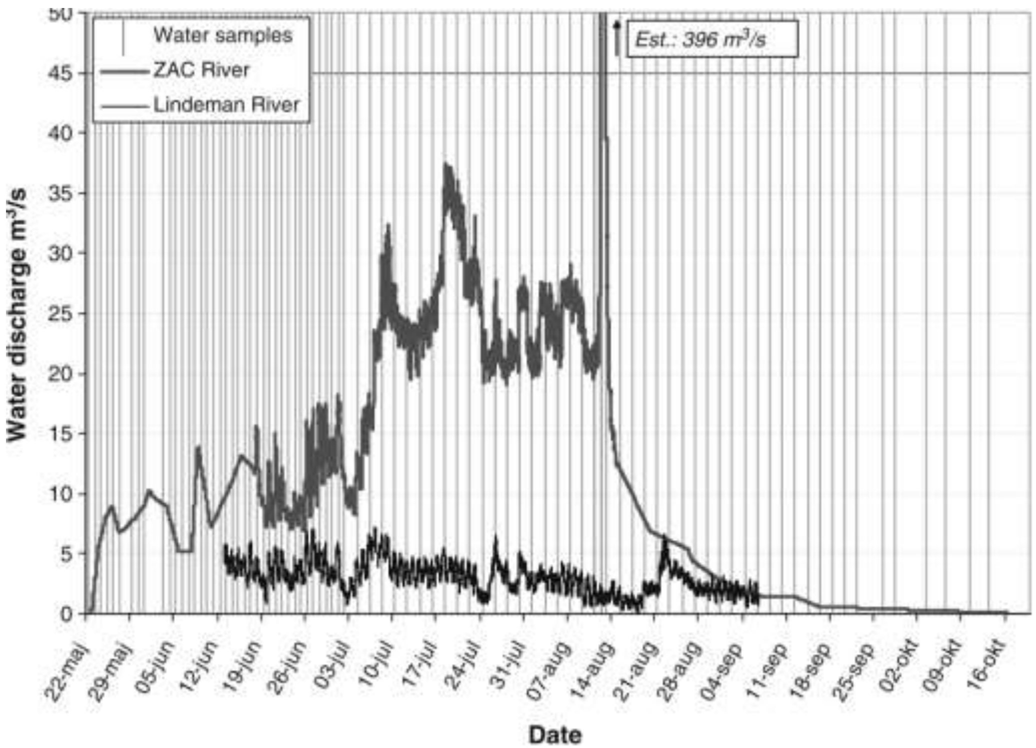


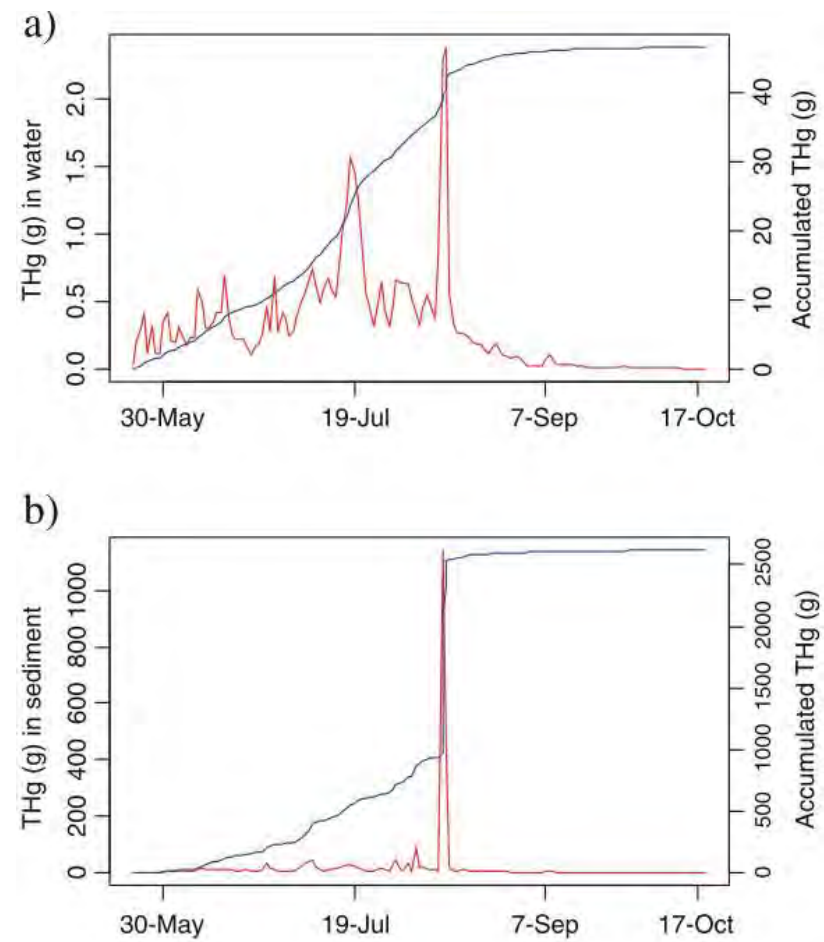
Weidick & Citterio, 2011

jökulhlaups

other impacts:

- mobilization of pollutants (e.g. Zackenberg River in 2009)





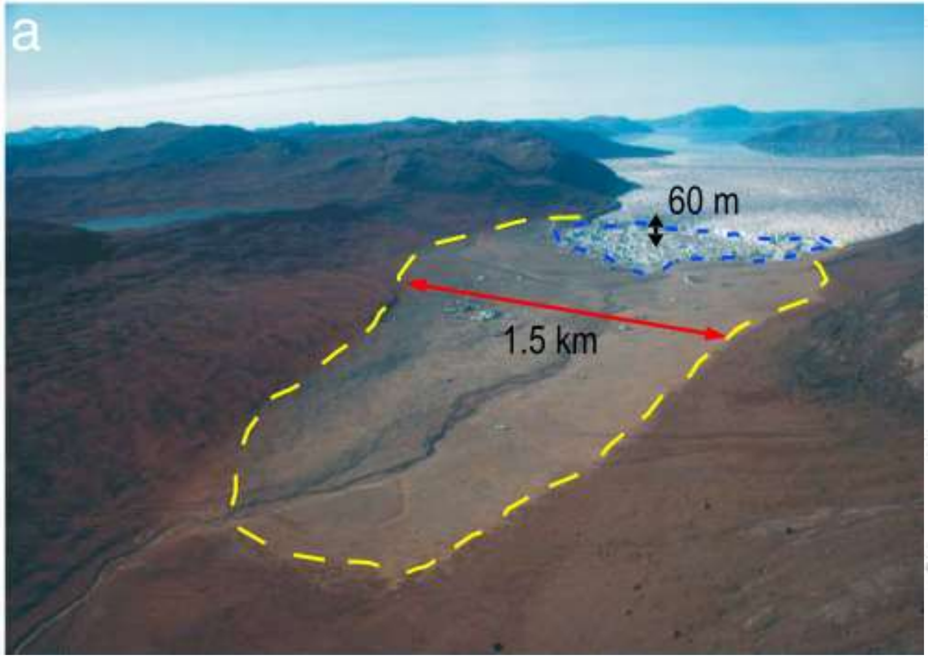
Rigét et al., 2014

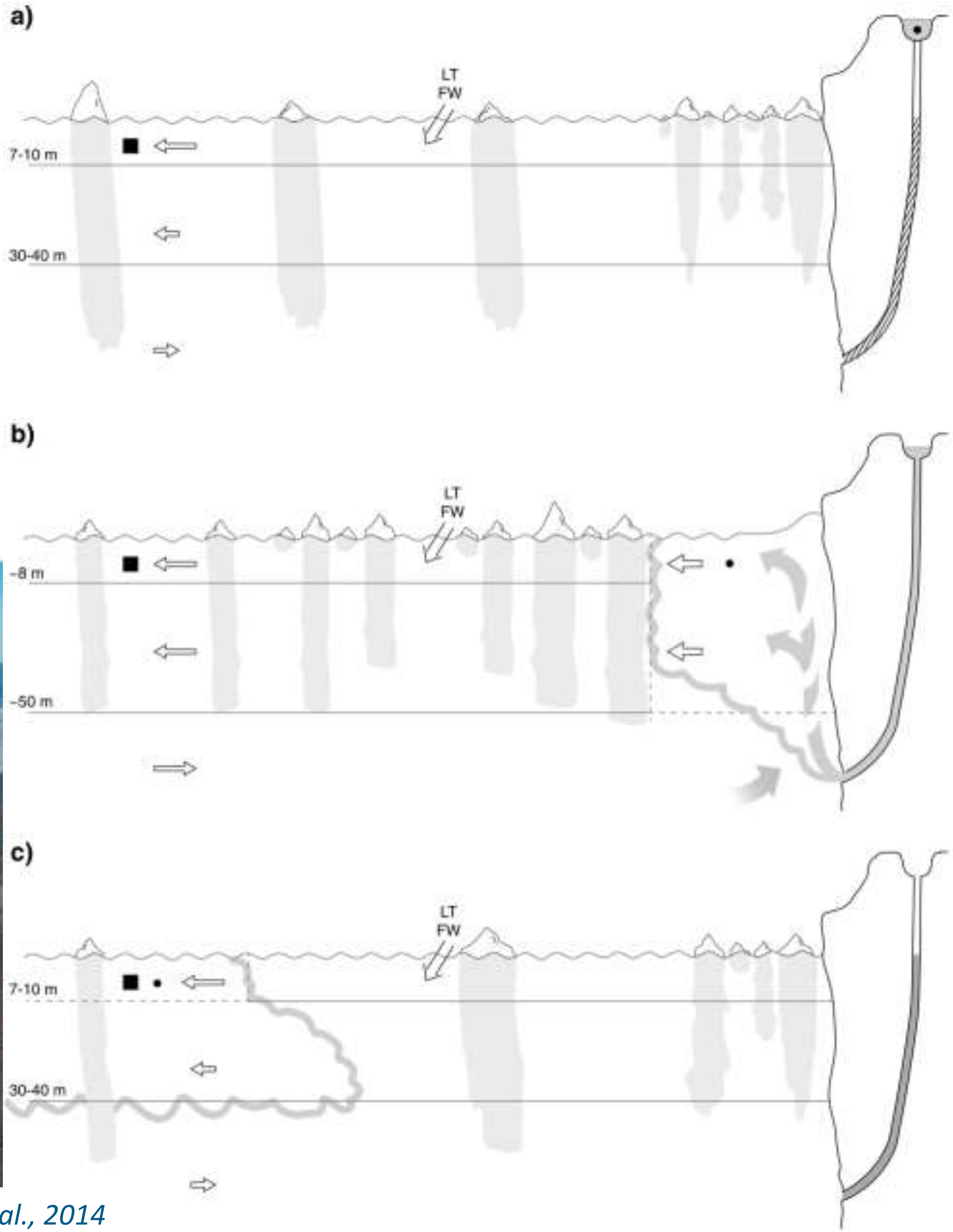
jökulhlaups

other effects downstream:

- mobilization of pollutants (e.g. Zackenberg River in 2009)

- temperature and salinity pulse detected in fjord





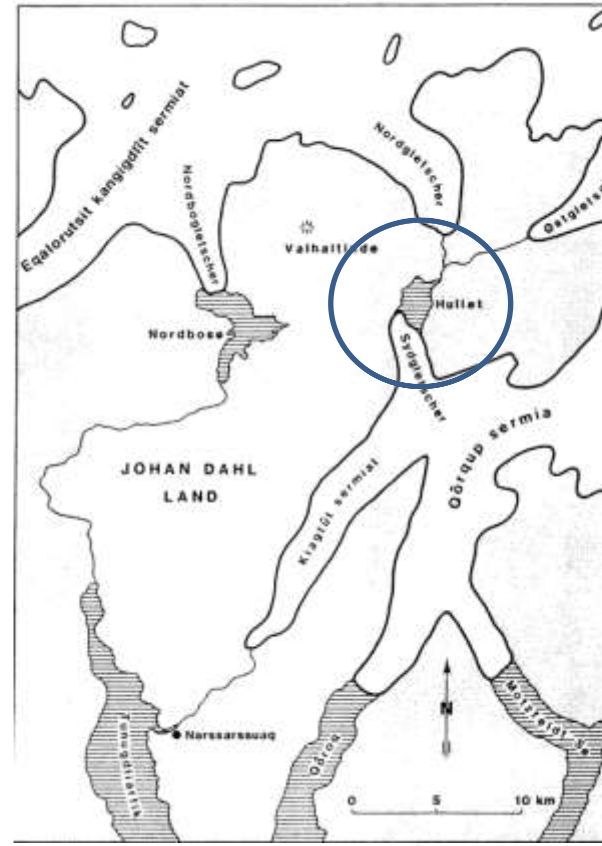
Kjeldsen et al., 2014

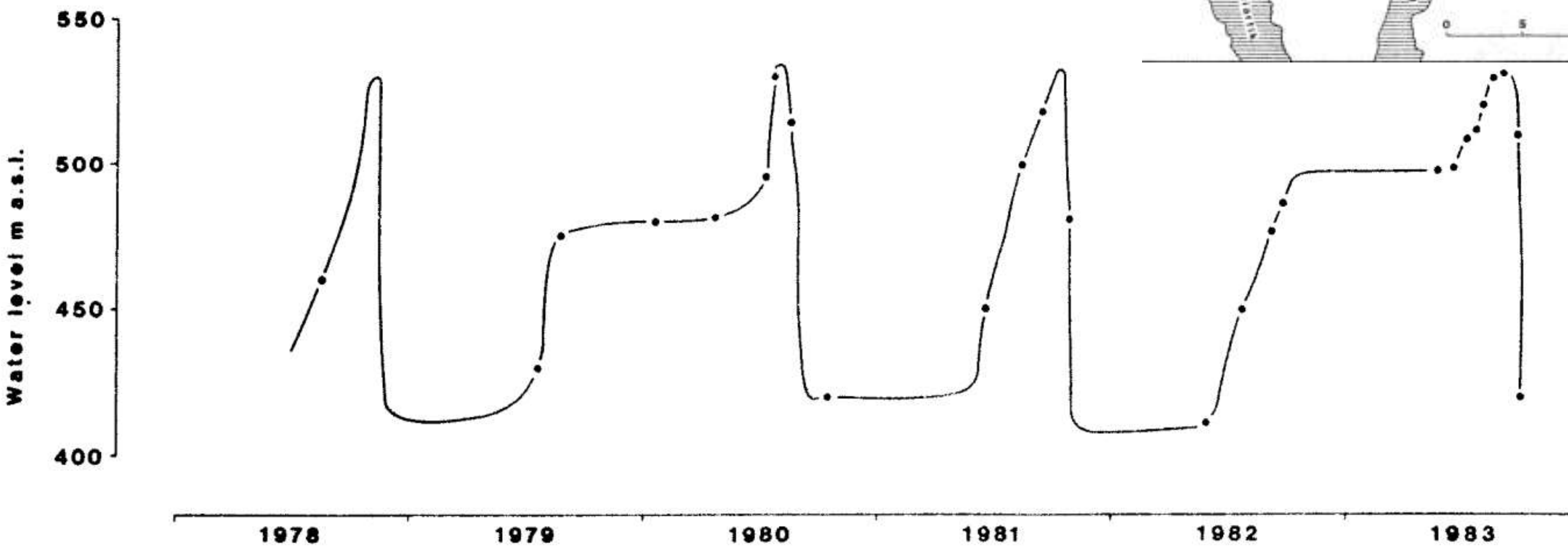
jökulhlaups

Ice-dammed lakes

periodic draining

good documentation for a few lakes, mainly in West and South Greenland, e.g. Hullet lake:





Clement, GGU 1983

jökulhlaups

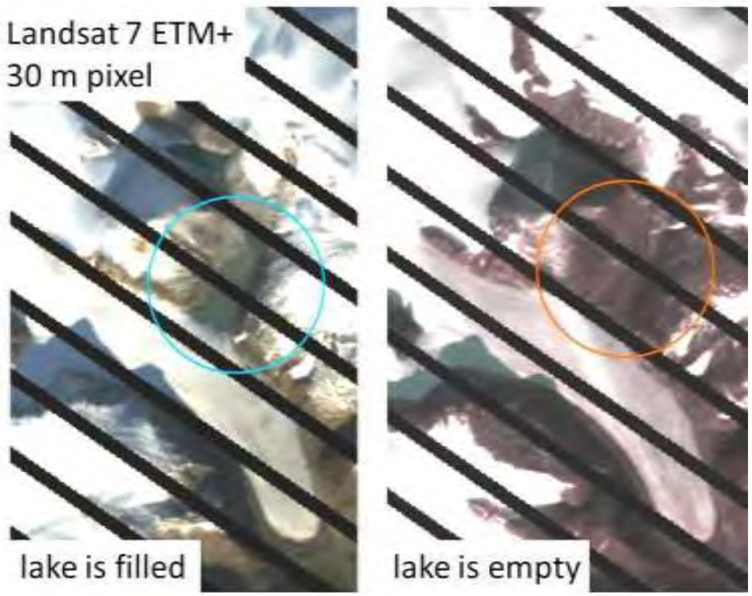
Ice-dammed lakes

Open questions:

→ wintertime draining events: known to happen, but what trigger them?

Limitations of current methods (visible spectrum):

- **clouds**
- **polar night**
- **pixel size**
- **revisit time**



GEM
GlacioBasis
Zackenberg

This work is funded in part by ENS through the GlacioBasis Monitoring Programme and GEM-A-4 analytical project.

jökulhlaups

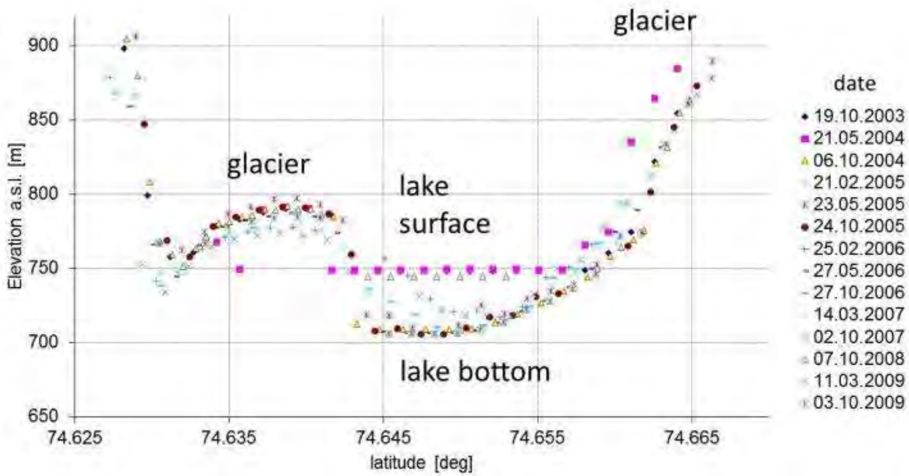
Ice-dammed lakes

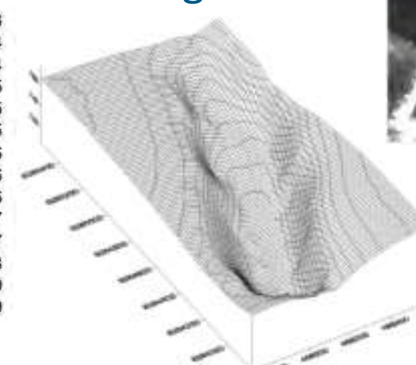
Open questions:

→ Possible to systematically detect GLOFs anytime and anywhere?

ICESat GLAS footprints

Lake stand and lake bottom profiles from ICESat GLAS. DEMs may also be produced From e.g. ASTER





GEM
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Zackenberg

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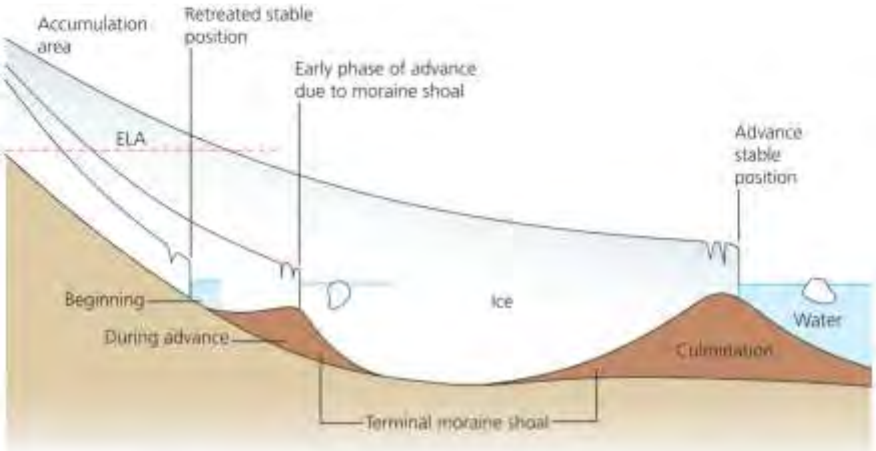
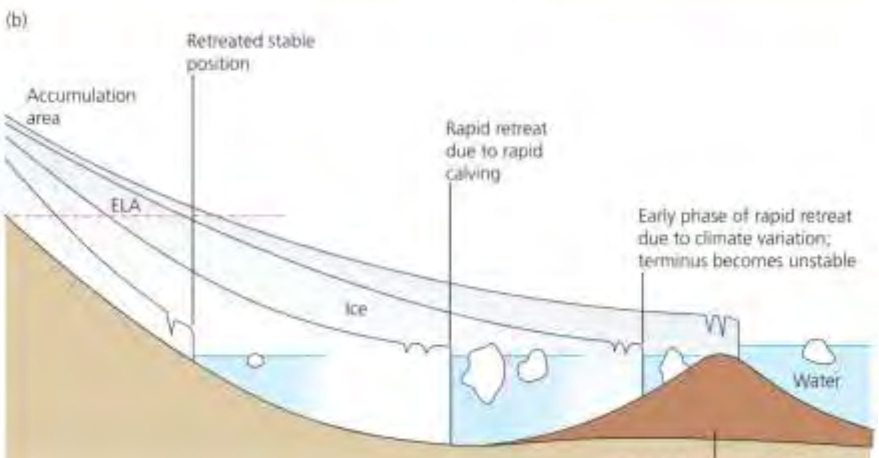
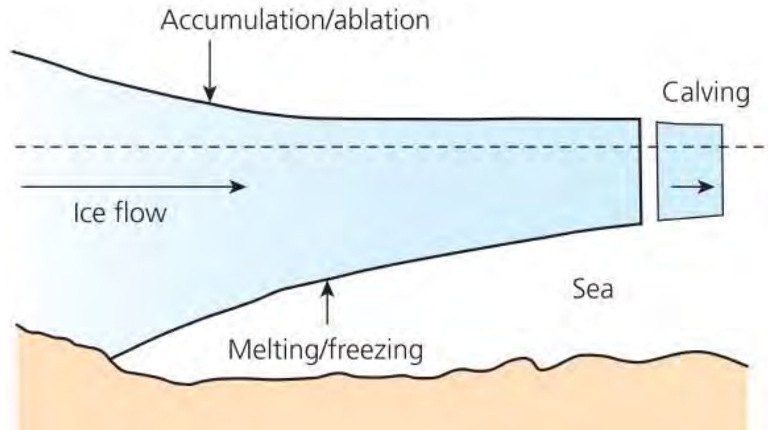
calving

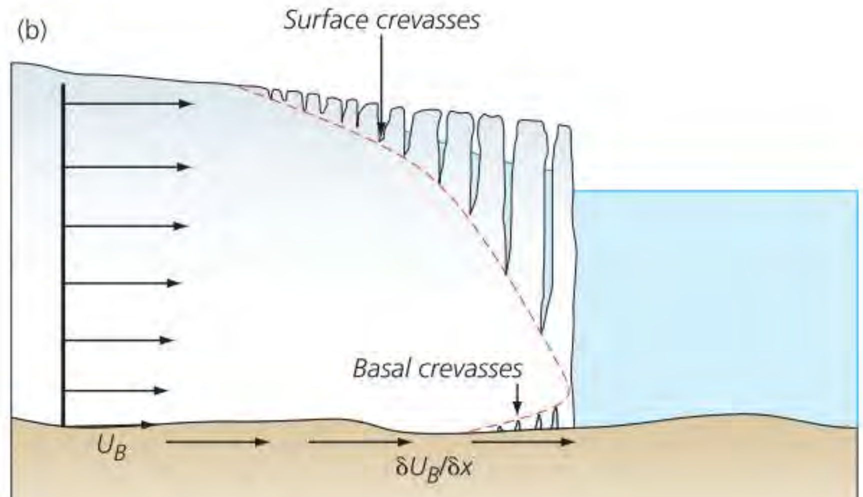
Complex process where surface meltwater, ice rheology, fjord water and fjord topography interact with outlet glaciers and ice shelves





Warren, 1992



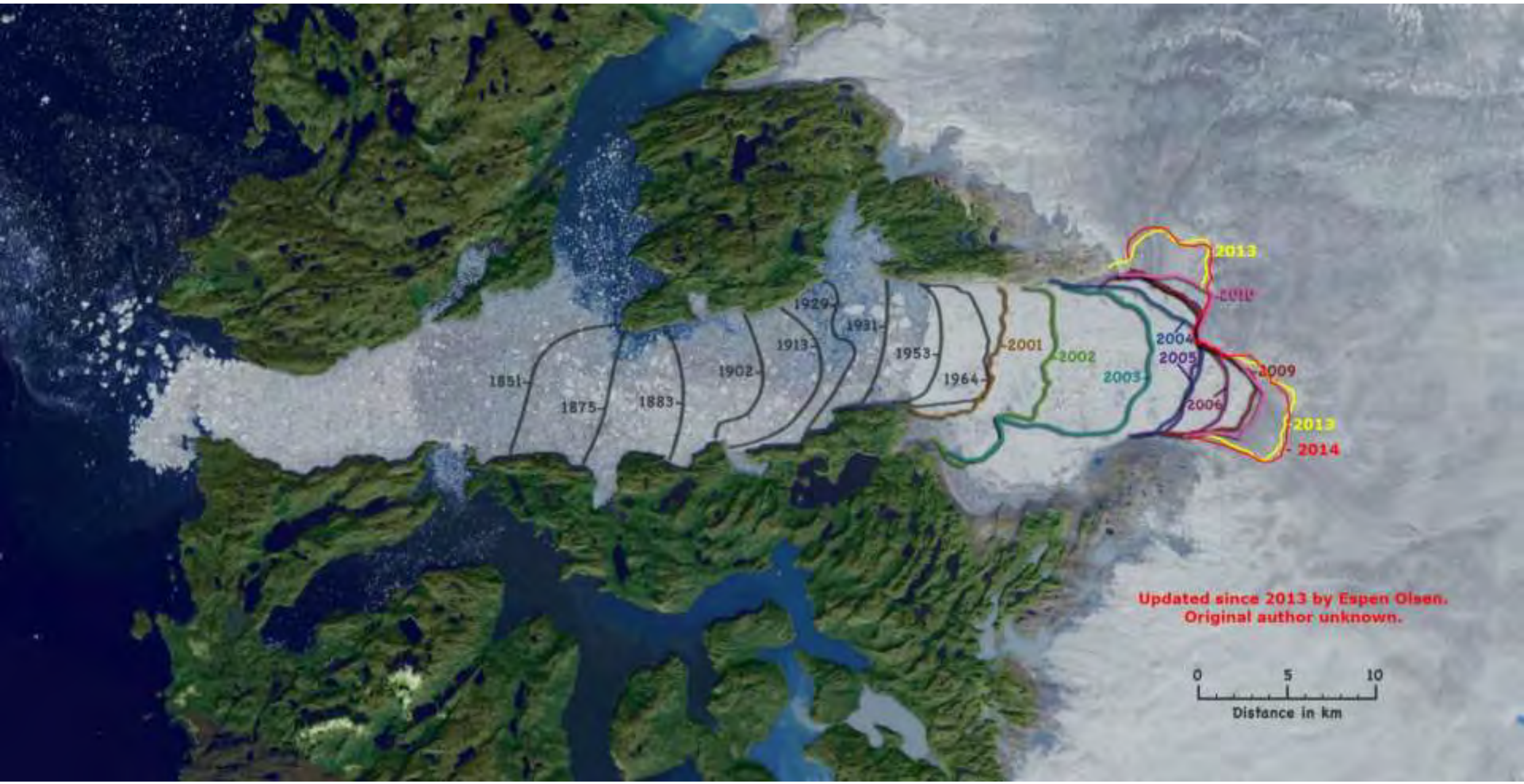


Benn et al., 2007

calving

Mobilize from small blocks to very large volumes

Jakobshavn.mp4 Jakobshavn.webm Jakobshavn.dk.flv



calving

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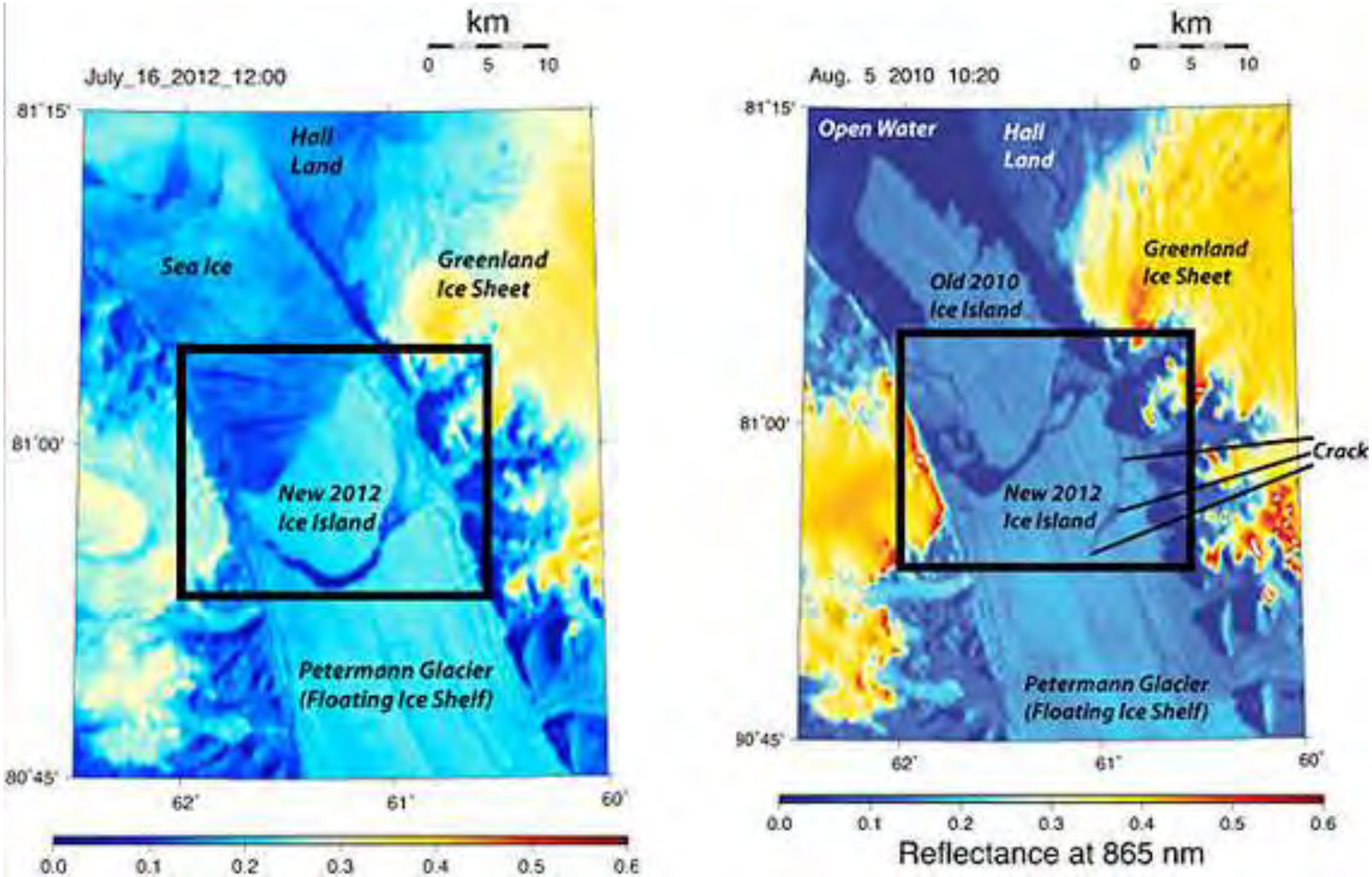


calving

Mobilize from small blocks to very large volumes

Almost always harmless to people...

calving

Mobilize from small blocks to very large volumes

Almost always harmless to people...

... but is the producer of icebergs

calving

Freshwater calving, here: Glaciar Perito Moreno (Argentina), from the ISS and from the ground in January 2004.

The ice dam separates an arm of Lago Argentino until it periodically breaks down.

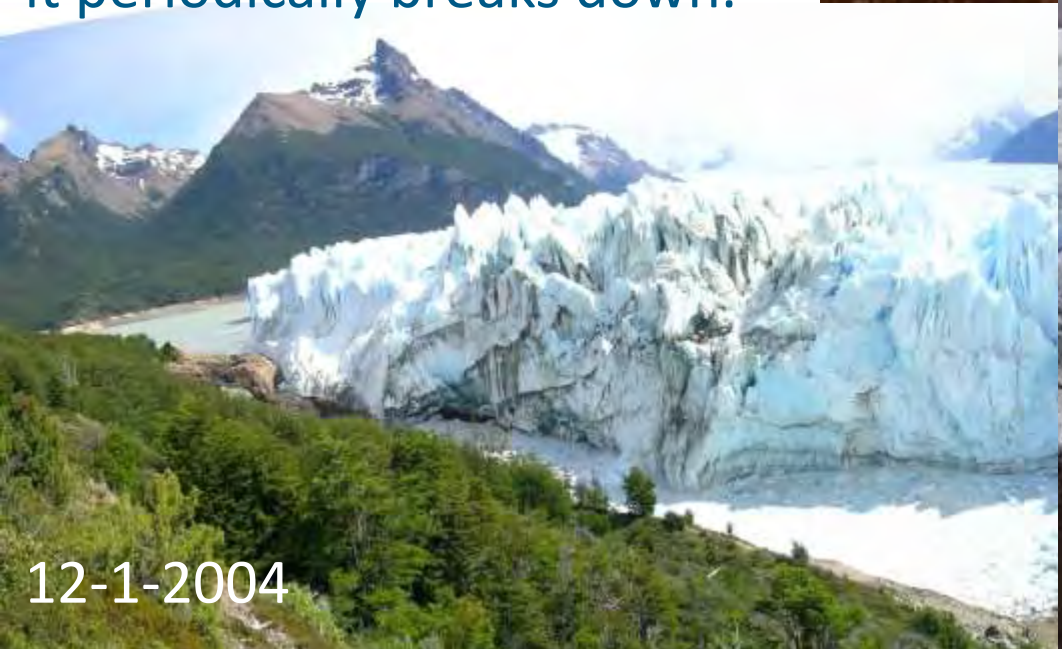
ISS 17-5-2012

12-1-2004

calving

Freshwater calving, here: Glaciar Perito Moreno (Argentina), from the ISS and from the ground in January 2004.

The ice dam separates an arm of Lago Argentino until it periodically breaks down.



glacier surges

Cyclical flow instabilities alternating between decades to century-long quiescence and short lived speed-ups (10-100x) and terminus advance. No external cause.

Tend to cluster in specific regions (e.g. Disko-Nuussuaq and the Stauning Alps)

Kuannersuit Glacier (Disko Island) →

1, 17/6/95	2, 24/9/95	3, 20/10/95
4, 20/5/96	5, 22/9/96	6, 24/6/97
7, 09/7/99	8, 30/9/99	(ca. +11 km)

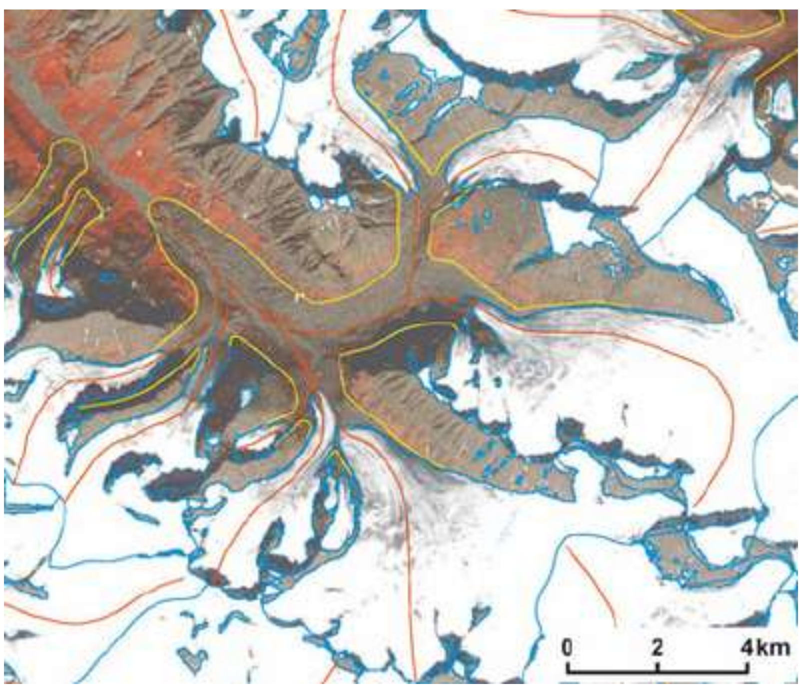
(Roberts et al., 2009 using TM, SPOT, Landsat sources)

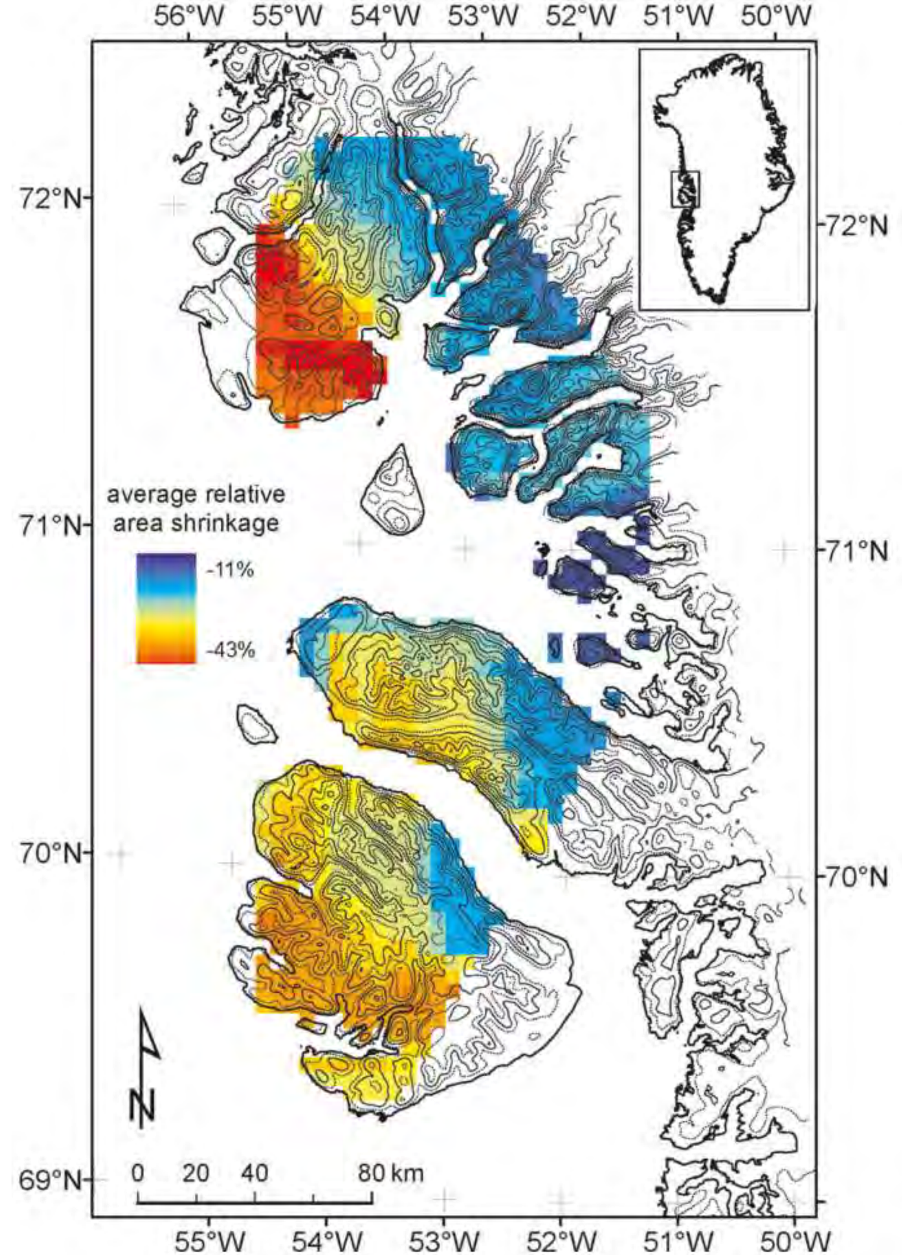
glacier surges

LIA maximum or surge?

Complicates extracting a climate signal from glacier fluctuations from space

Require expensive fieldwork or complicated data reduction





Citterio et al, 2009

glacier surges

Triggers models

- Hydrologic switch (temperate glaciers)
- Thermal switch (polythermal glaciers)
- Role of till layer

Accelerations usually begins in the upper reaches of the glacier and then propagate downglacier as a bulging surge front.

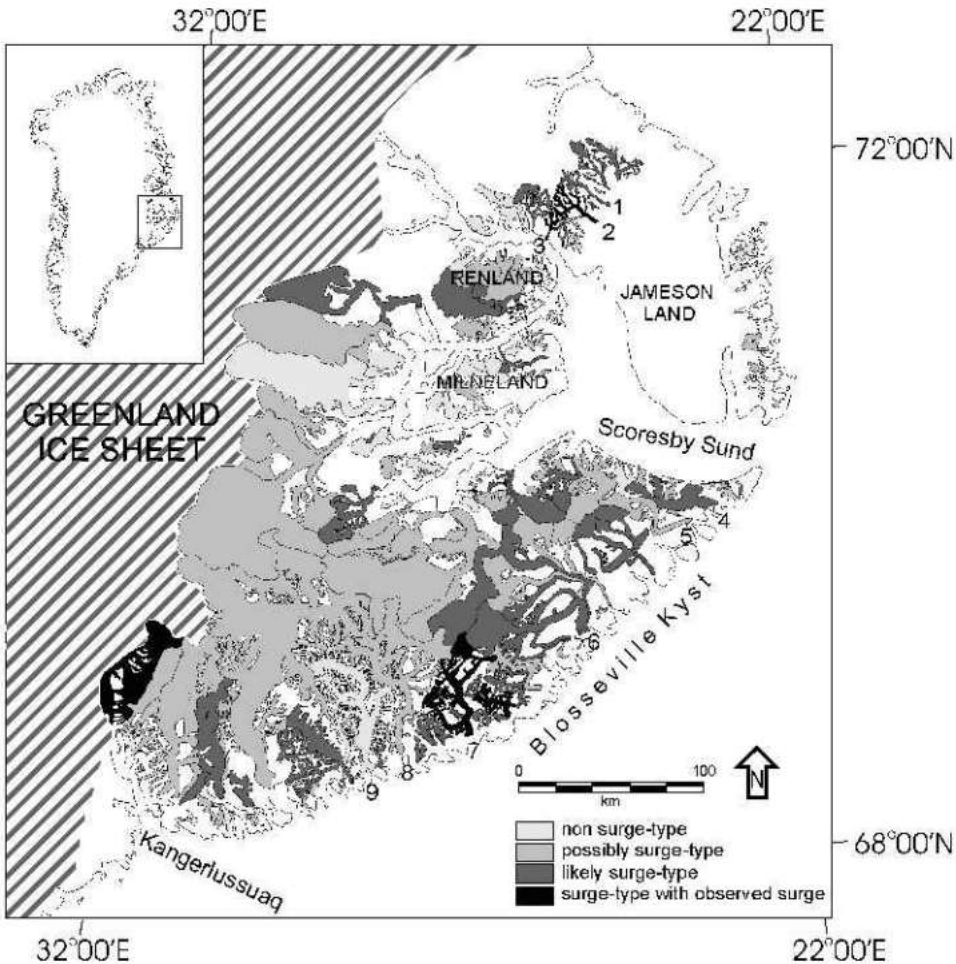
Glacier Surging, Table 1 Surge characteristics of a selection of surge-type glaciers worldwide, sorted by geographic region: [1]Svalbard, [2]Pamirs, [3]Karakoram, [4]Alaska, [5]Yukon Territory, [6]Greenland, [7]Iceland (After Jiskoot et al., 2001)

Glacier	Length km	Surge advance km	Lowering m	Thickening m	Volume displ. km^3	Calving rate $km^3\ a^{-1}$	Quiescence velocity $m\ d^{-1}$	Surge velocity $m\ d^{-1}$	Surge-front propagation $m\ d^{-1}$	Surge duration y	Quiescence duration y
Bodley[1]	16	2–3.5	−15	+60			0.5	1.4	6.5	7+	
Bakaninbreen[1]	17	0	−15	+40	0.67		0.0005–0.001	0.2–3	2.5–5	5–15	>85
Monacobreen[1]	40	2					0.006–0.008	0.5–5	–	7–11	
Skobreen[1]	8.2	0.2–0.4	−60	+40					7.8	>15	>100
Perseibreen[1]	11.5	0.35						2–2.5			130
Medveziy[2]	13	1.6	−100	+150	0.06		0.001–1.5	68–105	80	0.4–1	10–15
Chiring[3]	15.5	2.5	−150	+130	1–1.5					3	110
Variegated[4]	20	2–5	−50	+100			0.2	14–50	15–80	2	16–26
Bering[4]	200	9.7	−50				1	11–33	90	2–3	20–30
West Fork[4]	40		−60	+123	3.7		0.15	12	23	<1	50
Trapridge[a5]	4	1								10	30
Trapridge[b5]	4	0.45		10	0.00017		<0.02	0.07–0.12	0.08	>20	30
Sortebræ[6]	77	10	−270	+145	22	4.5–5.3	0.1–0.7	5–27	50–330	~2.5	40–50
Storstrømmen[6]	120	10	−80		50	10.8	0.4–0.8	4–5.5		5–6	70
Sermeq peqippoq[6]	10	2.8					0.008–0.01	1–13	190	6–7	>60
Brúarjökull[7]	50	8–10						125		0.4–2	70–100

Note: Trapridge[a] is from the 1940s surge and Trapridge[b] from the 1980s to 2000s slow surge (Frappé and Clarke, 2007).

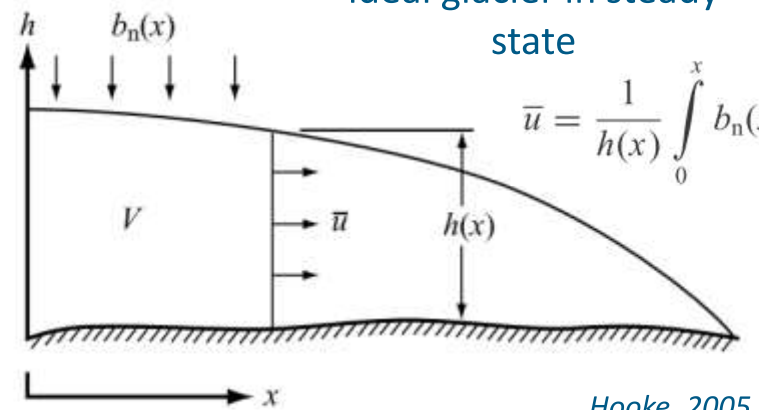
glacier surges

Impossible to predict the surge initiation, but possible to detect the flow imbalance and evidences of past surges.



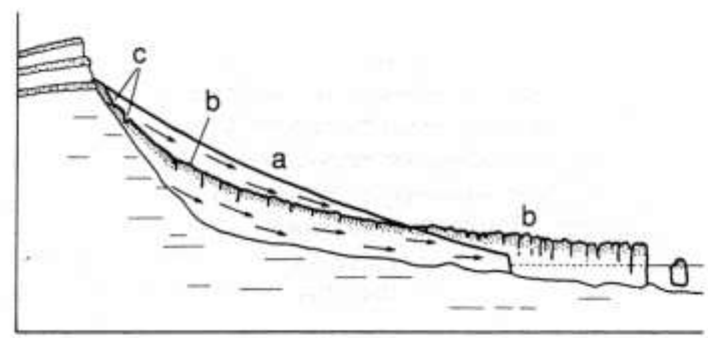
Jiskoot et al., 2003

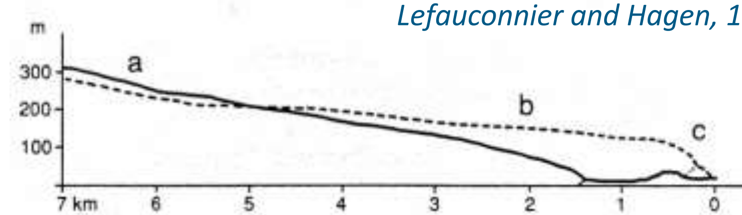
ideal glacier in steady state



$$\bar{u} = \frac{1}{h(x)} \int_0^x b_n(x)\, dx$$

Hooke, 2005

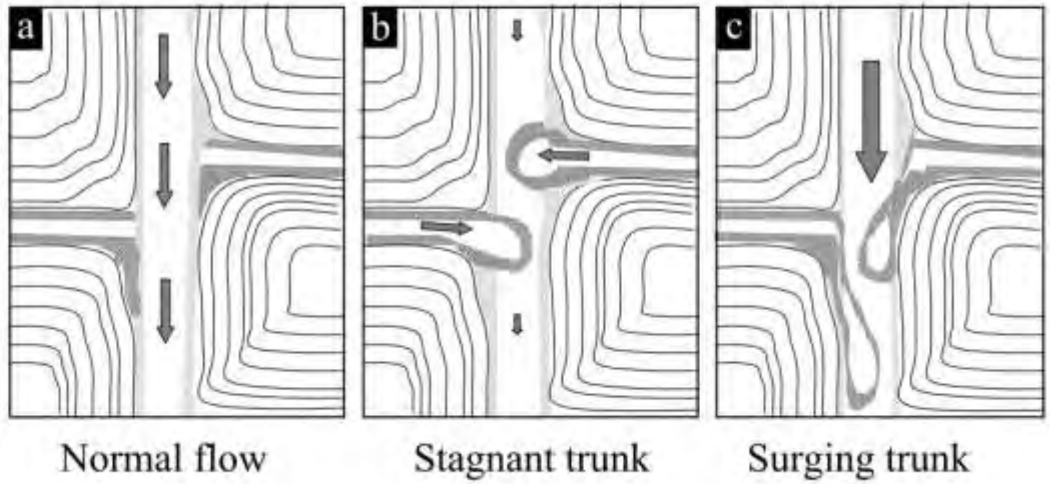




Lefauconnier and Hagen, 1991

glacier surges

Impossible to predict the surge initiation, but possible to detect the flow imbalance and evidences of past surges.



3: The formation of 'tearshaped' elongated moraine loops (After: Gripp, 1929; Croot, 1

Jiskoot, 2003

glacier surges

'Surges' initiated by external causes: rock avalanches

glacier surges

‘Surges’ initiated by external causes: rock avalanches

Punta Thurwieser,
Italy, 03-10-2004

glacier surges

‘Surges’ initiated by external causes: rock avalanches

glacier surges

‘Surges’ initiated by external causes: rock avalanches

glacier surges

'Surges' initiated by external causes: mining activity

Kumtor
gold mine,
Kyrgyzstan

(Jamieson et al., 2015)

glacier surges

'Surges' initiated by external causes: mining activity

glacier surges

‘Surges’ initiated by external causes: mining activity

glacier surges

'Surges' initiated by external causes: mining activity

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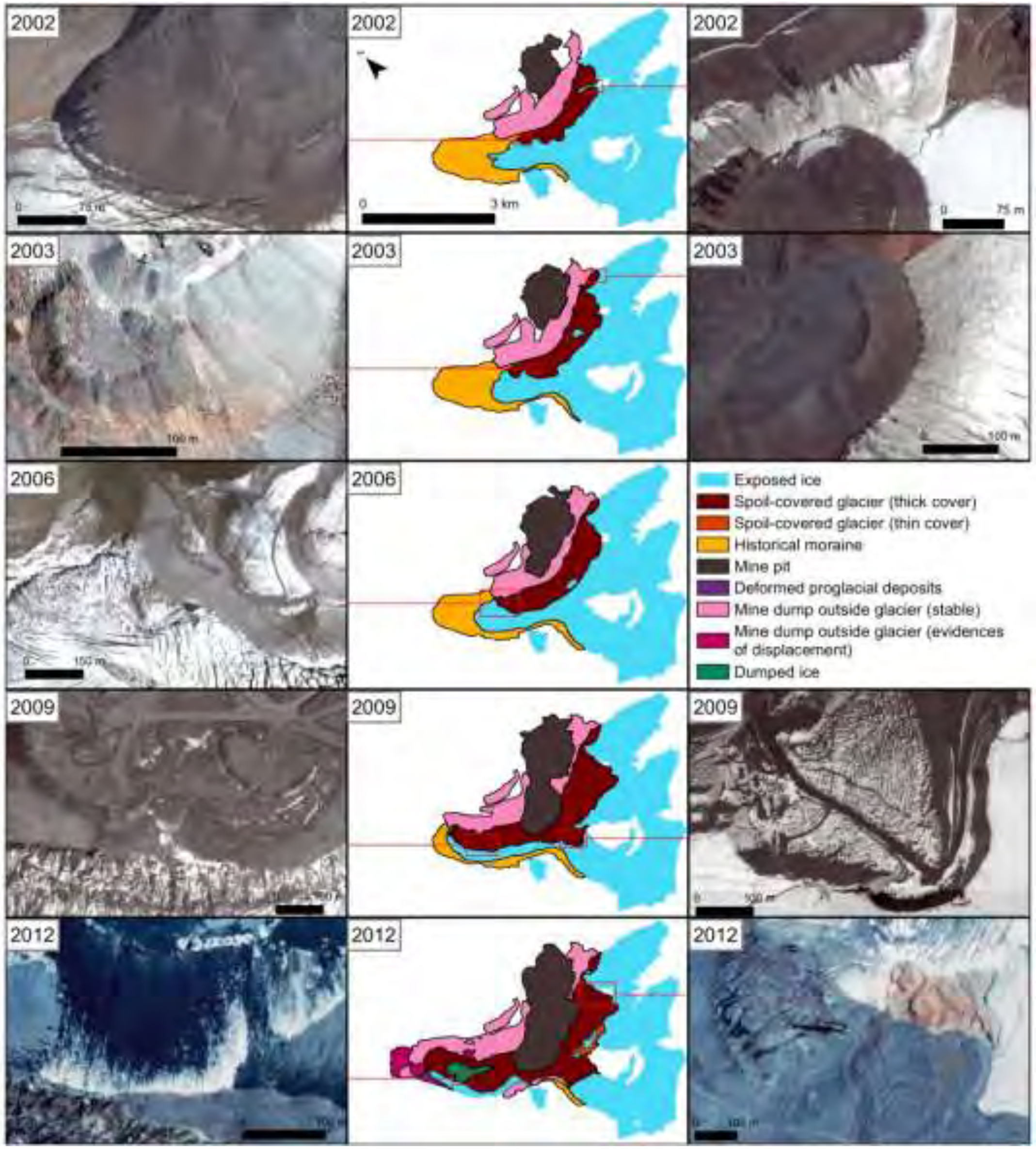

glacier surges

'Surges' initiated by external causes: mining activity