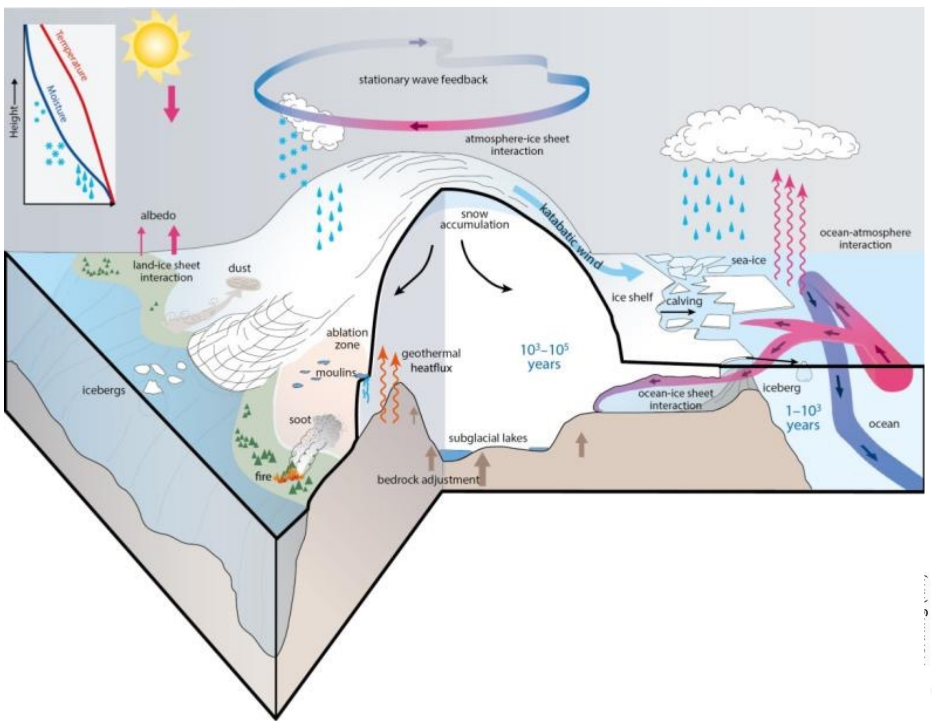
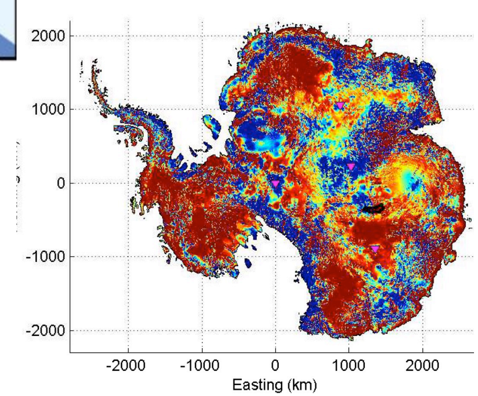
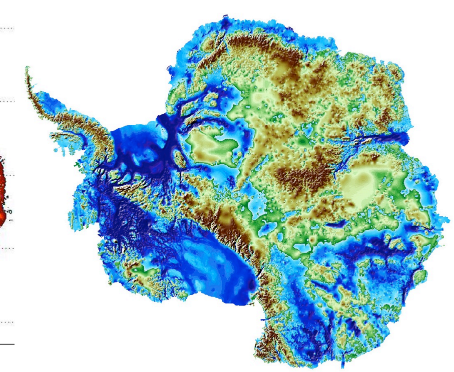
Glaciology
EESCGU4220

Lecture 2: Introduction to Glaciology



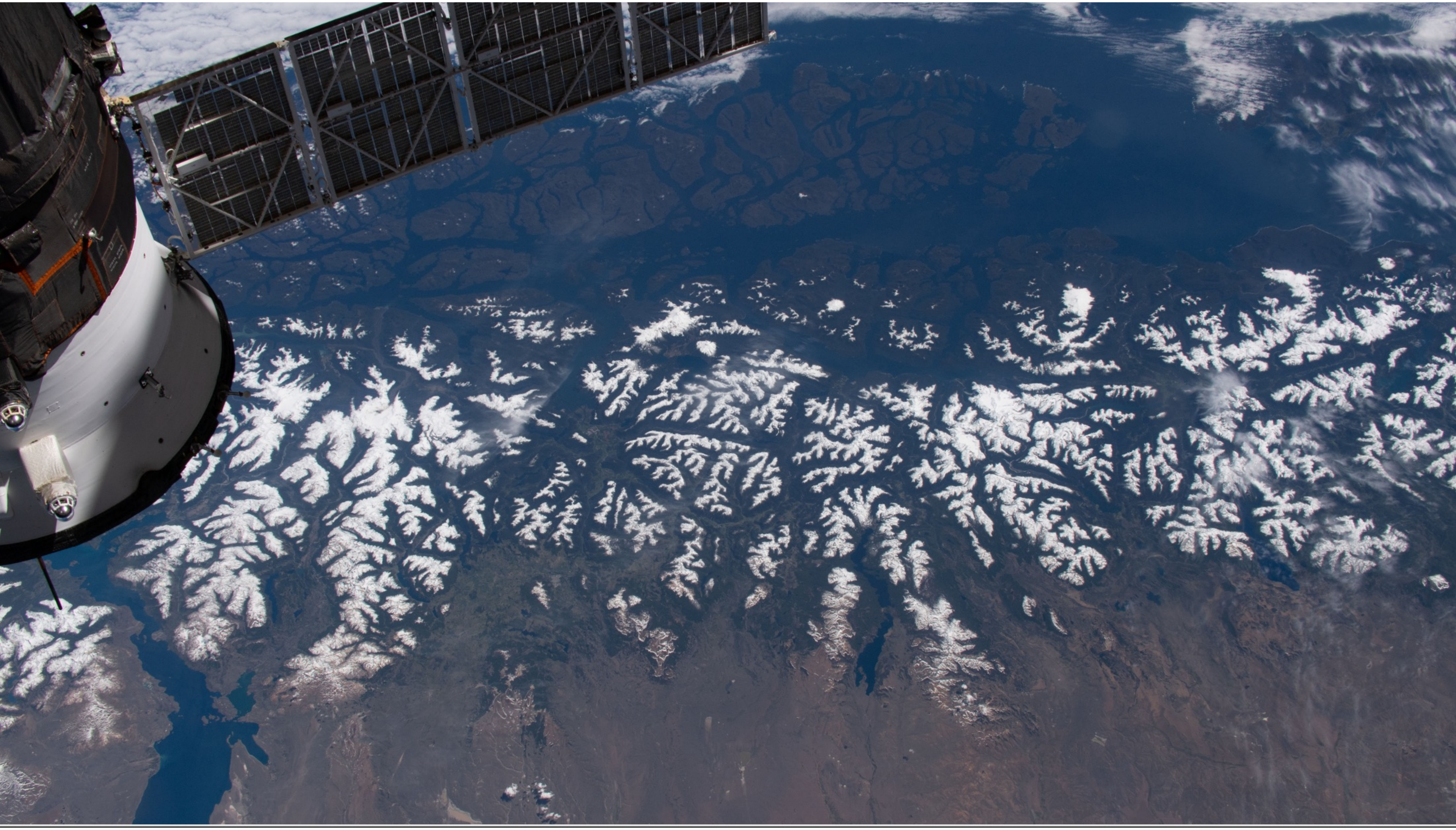




Today

- Why study glaciers?
- Early ideas
- Modern glaciology
- Characterizing glaciers
- Mass balance

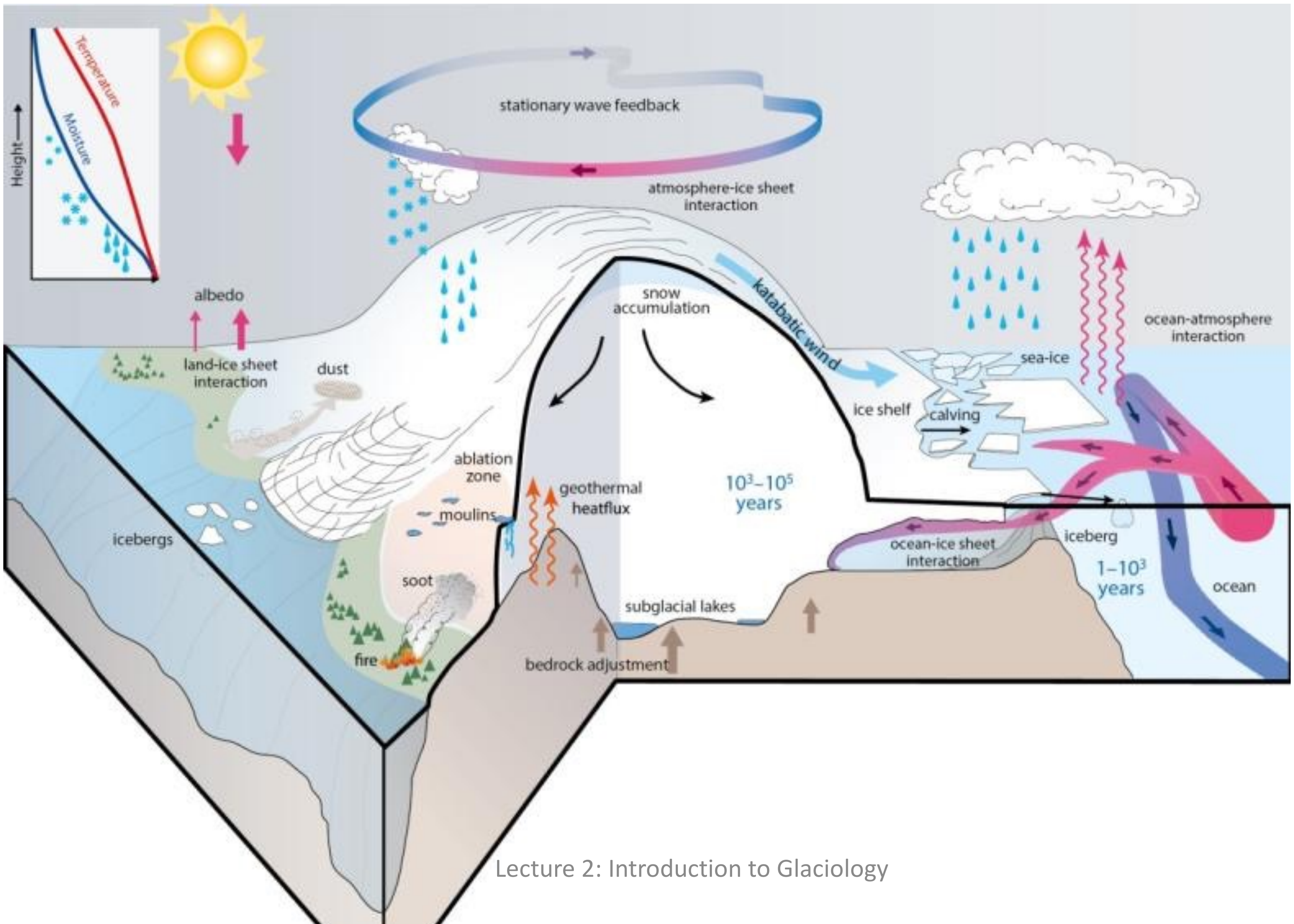
[reminders: Slack, lecture slides are in canvas]



Why study glaciers?

Why study glaciers?

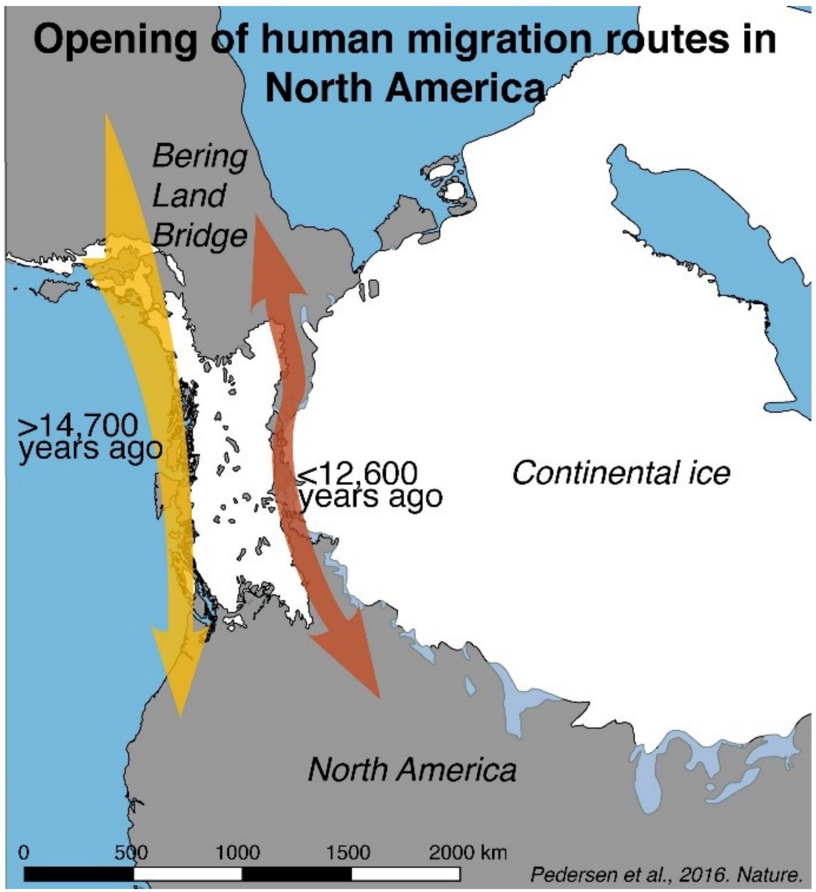
1. Fascinating processes



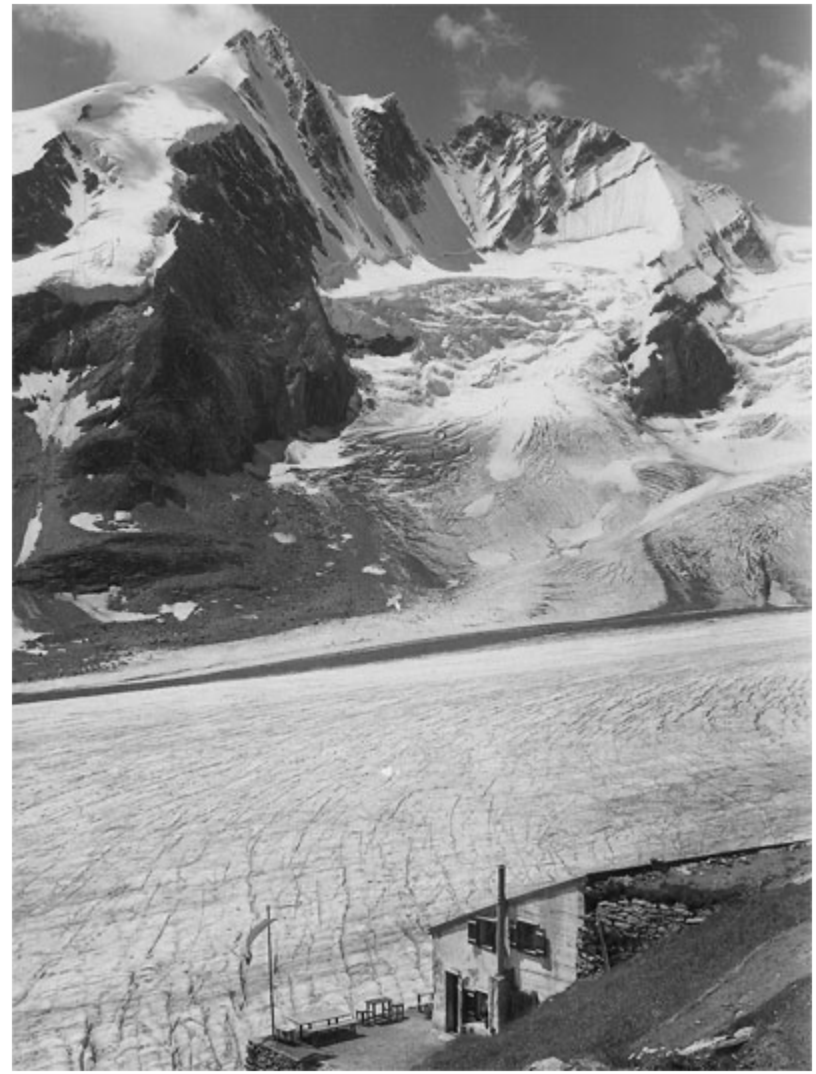
Why study glaciers?

2. Dynamic

Landscape-scale changes on human timescales!



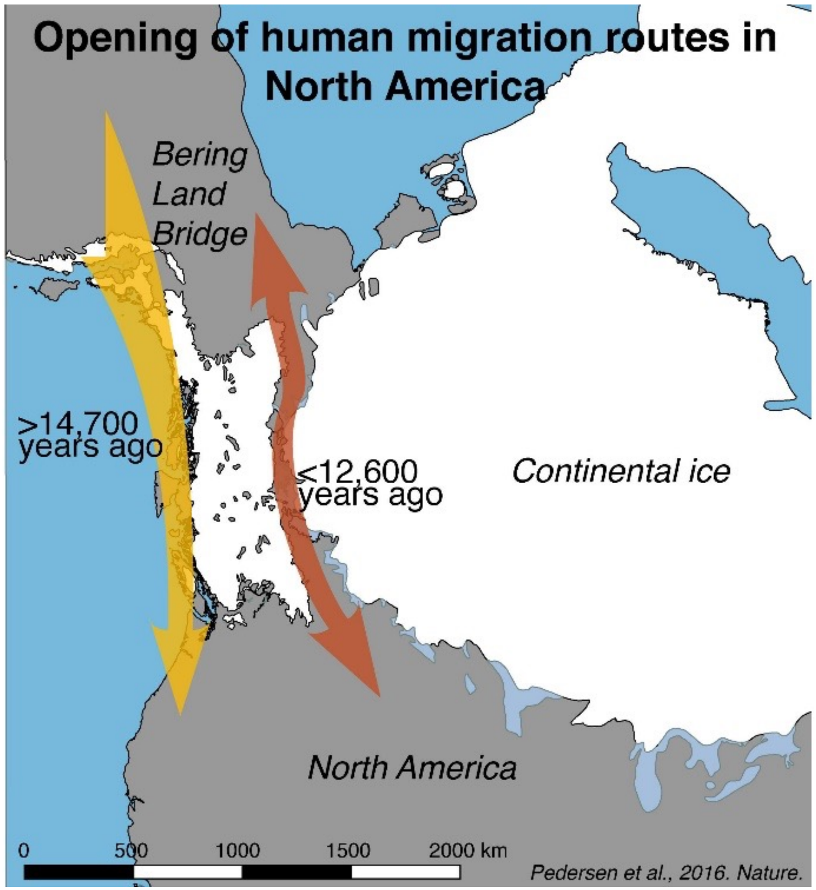
Pasterze Glacier 1990



Why study glaciers?

2. Dynamic

Landscape-scale changes on human timescales!



Pasterze Glacier 2009

Why study glaciers?
2. Dynamic

Landscape-scale changes on human timescales!

Mendenhall Glacier

Google earth engine time lapse

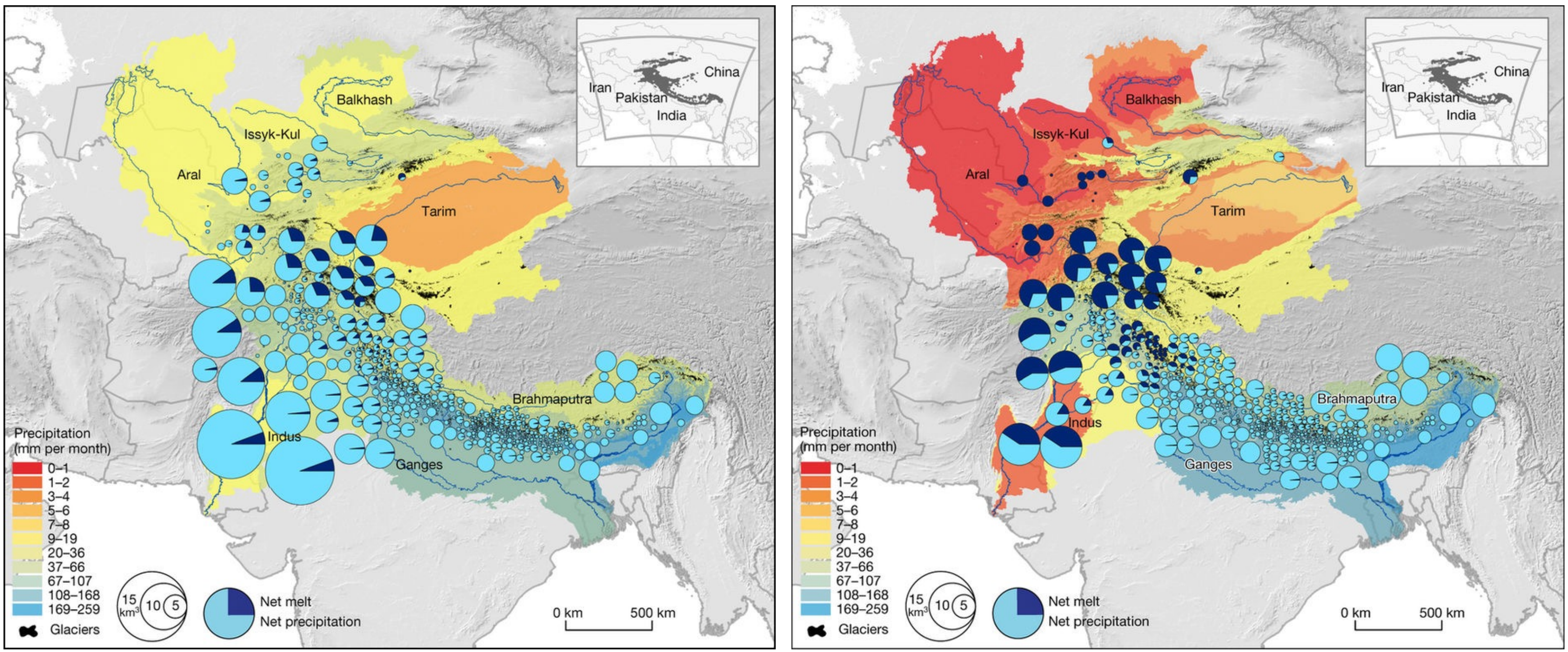
https://earthengine.google.com/iframes/timelapse_player.html

Why study glaciers?

3. Societal impact

Mountain glaciers supply water to
large populations (800 M in high-mountain Asia)

Particularly during droughts.



Pritchard et al. (2017)

Why study glaciers?

3. Societal impact

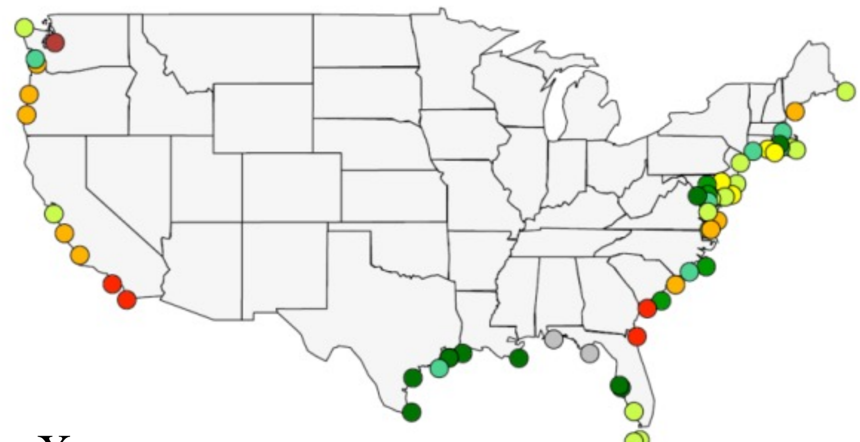
Shrinking glaciers and ice sheets raise sea level.

[The ice sheets] ‘will *likely* make a contribution in the range of 0.03 to 0.20 m [to sea-level rise] by 2081−2100’

ipcc INTERGOVERNMENTAL PANEL ON climate change

2 m storm surges are more than twice as rare as 1 m storm surges.

How often will today’s ‘100-year storm surge’ occur in 2050?



Every X years.

X = 1, 2, 5, 10, 20, 30, 50, 75, 100

Tebaldi and others (2012)

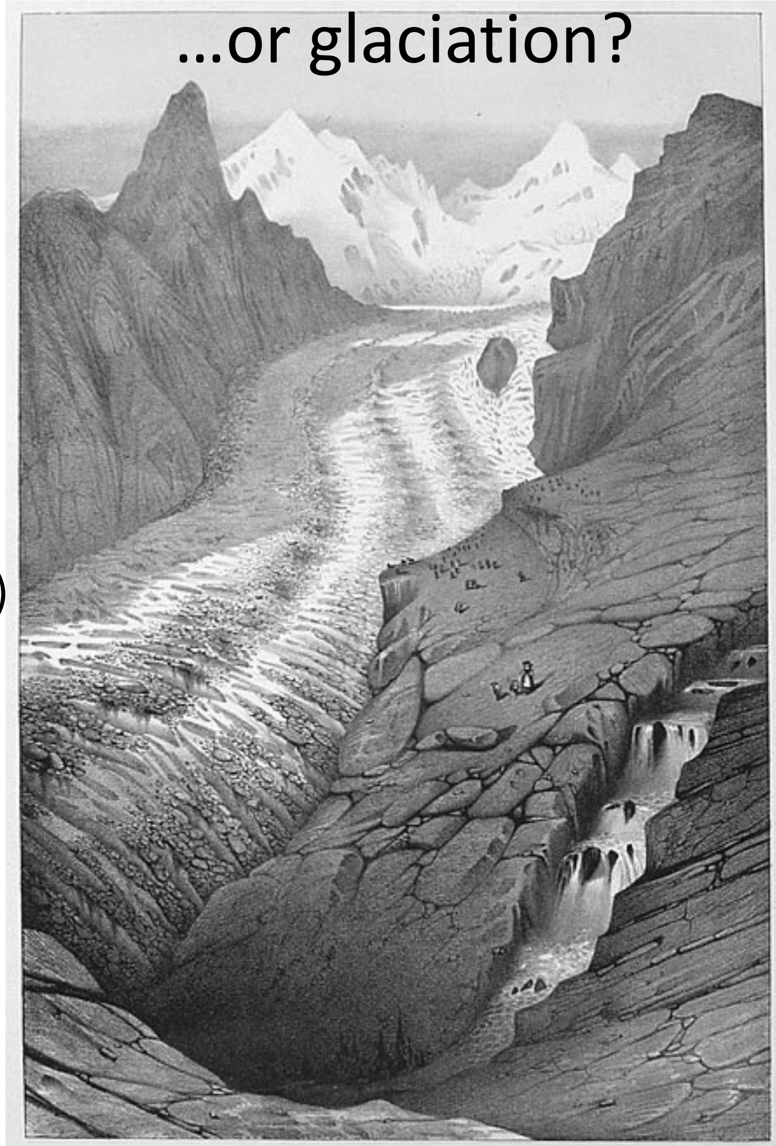
Early ideas

Erratics and 'drift' needed explaining.

Louis Agassiz
(1807 - 1873)

Was it a deluge…

…or glaciation?



Debating glacier theory website,
K. Montgomery

Early ideas

The Glacier Theory.

James Forbes
(1809 – 1868)

Stiff and rigid as it appears, no one can doubt that it either flows, or once has flowed.

It melts—it must melt; it lies on warm ground yielding crops perhaps within a hundred yards of its lower extremity

Evident therefore it must be, upon this ground alone, that a glacier glides imperceptibly down its valley, and this independent of all direct measurements of its motion.

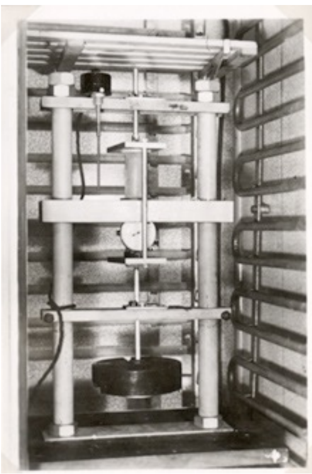
Forbes (1842)

The start of quantitative glaciology

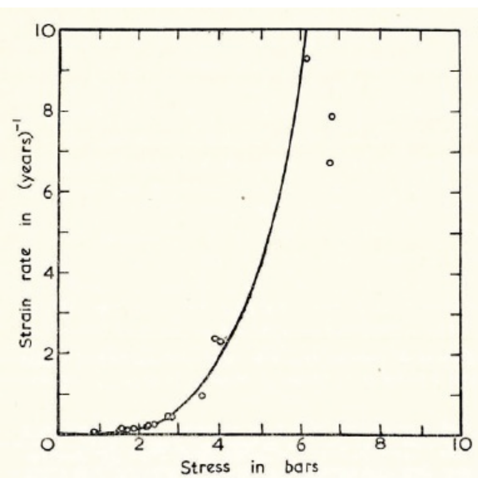
In the 1950's physicists started getting interested in ice flow, putting glaciology on a theoretical footing.

EXPERIMENTS ON THE DEFORMATION OF ICE

By J. W. GLEN



Glen (1952)



THE MECHANICS OF GLACIER FLOW

By J. F. NYE

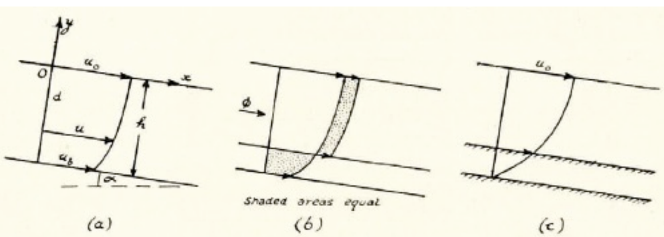
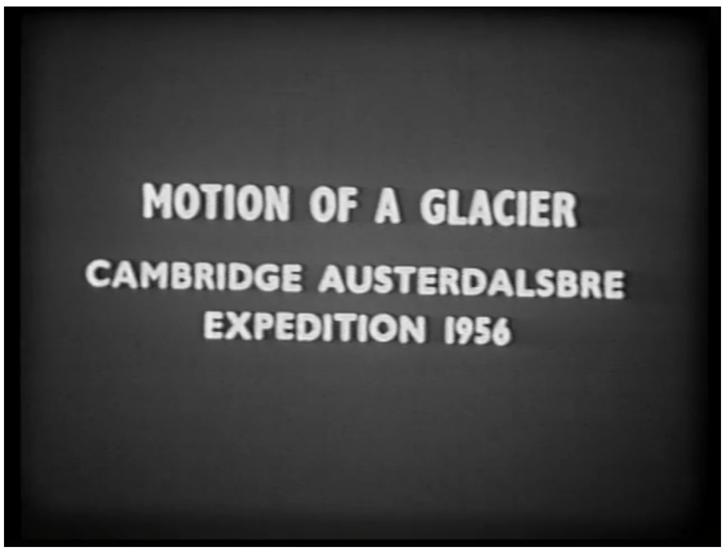


Fig. 2. Laminar flow down an inclined plane

Nye (1952)

The first glacier flow time lapse
Austersdalsbreen, Norway, 1956

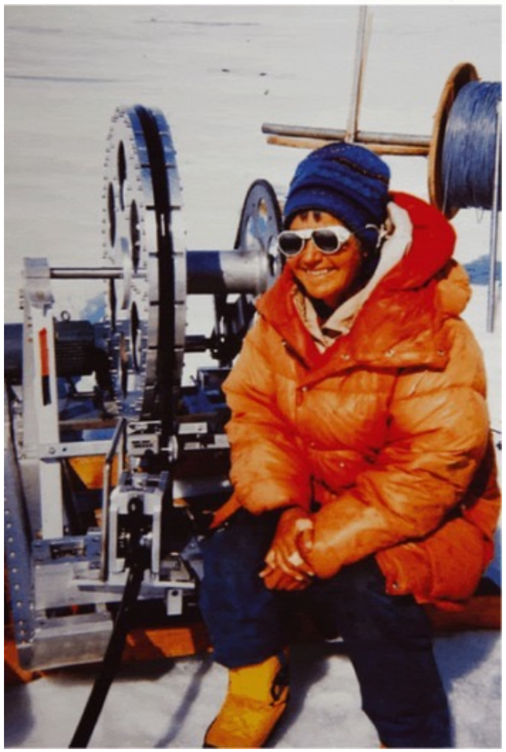
https://youtu.be/5w38d4GL2O4?t=2321



Austerdalsbreen, Norway, 2011

The start of quantitative glaciology

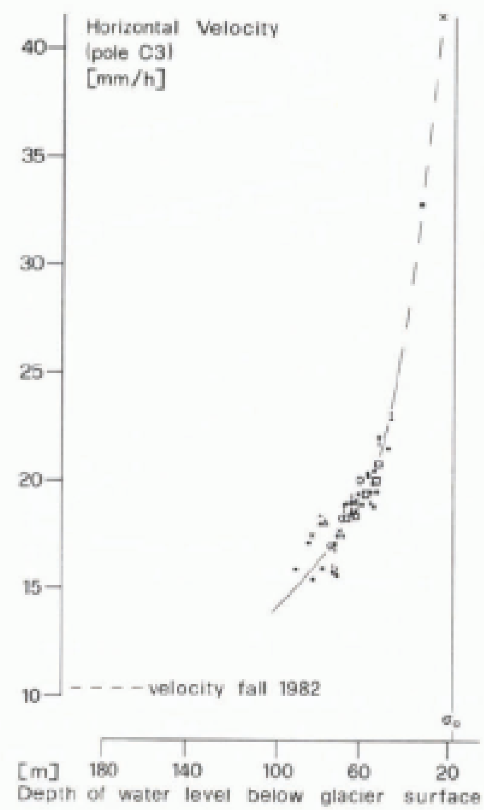
Almut Iken



Journal of Glaciology, Vol. 32, No. 110, 1986

COMBINED MEASUREMENTS OF SUBGLACIAL WATER PRESSURE AND SURFACE VELOCITY OF FINDELENGLETSCHER, SWITZERLAND: CONCLUSIONS ABOUT DRAINAGE SYSTEM AND SLIDING MECHANISM

By ALMUT IKEN and ROBERT A. BINDSCHADLER



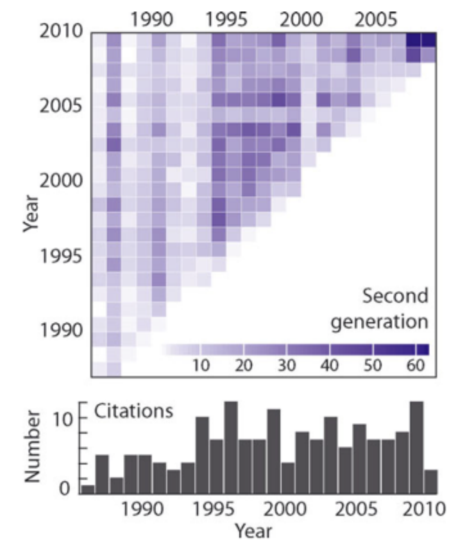


Fig. 6. The deep influence of Iken's work on glacier sliding is demonstrated by the longevity and intensity of citations of a hallmark *Journal of Glaciology* paper. Top: Color map of 4108 'second-generation' citations of papers citing Iken and Bindschadler (1986). Bottom: One hundred and sixty-four 'first-generation' citations of the same paper by year. Citations of these papers are mapped in the top panel. Citation database downloaded from the Web of Science, August 2010.

Women in glaciology, a historical perspective

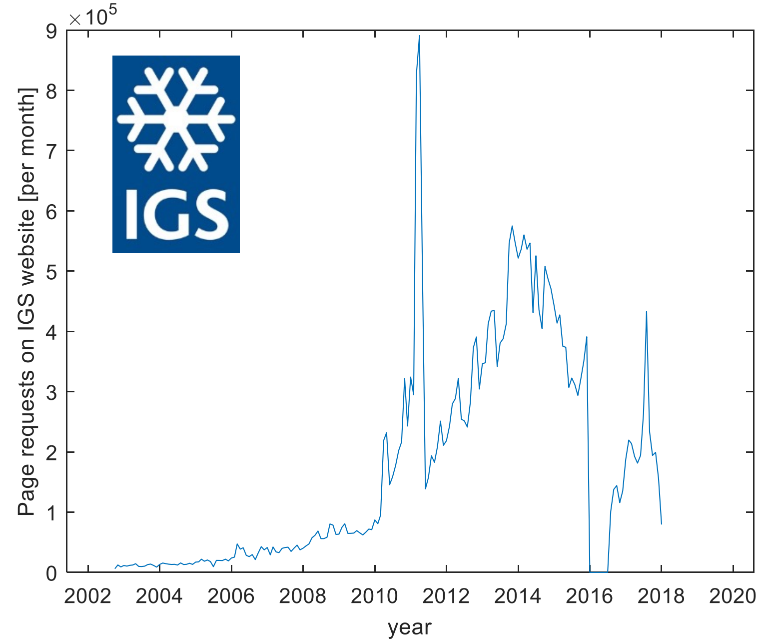
Christina L. HULBE,[1] Weili WANG,[2] Simon OMMANNEY[3]

Modern glaciology

- Interdisciplinary
- Under-staffed, but growing rapidly
- Immature

(compared to some disciplines)

International Glaciology Society website



CRYOLIST
Email list for everyone interested in snow and ice

6439 members (Jan 6th 2020)
(up from 5444 on Jan 12th 2018)

Understanding of glaciers has improved dramatically over the past half-century or so. Modern techniques of measurement would surely astonish Forbes and Agassiz, as would the abundance of information now available to evaluate theoretical models. Yet the deep inadequacies of the science should be kept in mind.

Cuffey and Paterson (2010)

Papers published in International Glaciological Society journals, by gender

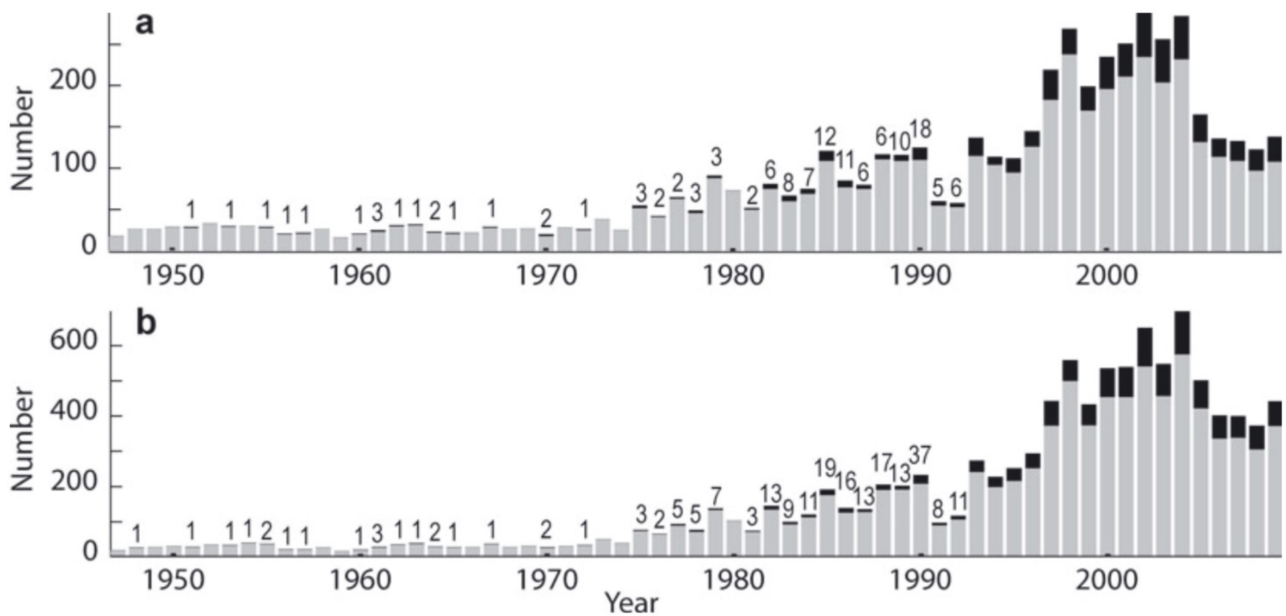


Fig. 1. Contributions to the *Journal* and *Annals of Glaciology* from 1947 to 2009, classified by author sex. Grey bars indicate male authors and black bars indicate female authors, and the total number of female authors is indicated until it is consistently larger than 10. (a) Classified first authorships. (b) All classified authorships. The author database was provided by the IGS in August 2010. The author classification is geographically diverse and we were able to identify author sex for approximately 72% of all papers and 70% of first authors. Emphasis was placed on classifying authors cited for more than one paper.

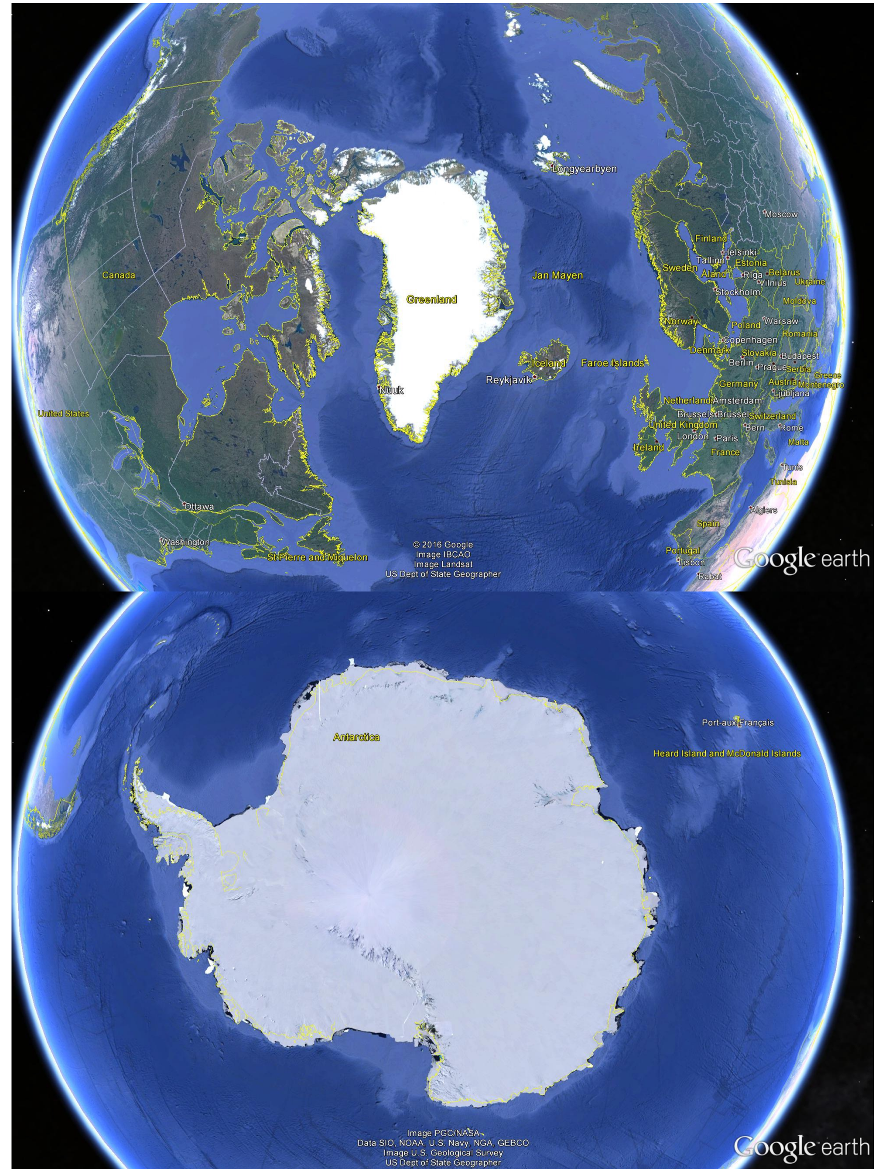
Women in glaciology, a historical perspective

Christina L. HULBE,[1] Weili WANG,[2] Simon OMMANNEY[3]

Categorizing glaciers and ice sheet

…by size and setting…

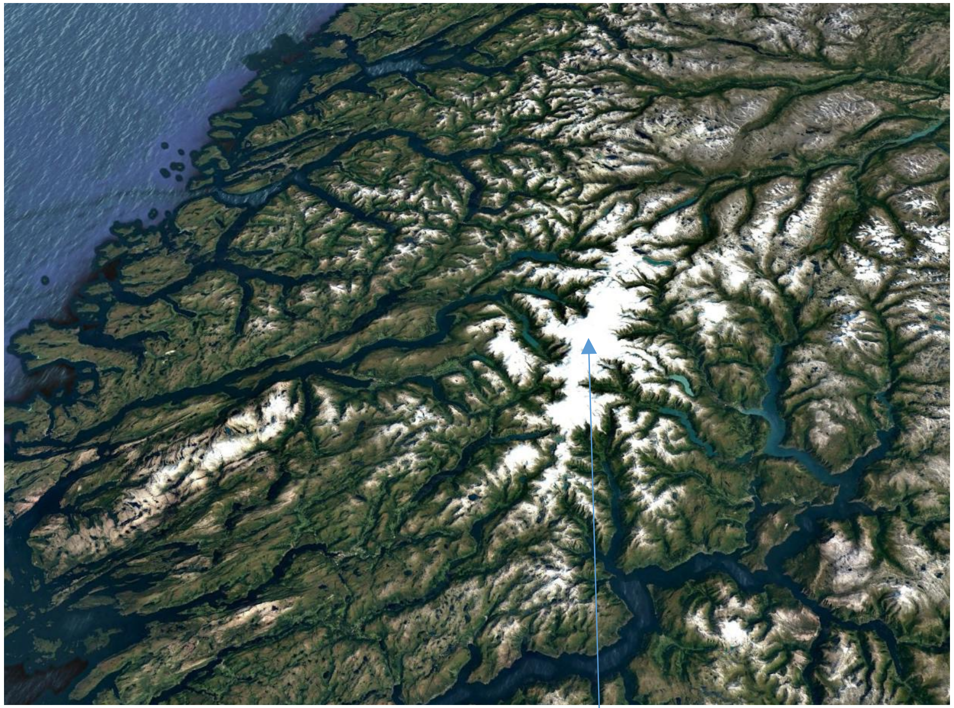
Continental ice sheets O(1000 km)
Ice caps
Ice streams
Outlet glaciers
Valley glaciers
Piedmont glaciers
Cirque glaciers
Hanging glaciers



Categorizing glaciers and ice sheet

…by size and setting…

Continental ice sheets
Ice caps O(10-100 km)
Ice streams
Outlet glaciers
Valley glaciers
Piedmont glaciers
Cirque glaciers
Hanging glaciers

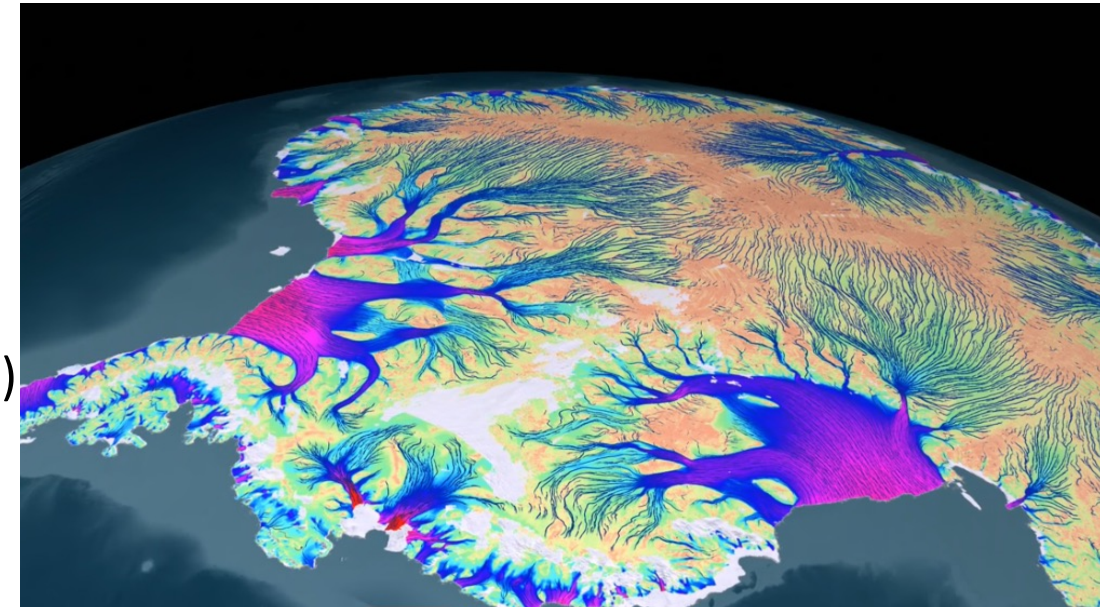


Jostedalsbreen, Norway

Categorizing glaciers and ice sheet

…by size and setting…

Continental ice sheets
Ice caps
Ice streams O(10-1000 km)
Outlet glaciers
Valley glaciers
Piedmont glaciers
Cirque glaciers
Hanging glaciers

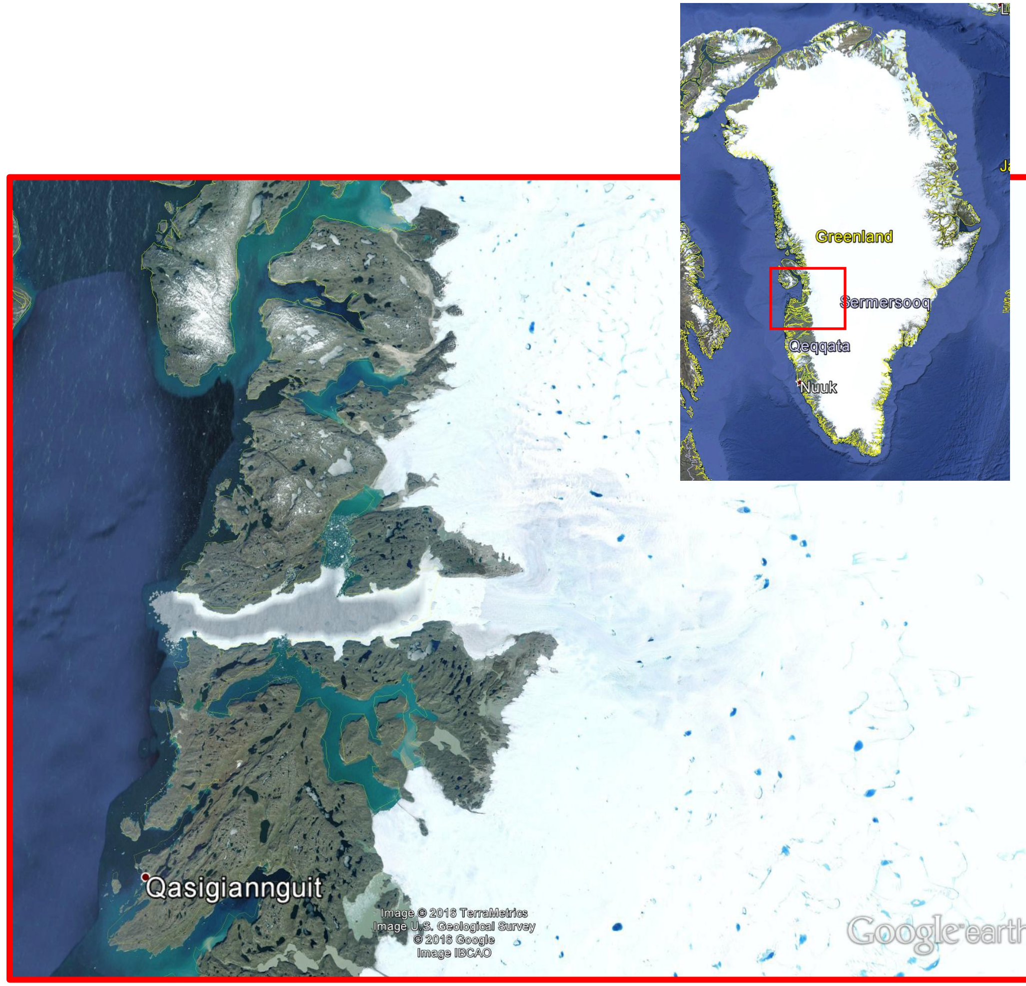


The surface of a West Antarctic Ice Stream

Categorizing glaciers and ice sheet

…by size and setting…

Continental ice sheets
Ice caps
Ice streams
Outlet glaciers O(1-10 km)
Valley glaciers
Piedmont glaciers
Cirque glaciers
Hanging glaciers



Jakobshavn Isbræ, West Greenland

Categorizing glaciers and ice sheet

…by size and setting…

Continental ice sheets
Ice caps
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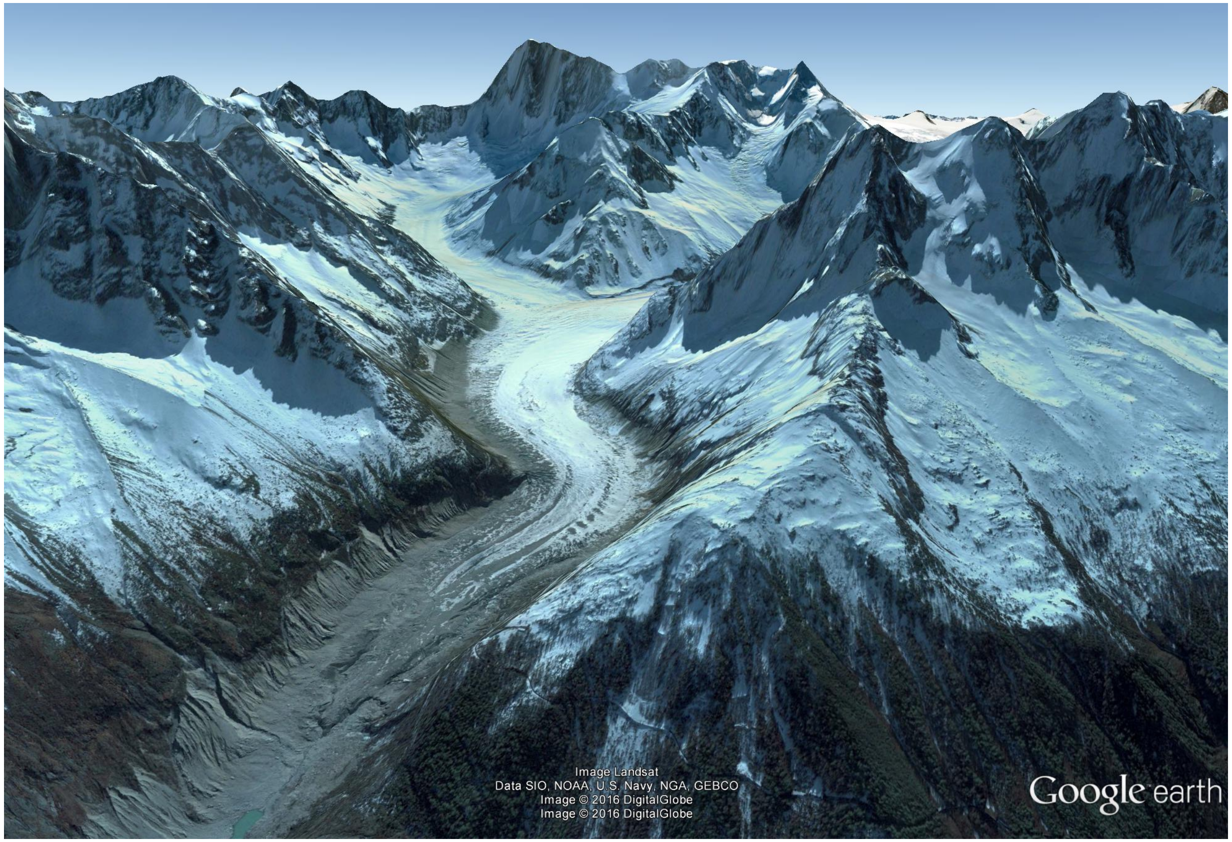
Hanging glaciers



Mer de Glace, Mont Blanc Massif, France

Categorizing glaciers and ice sheet

…by size and setting…

Continental ice sheets
Ice caps
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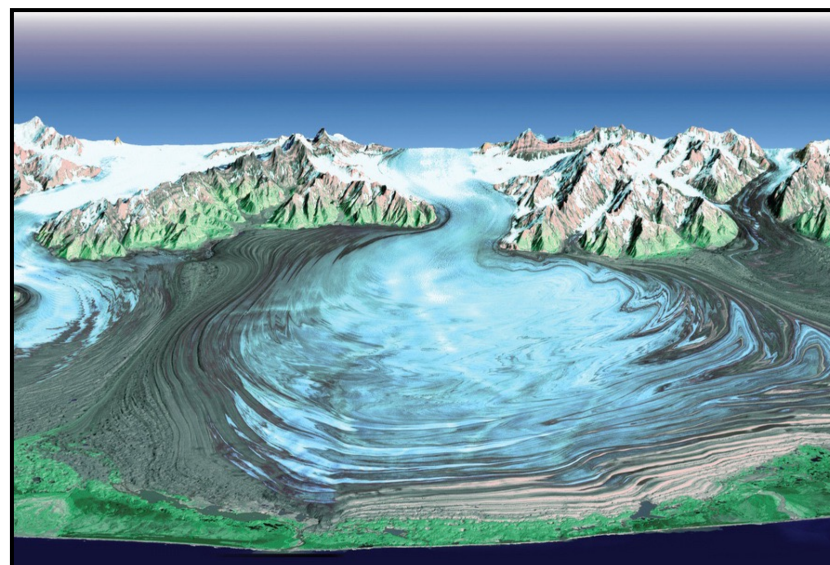
Cirque glaciers
Hanging glaciers

Elephant's Foot Glacier, North East Greenland

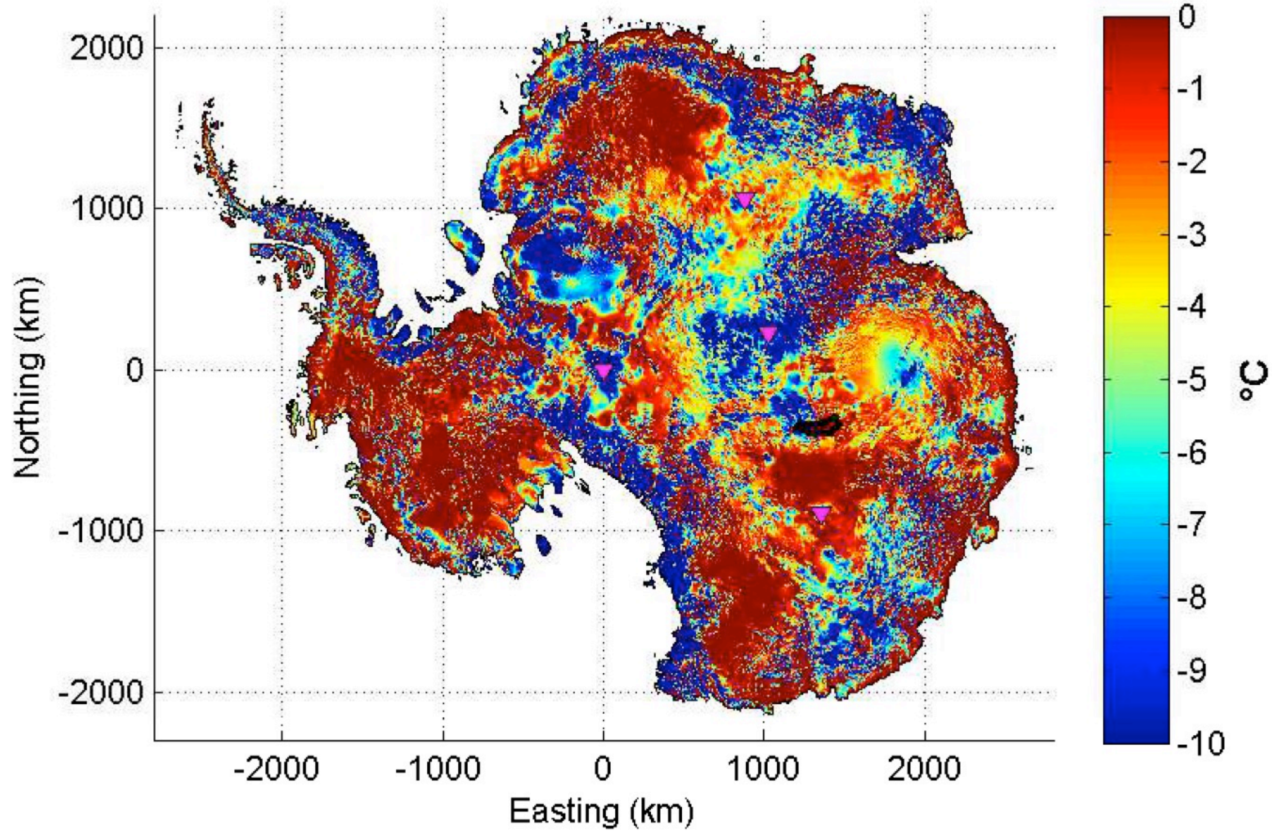


Malspina Glacier, Alaska

Categorizing glaciers and ice sheet

…by basal temperature…

Warm-based
or cold-based.

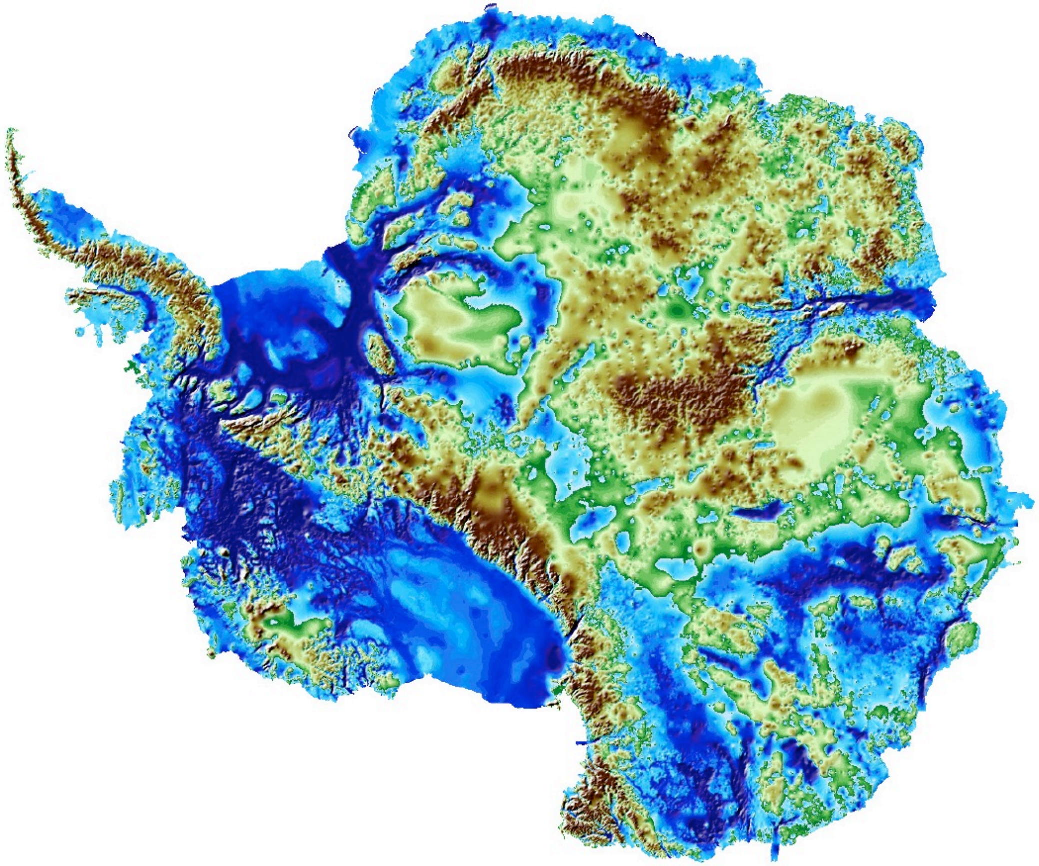


Van Liefferinge and Pattyn (2013)

Categorizing glaciers and ice sheet

…or by their relation to the ocean…

Marine-based ice is grounded below sea level.

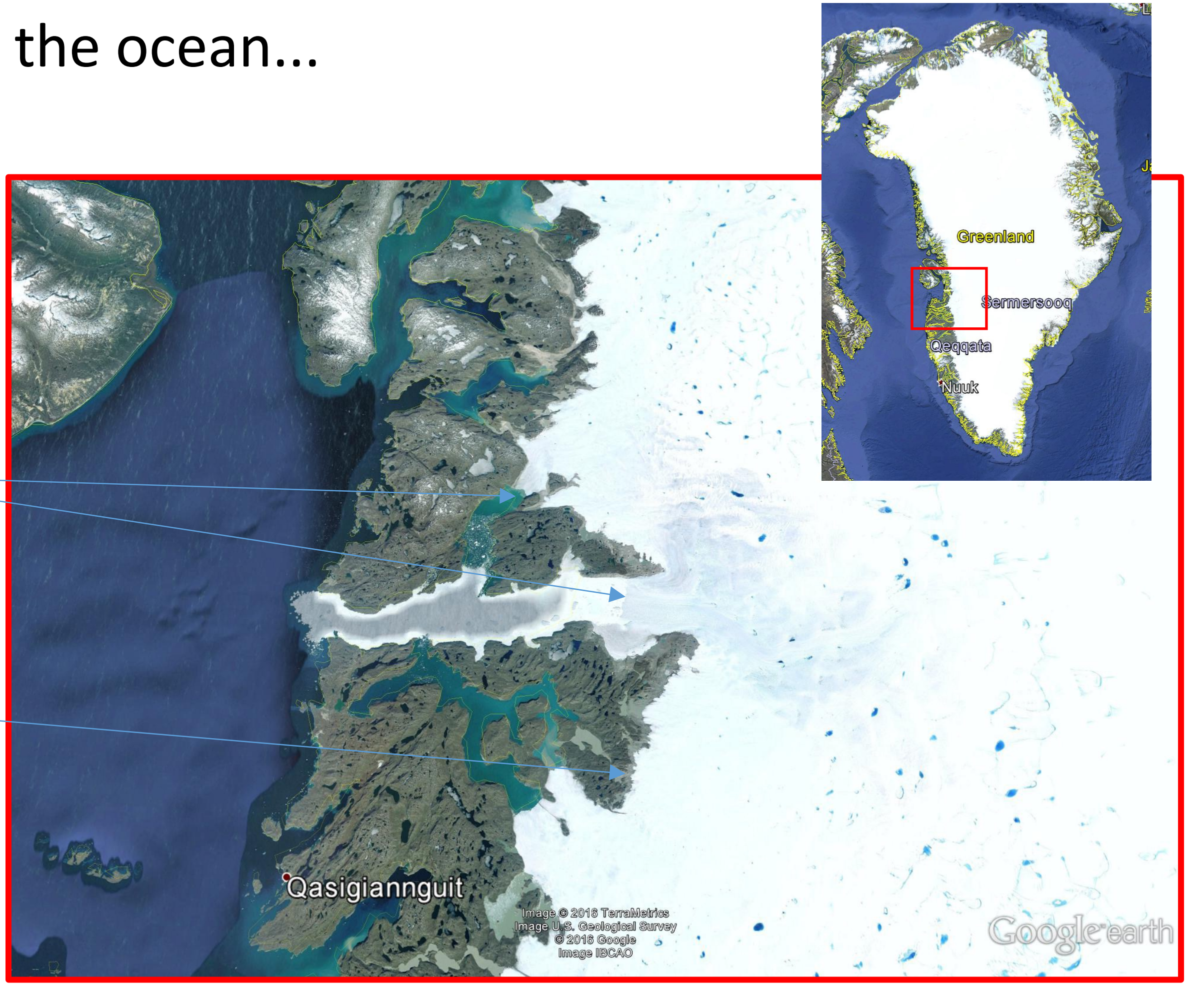


Categorizing glaciers and ice sheet

…or by their relation to the ocean…

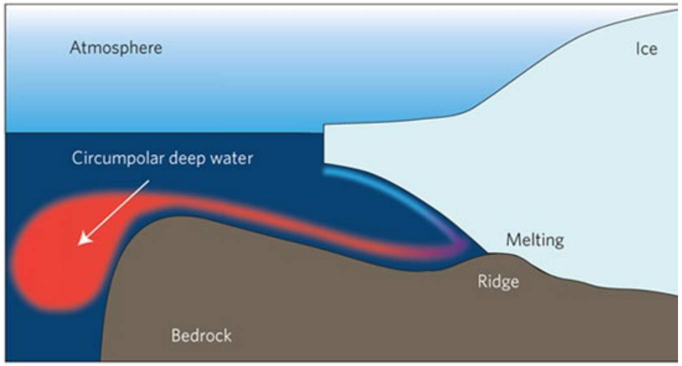
Marine-terminating glaciers flow directly into the ocean.

Land-terminating glaciers terminate on land.



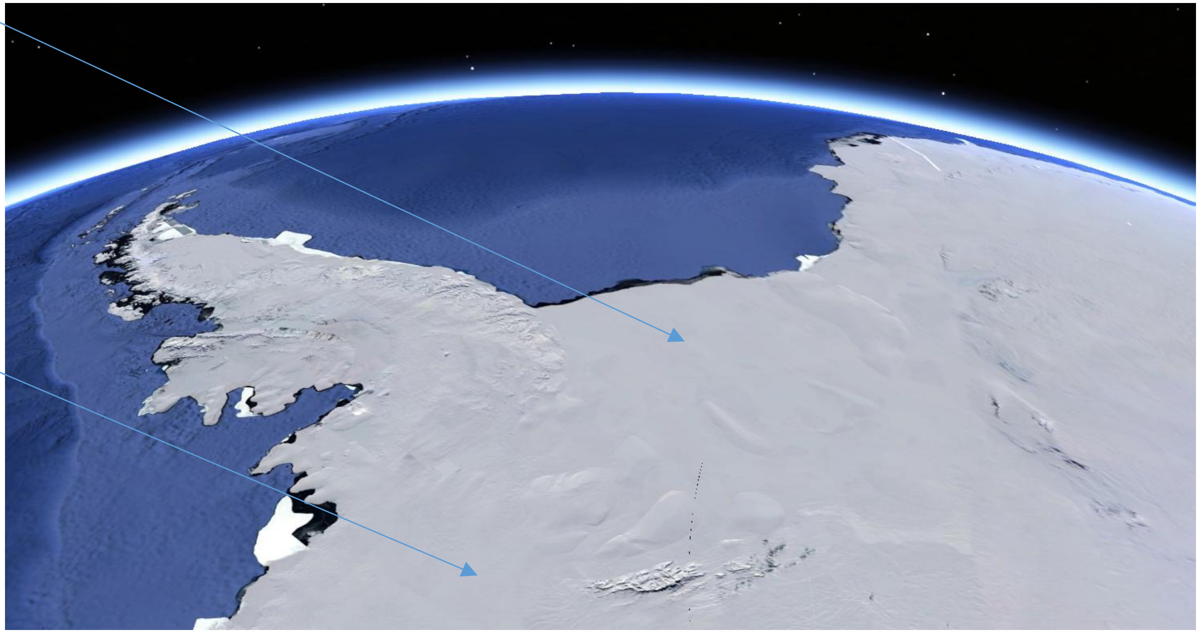
Categorizing glaciers and ice sheet

…or by their relation to the ocean…



Floating ice shelves float on the ocean.

Grounded ice rests on land



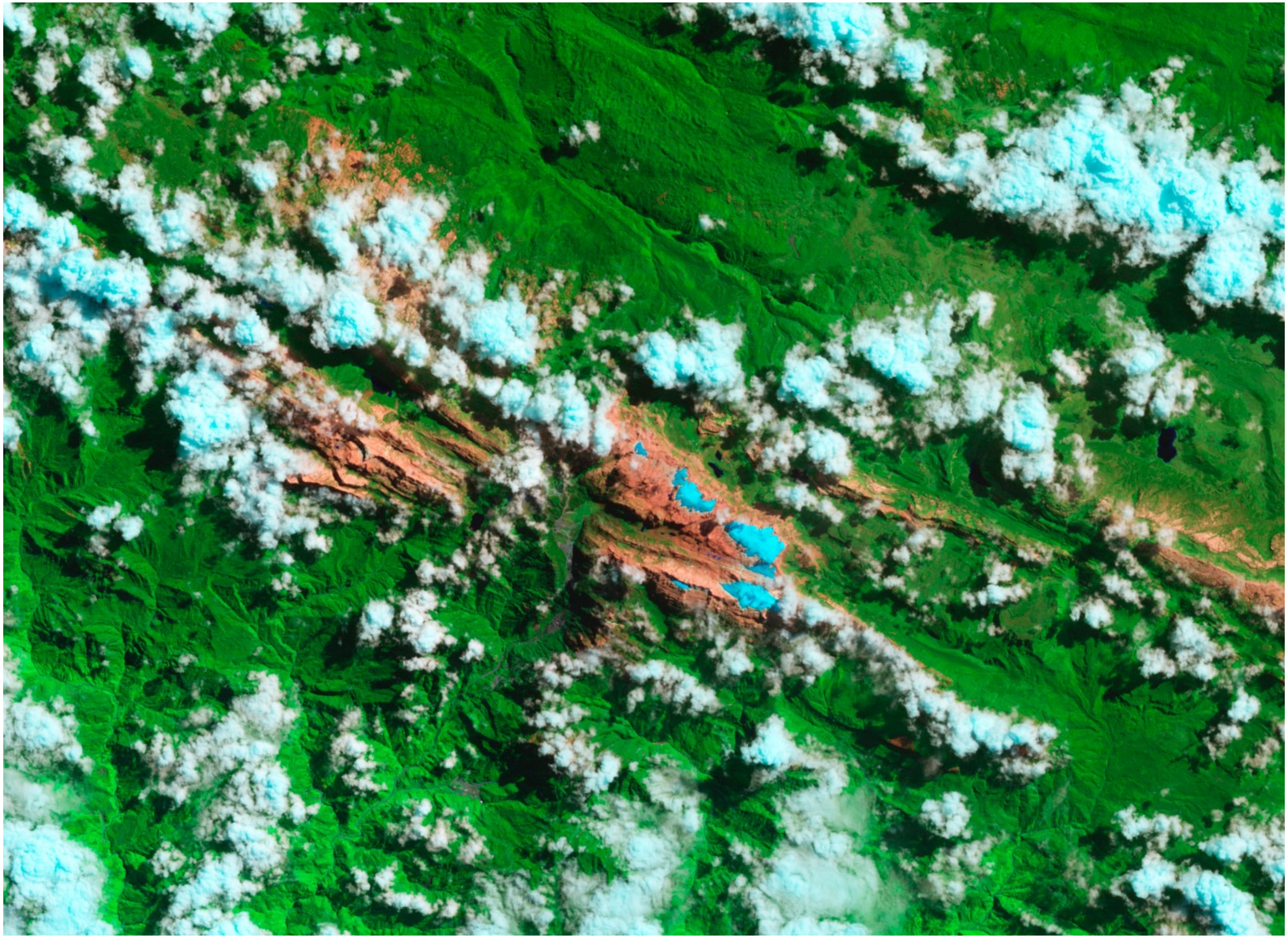
Categorizing glaciers and ice sheet

…or by their geographic location.

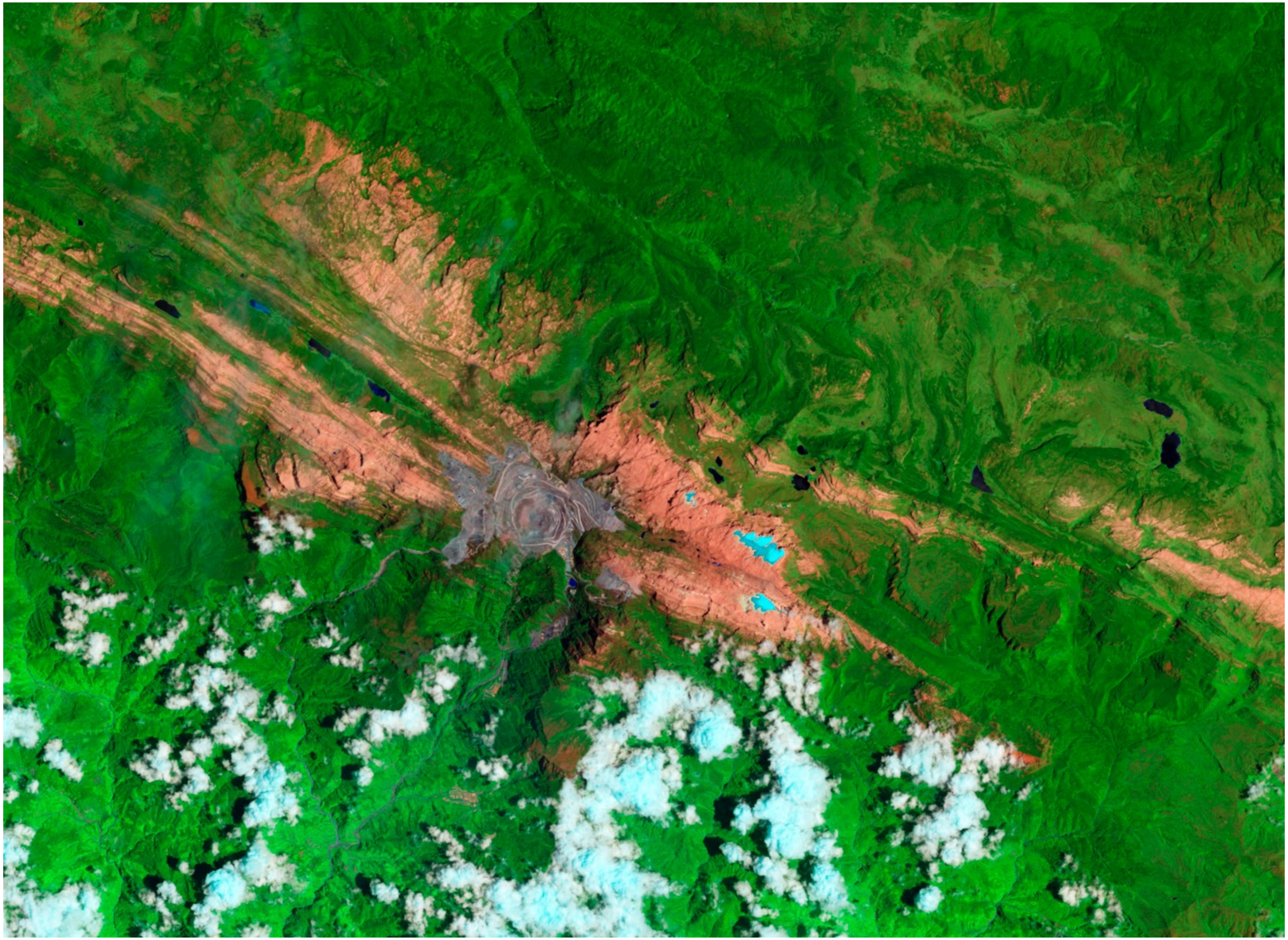
Tropical glaciers and extra-tropical glaciers

Jomelli et al. (2011)

May 26, 1989



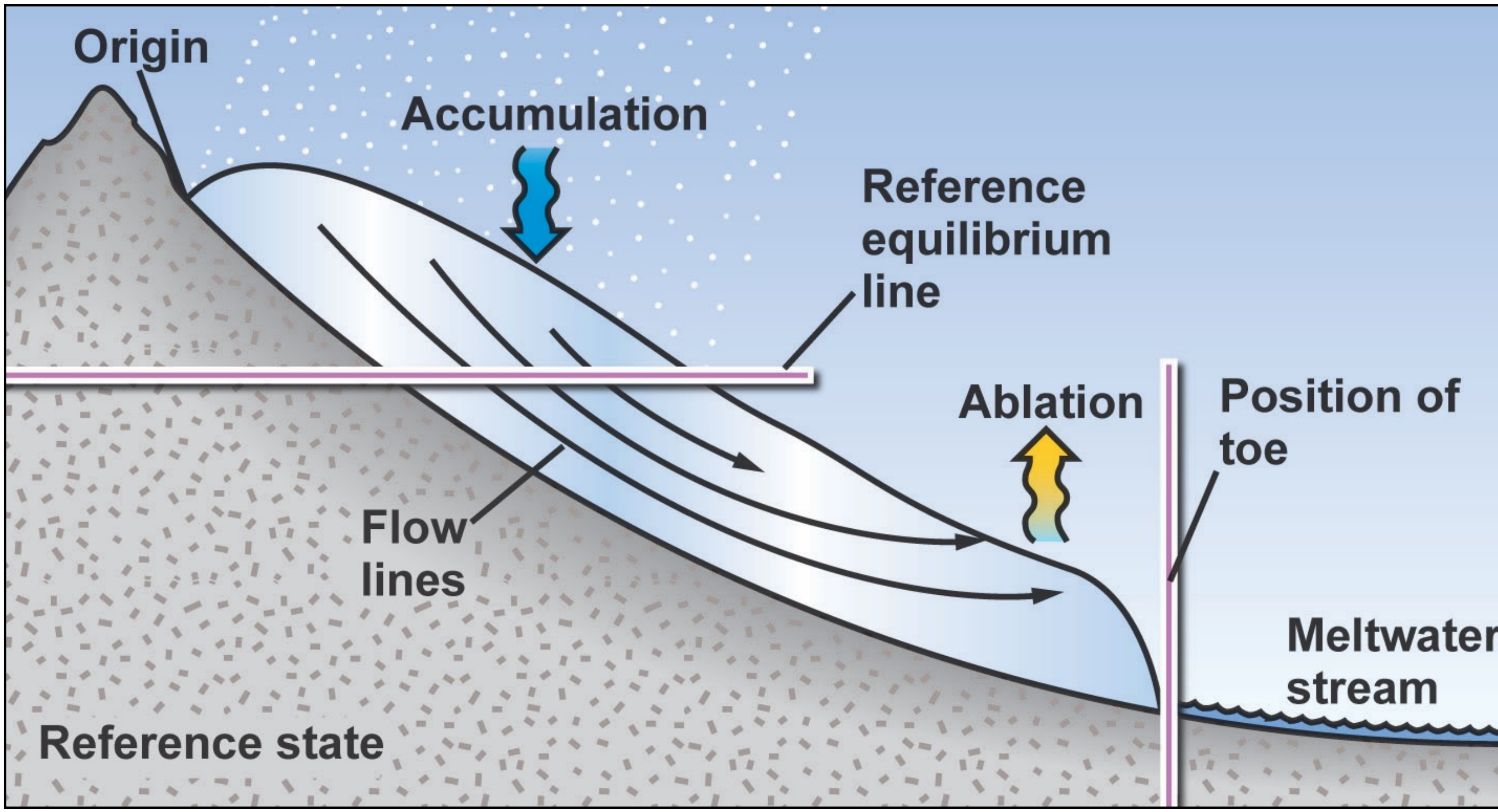
October 9, 2009



Mass balance

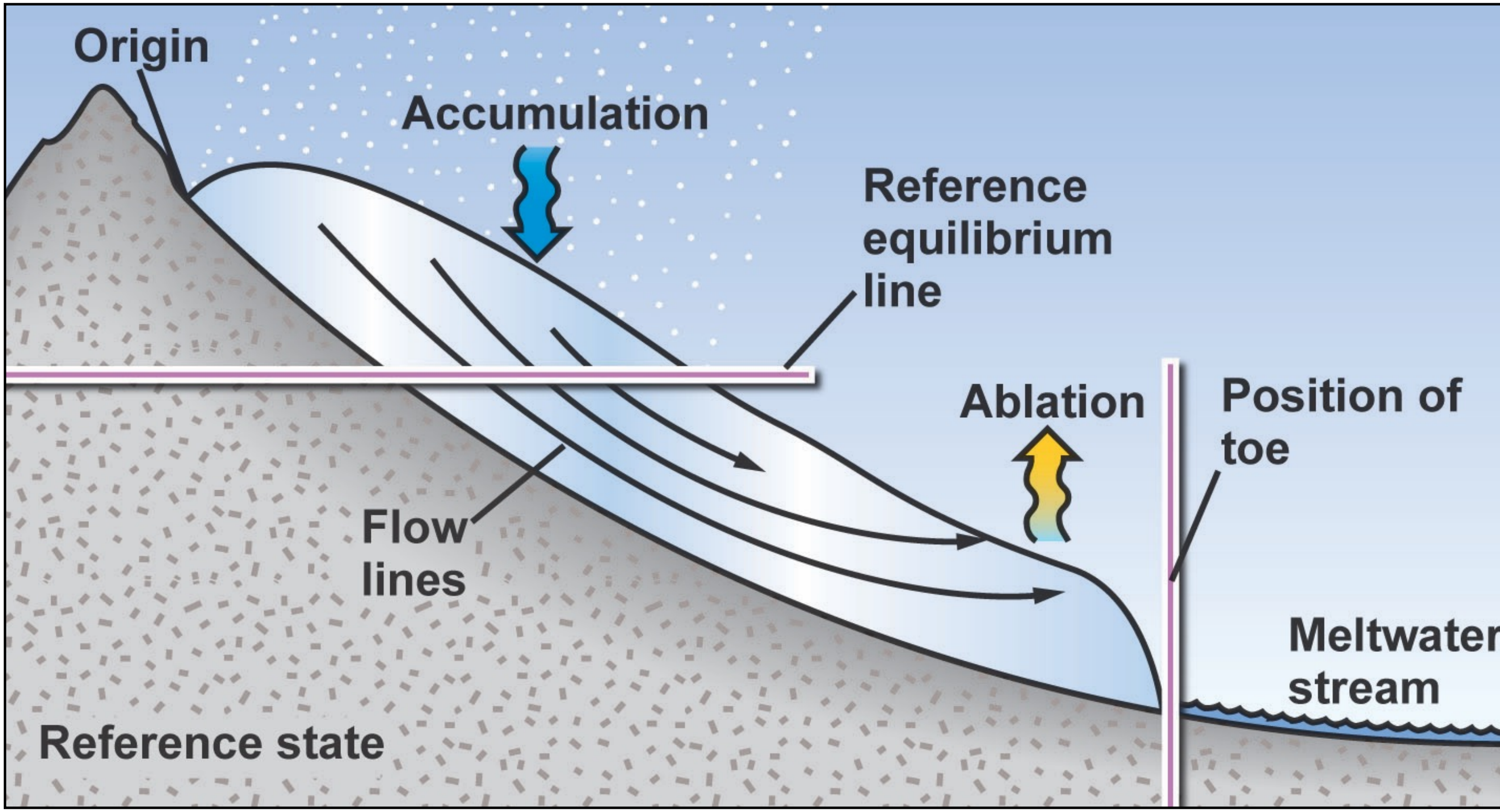
Mass balance

Mass balance = total mass gain – total mass loss



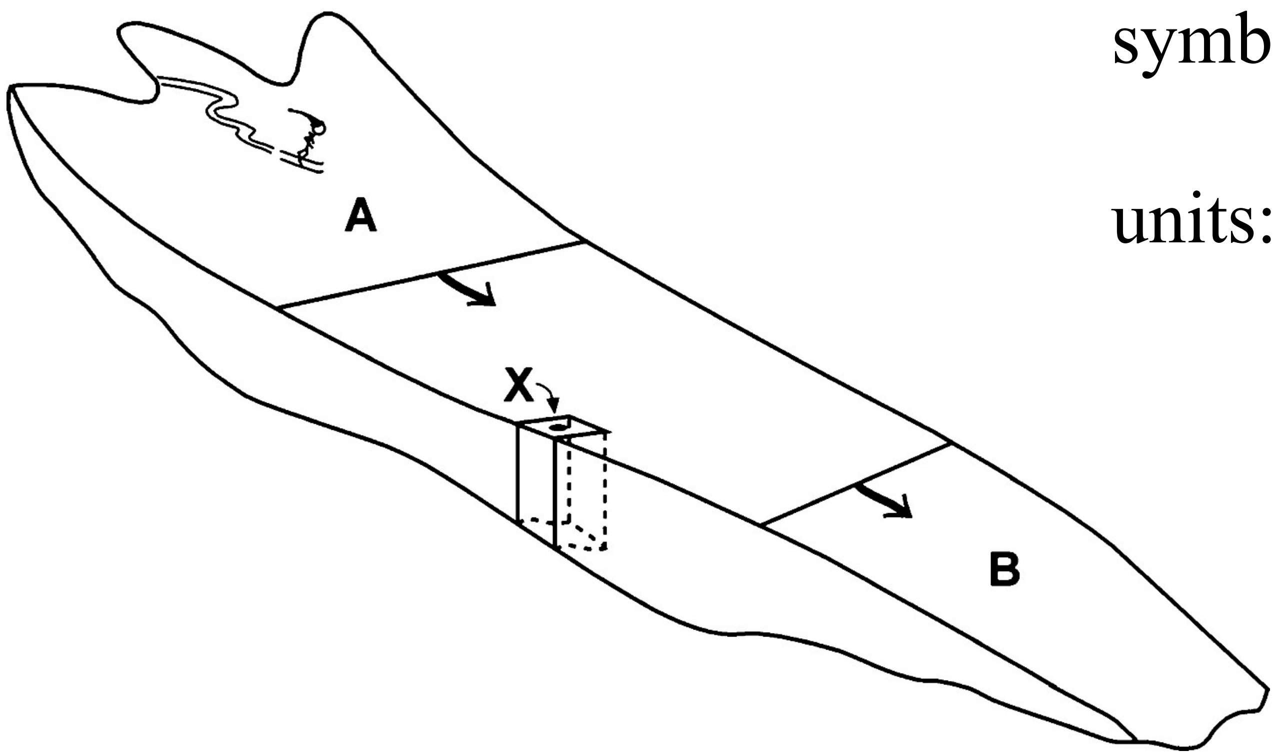
Mass balance

Mass balance = accumulation – ablation



Specific mass balance

Change in mass per unit area



symbol: b

units: kg m^{-2}

Cuffey and Paterson (2010)

Specific mass balance

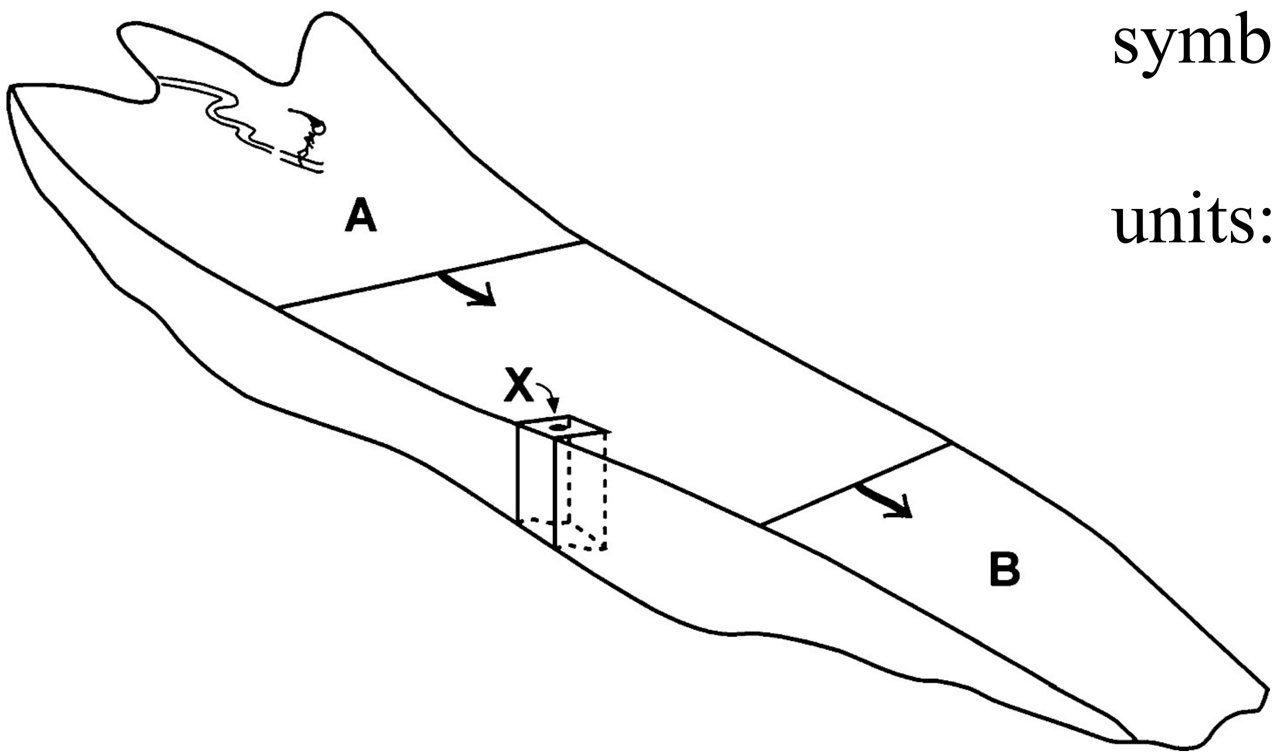
Change in mass per unit area

Includes surface, englacial and basal components.

(not ice flow)

symbol: *b*

units: kg m^{-2}



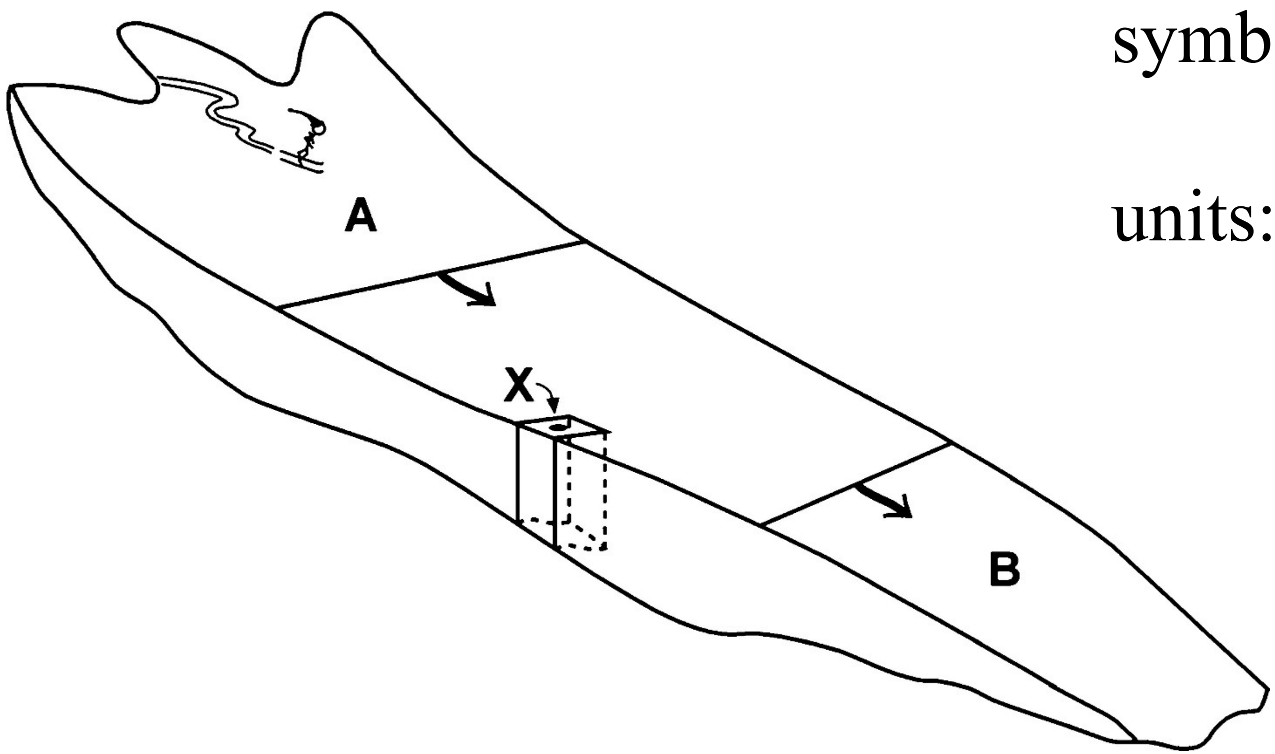
Cuffey and Paterson (2010)

Specific mass balance rate

Change in mass per unit area per unit time

Includes surface, englacial and basal components.

(not ice flow)



symbol: $\dot{b}$

units: kg m^{-2} a^{-1}

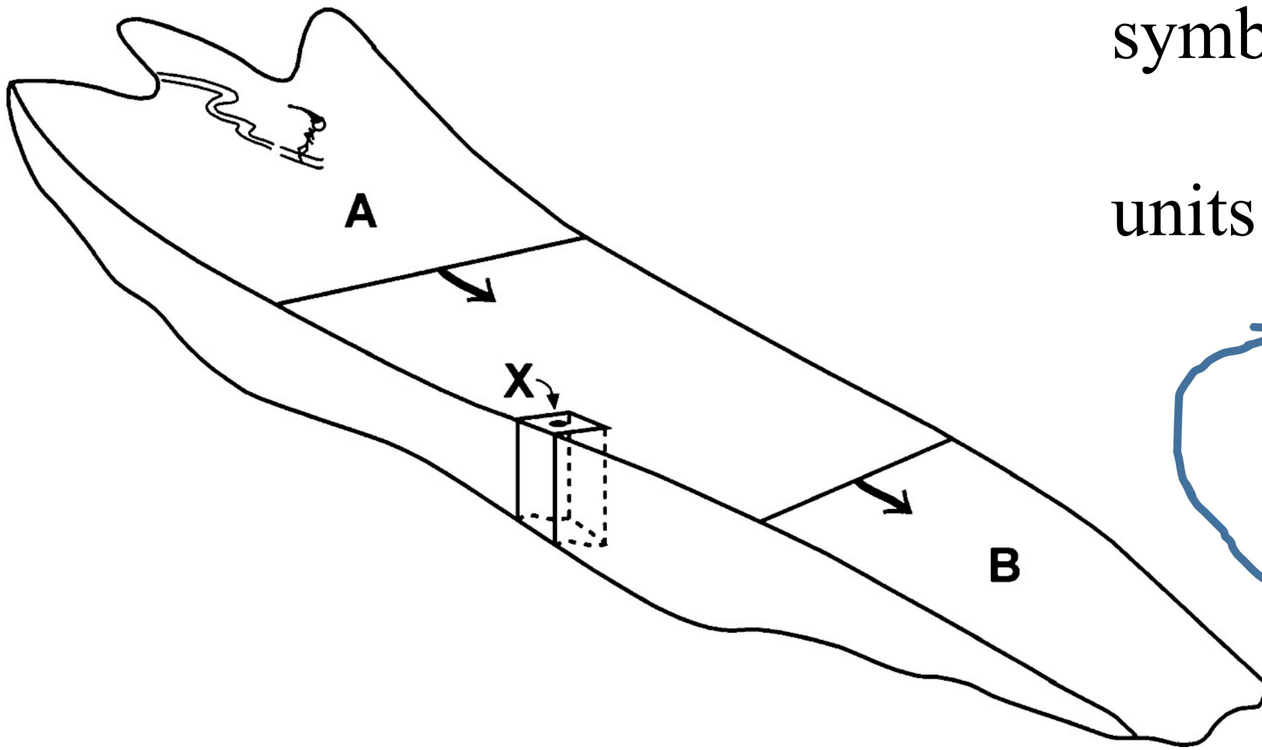
Cuffey and Paterson (2010)

Specific mass balance rate

Change in mass per unit area per unit time

Includes surface, englacial and basal components.

(not ice flow)



symbol: $\dot{b}$

units: kg m^{-2} a^{-1}

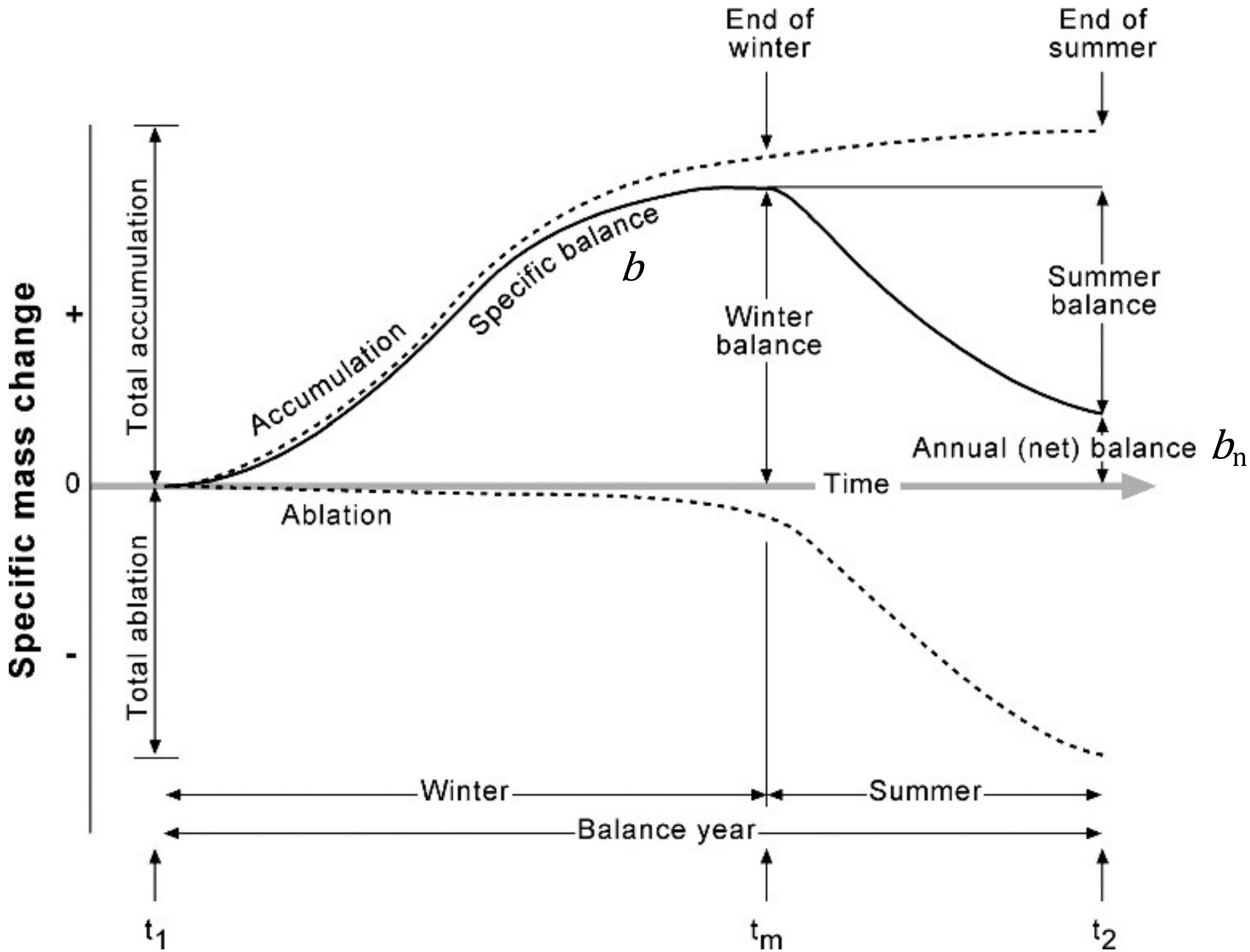
m a^{-1}

m w.e. a^{-1}

This is "ice-equivalent" used in ice-sheet modelling.

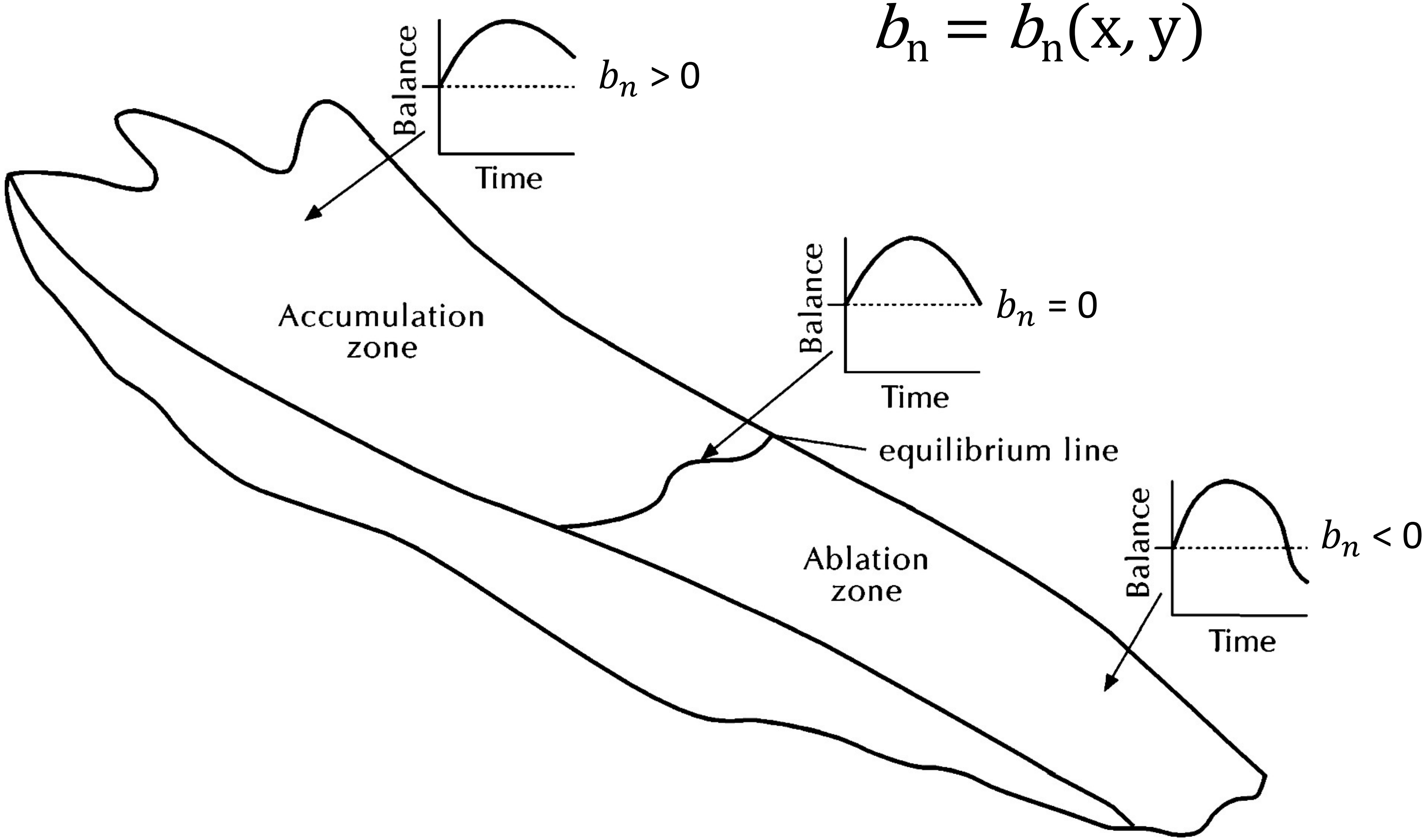
Cuffey and Paterson (2010)

Annual or net specific balance, b_n



Spatially-varying net specific balance

$$b_{\mathrm{n}} = b_{\mathrm{n}}(\mathrm{x}, \mathrm{y})$$



Cuffey and Paterson (2010)

Summary

- We study glaciers because they behave in fascinating, dynamic, and impactful ways.
- Glaciology is a relatively young science, which started becoming quantitative in the 1950’s.
- Glaciologists categorize glaciers and ice sheets in terms of their size, setting, basal thermal regime, relation with ocean.
- Specific mass balance varies in space.
- Glacier mass balance applies to the whole glacier.

Next Lecture:

Surface facies

Processes in the accumulation zone:

-- Drivers of accumulation patterns

-- Firn densification

-- Meltwater refreezing

Before next lecture:

Reading

Regina Hock's notes on glacier mass balance.

In some cases very detailed, but read through it to get a feel for some of the things we will talk about on Tuesday:

https://glaciers.gi.alaska.edu/sites/default/files/mccarthy/Notes_massbal_Hock.pdf

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Van Liefferinge, B. and Pattyn, F., 2013. Using ice-flow models to evaluate potential sites of million year-old ice in Antarctica. *Climate of the Past*, *9*(5), p.2335.

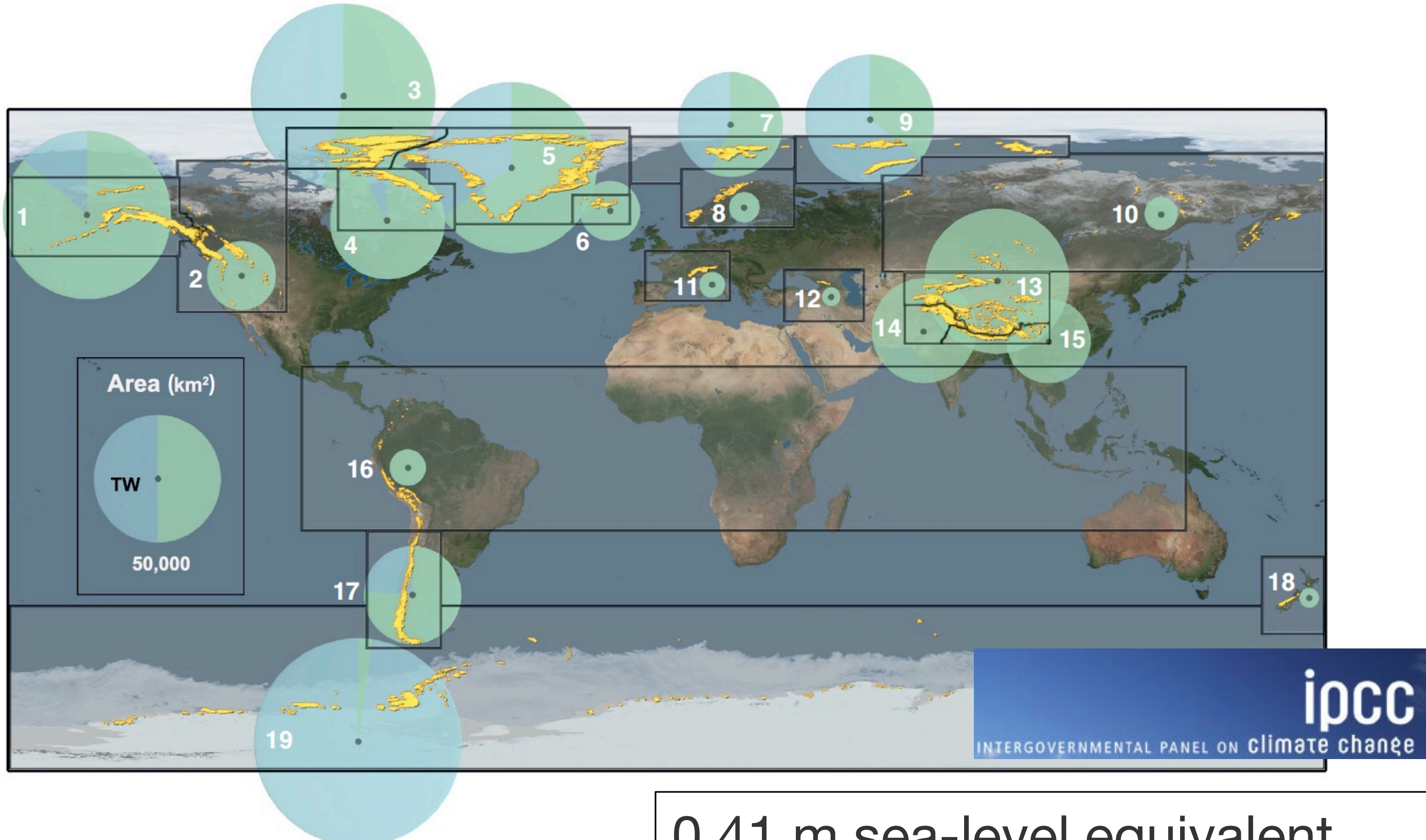
More from Forbes (1842)

A glacier, in the customary meaning of the term, is a mass of ice, which, descending below the usual snow line, prolongs its course down the cavity of one of those vast gorges which furrow the sides of most mountain ranges. It is better represented by a frozen torrent than by a frozen ocean. Any one placed so as to see a glacier in connexion with the range from which it has its origin, at once infers that it is, in some sense or other, the outlet of the vast snow fields which occupy the higher regions. It is impossible to doubt that it results from, and is renewed by the eternal ice-springs of those riverless wilds. None who has ever seen or even clearly conceived a lava-stream, can fail to find in it the nearest analogue of a glacier. Stiff and rigid as it appears, no one can doubt that it either flows, or once has flowed. Were the glacier like the flood of molten stone, the result of one great eruptive action, then its existence beneath the limits of the general snow line would be inexplicable. It melts—it must melt; it lies on warm ground yielding crops perhaps within a hundred

yards of its lower extremity; the sun beats perpetually upon its icy pinnacles, which, though they reflect much, must retain some of the incident heat; and we see, accordingly, in a summer's day the glazier oozing out its substance from every pore—above, beneath, within. And yet, with all this the glacier wastes not; always consuming, it is never destroyed. Evident therefore it must be, upon this ground alone, that a glacier glides imperceptibly down its valley, and this independent of all direct measurements of its motion. These, as we shall presently show, fully corroborate the inference.

The glacier therefore moves progressively, or, if the reader pleases—it *flows*.

Global distribution of glaciers



0.41 m sea-level equivalent
IPCC AR5 (Vaughan et al, 2013)