ESS 203 - Glaciers and Global Change

Monday March 8, 2021.

Outline for the day

- Today's highlights on Wednesday – *Alex Kissel*
- Last Friday's highlights – *Evan Carroll*

- Glacier surges
- Tidewater Glaciers

Missed any class HW assignments?

- Get credit for missed HW.
- Amnesty Interglacial in effect until March 18.

HW 26 for Wednesday

Reading Assignment – short article from *Science:*

Joughin, I. et al., 2014. Marine Ice Sheet Collapse potentially underway for the Thwaites Glacier Basin, West Antarctica. *Science* 344, 735-738.

You can download it from Canvas

> Files > HomeWork > Joughin_2014_WAIS_collapse_Science.pdf

(A commentary on the article in the same issue of *Science* is also attached to the pdf.)

Writing Assignment

Answer our 3 questions about scientific papers

- What question is being addressing?
- What answer do the authors find?
- What points on the paper are still unclear to you?

What is a Glacier Surge?

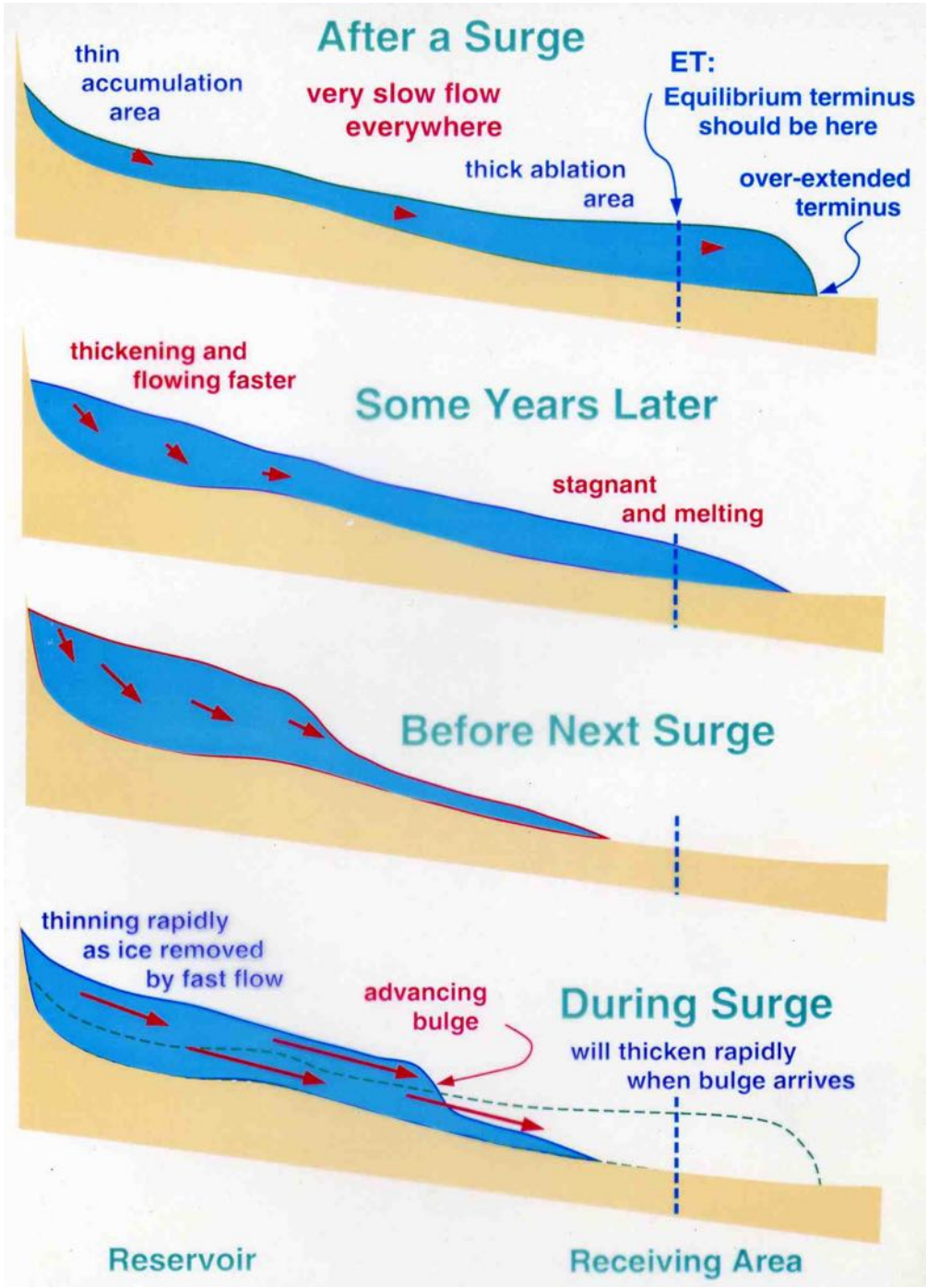
The Surge

- High speed (10 times normal speed, or more).
- Brief (1/10 of a surge cycle).
- Large ice displacement (>1/10 length of the glacier).
- Ice discharged from reservoir to receiving area.

The Quiescent Phase

- Lasts much longer than the surge.
- Speed of ice relatively low.
- Accumulated ice displacement is small.
- Reservoir recharges, receiving area wastes away.

- Surges are quasi-periodic (10-100 year cycle).
- Surges are triggered primarily by causes within the glaciers or at the glacier bed, rather than by external factors such as climate.

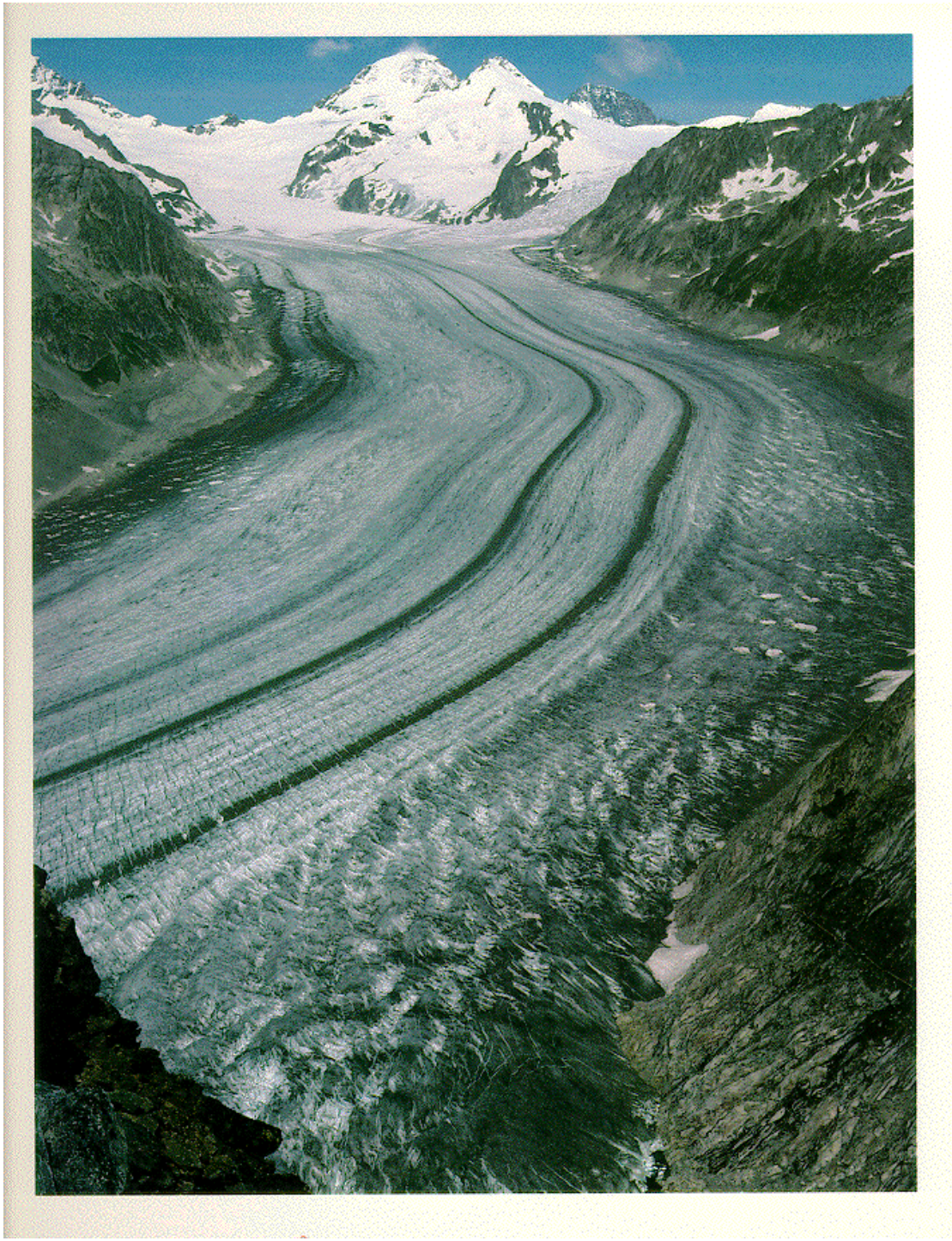


Changes through a Glacier Surge Cycle

Is this a Surge-Type Glacier?

Aletsch Gletscher
Switzerland

Hambrey and Alean,
Glaciers, ed. 1



Is this a Surge-Type Glacier?

59. The generation of looped and folded moraine patterns by periodic surges of a valley glacier with steady state tributary, Susitna Glacier, Alaska Range. (a) 1941, (b) 1966

Post and LaChapelle, *Glacier Ice*

Susitna Glacier, AK, 1941

Susitna Glacier, a few years later

Susitna Glacier, AK, 1966

Post and LaChapelle, *Glacier Ice*

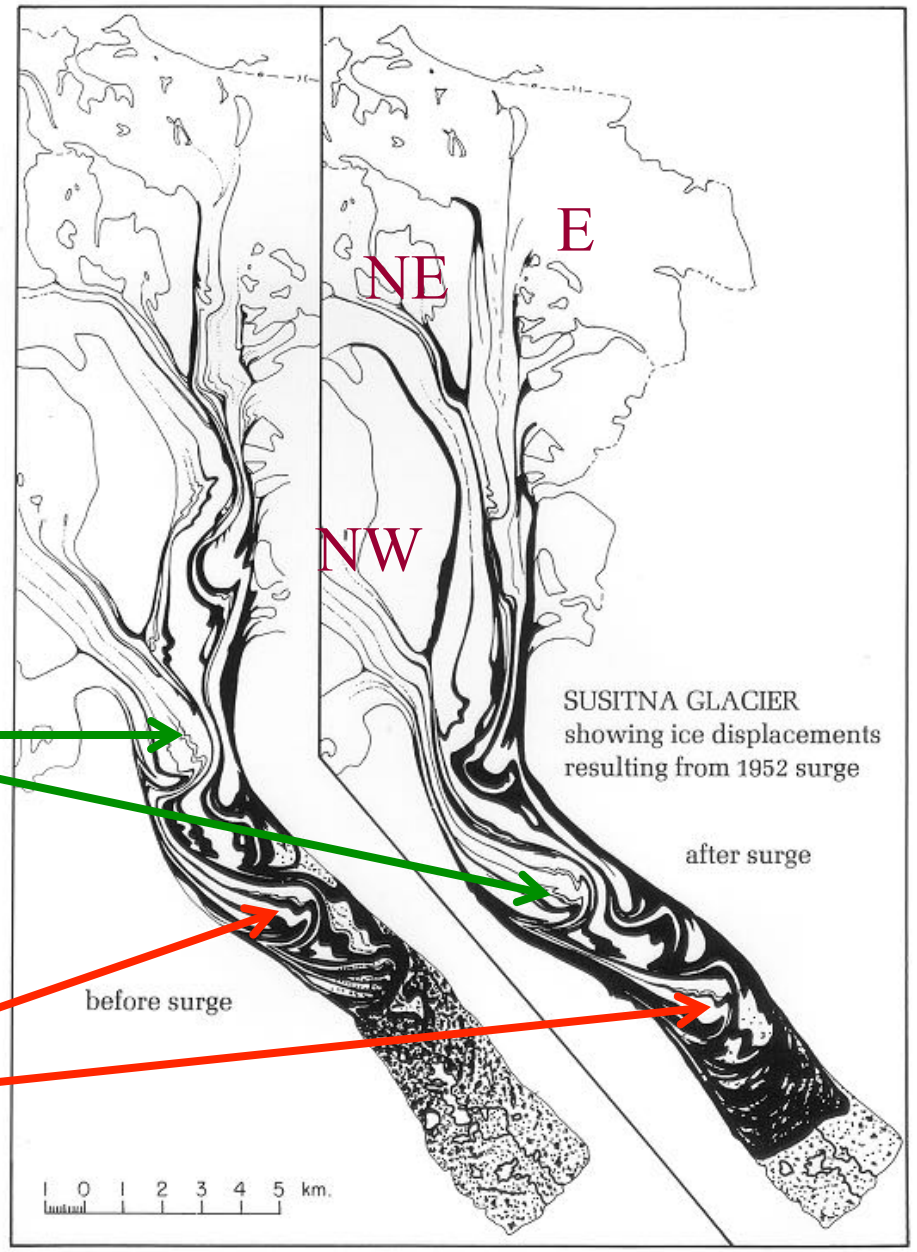
What Happened?

Susitna Glacier, AK

- East Tributary and NE Tributary can surge.
- NW Tributary does not.

- East and NE Tributaries both surged in 1951-1952.
- Slowly advancing lobe from NW tributary was swept down the valley by surging NE branch.

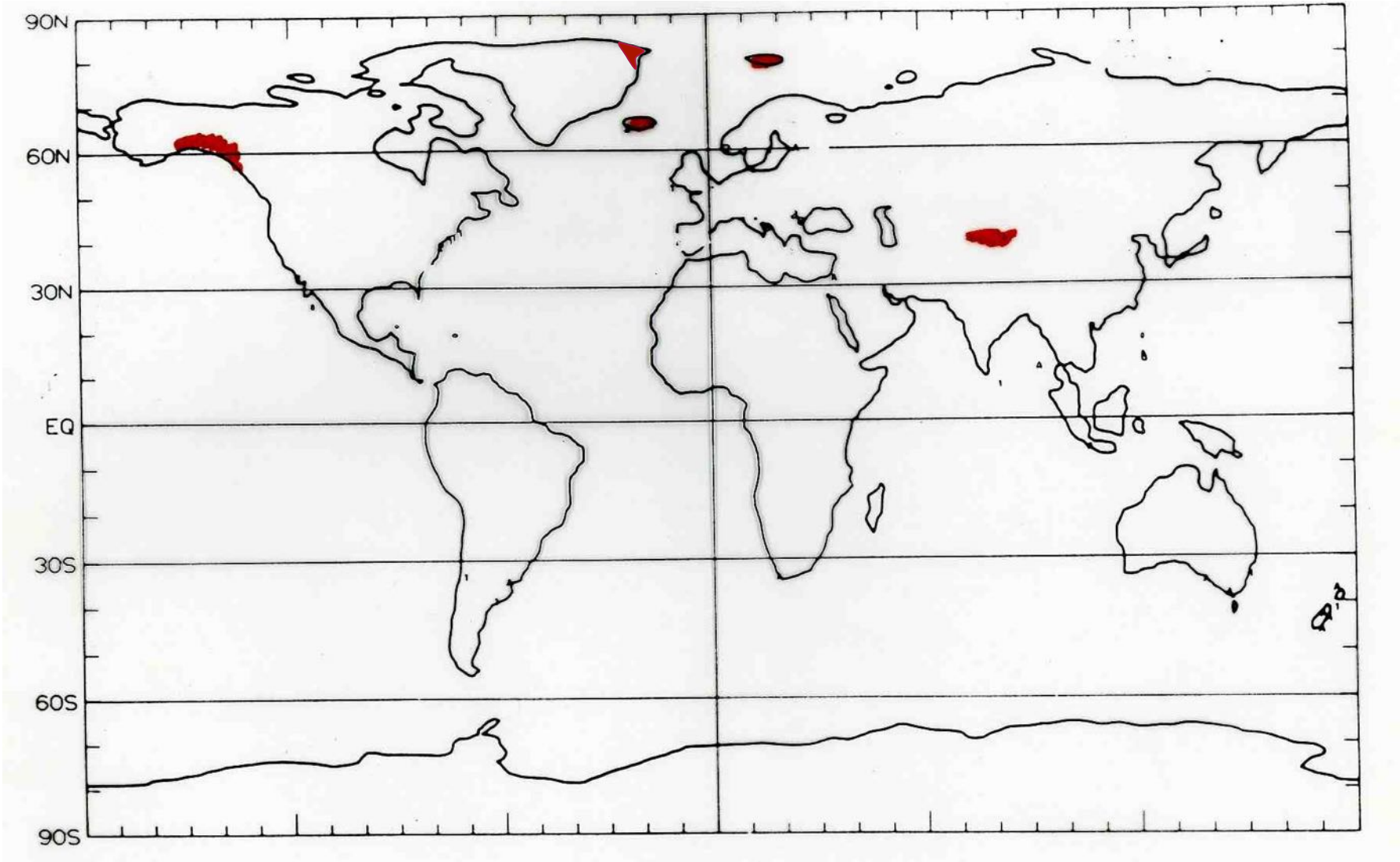
- It had happened before.



60. *Sketch maps of Susitna Glacier surge and moraine patterns*

Post and LaChapelle, *Glacier Ice*

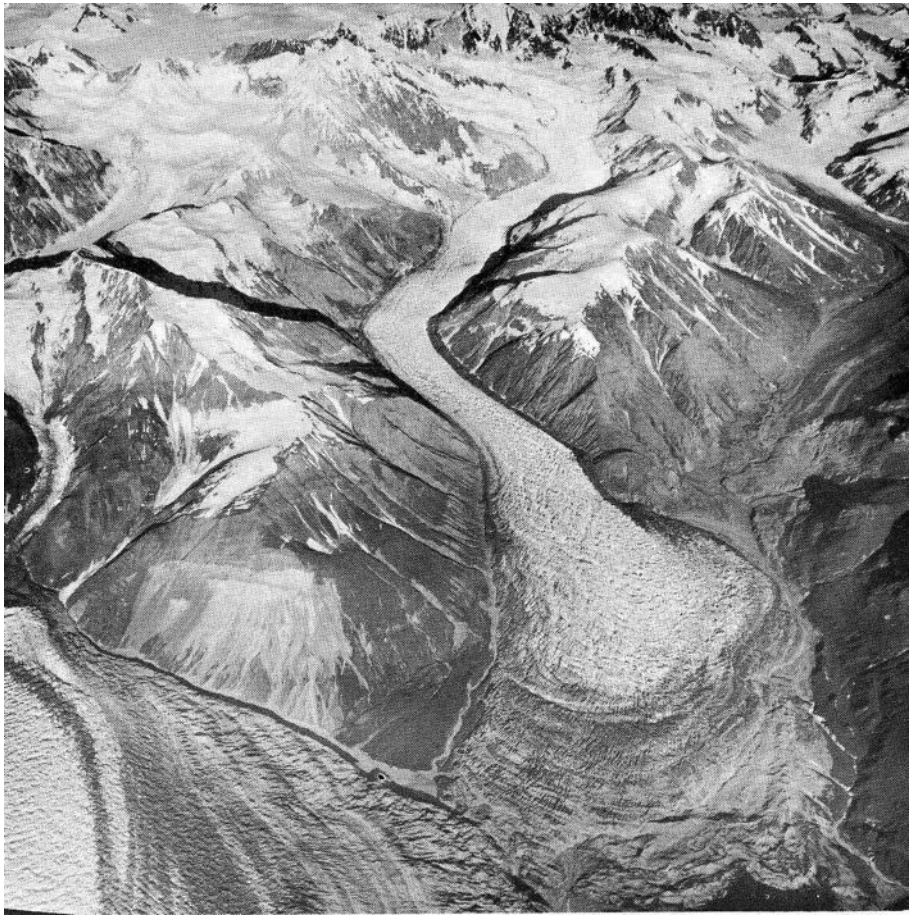
Where are the Surging Glaciers?



Distribution is far from random!

Variegated Glacier – 1964-65 Surge

Pre-surge



Post-surge

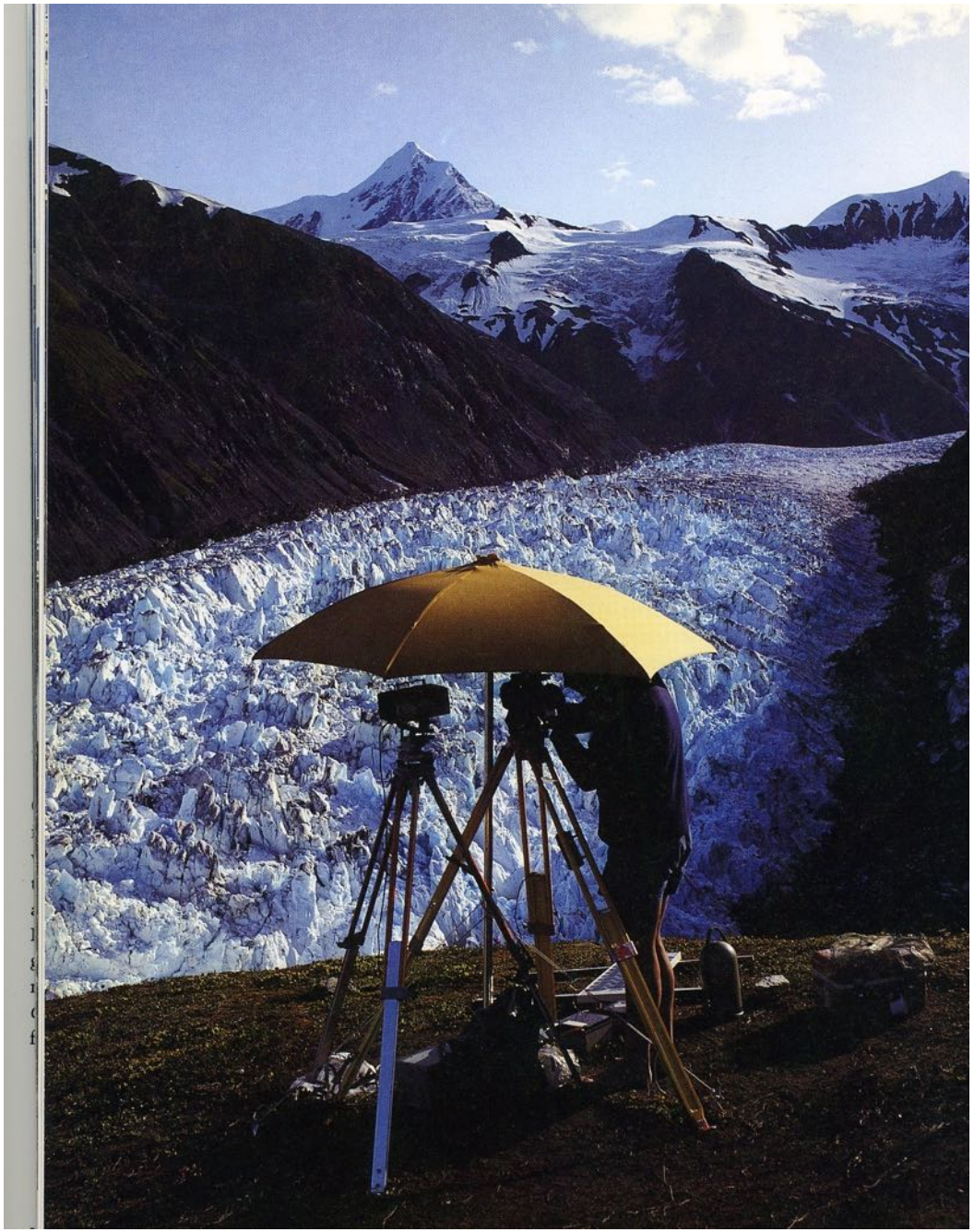
Paterson, W.S.B. 1969. *The physics of glaciers*. 1st ed.

Variegated Glacier

- Surged again in 1982-1983
- Research team from UW, UAF and Cal Tech was waiting.

Kamb, B. et al. 1985. *Science* 227(4686)

(photo Hambrey and Alean, *Glaciers*)



Variegated Glacier – the Map

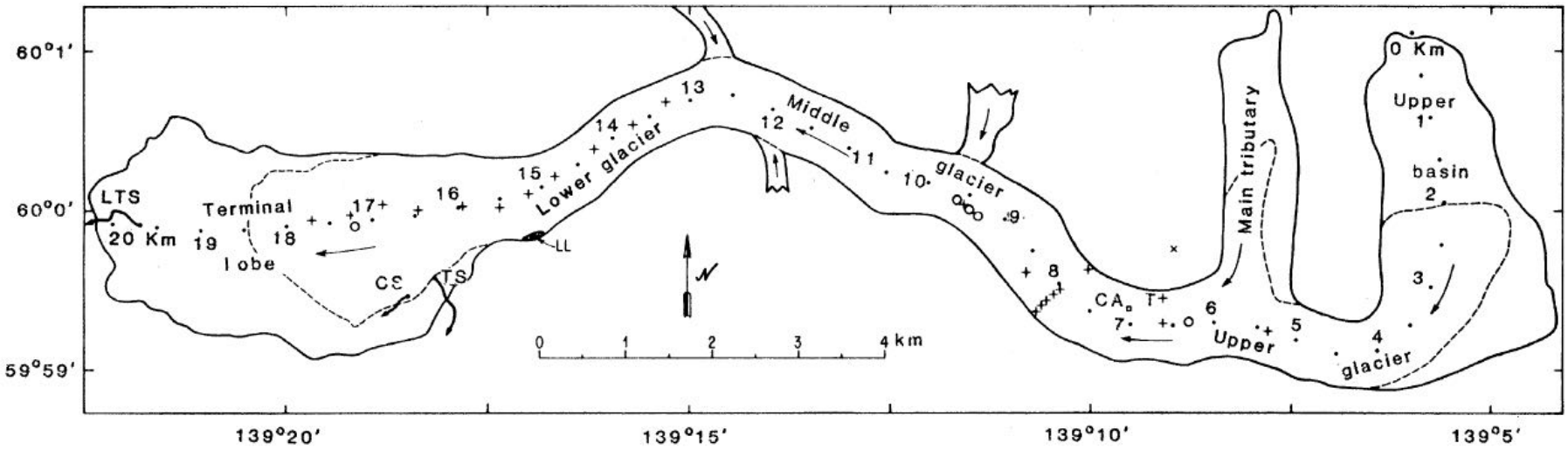


Fig. 1. Map of Variegated Glacier, Alaska, showing the longitudinal coordinate scale (0 to 20 Km) by which locations on the glacier are referenced in the text. Light arrows indicate the general direction of glacier flow. Heavy arrows show outflow streams near the terminus. The dashed line shows the boundaries of the part of the glacier that surged in 1983. Crosses indicate approximate positions of reference markers for which ice-flow velocity data are given in the text. Open circles are approximate positions of boreholes drilled to the glacier bed. The point labeled CA is the location of a crevasse whose water content was observed during February through May 1983. The location of a seismometer on bedrock is shown with an × north of Km 6.5; LL designates the location of the lake shown in the cover photo and discussed in the text; LTS signifies the lower terminus stream; CS and TS are other outflow streams.

(Kamb, et al., 1985. *Science*)

Variegated Glacier – the Changes

Ice filled the lower valley to a level ~100 meters above the pre-surge surface.

(Kamb, et al., 1985. *Science*)

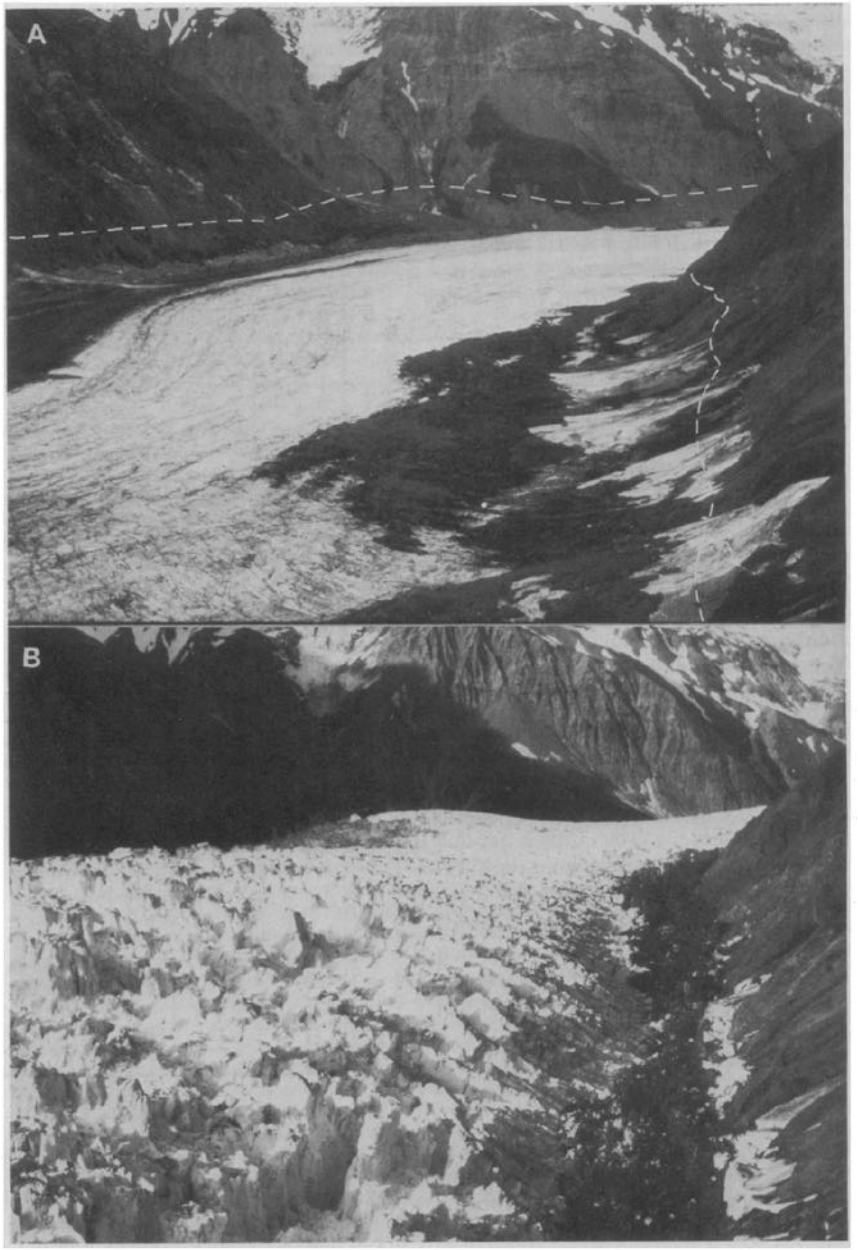
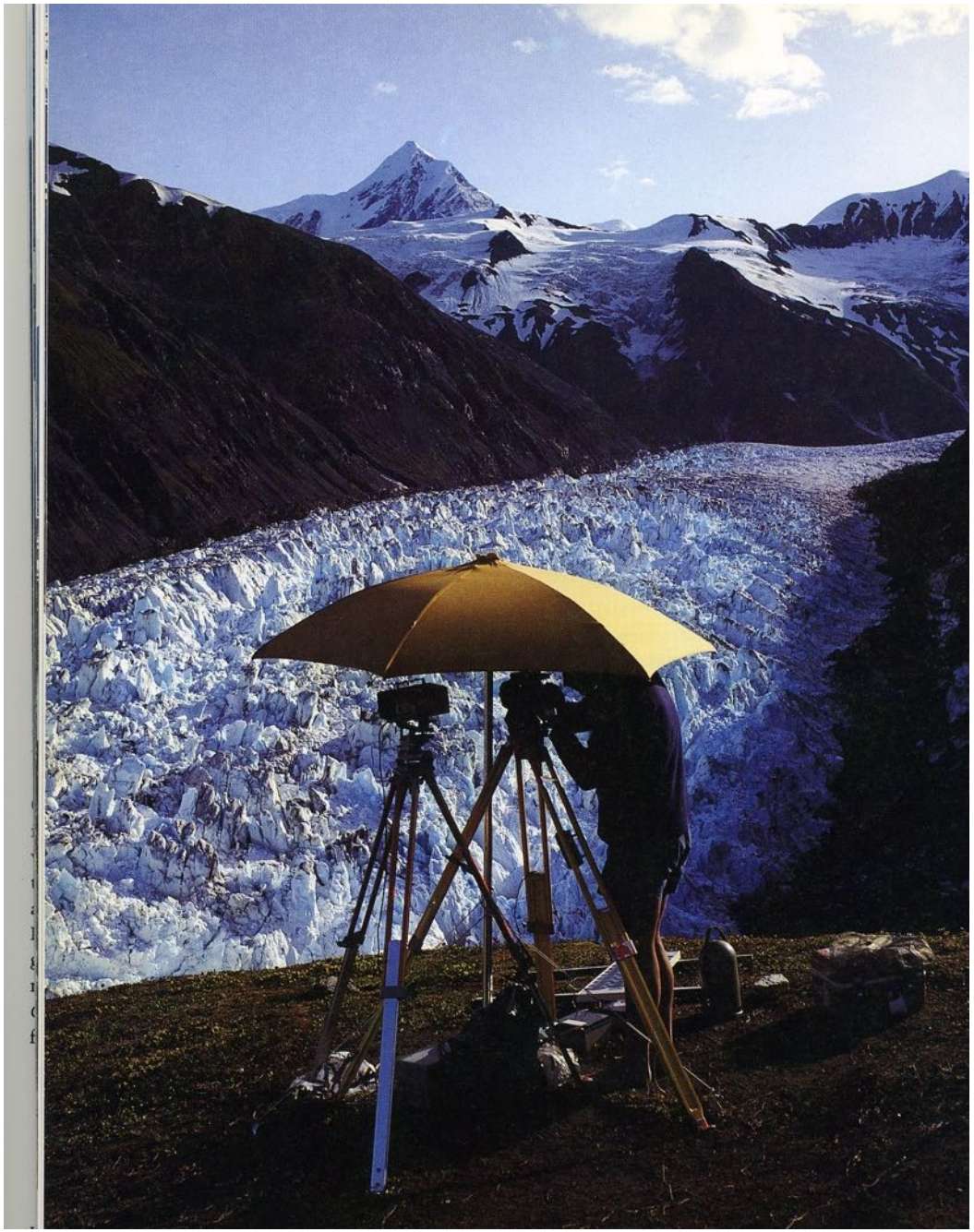


Fig. 3. Views of Variegated Glacier near Km 13 taken from the same point before the surge, July 1982 (A), and during the surge, 4 July 1983 (B). The view is upglacier. The scale, which is identical in (A) and (B), can be judged from the fact that the width of the glacier is approximately 1 km. In (A) the position of the ice surface in surge, as seen in (B), is marked with dashed lines.

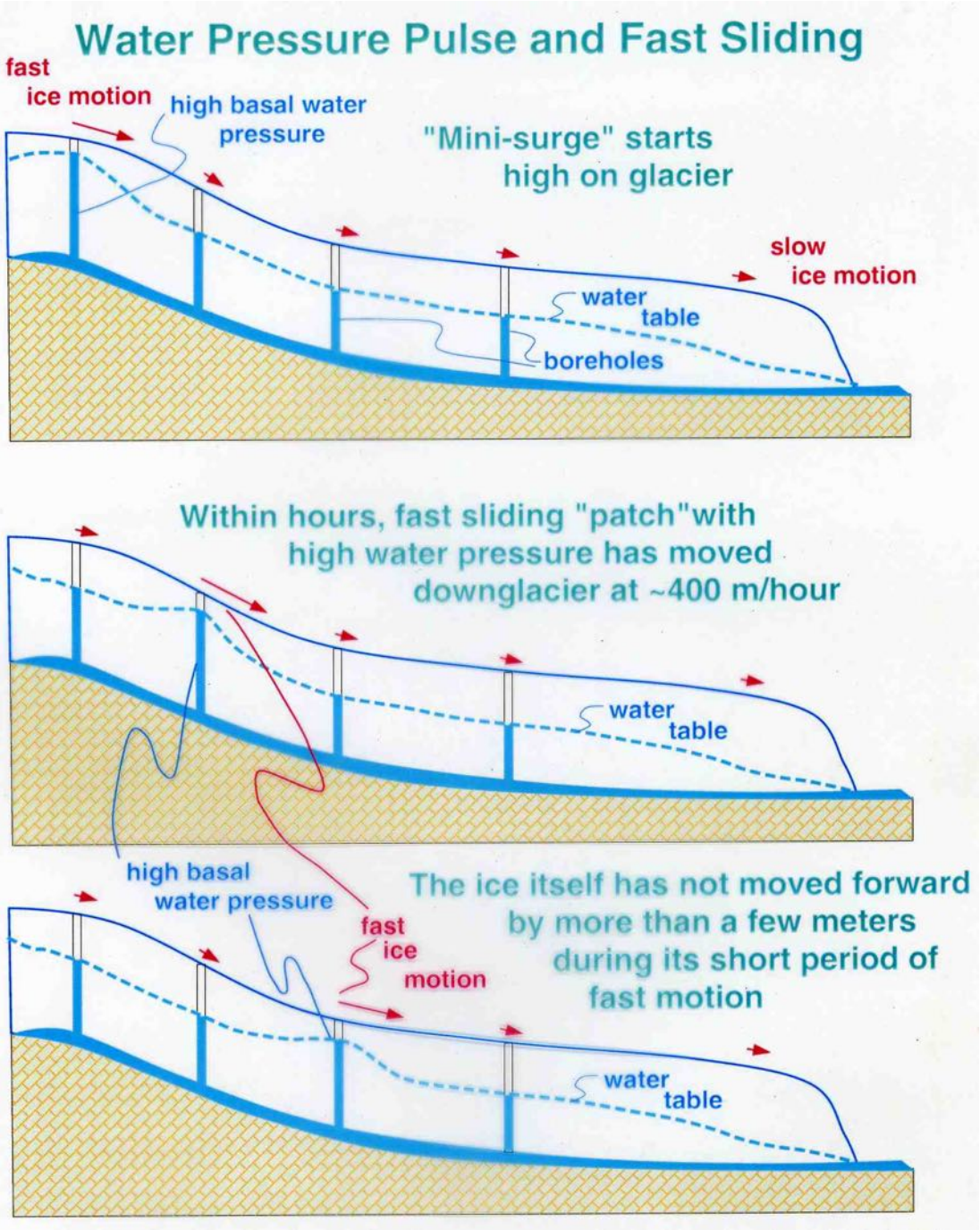
Variegated Glacier – the Movie

- Time-lapse cameras watched the surge

- Let's watch it now …
- Bulge arrives on lower glacier
/Users/edw/Desktop/STUFF/VIDEO/VARIEGATED_SURGE_1983/MOV/VG83_main_stream_arrival_Mpeg4_u1.mov



(photo Hambrey and Alean, *Glaciers*)

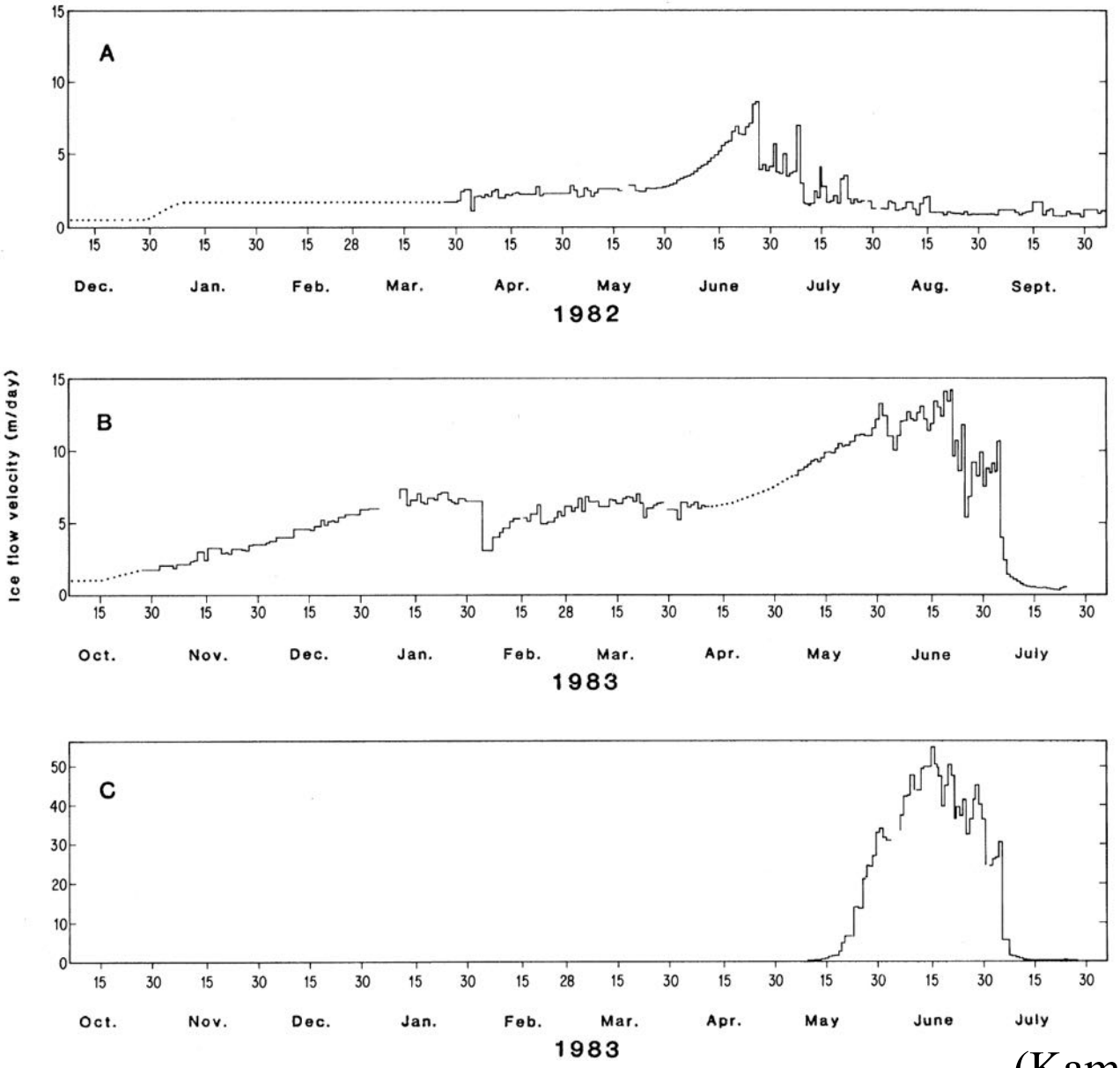


Variegated Glacier – mini-surges (not a good name in hindsight)

- Pulses of high water pressure travelled down the glacier at ~400 m hr^{-1}.

- Ice above the high-pressure water moved noticeably faster for a period of a few hours as the pulse in water pressure passed by.

Variegated Glacier – speed *vs* time



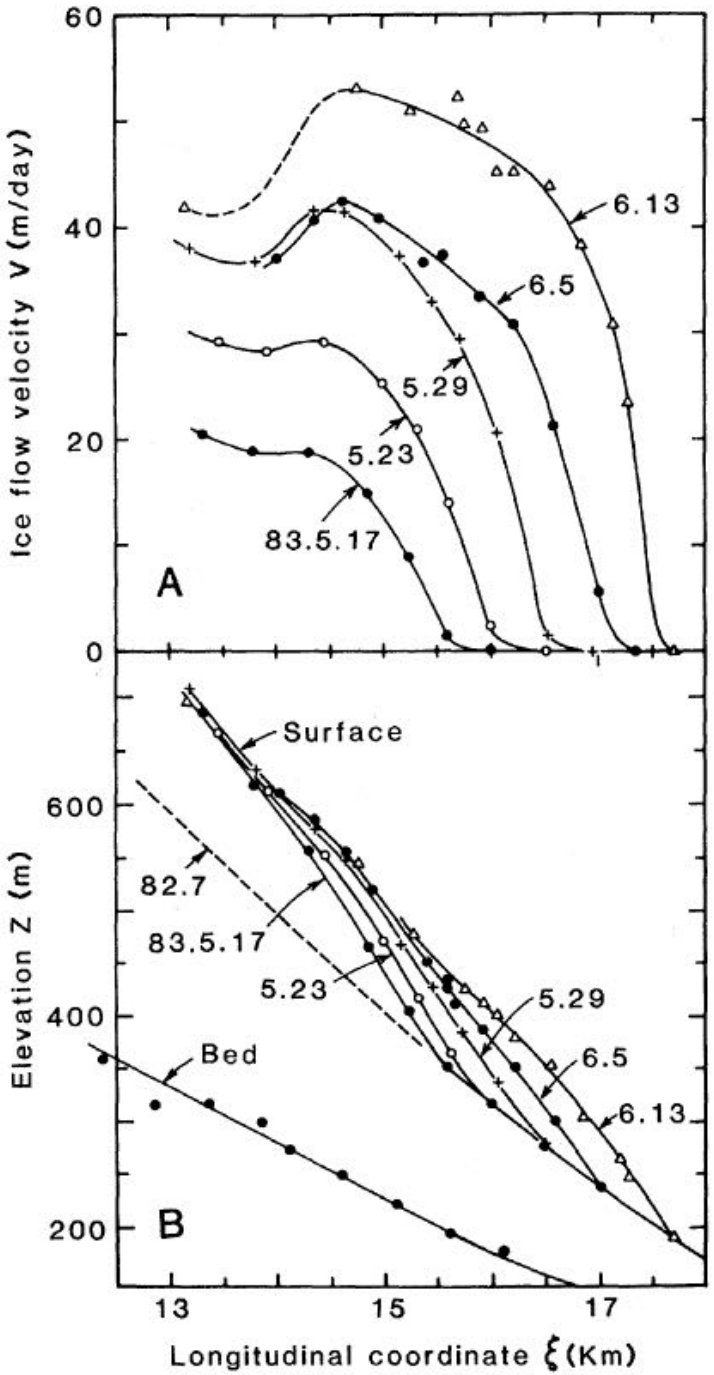
Upper glacier

Upper glacier

Lower glacier

(Kamb, et al., 1985. *Science*)

Variegated Glacier – the bulge

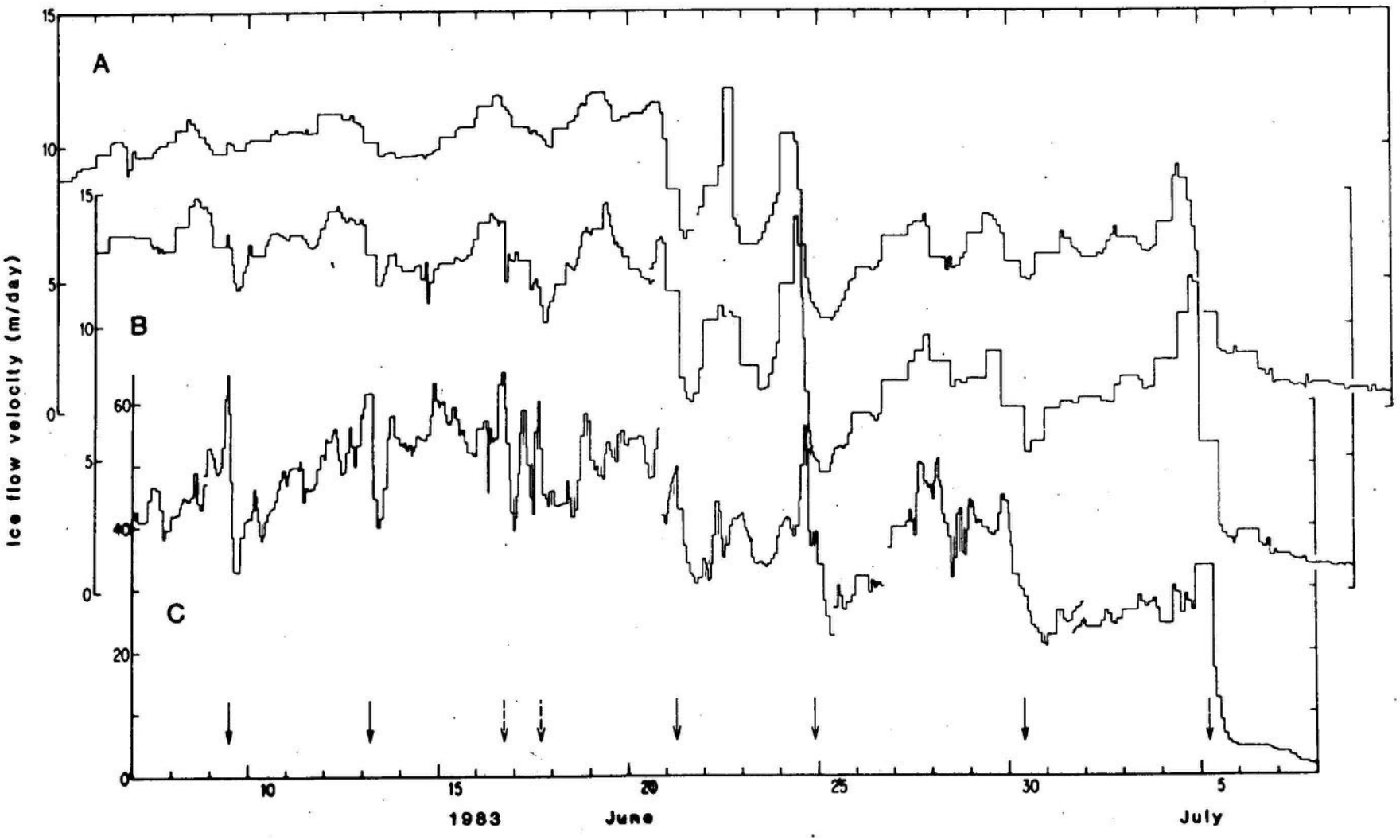


Ice velocity at bulge,
May-June 1983

Bulge shape,
May-June 1983

(Kamb, et al., 1985. *Science*)

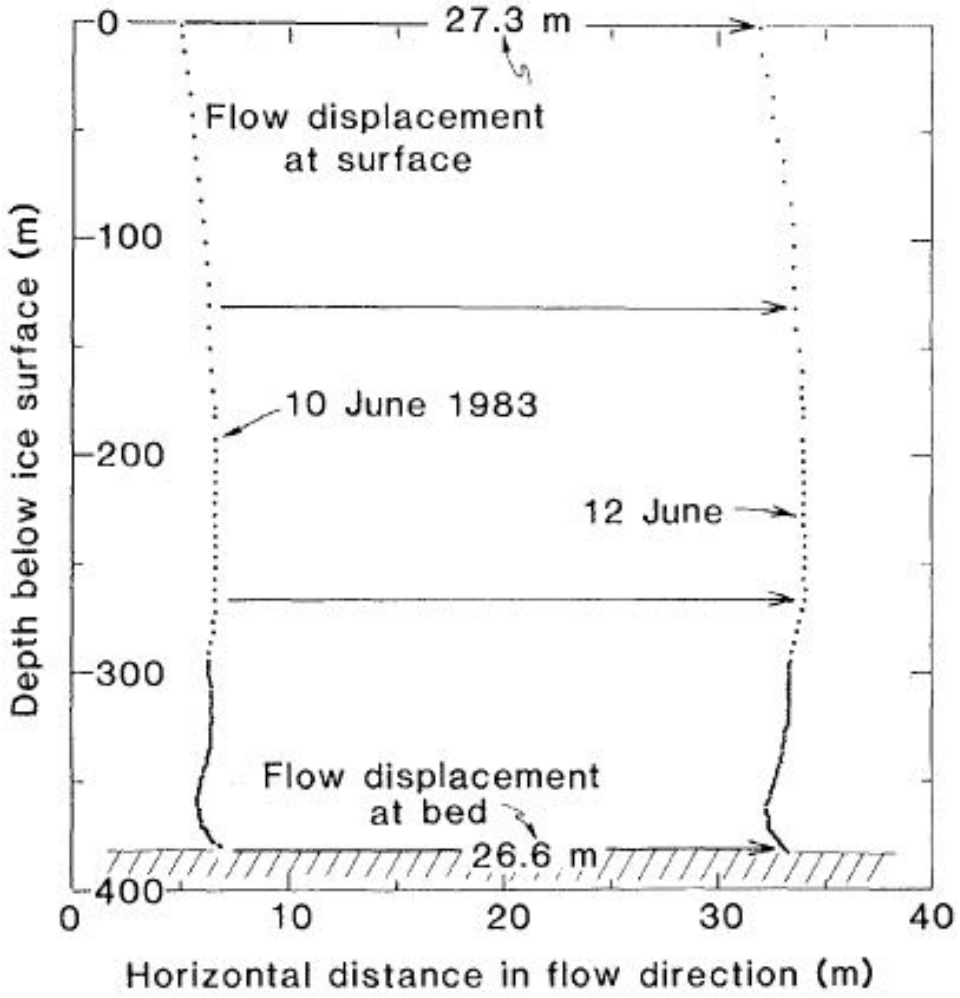
Variegated Glacier – termination of the surge

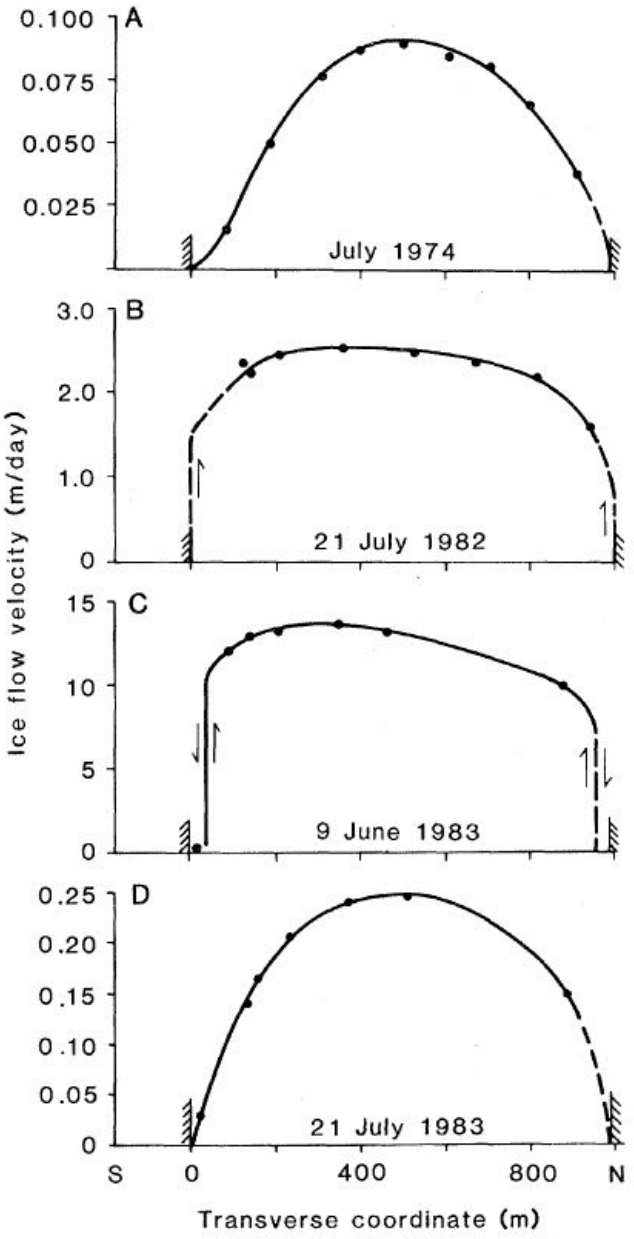


- It stopped abruptly everywhere on July 4

(Kamb, et al., 1985. *Science*)

Variegated Glacier – plug flow





- Fast motion was due to sliding, not internal deformation.

(Kamb, et al., 1985. *Science*)

Variegated Glacier – shear margins

- During surge, glacier moved very fast only a few meters in from the margins.
- Dirty water under pressure came up out of the cracks

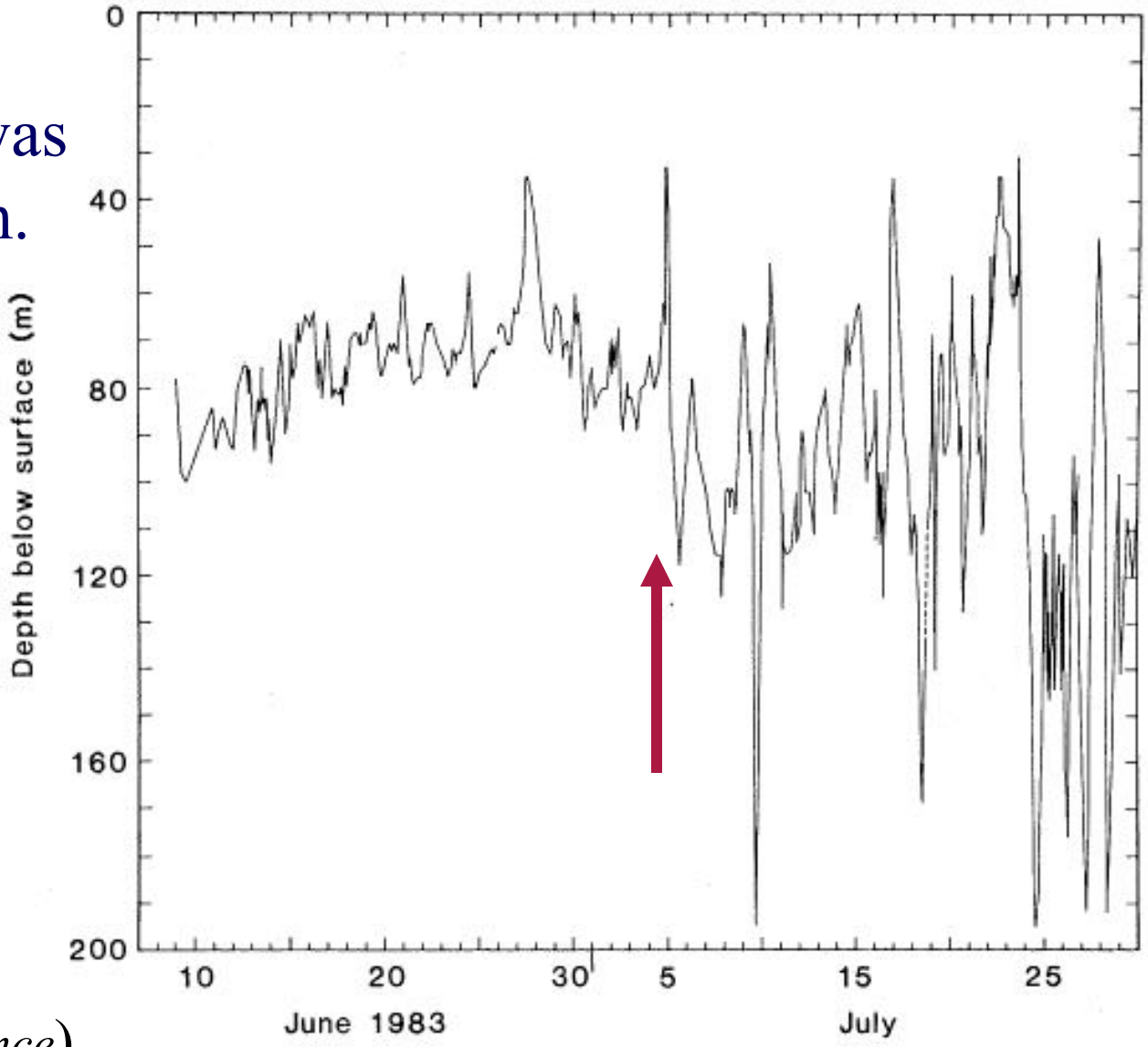
(Kamb, et al., 1985. *Science*)

Fig. 8. Aerial view of marginal wrench fault on the southwest side of the glacier at Km 8.5, looking southeast. The fault is the vertical black line in the lower center. It is a deep cleft blackened by rock debris. Ice to the left is moving toward the observer at ~10 m/day while ice to the right is practically stationary.

Variegated Glacier – water pressure

During surge, water pressure was consistently high.

- Surge ended on July 4
- Water pressure dropped, became erratic after July 4.

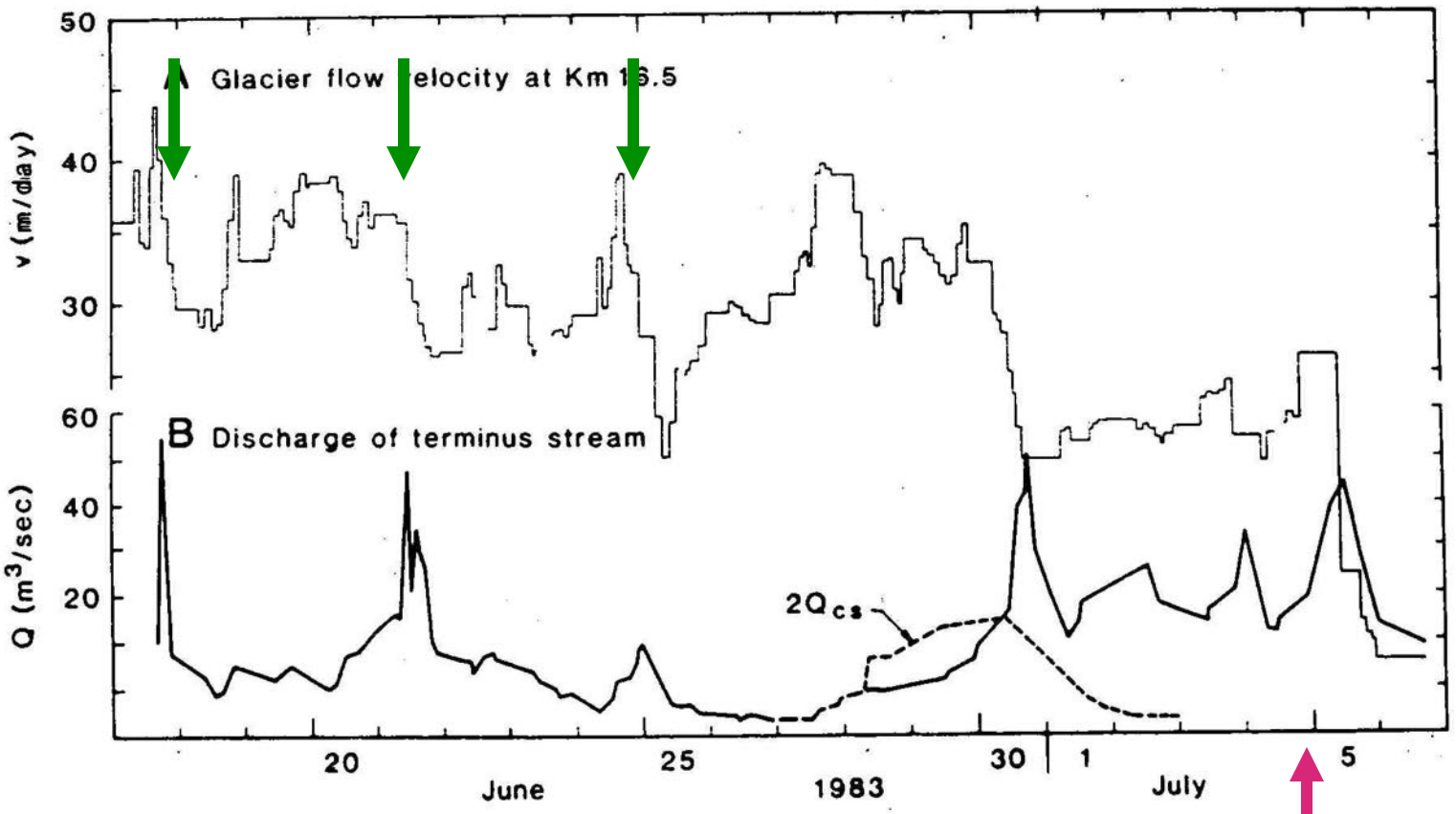


(Kamb, et al., 1985. *Science*)

Variegated Glacier – the stream

Ice speed

Stream flow

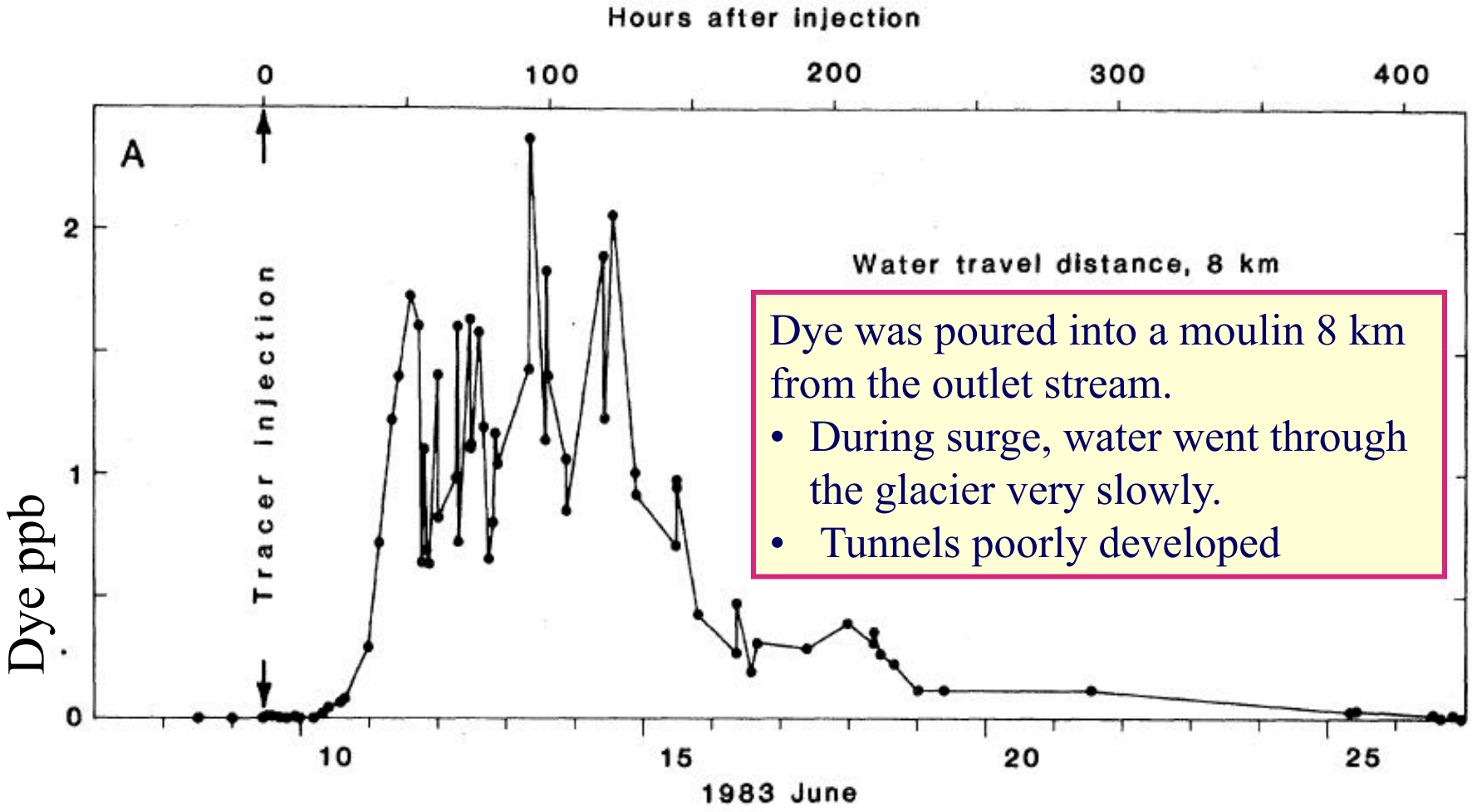


• As surge ended, the glacier discharged a lot of water.

Ice had previously slowed down whenever there was big discharge of water)

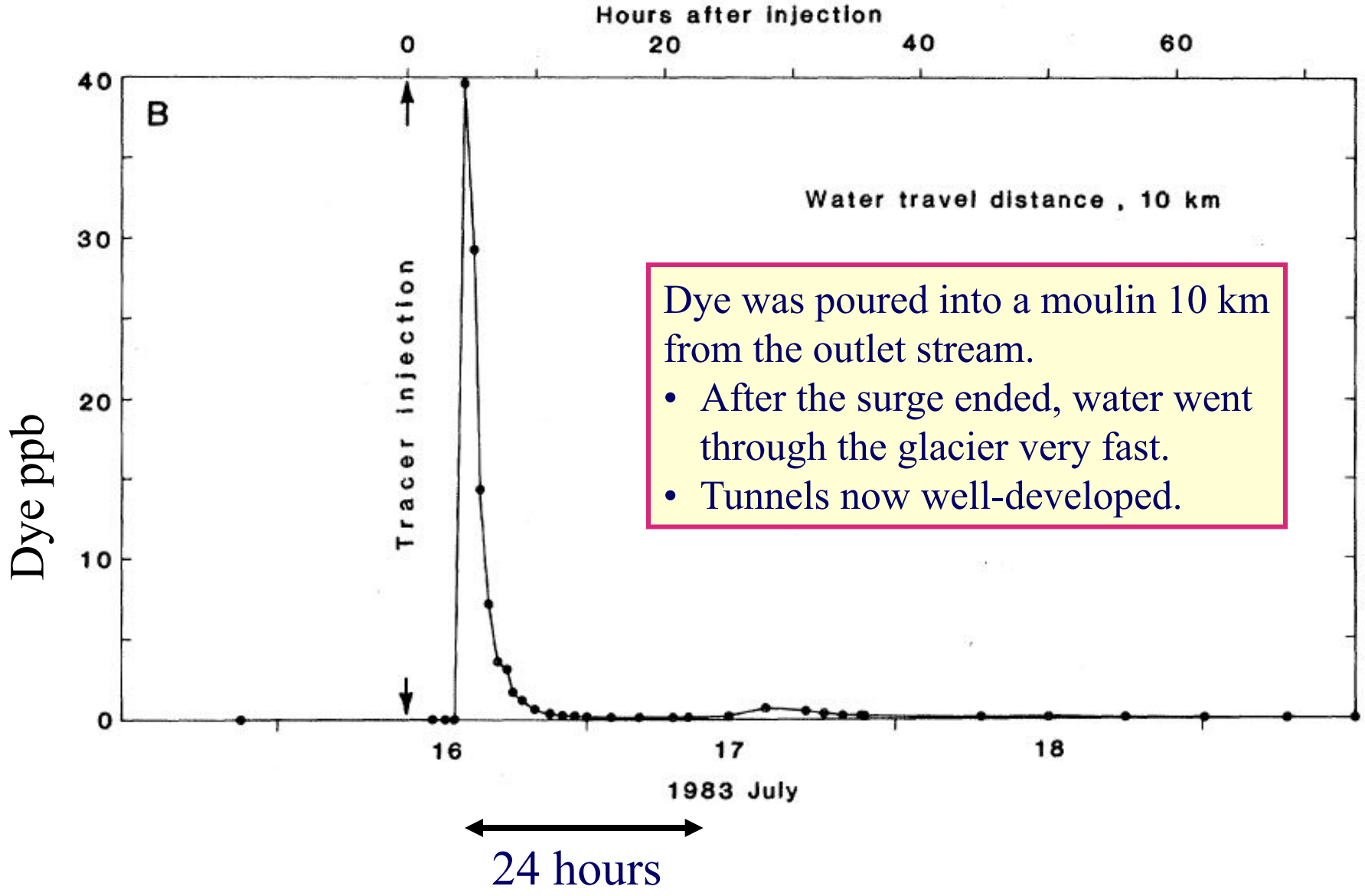
(Kamb, et al., 1985. *Science*)

Variegated Glacier – dye tracing - I



(Kamb, et al., 1985. *Science*)

Variegated Glacier – dye tracing -II



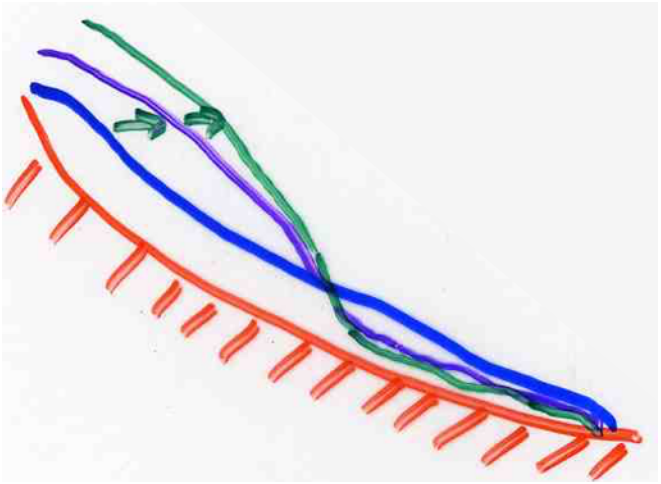
Dye was poured into a moulin 10 km from the outlet stream.

- After the surge ended, water went through the glacier very fast.
- Tunnels now well-developed.

(Kamb, et al., 1985. *Science*)

Variegated Glacier – pre-surge

Glacier too sluggish to disrupt tunnels by fast flow.

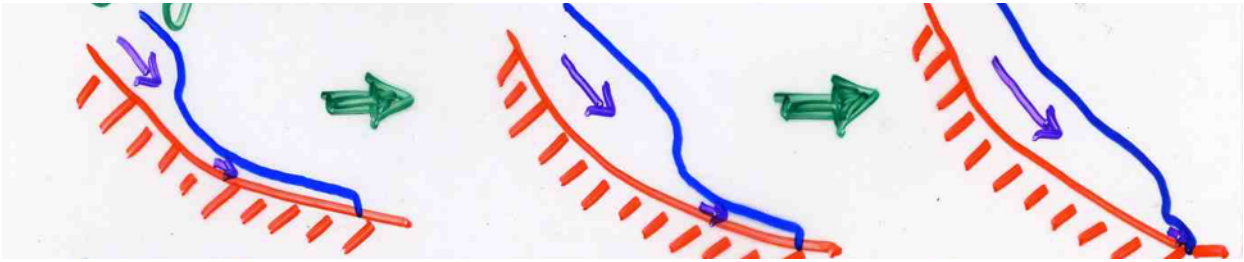


- Bed drains efficiently
- Accumulation area thickens
- Ablation area stagnates and thins.

- Glacier steepens,
- ice in reservoir area flows faster each year.

Variegated Glacier – during surge

- Reaches threshold where flow disrupts conduits as they form
- Glacier flows faster, no conduits can form.
- Kinematic bulge propagates into stagnant ice



- Big volume of ice moved to lower stretches of glacier.
- Water escapes, surge stops.
- Tunnels now drain bed.
- Wait decades to build up steep slope again.

Black Rapids Glacier

Surged to fame in winter 1937 when it threatened to over-run the Black Rapids Road House on the Richardson Highway, the only road access to Fairbanks (which was then closed for the winter).

The police in Fairbanks thought the innkeepers were drinking too much, when they reported on the radio that the ice was coming …

Curious scientists talk about surging glaciers

In your Break-out rooms, please discuss how you would explain glacier surges to a nonscientist.

- What should they know?
- Why should they care?

https://docs.google.com/document/d/1pIN_SID6G14tp7I4hTVTlA-pNk-sN9KThg65dSJnANE/edit

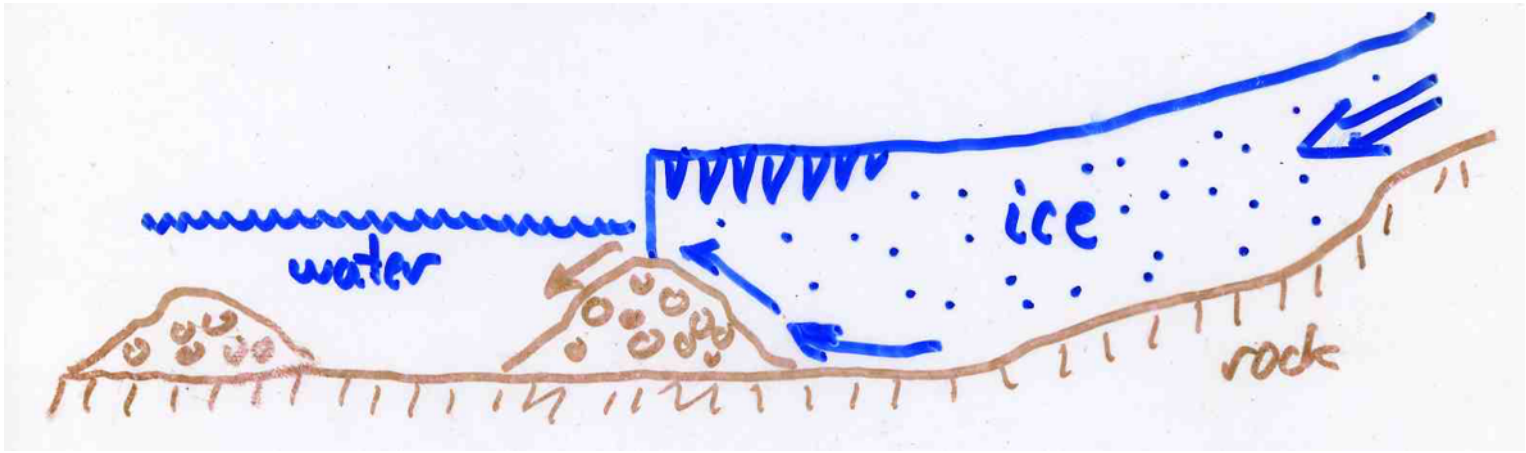
Tidewater Glaciers

- Terminus is in ocean
- Terminus is grounded, not floating
- Glaciers advance and retreat over time scales of a century

- These are not surge-type glaciers (i.e. not controlled by bed changes)
- Yet cycle not closely tied to climate changes on the surface either …

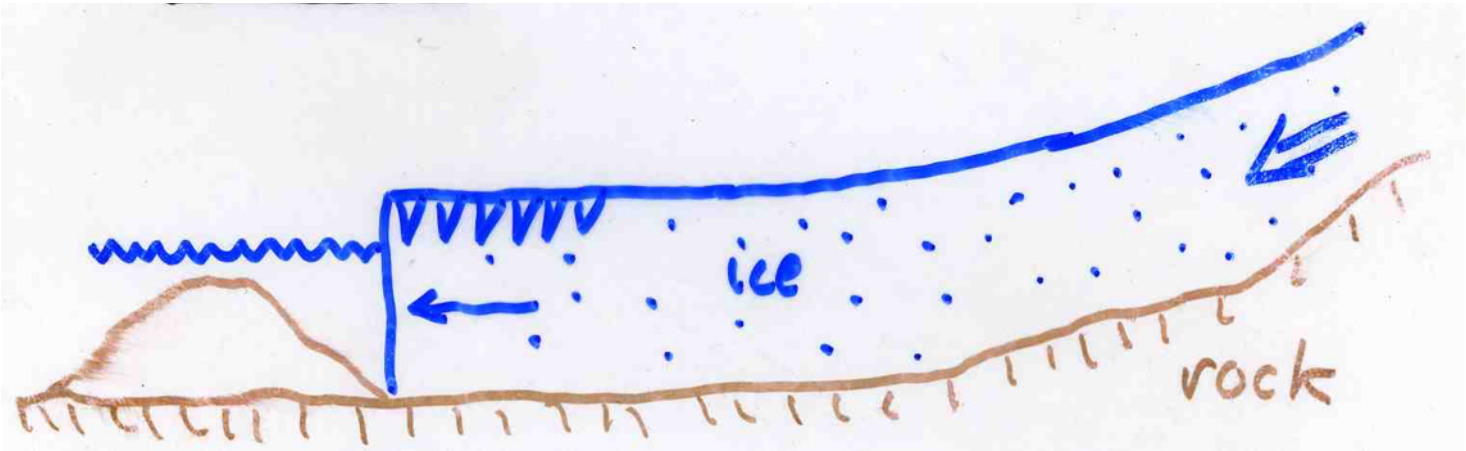
Columbia Glacier AK
June 2005 W.Tad Pfeffer

Tidewater Glaciers – the Advance



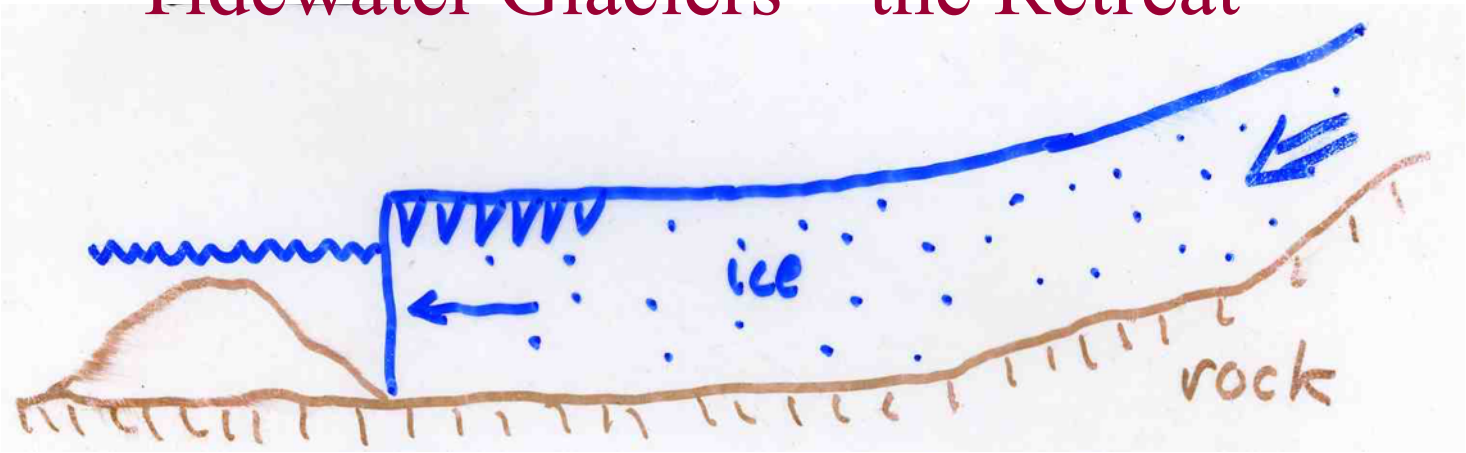
- Glacier advances along a fiord
- Subglacial rivers build a moraine shoal or delta in front
- Shoal protects glacier terminus from sea water

Tidewater Glaciers – the Critical Moment



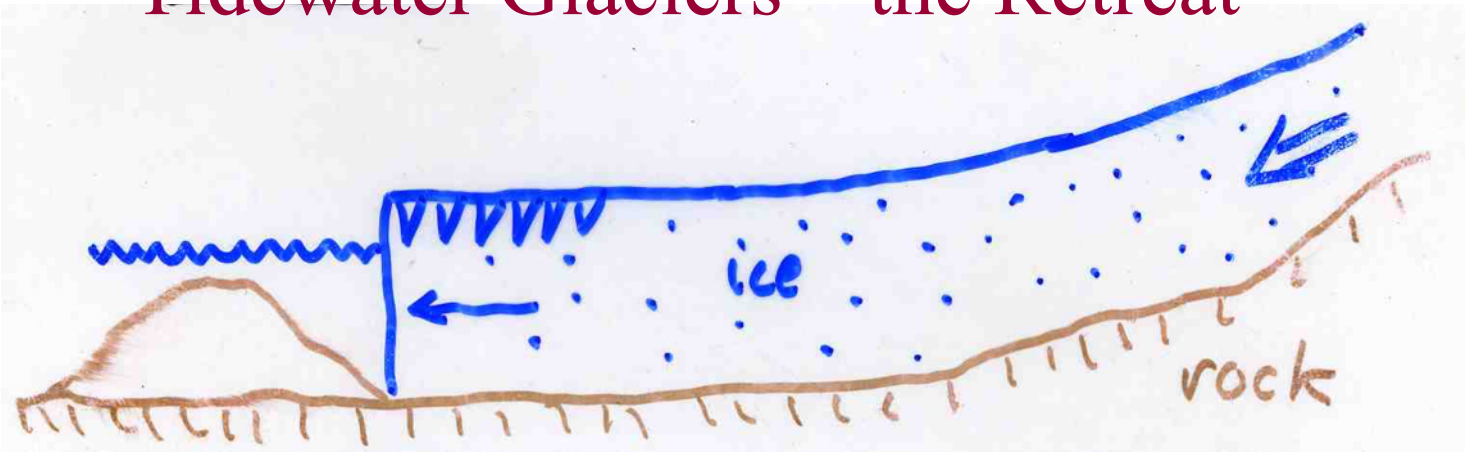
- Glacier retreats just a little from the shoal
- (this could be result of a minor climate change).
- Seawater can now get at the terminus to melt and undermine it.
- Water deepens as glacier retreats into glacially scoured fiord.

Tidewater Glaciers – the Retreat

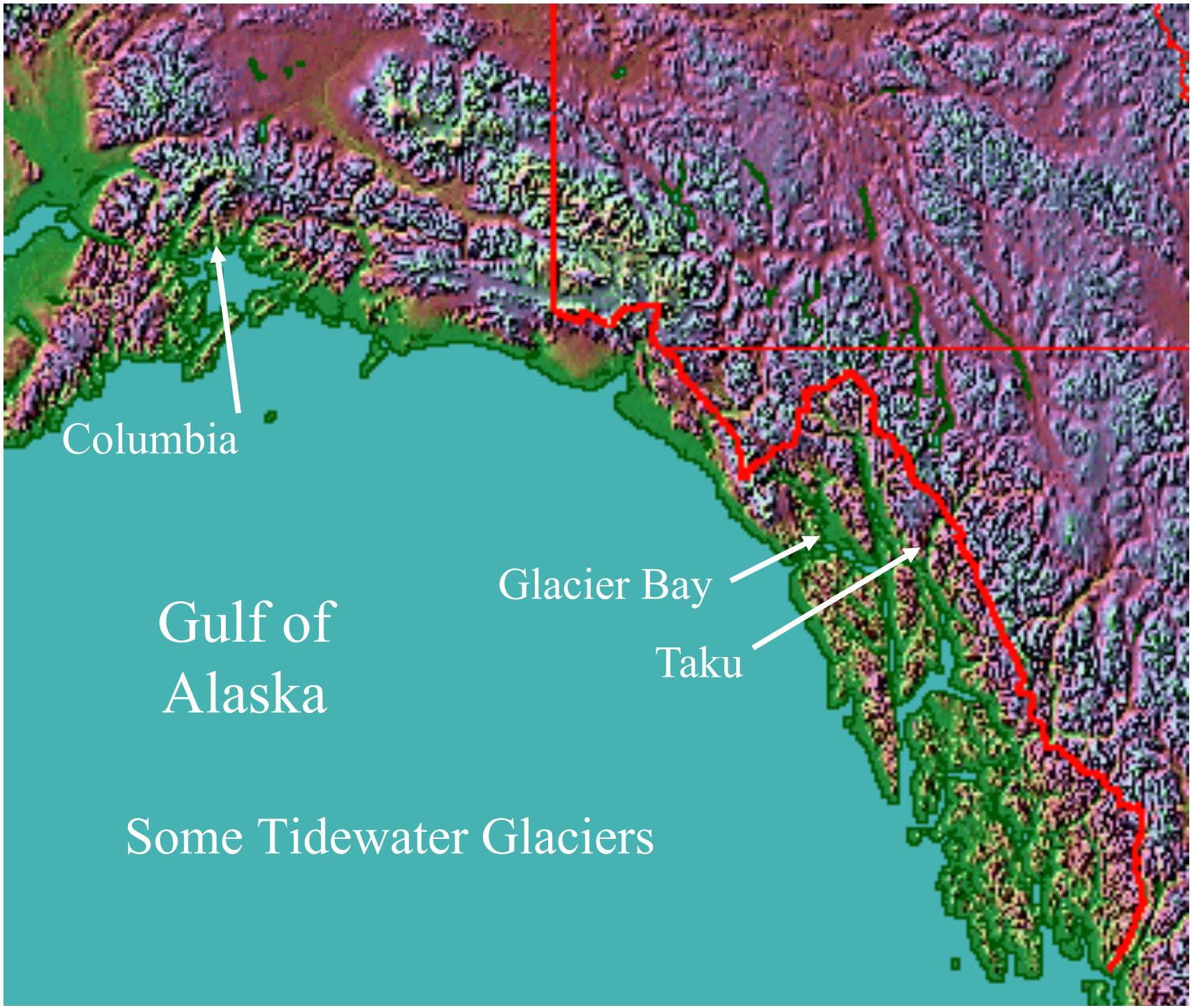


- Water deepens as glacier retreats into glacially scoured fiord.
- Calving rate increases rapidly with water depth.
- Retreat accelerates.
- There is no going back to the moraine shoal.
- Glacier must retreat all the way back to dry land.
- Only then can it can start another advance, with its terminus protected by a new moraine shoal.

Tidewater Glaciers – the Retreat

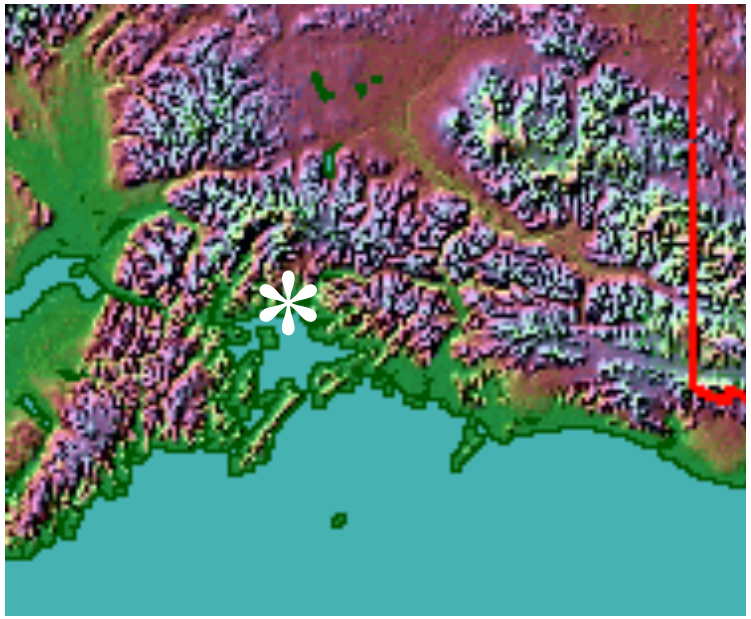


- Retreat is initiated by climate changes
- But climate response (retreat) is strongly amplified by tidewater physics

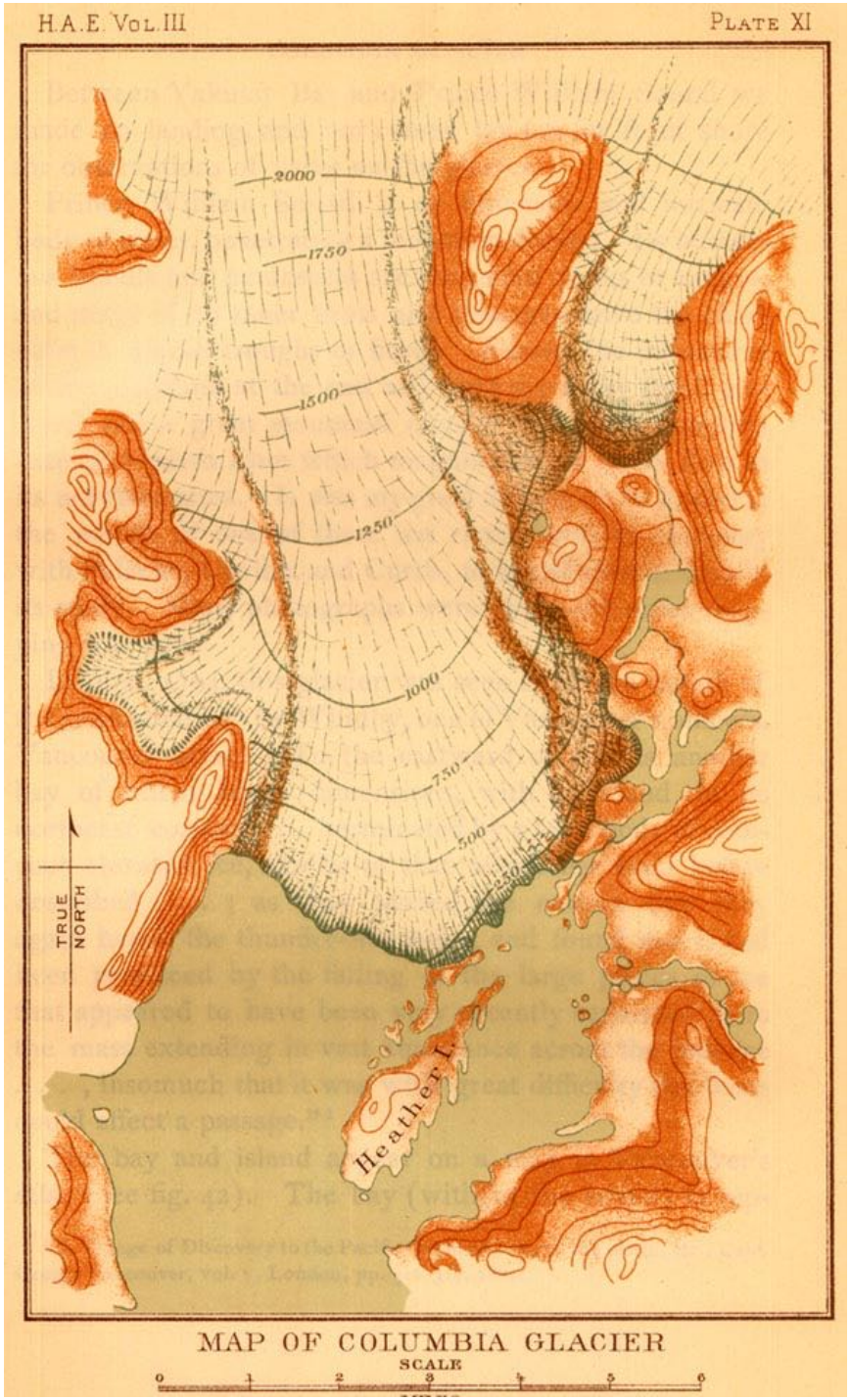

Columbia
Glacier Bay
Taku
Gulf of
Alaska
Some Tidewater Glaciers

Columbia Glacier 1899 Harriman Expedition

Terminus was on a shoal near Heather Island



http://www.pbs.org/harriman/maps/historic_maps.html



Columbia Glacier 1979

Terminus was still on the shoal near Heather Island in 1979

Austin Post 1979

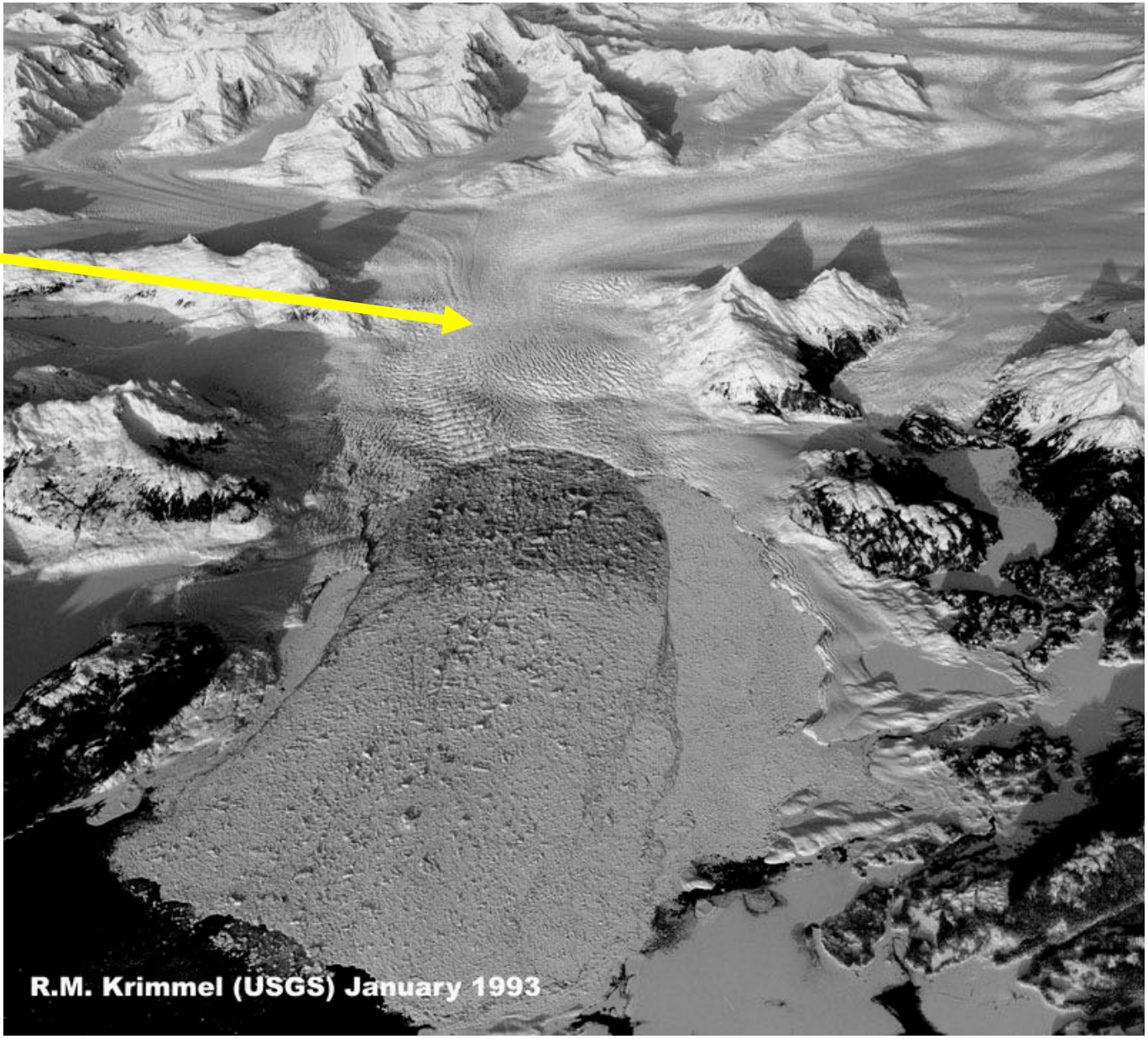
Columbia Glacier

- Retreat began in 1982 just as North Slope oil began to ship from Port Valdez

- Exxon Valdez was taking a course to avoid small bergs from Columbia Glacier when it went aground.

Columbia Glacier 1993

Terminus was back almost to Kadin-Great Nunatak Gap by 1993.



- Larger icebergs are trapped in the bay by the shoal

Bob Krimmel 1993

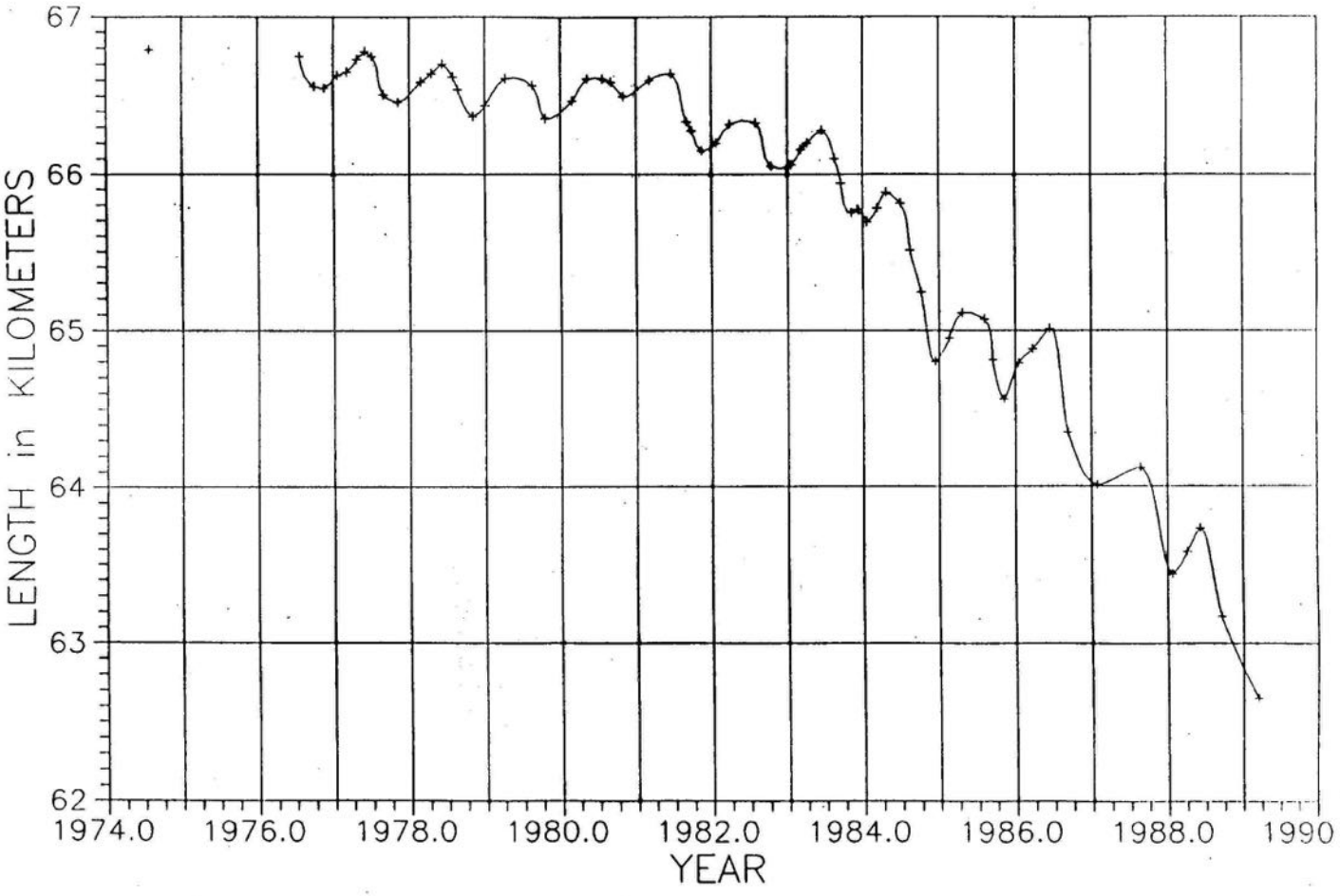
Columbia Glacier 2004

Terminus was in the Kadin-Great Nunatak Gap by 2004.

- Has retreated 16 km
- Speed at terminus ~10 km/yr

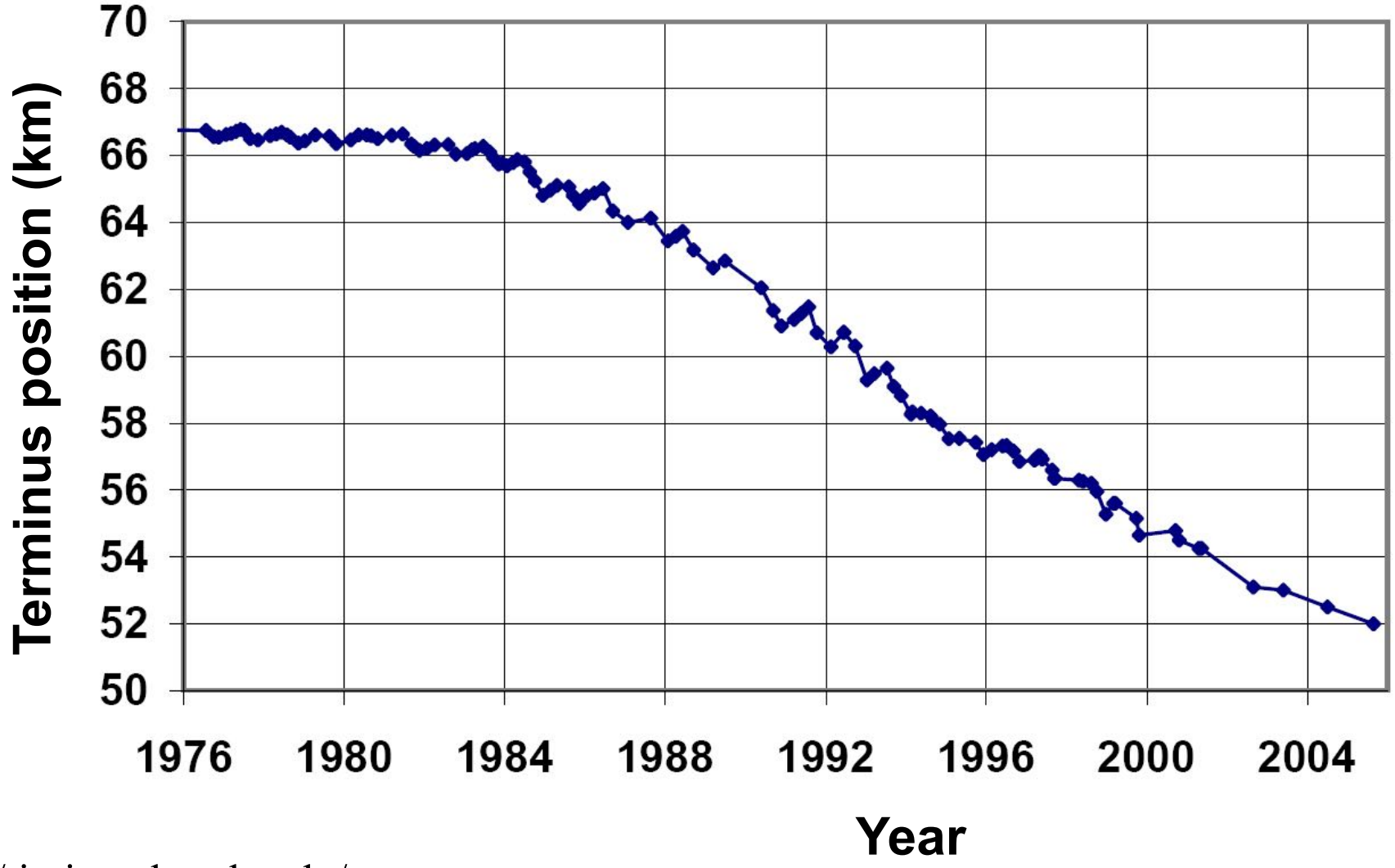
W. Tad Pfeffer 2004

Columbia Glacier – the retreat begins



- Glacier retreated 4 km in first 7 years
- Similar rate has been maintained since

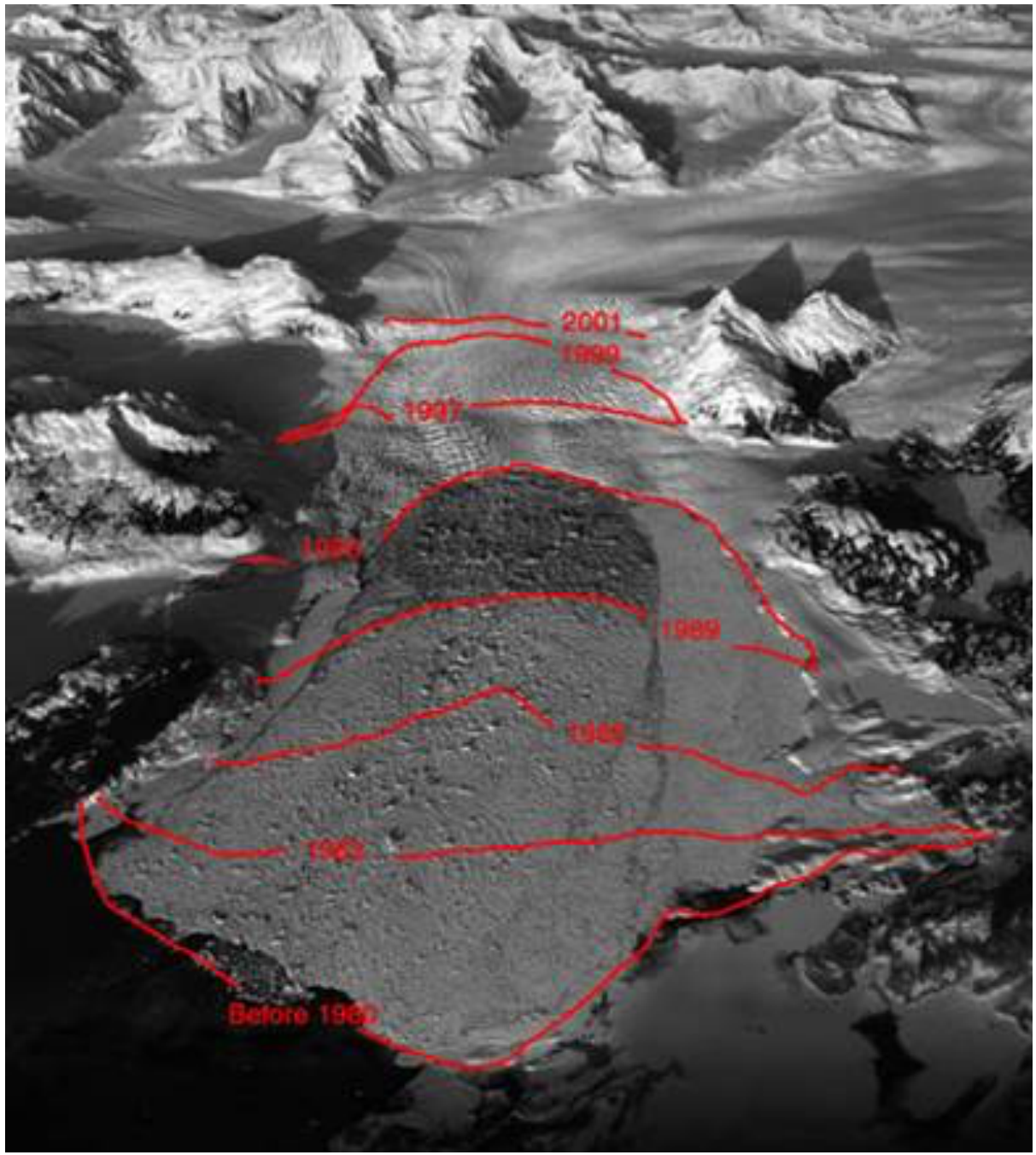
Columbia Glacier Retreat 1980-2005



http://tintin.colorado.edu/

Columbia Glacier Retreat 1980-2001

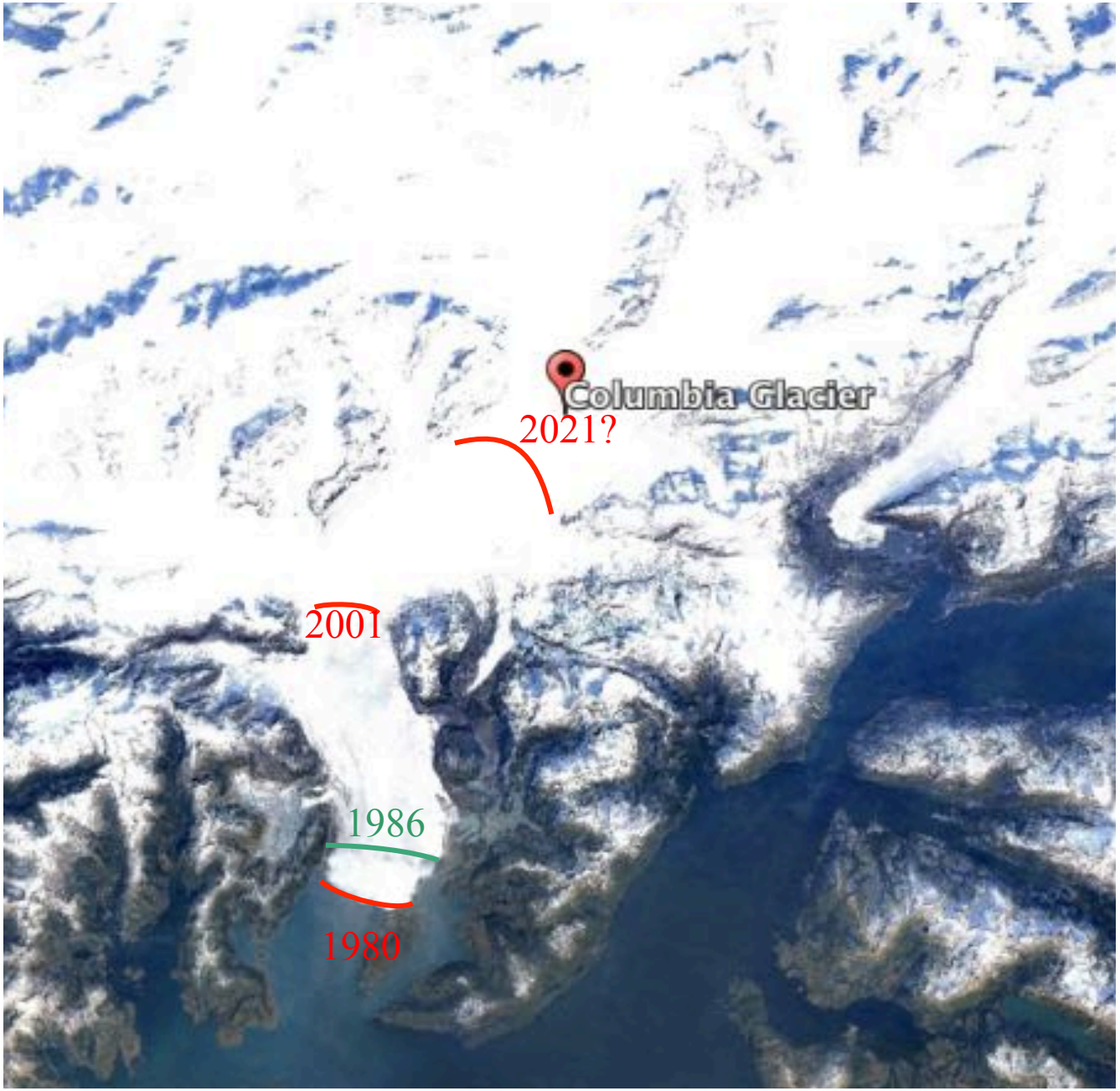
- Retreated >15 km
- Bed does not reach sea level until 15 km upstream



http://tintin.colorado.edu/group/columbia/SciObj.html

Columbia Glacier
Sept 1986

- Retreated several km
- Moraine traps bigger icebergs



Google Earth

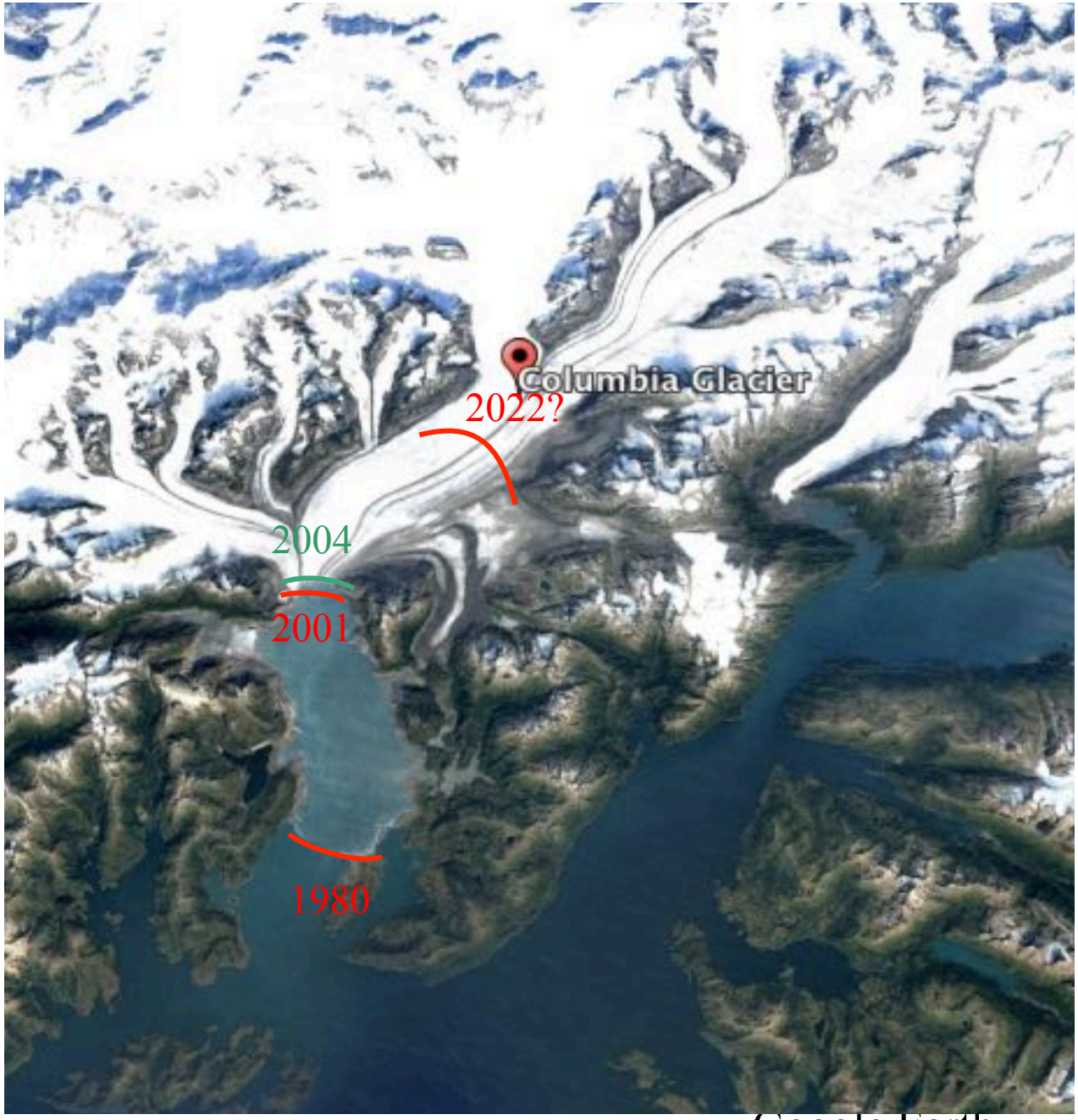
Columbia Glacier
Sept 1996

- Still retreating rapidly.

Google Earth

Columbia Glacier
Sept 2004

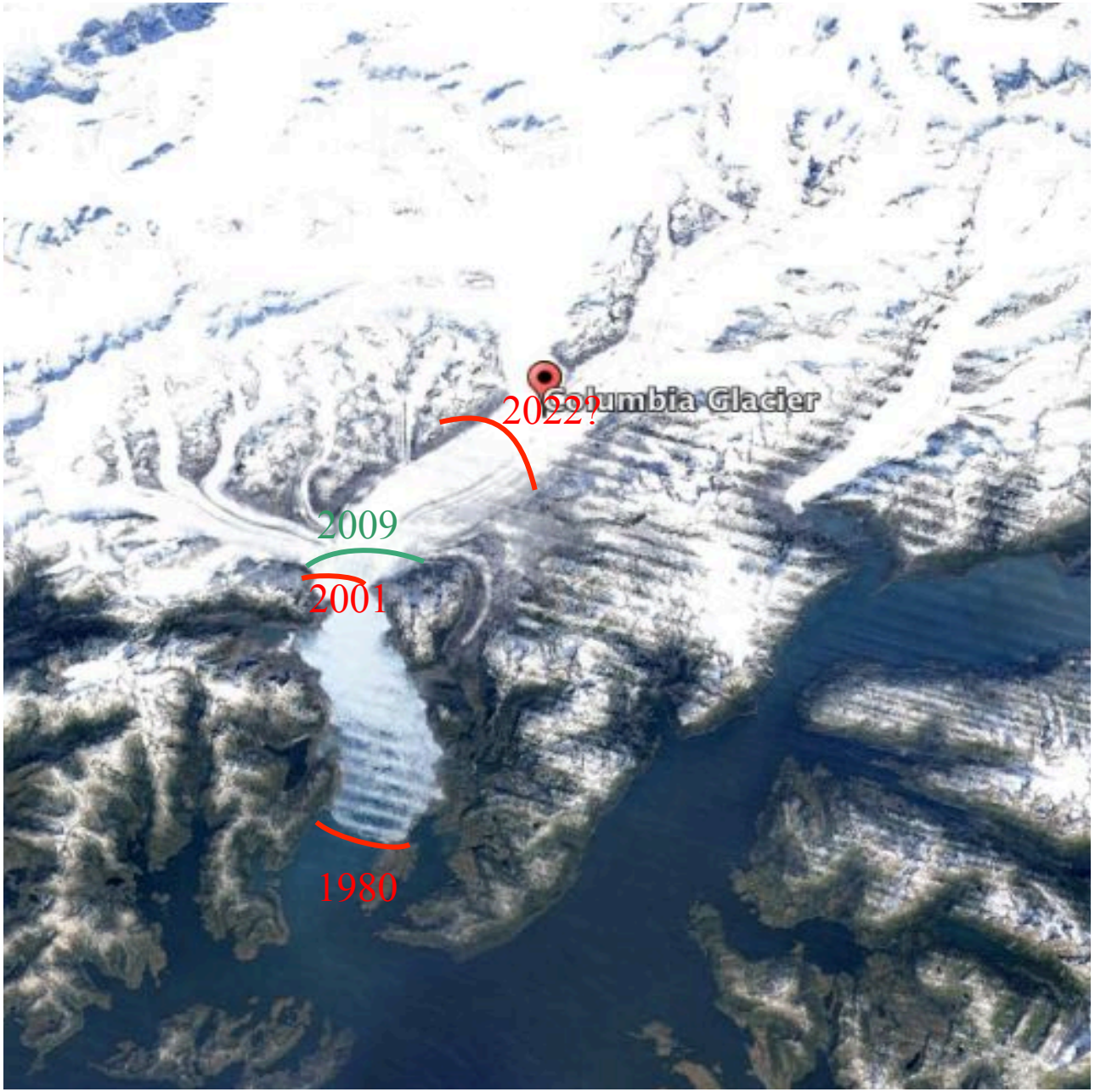
- Retreat slowed down dramatically getting through narrow gap at Great Nunatak



Google Earth

Columbia Glacier
Sept 2009

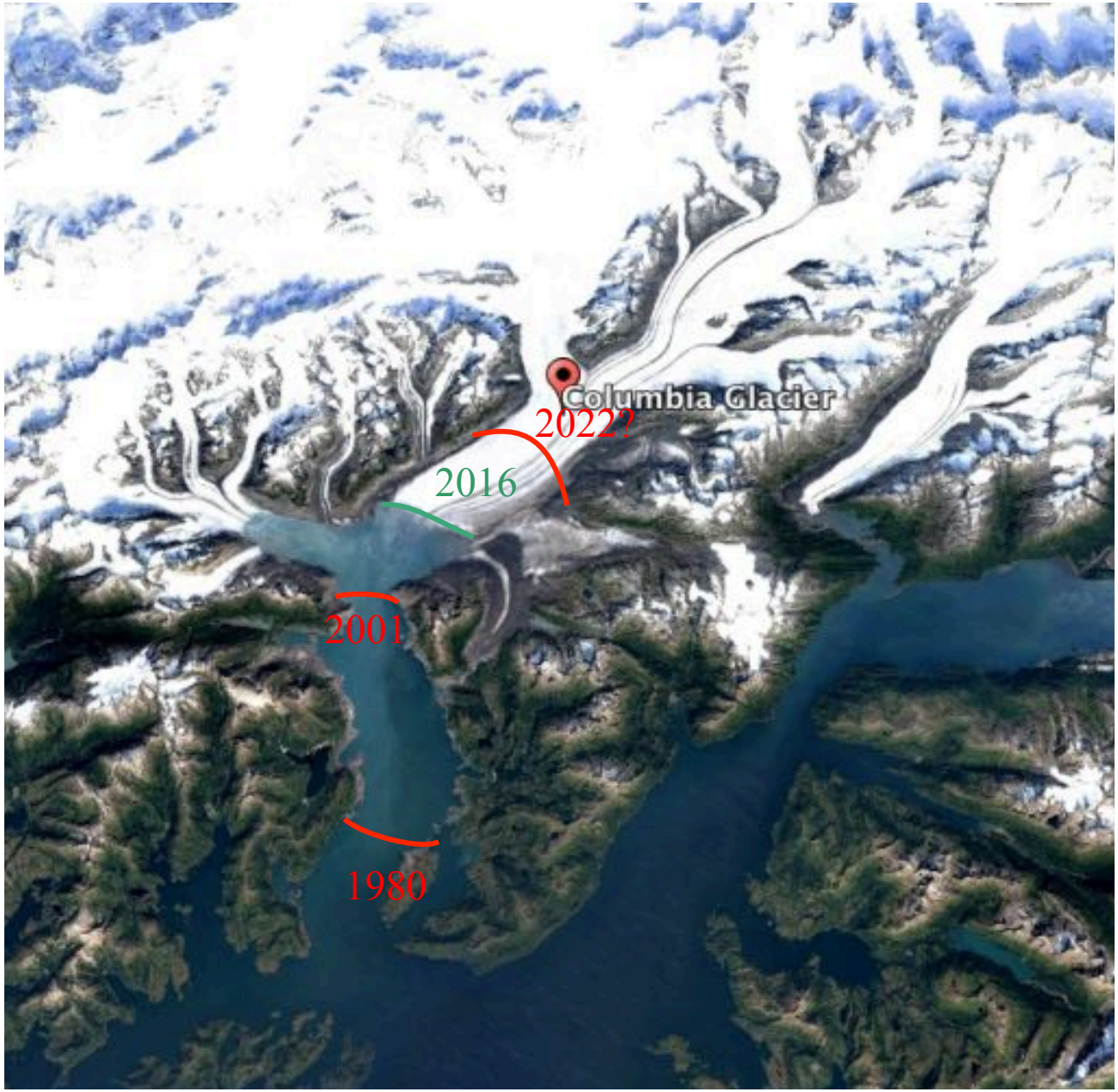
- 2 tributaries are now separated



Google Earth

Columbia Glacier
Sept 2016

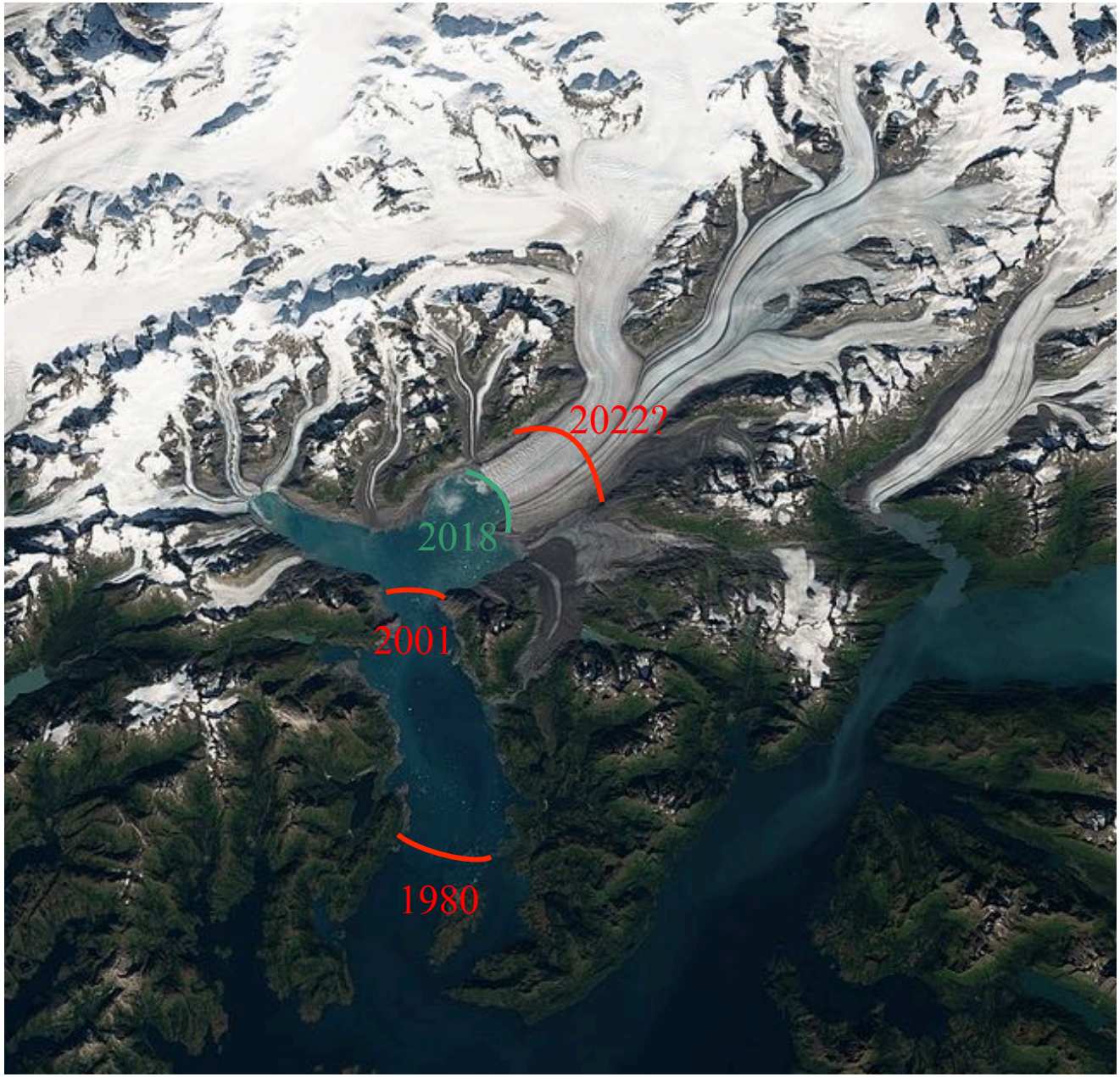
- Retreat slowing down again.
- Bed elevation is closer to sea level.



Google Earth

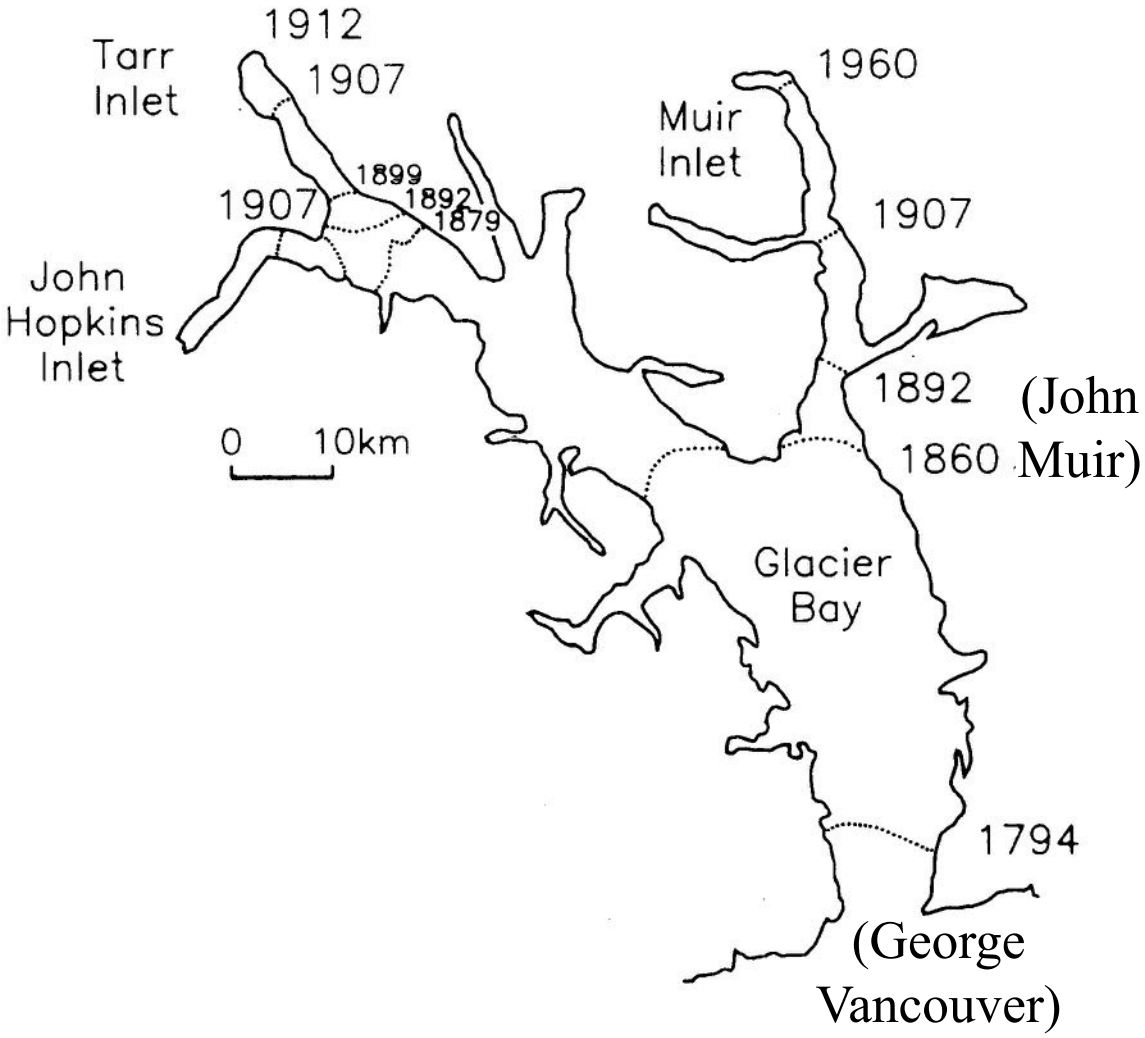
Columbia Glacier
Sept 2018

- Retreating very slowly.
- Expected to stop in the next few years, where bed reaches sea level.

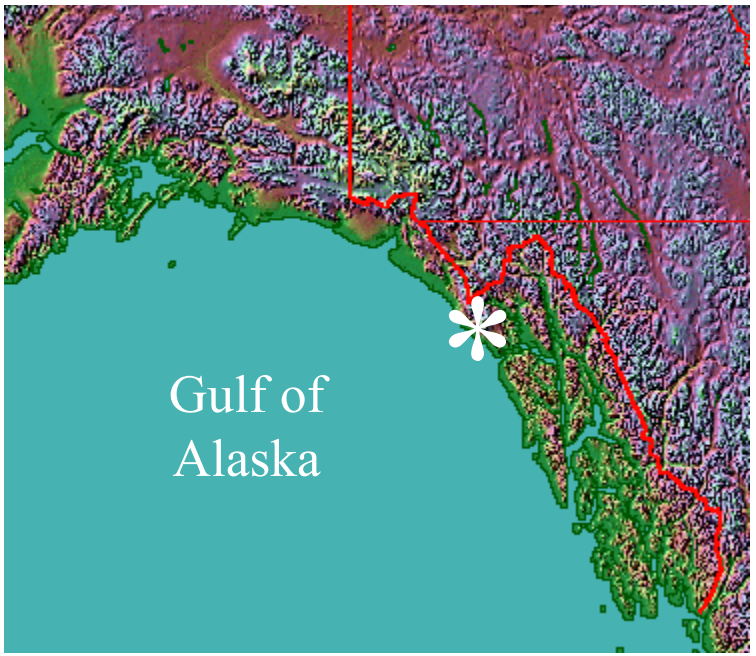


Google Earth

Glacier Bay

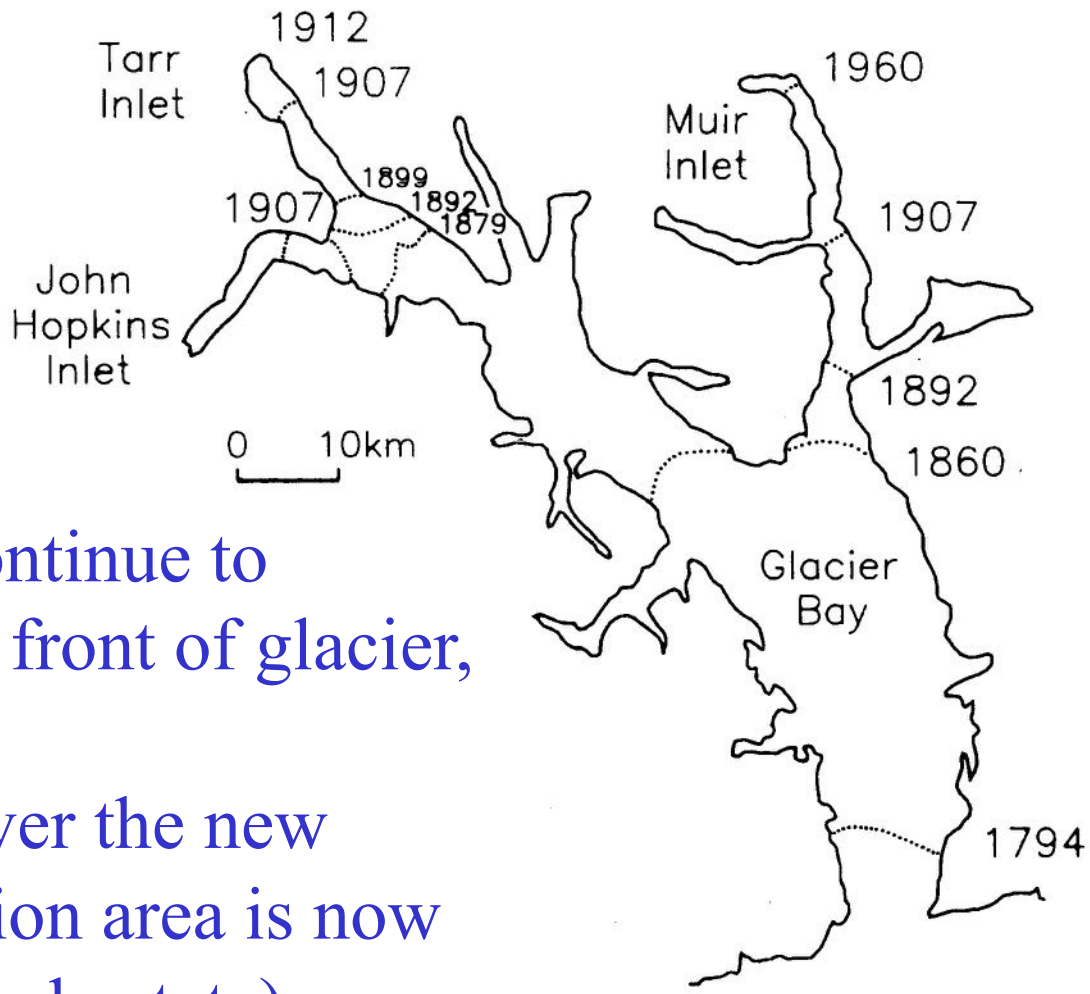


- Glaciers have been retreating for over 200 years.



Glacier Bay

- Glaciers have been retreating for over 200 years.
- Retreat stops when glacier comes back out of the sea.
- Subglacial rivers continue to deposit sediment in front of glacier, filling in fiord.
- Glacier advances over the new sediments (its ablation area is now far too small for steady state).
- Cycle repeats.



Glacier Bay Today

150 km of cruise-ship delights …

Google Earth

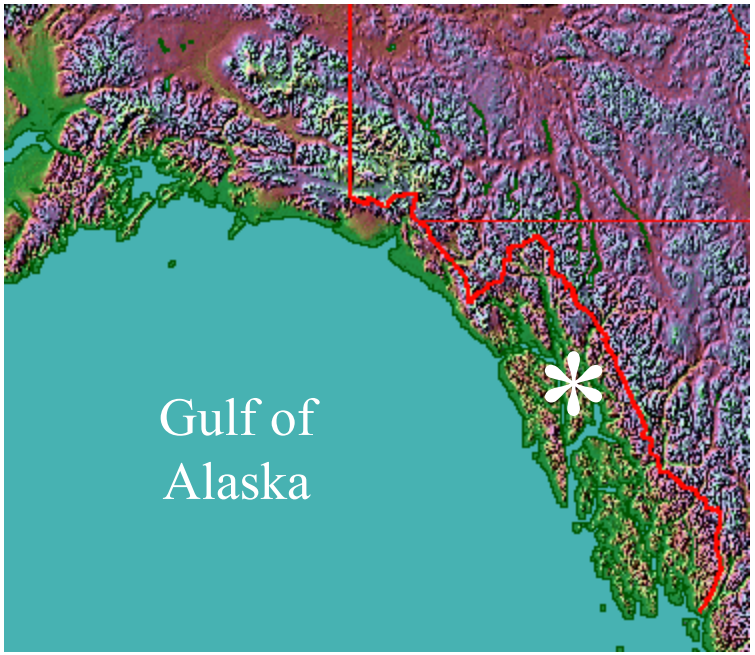
Glacier Bay in the Future

Barring major climate changes, the glaciers will advance again.

•Note the sediment deposits in Queen Inlet in front of Carroll Glacier

Taku Glacier – the advance

- Taku Glacier is 30 km from Juneau (Alaska state capital)
- Taku Glacier has high sediment output into the fiord.
- Taku Glacier is advancing into Taku Inlet.
- Until 2019, it was advancing over a braided-stream flood-plain that used to be a navigable part of the fiord early in the 20th Century.



Taku Glacier advances as Taku Inlet fills with sediment

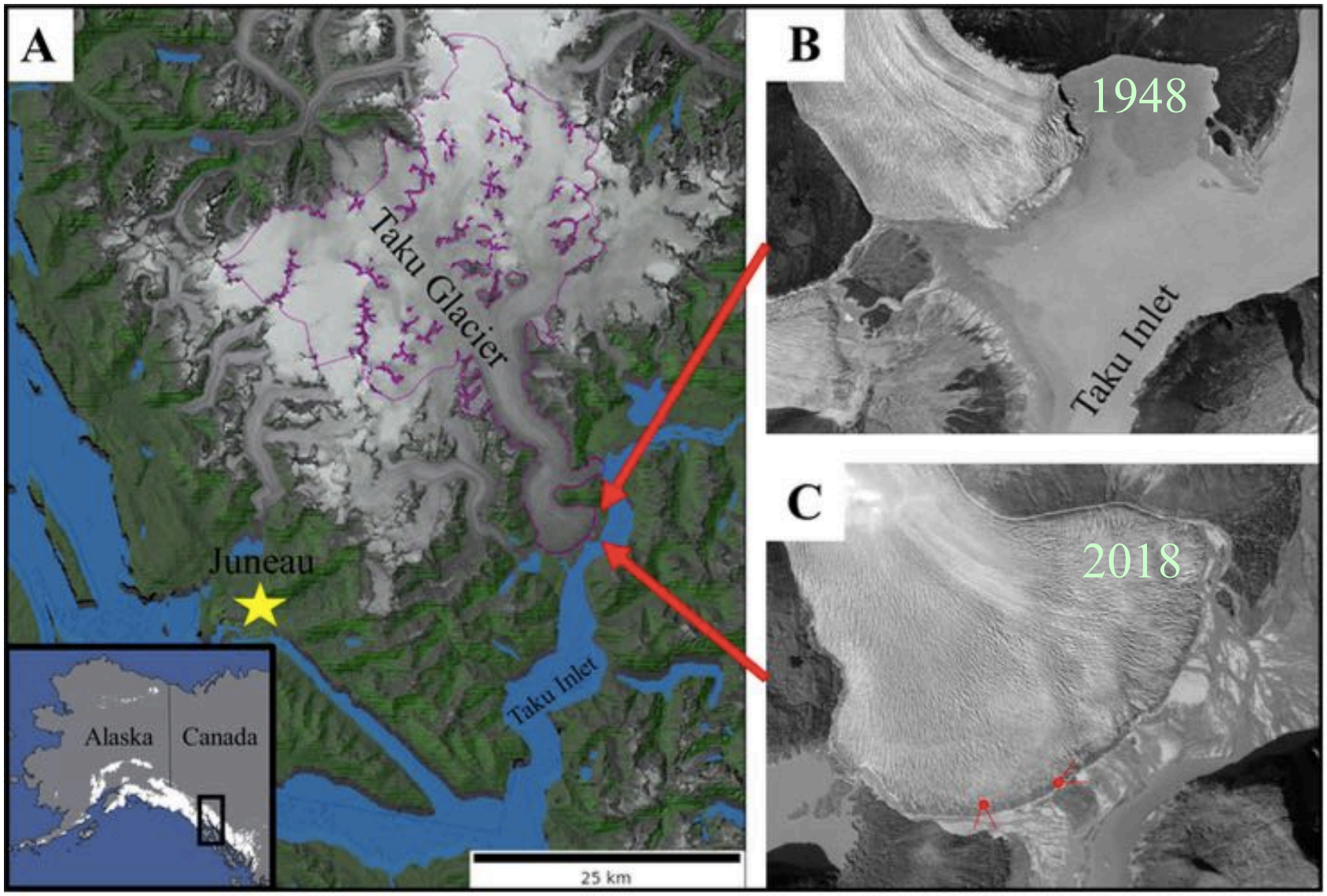
NASA WorldWind Landsat7

Imminent Retreat of Taku Glacier

August 2019. Matt Nolan

https://eos.org/science-updates/the-imminent-calving-retreat-of-taku-glacier

The advance

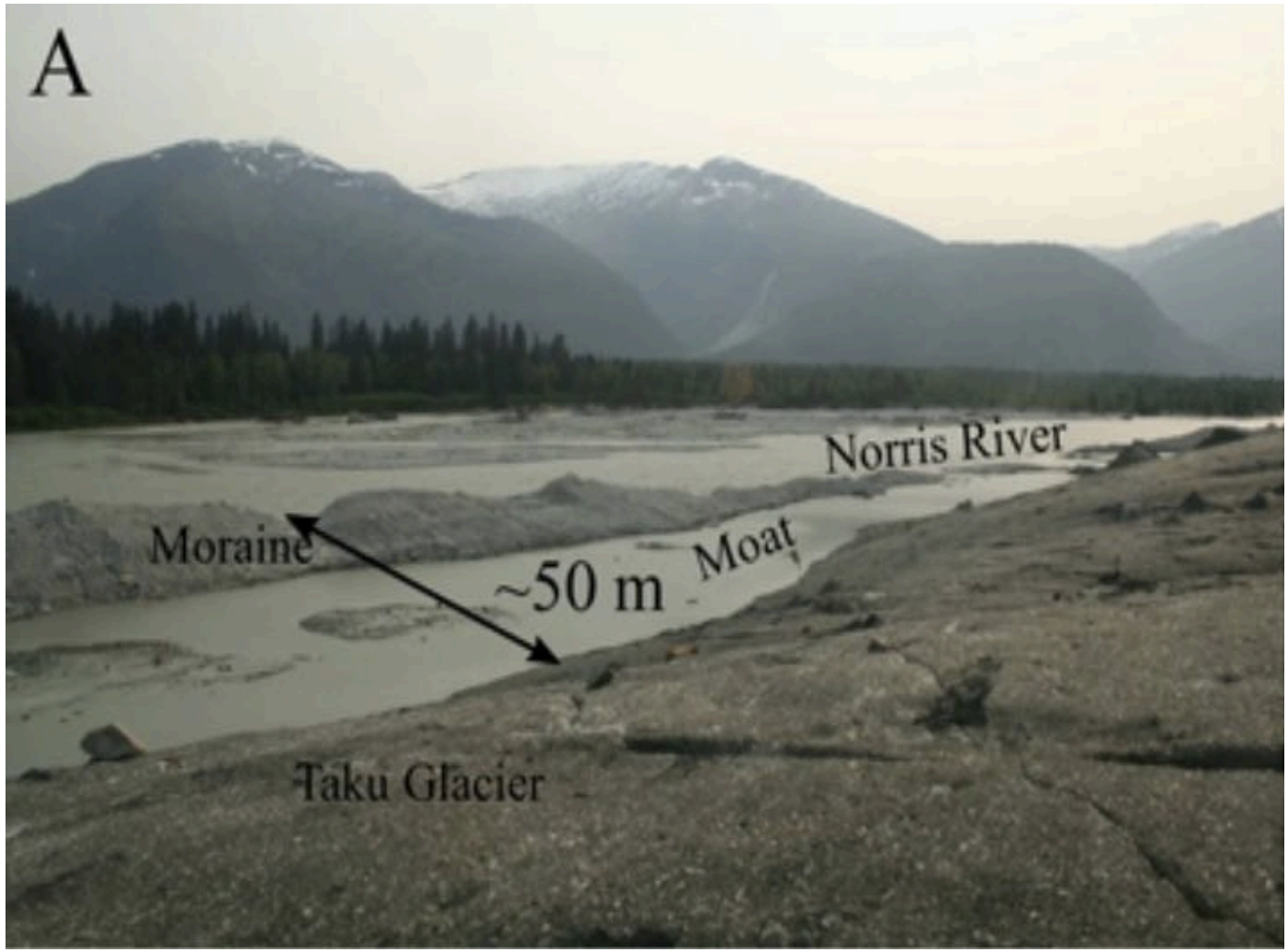


https://eos.org/science-updates/the-imminent-calving-retreat-of-taku-glacier

Advance has slowed since 1980

Retreat phase appears to have begun in 2018.

- A moat has opened in front of the glacier
-



https://eos.org/science-updates/the-imminent-calving-retreat-of-taku-glacier

More evidence of retreat starting

The moraine is no longer being pushed and deformed

- Vegetation is taking hold on the stationary moraine
-

https://eos.org/science-updates/the-imminent-calving-retreat-of-taku-glacier

Tidewater glaciers and climate change

- Tidewater glaciers have an advance/retreat cycle over centuries
- Retreat can be triggered by a small climate change, but once initiated, retreat is often inevitable
    - severe terminal ablation by warm water.
- Once a tidewater glacier retreats back out of the water, a re-advance is often inevitable
    - marine and subaerial ablation strongly reduced
    - but accumulation upstream still strong

The tidewater cycle response

- can strongly amplify minor climate changes when the glacier is extended
- but is insensitive climate changes at other points in the cycle.

Global connection to climate is weak

Glacier Bay

- Retreat began in 19th C, but re-advance may be starting

Columbia Glacier

- Retreat began late in 20th C, but retreat may end soon

Taku Glacier

- Advance began late in 20th C, but retreat may be starting

However, ongoing strong global warming may change this if the advance phase is broken

- They might all just retreat in future.

Summary

- Non-surging glaciers that end on land respond most directly to climate (precipitation and melt on upper surface).
- Surge-type glaciers are relatively rare, except in Alaska-St Elias, Iceland, and Svalbard. Surges reflect changes in the subglacial hydrology conditions (sliding at lower surface).
- Tidewater glaciers advance and retreat in response to ablation and calving conditions (melting by seawater at the terminal front).