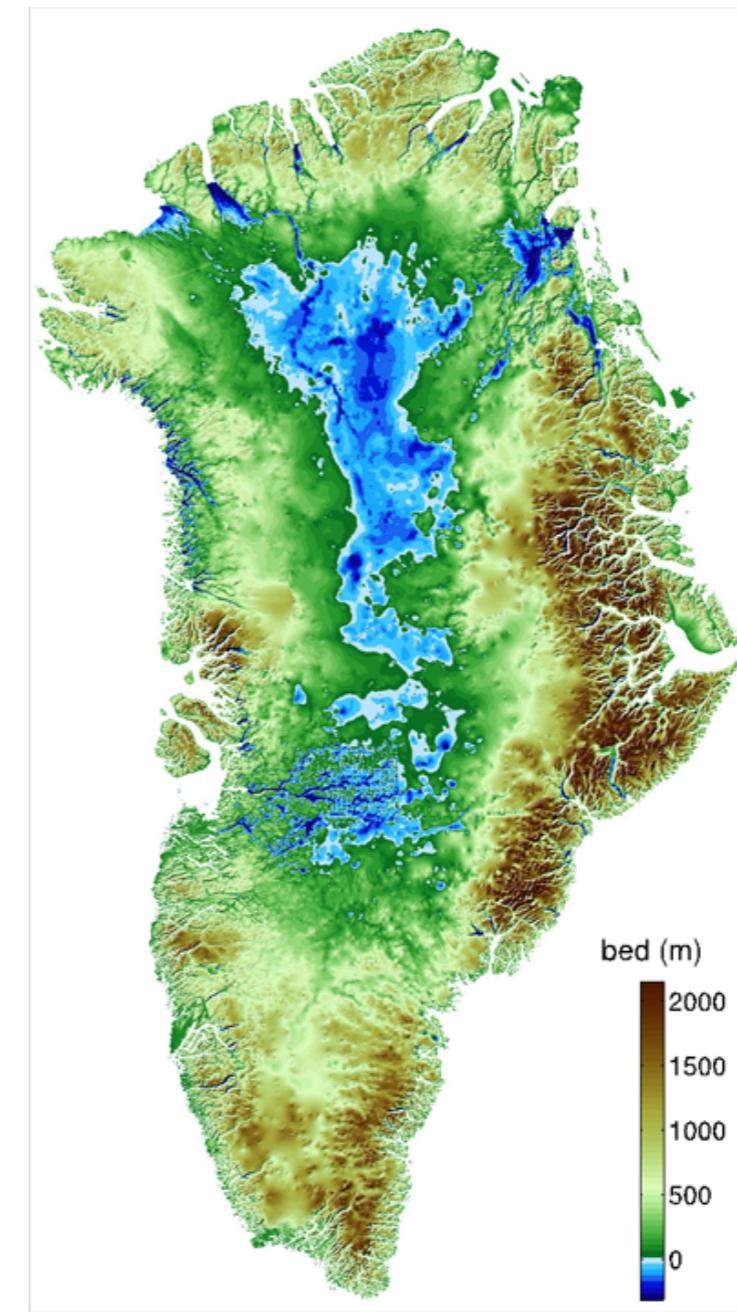
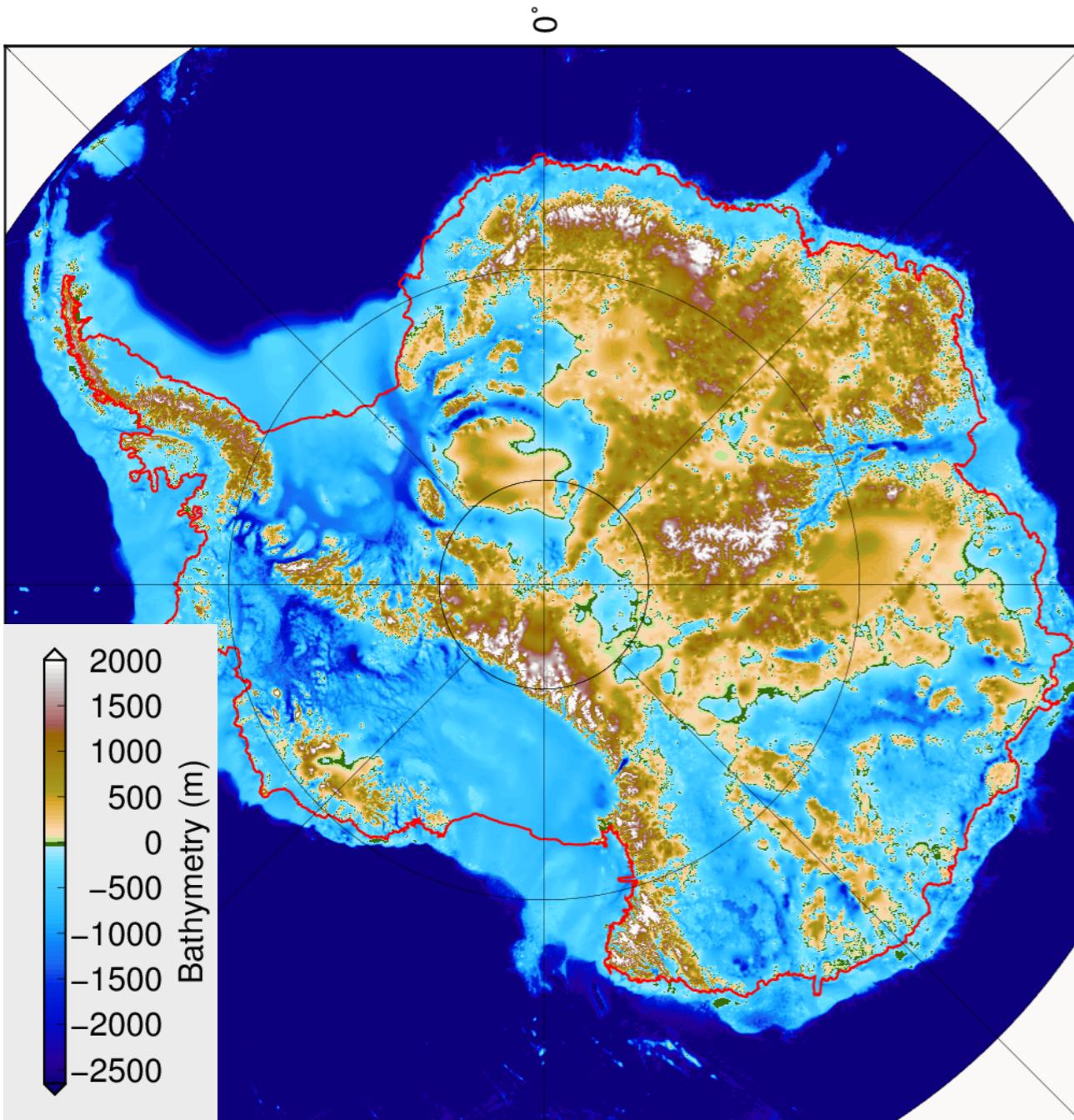


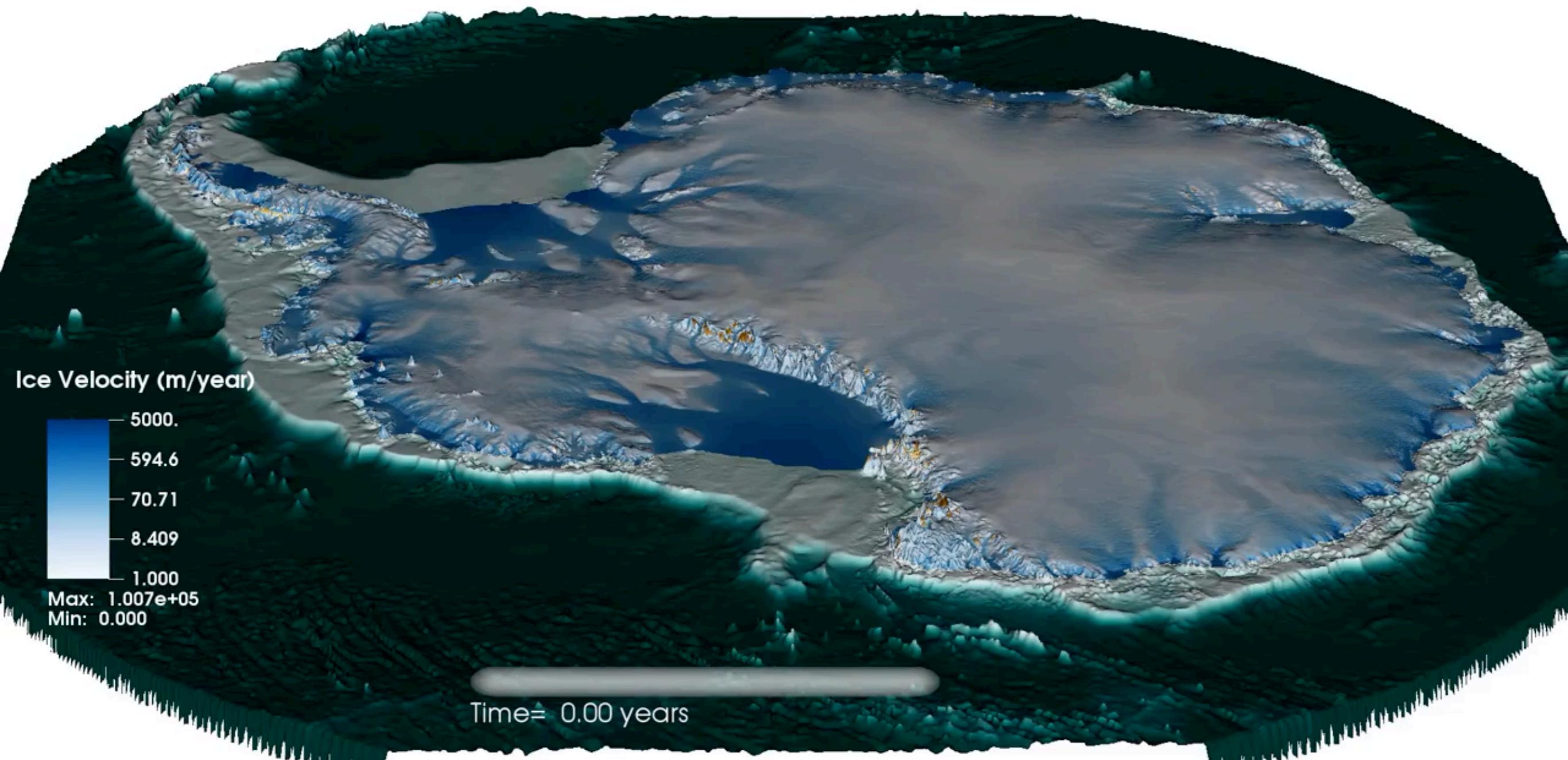
Marine Ice Sheets

What is a marine ice sheet?



An ice sheet (or part of one) where the ice bottom is below sea level

What is a marine ice sheet?



Martin et al. 2019

Marine ice sheets are special because the ocean will remain in contact with the ice even if part of the ice sheet retreats

Why do we care about marine ice sheets?

John Mercer, grizzled coffee drinker



Nature Vol. 271 26 January 1978

321

West Antarctic ice sheet and CO₂ greenhouse effect: a threat of disaster

J. H. Mercer

Institute of Polar Studies, The Ohio State University, Columbus, Ohio 43210

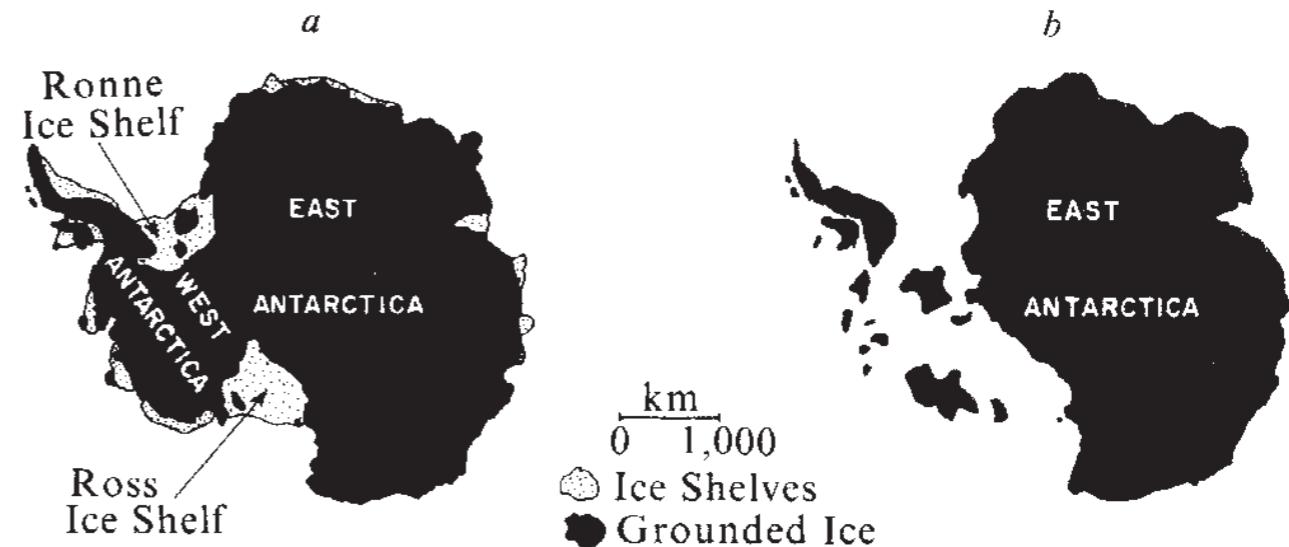


Fig. 3 a, Antarctic ice cover today, and b, after a 5–10 °C warming.

The continued contact of marine ice sheets with the ocean makes them especially susceptible to melting due to changes in climate

Why do we care about marine ice sheets?

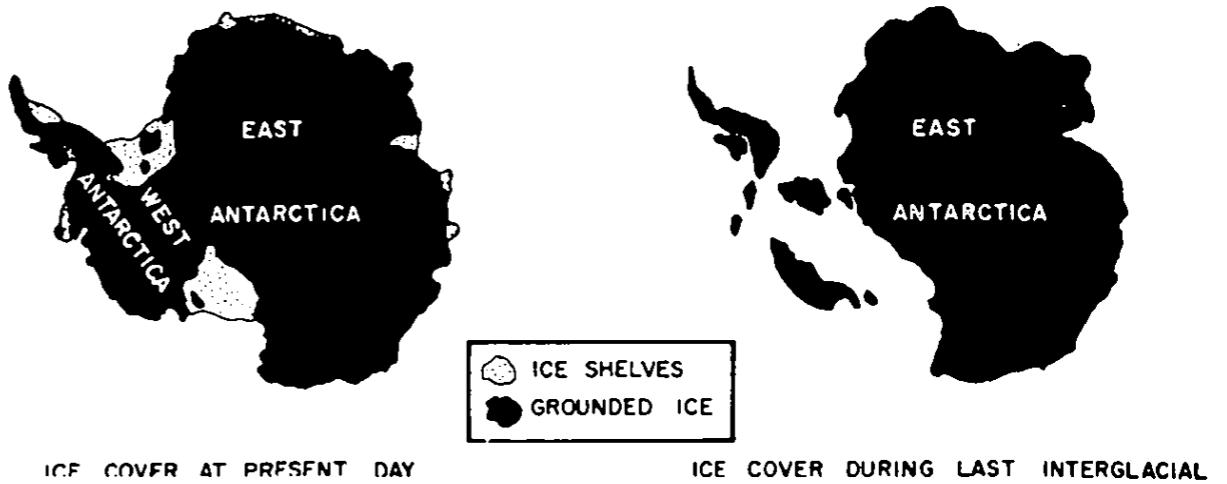
John Mercer, grizzled coffee drinker



ANTARCTIC ICE AND SANGAMON SEA LEVEL¹

John H. MERCER
Institute of Polar Studies,
Ohio State University, USA

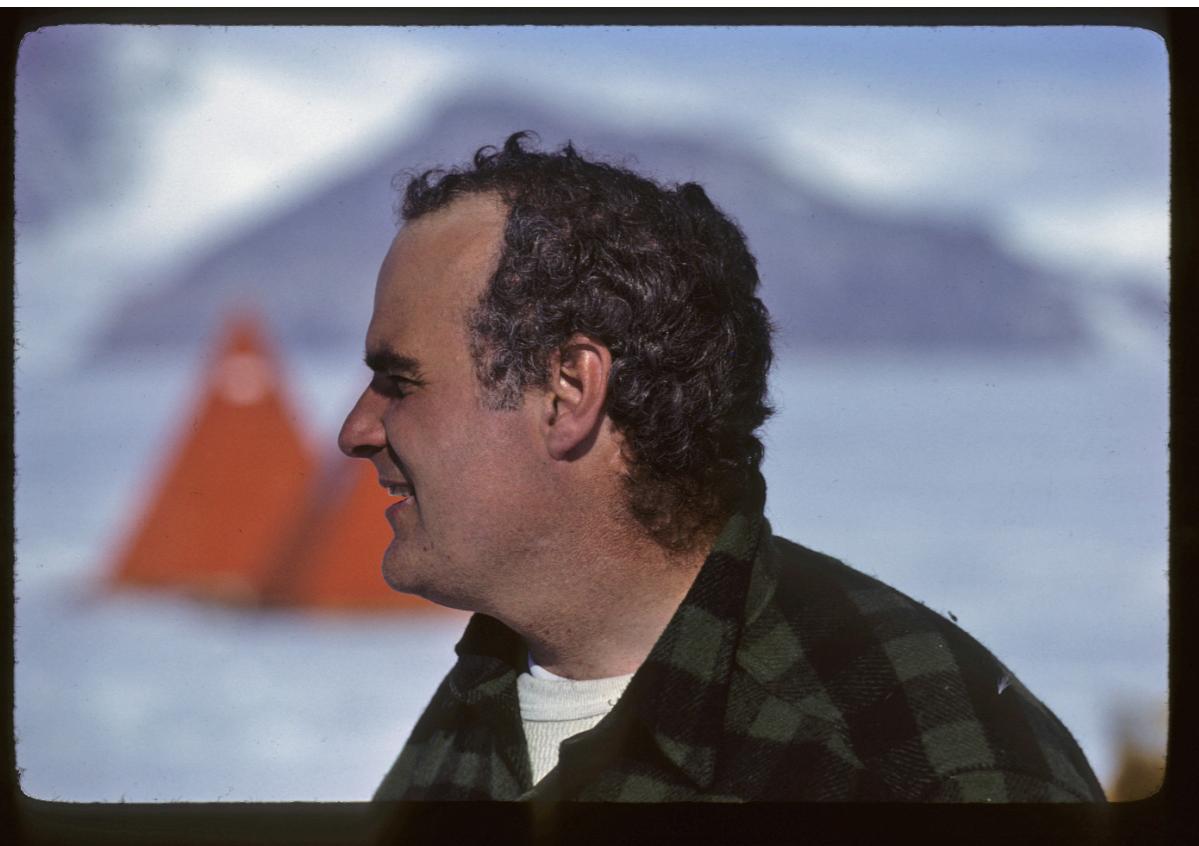
(1968)



The continued contact of marine ice sheets with the ocean makes them especially susceptible to melting due to changes in climate

Why do we care about marine ice sheets?

Terry Hughes



VOL. 78, NO. 33

JOURNAL OF GEOPHYSICAL RESEARCH

NOVEMBER 20, 1973

Is the West Antarctic Ice Sheet Disintegrating?

T. HUGHES

Institute of Polar Studies, The Ohio State University, Columbus, Ohio 43210

SIR,

The weak underbelly of the West Antarctic ice sheet

Possible collapse of the West Antarctic ice sheet by surges of Thwaites and Pine Island Glaciers into the Pine Island Bay polynya of the Amundsen Sea was a subject addressed in papers by Lingle and Clark (1979) and Thomas (1979), and in abstracts by Denton and others (1979) and Hughes (1979), that were published in Vol. 24, No. 90 of the *Journal of Glaciology*. This concept was first developed in 1975 by George H. Denton and me as part of our CLIMAP responsibilities to reconstruct the maximum Antarctic ice sheet and then to disintegrate the marine West Antarctic portion. Lingle and Clark (1979) have

The continued contact of marine ice sheets with the ocean makes them especially susceptible to melting due to changes in climate

Why do we care about marine ice sheets?

Can't...escape...Hans Weertman



Journal of Glaciology, Vol. 13, No. 67, 1974

STABILITY OF THE JUNCTION OF AN ICE SHEET AND AN ICE SHELF

By J. WEERTMAN

(Departments of Materials Science and Geological Sciences, Northwestern University, Evanston, Illinois 60201, U.S.A. and U.S. Army Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire 03755, U.S.A.)

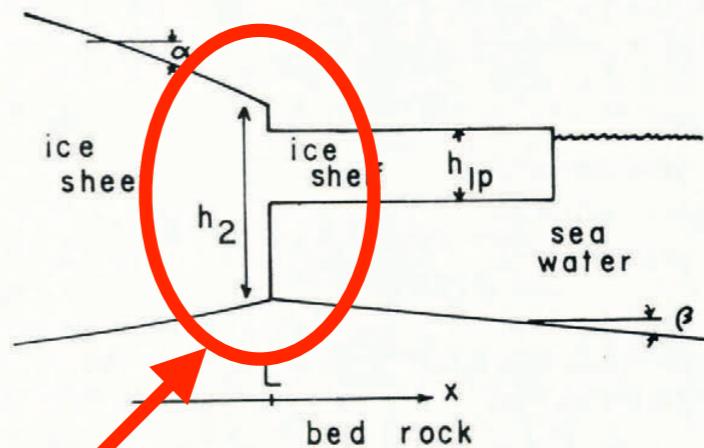


Fig. 2. Junction between ice sheet and ice shelf. No restriction on thickness of ice sheet at $x=L$. Perfect plasticity approximation.

What's this thing?

The New York Times

Antarctic Dispatches  Part 1 2 3



MILES OF ICE COLLAPSING
INTO THE SEA

May 18, 2017

Q Search | US edition ▾
**The
Guardian**

Glacial melting in Antarctica may
become irreversible

WP Washington Post

Unprecedented data confirms that Antarctica's most
dangerous glacier is melting from below

Scientists call this "marine ice sheet instability." ... part of the cavity, yet it is the crucial part for ice dynamics, glacier stability, fast retreat."

Jan 30, 2020

USA
TODAY

Antarctic glaciers melting 'passed point of no return'

Traci Watson Special for USA TODAY

Published 5:25 p.m. ET May 12, 2014 | Updated 9:14 a.m. ET May 13, 2014

SCIENTIFIC
AMERICAN®

SUSTAINABILITY

Geologists Drill into Antarctica and Find Troubling Signs for Ice Sheets' Future

RollingStone

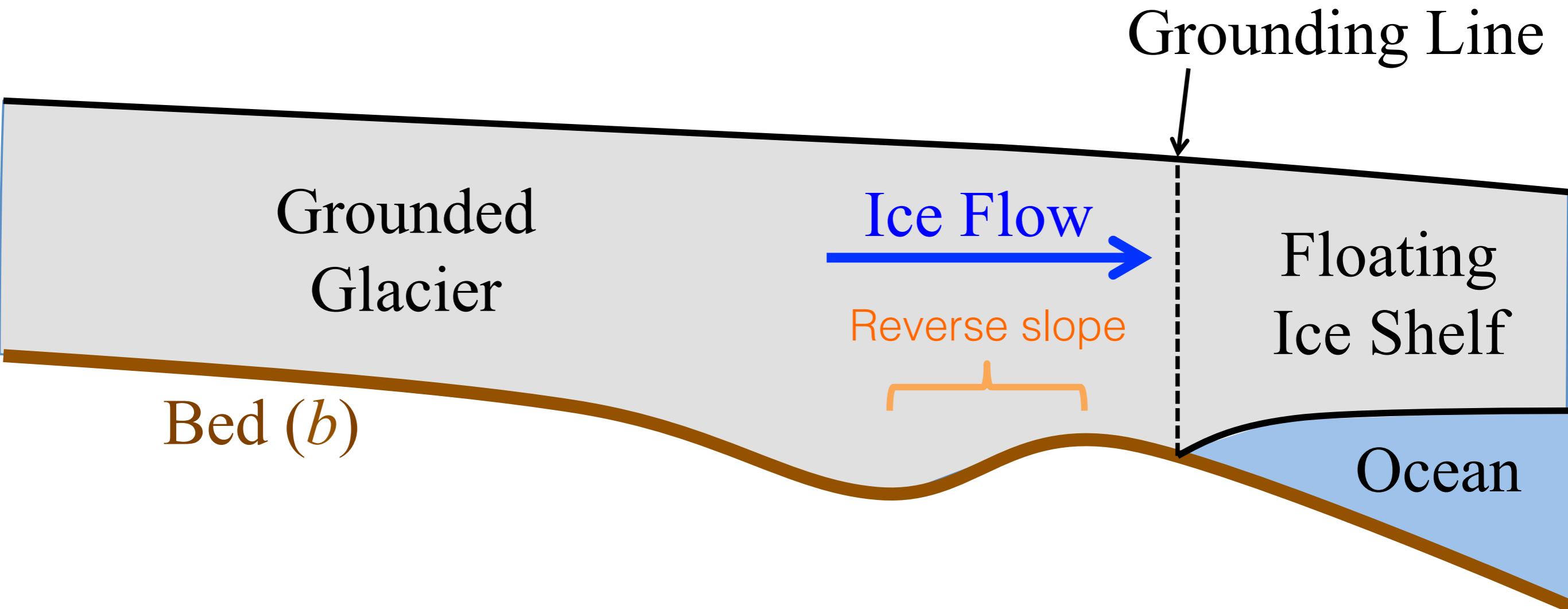
The Doomsday Glacier

In the farthest reaches of Antarctica, a nightmare scenario of crumbling ice – and rapidly rising seas – could spell disaster for a warming planet.

By JEFF GOODELL 

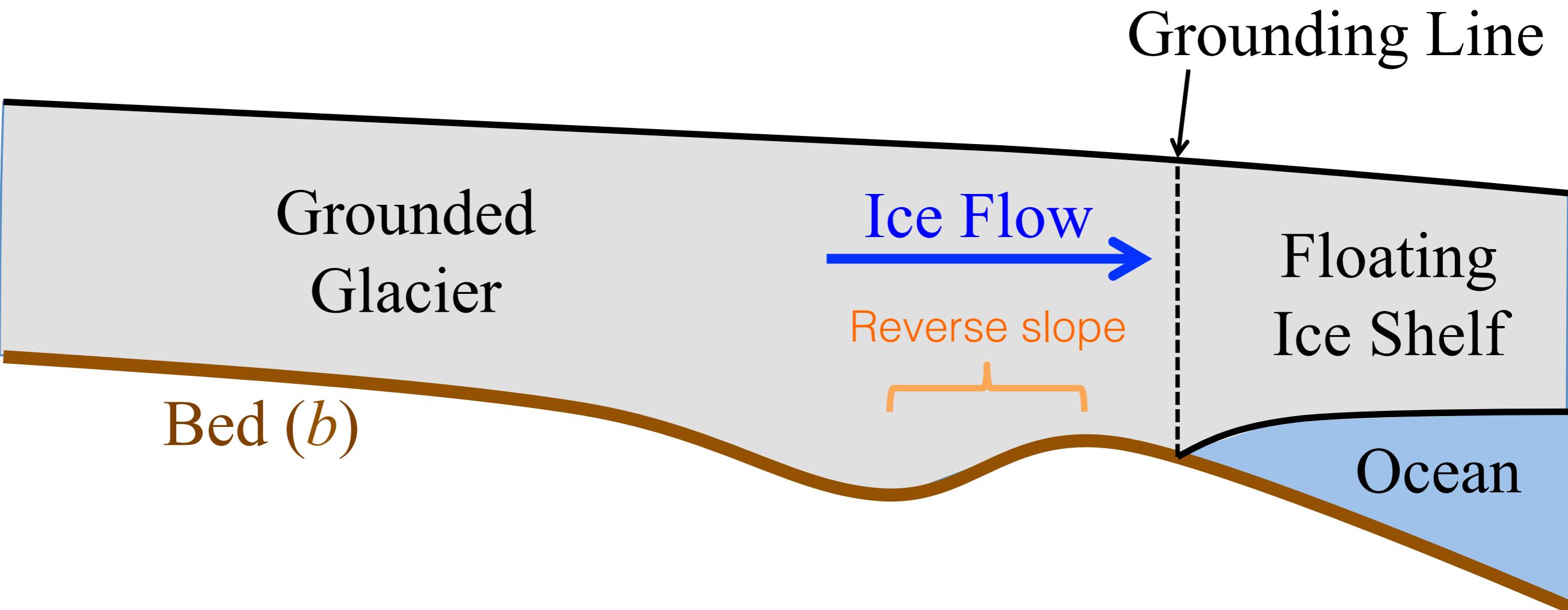


Step 1: What is a grounding line?



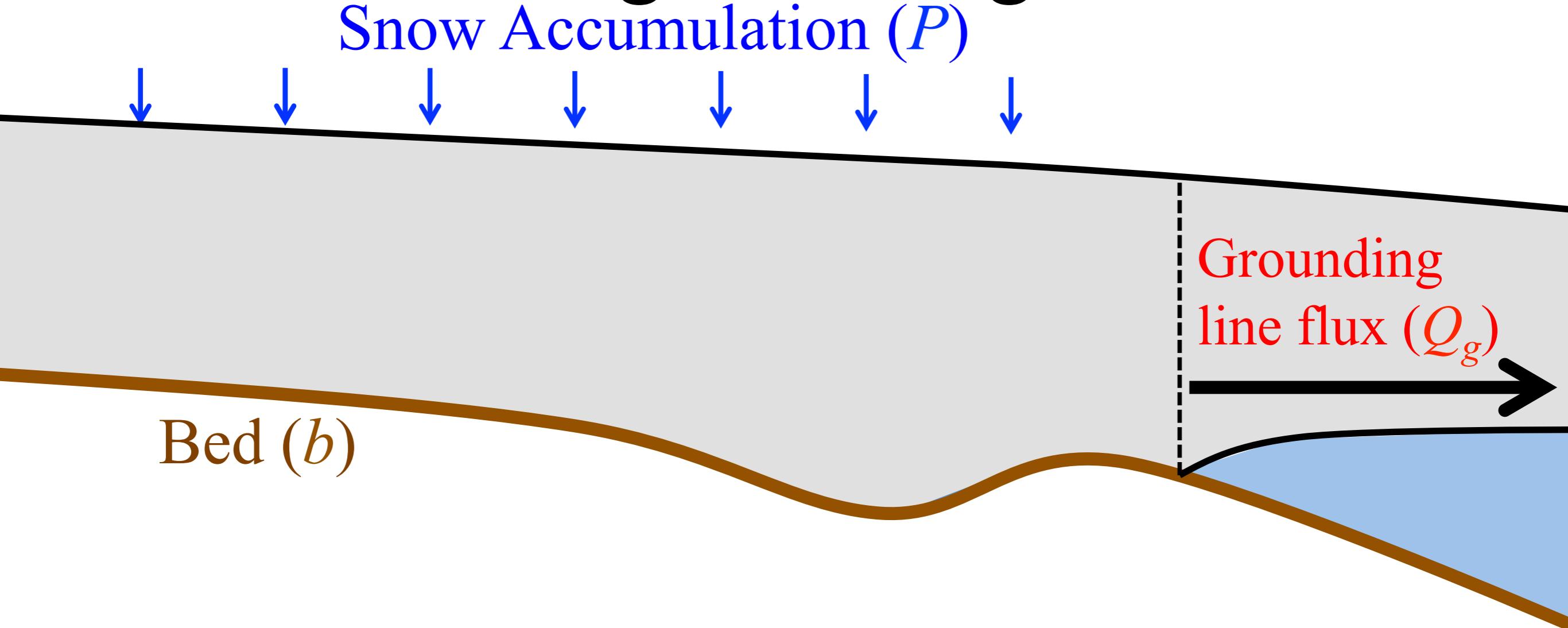
The grounding line is the place where ice is last in contact with the bed (in theory)

Step 1: What is a grounding line?



Once ice goes through the grounding line, it either becomes part of the floating ice shelf or calves as an iceberg, and so it begins to contribute to global sea level (buoyancy is compensated by ocean)

Step 2: How fast does ice flow across grounding line?



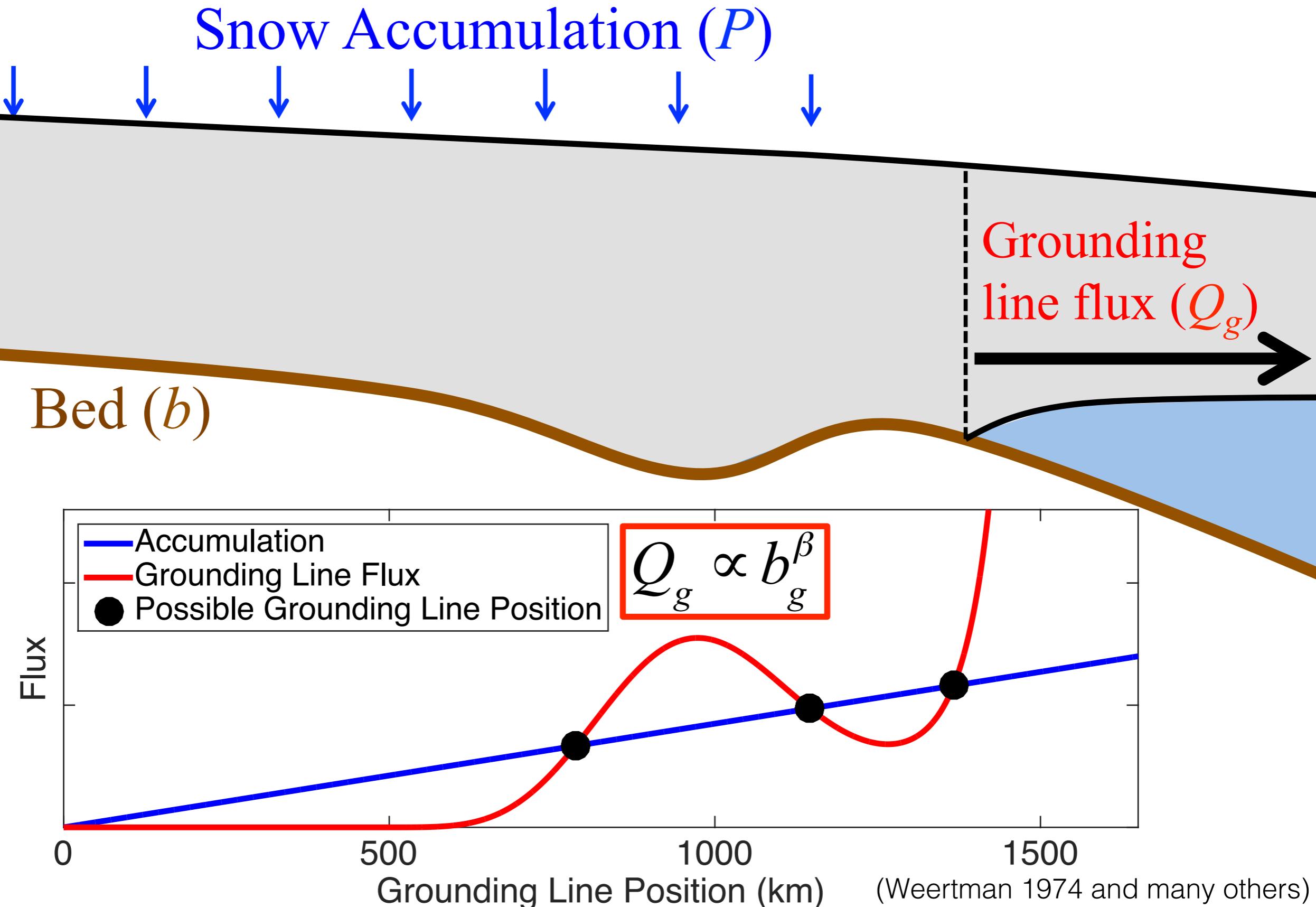
**Ice enters the ice sheet through snow fall...
and leaves by flux through the grounding line.**

So, what determines the ice flux through the grounding line: Q_g ?

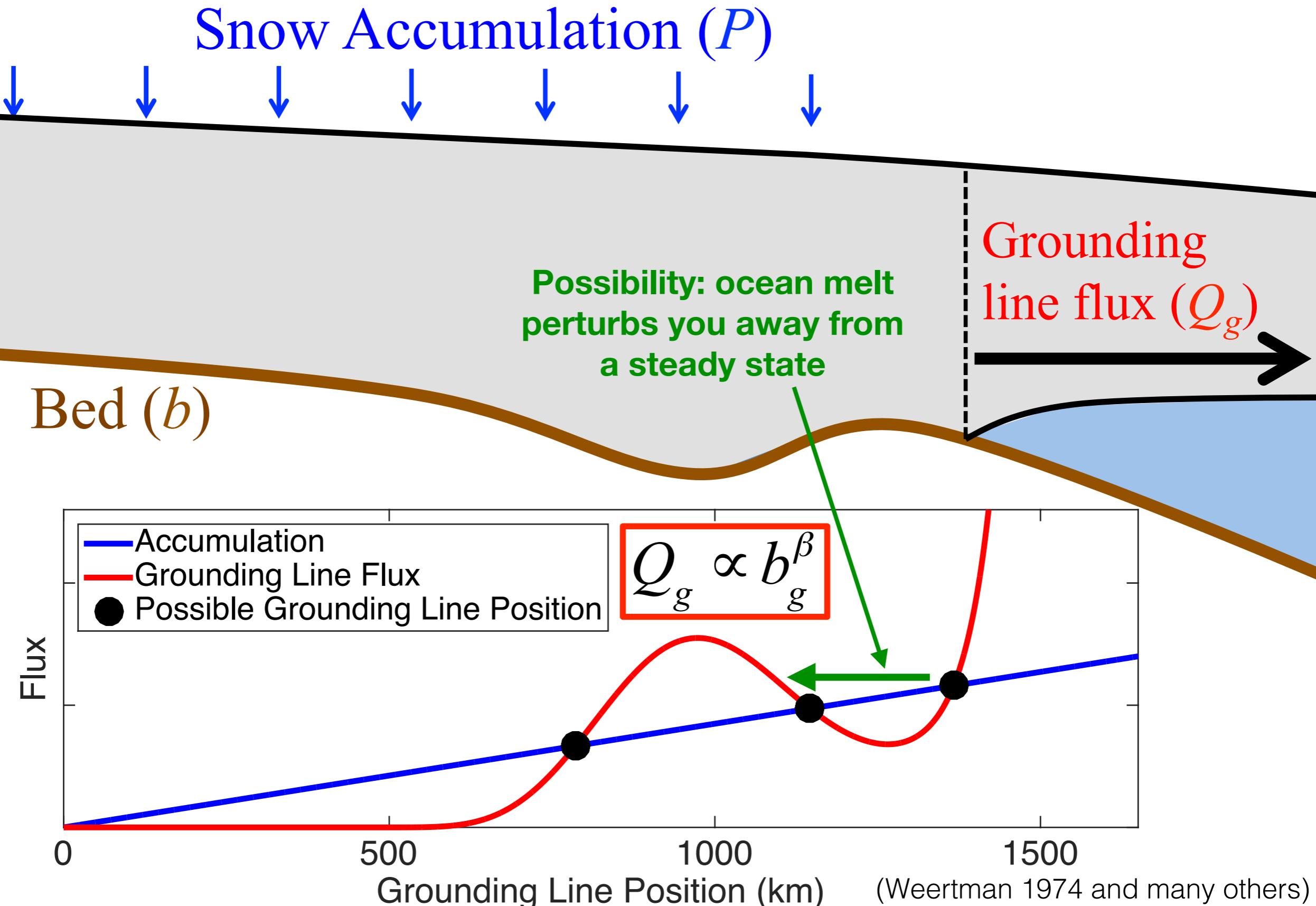
Grounding line flux

- To the board! (Hindmarsh 2012 version of Schoof 2007)

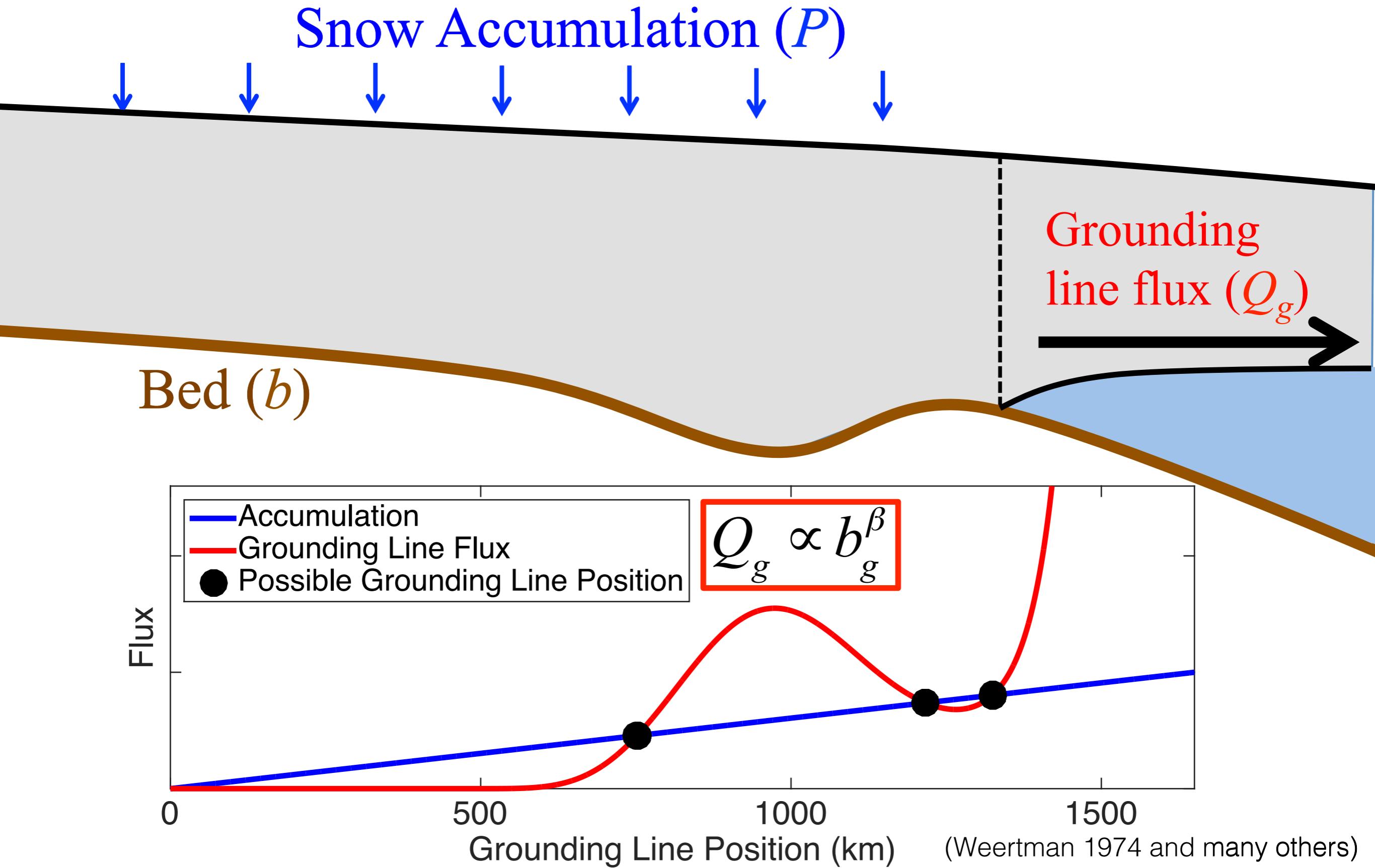
Step 3: Is the grounding line stable?



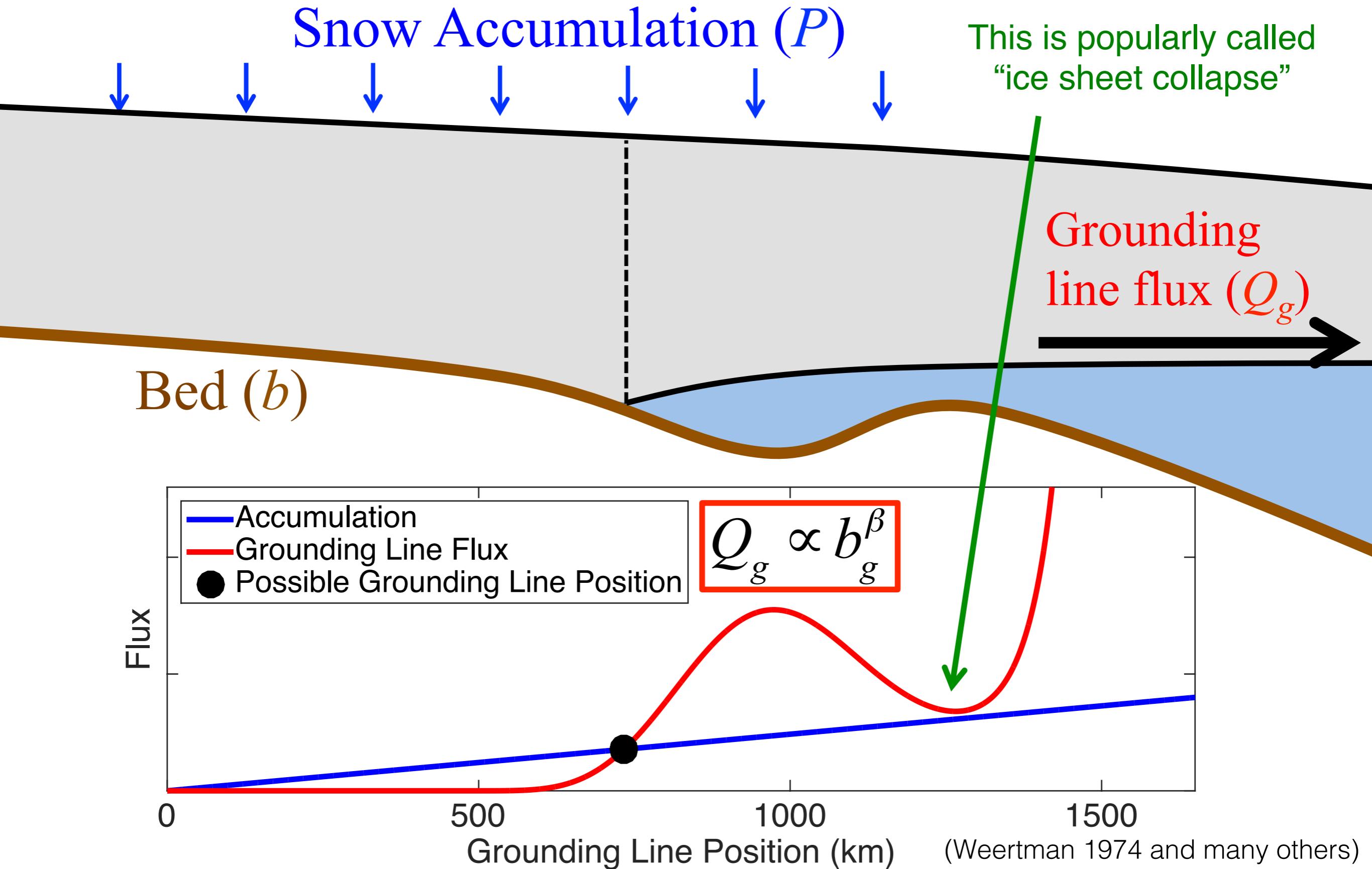
Step 3: Is the grounding line stable?



Step 3: Is the grounding line stable?

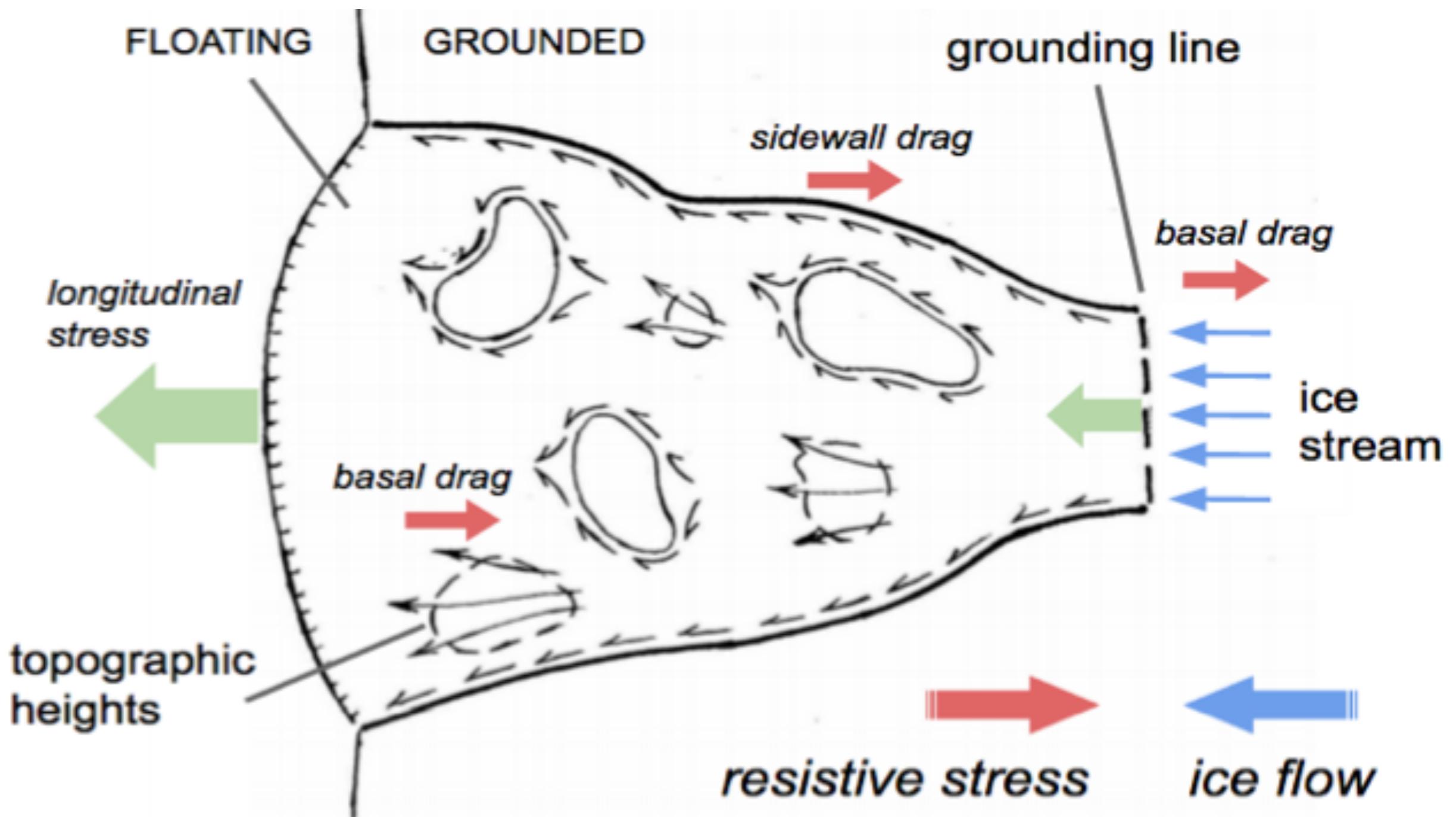


Step 3: Is the grounding line stable?

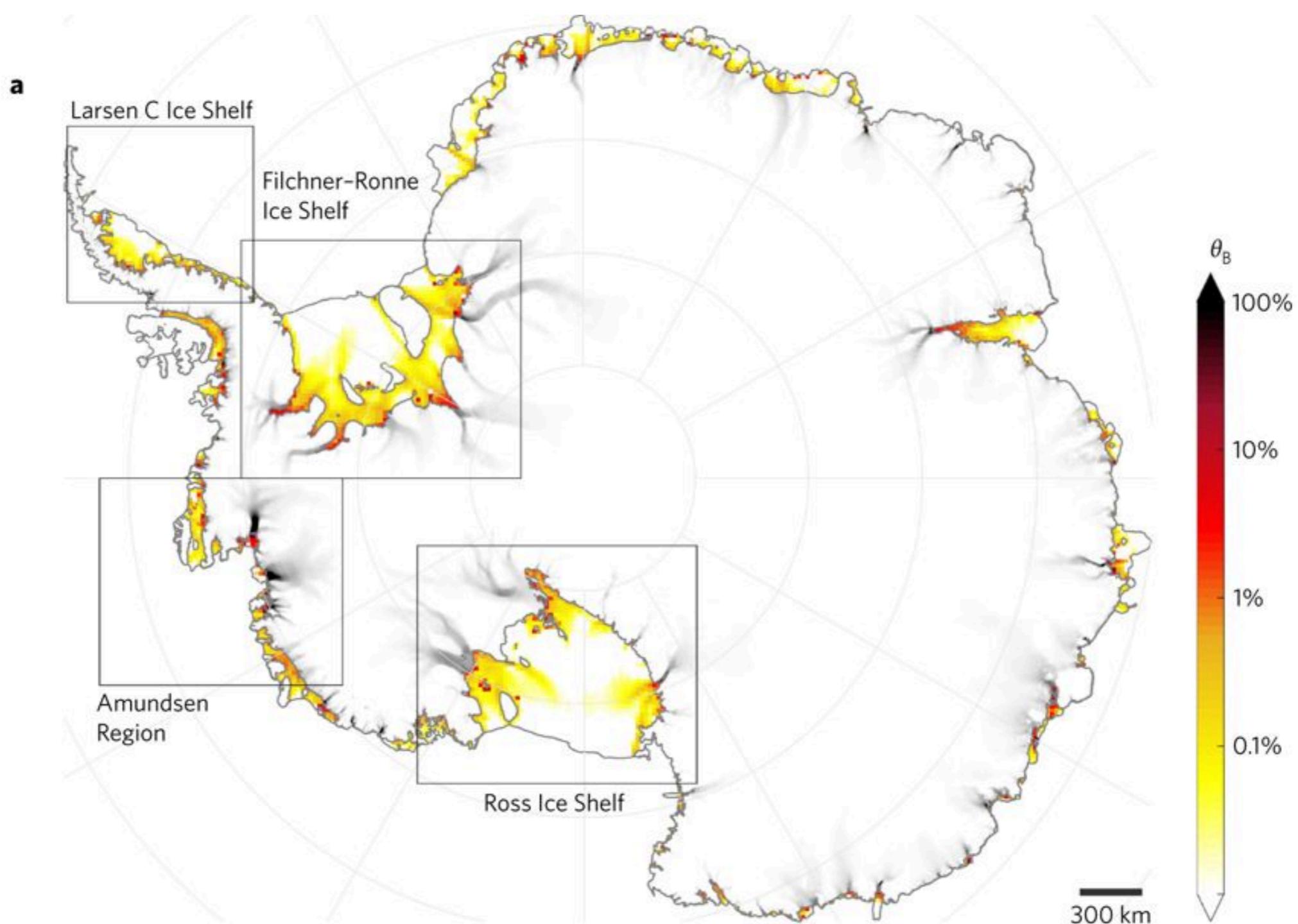


What else plays a role in marine ice sheet stability?

Ice shelf buttressing!



Ice shelf buttressing



Ice shelf buttressing

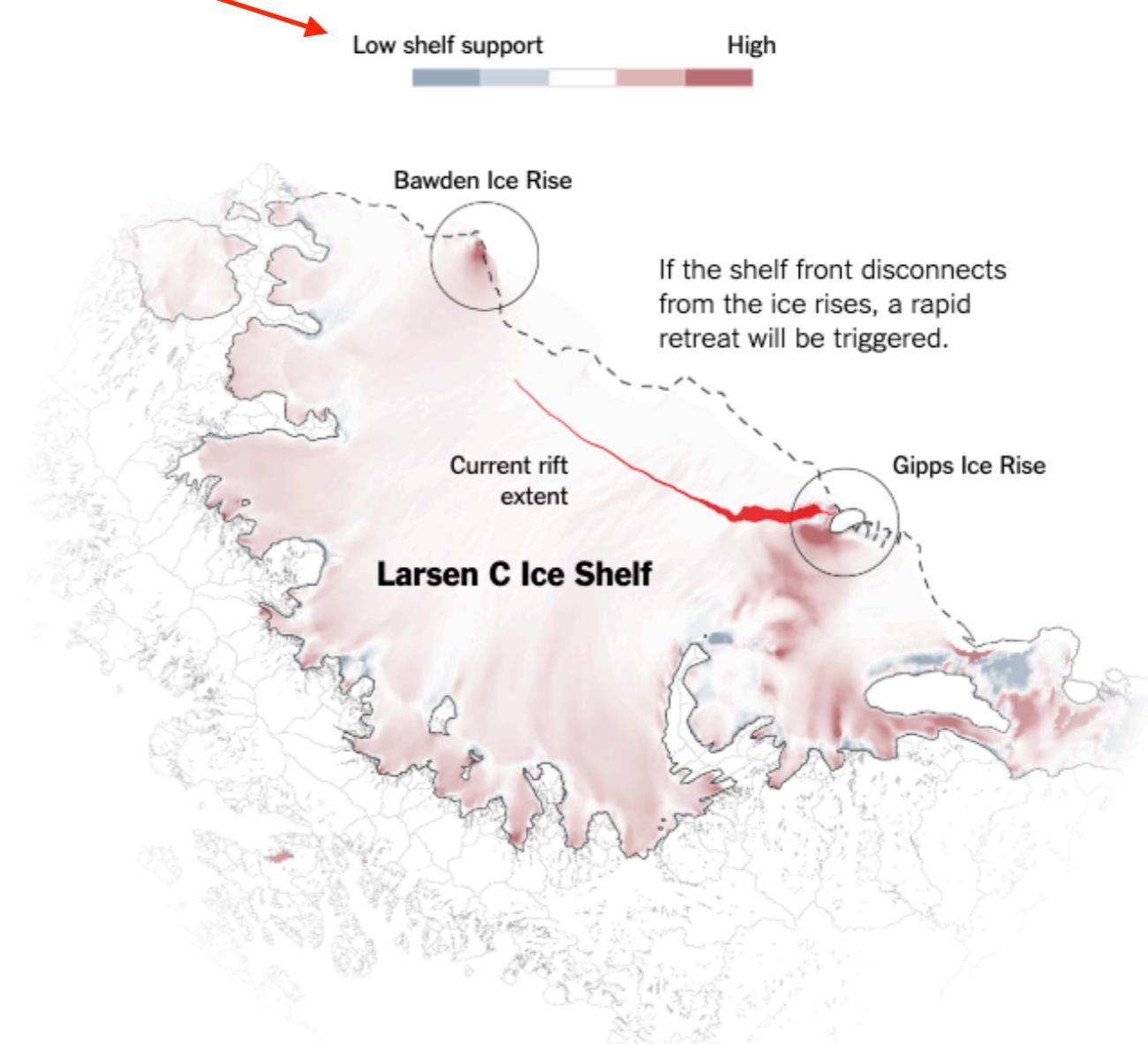
When ice sheet dynamics makes it into the New York Times

The New York Times

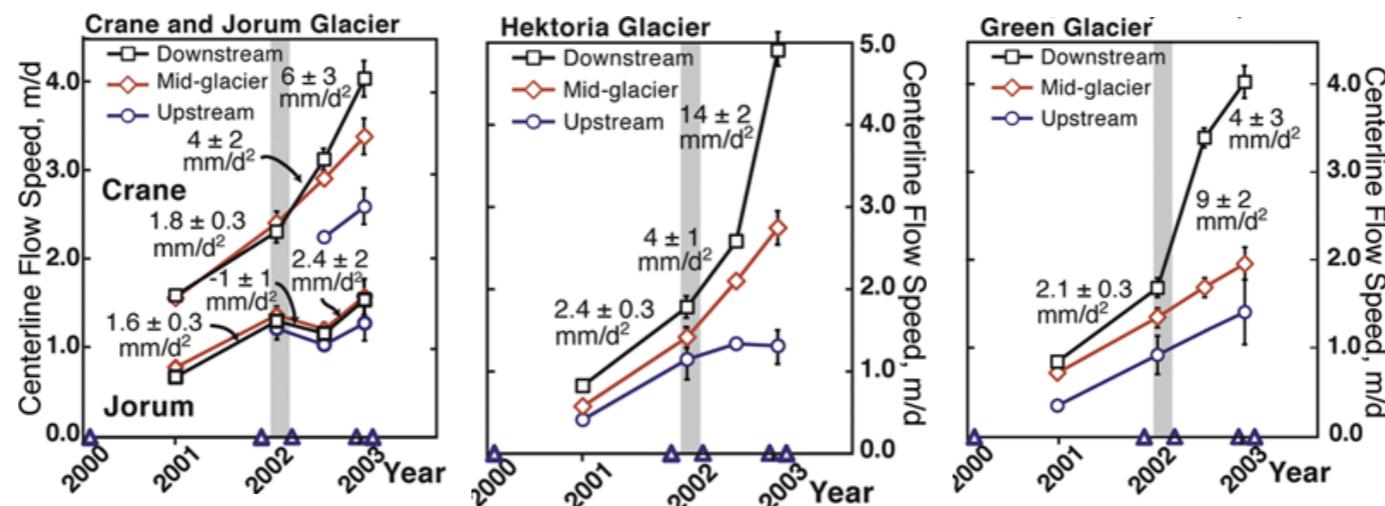
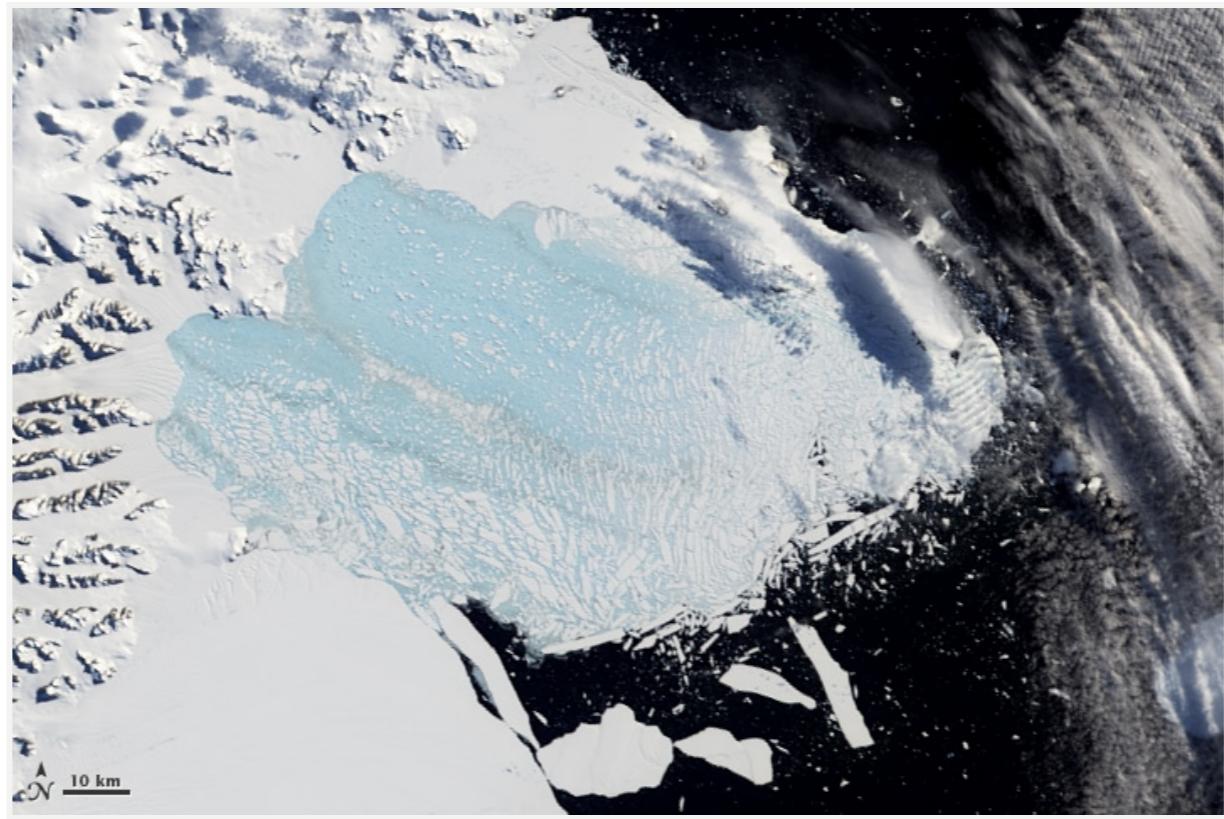
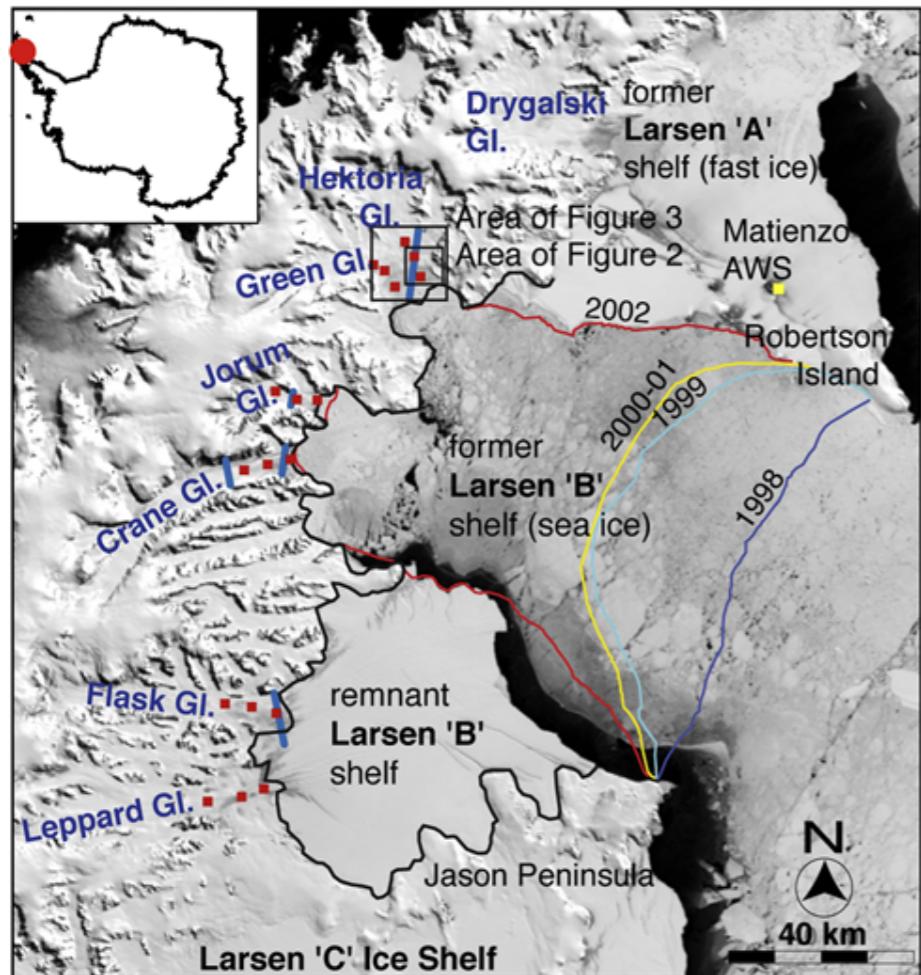
A Crack in an Antarctic Ice Shelf Grew 17 Miles in the Last Two Months

By JUGAL K. PATEL FEB. 7, 2017

A rapidly advancing crack in Antarctica's fourth-largest ice shelf has scientists concerned that it is getting close to a full break. The rift has accelerated this year in an area already vulnerable to warming temperatures. Since December, the crack has grown by the length of about five football fields each day. [RELATED ARTICLE](#)



Ice shelf collapse and ice speedup

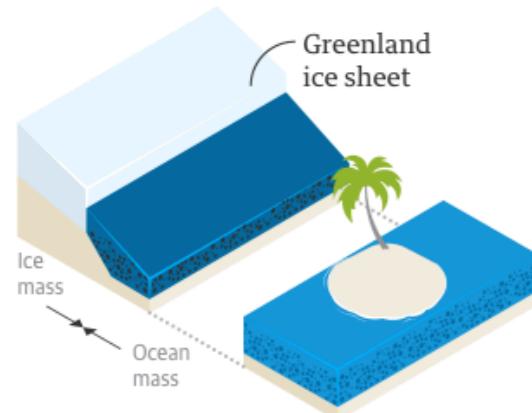


Scambos et al. 2004

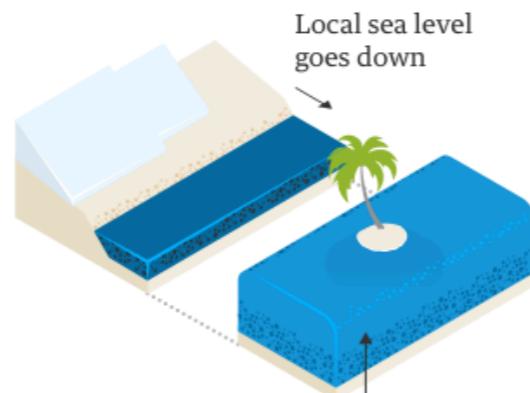
Gravity and the solid earth

Gravity

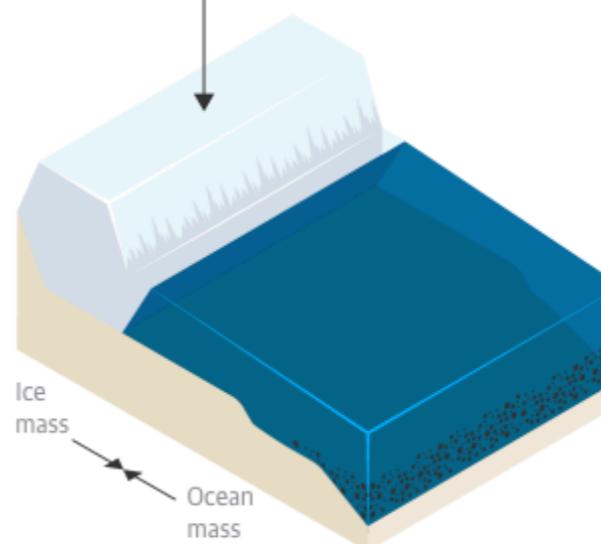
Ice sheets attract water because of gravity



As their mass decreases, they have less gravitational pull. This makes water flow away

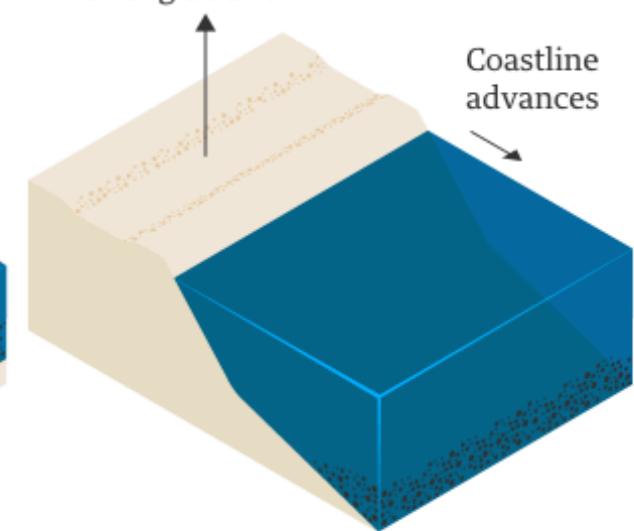


Ice sheets pressed down on the Earth's crust

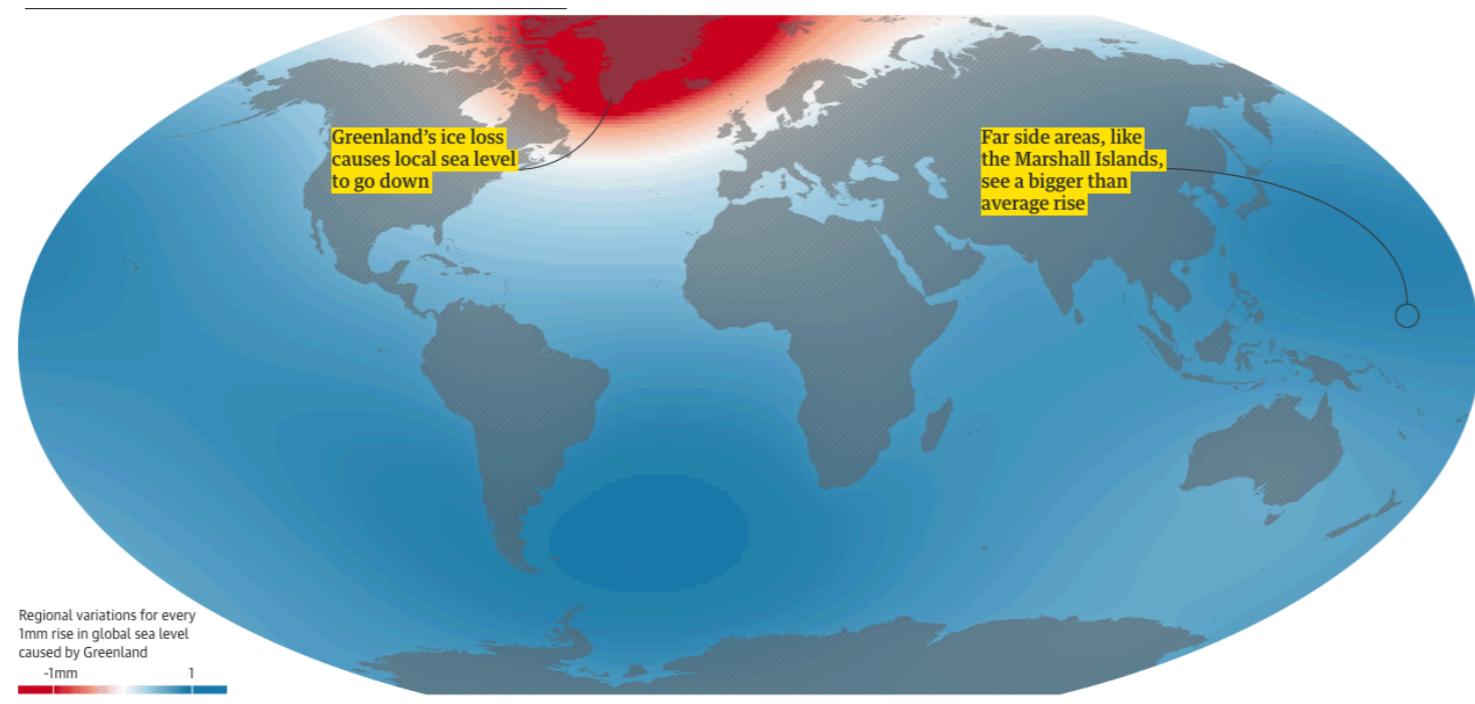


Glacial rebound

The Earth's surface slowly rebounds after glaciation

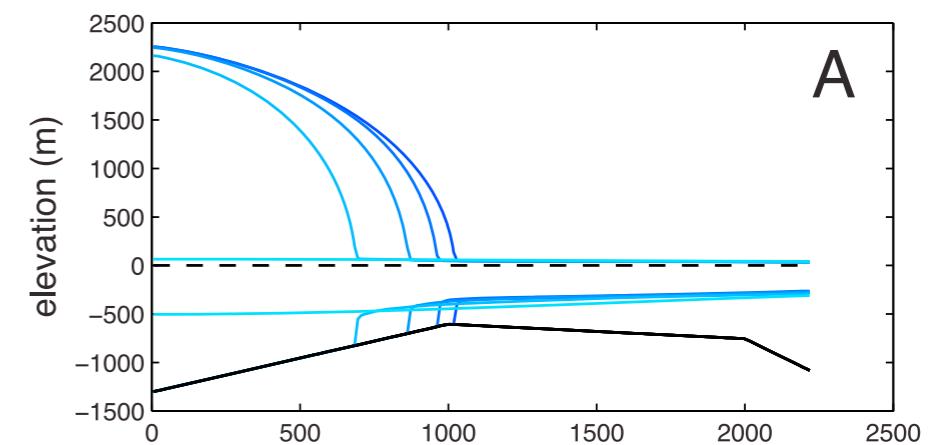


Guardian graphic. Source: Dr Pippa L. Whitehouse

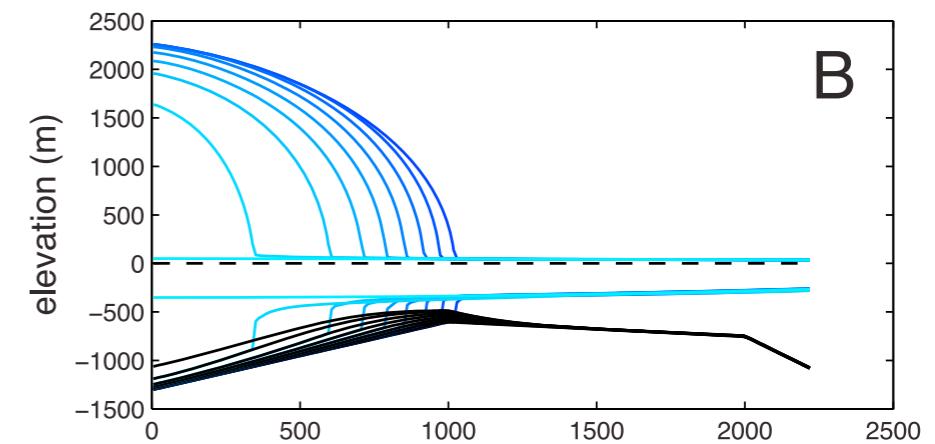


Gravity and the solid earth

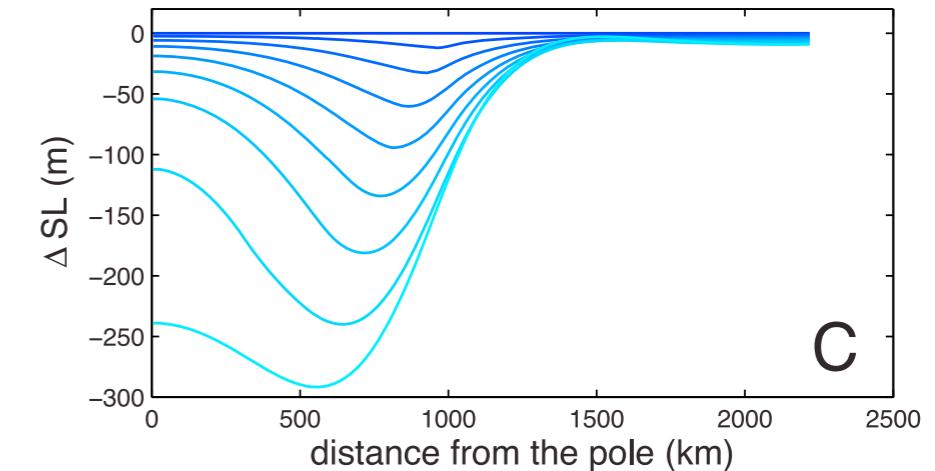
No change in gravity or Earth surface



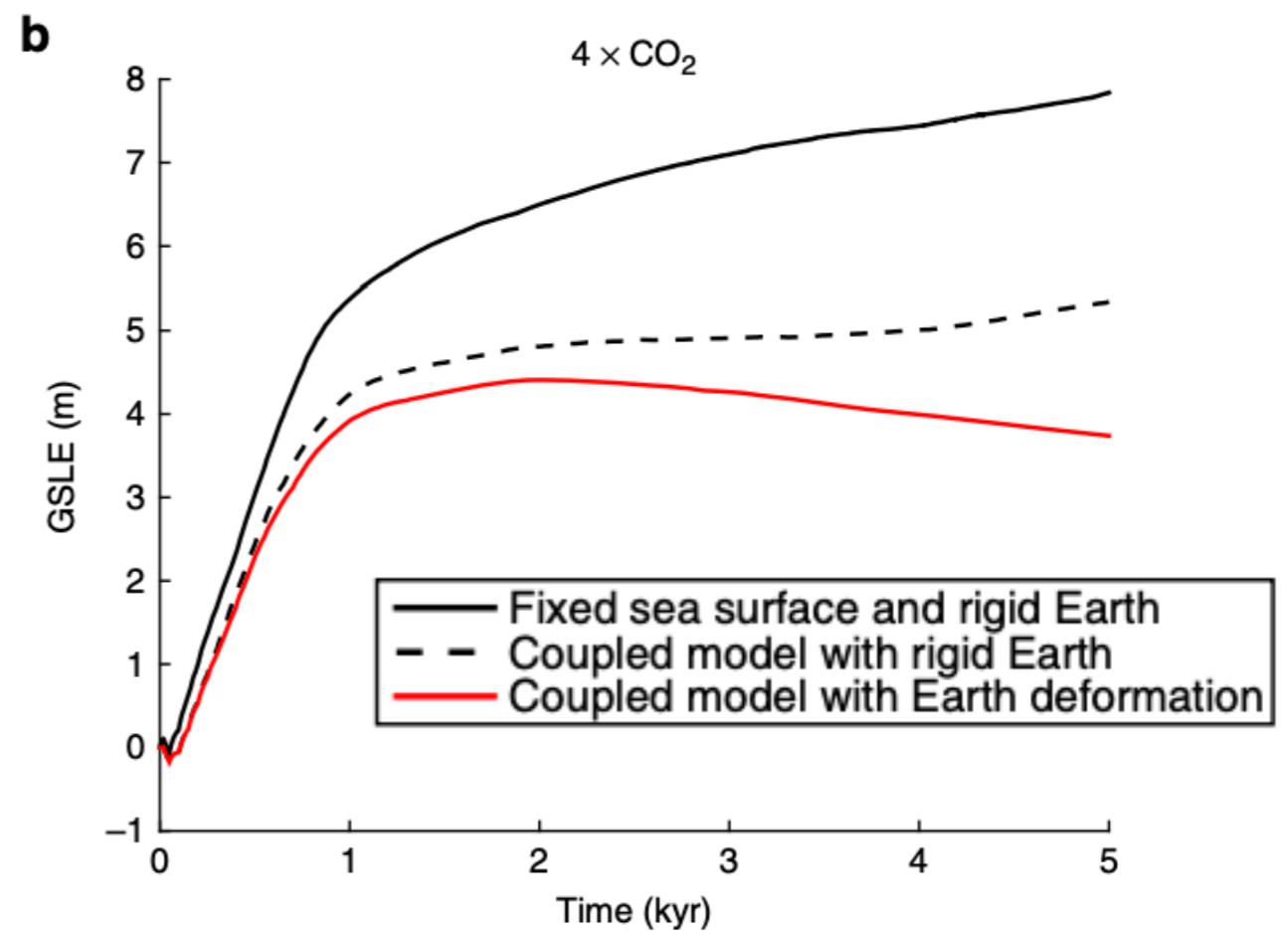
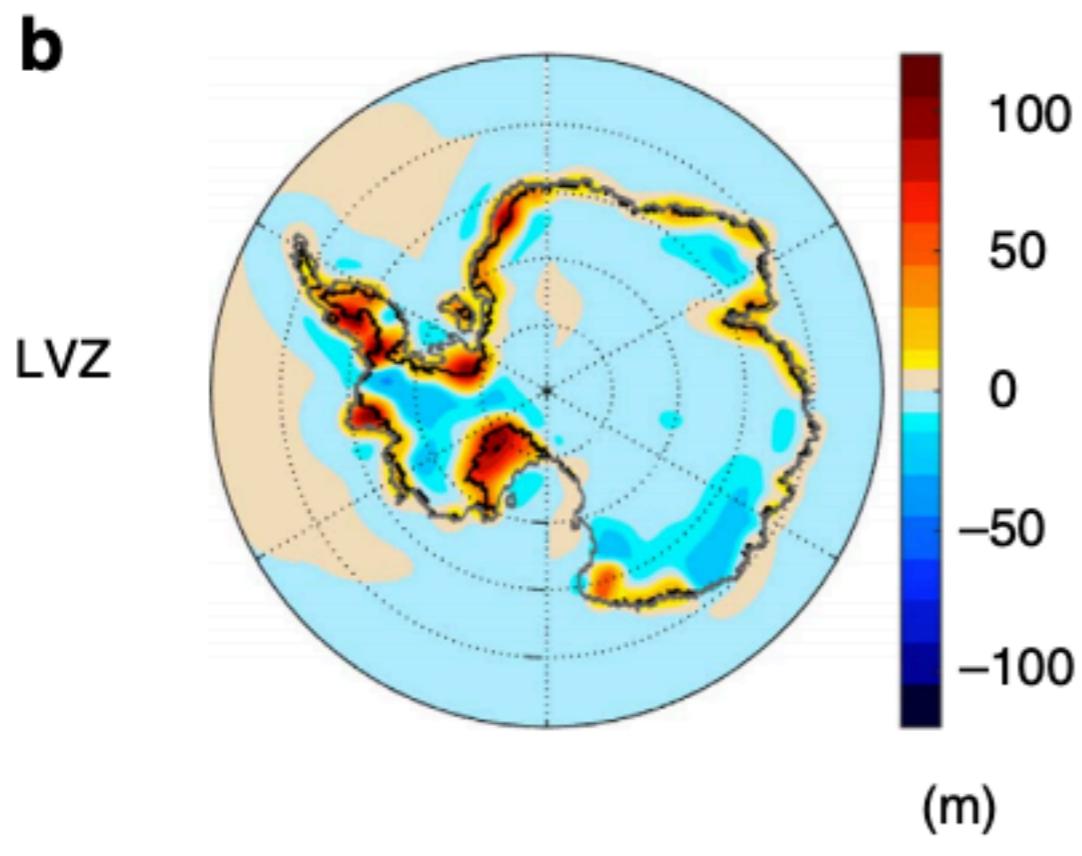
Response in gravity and Earth surface



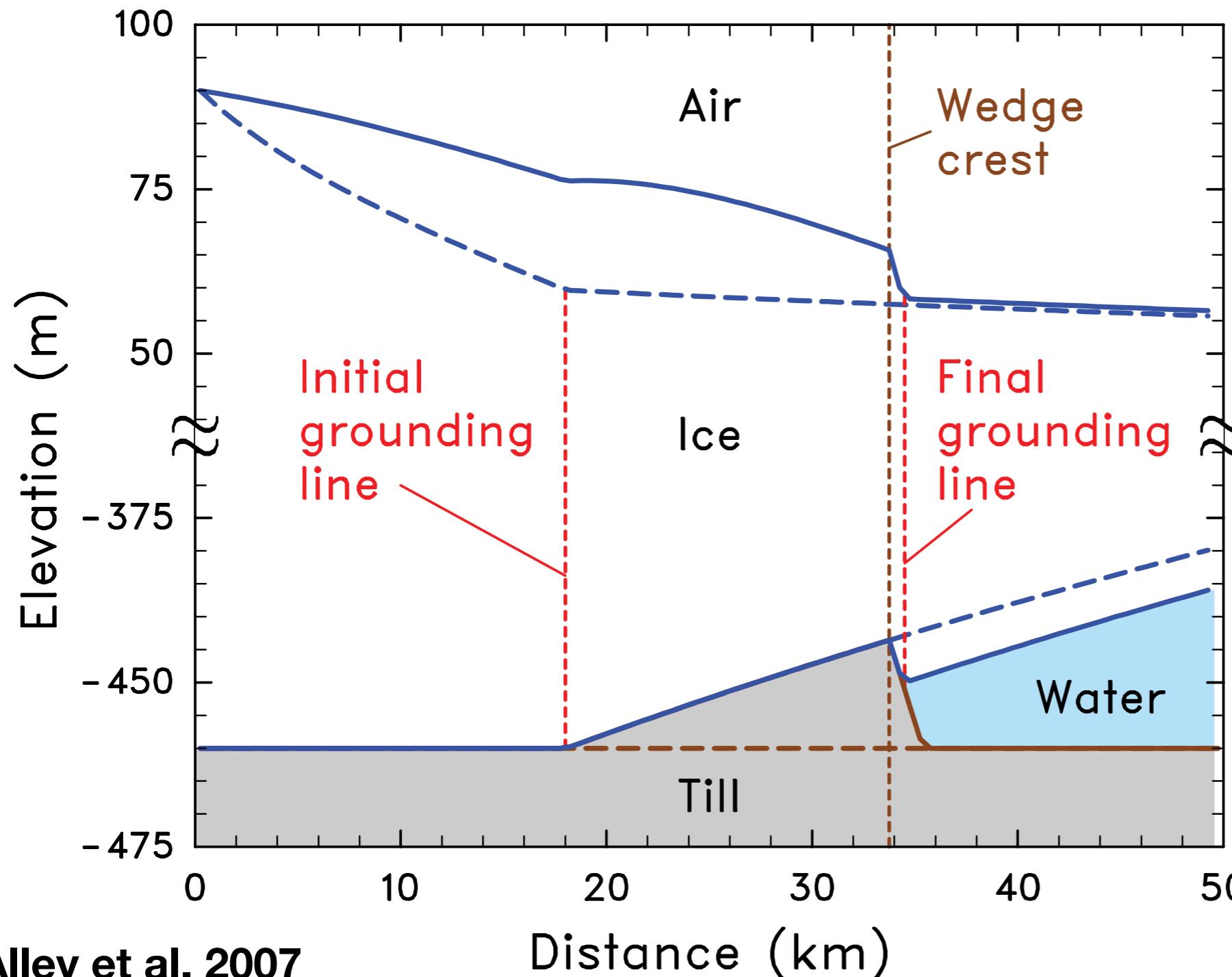
Change in relative sea level



Gravity and the solid earth

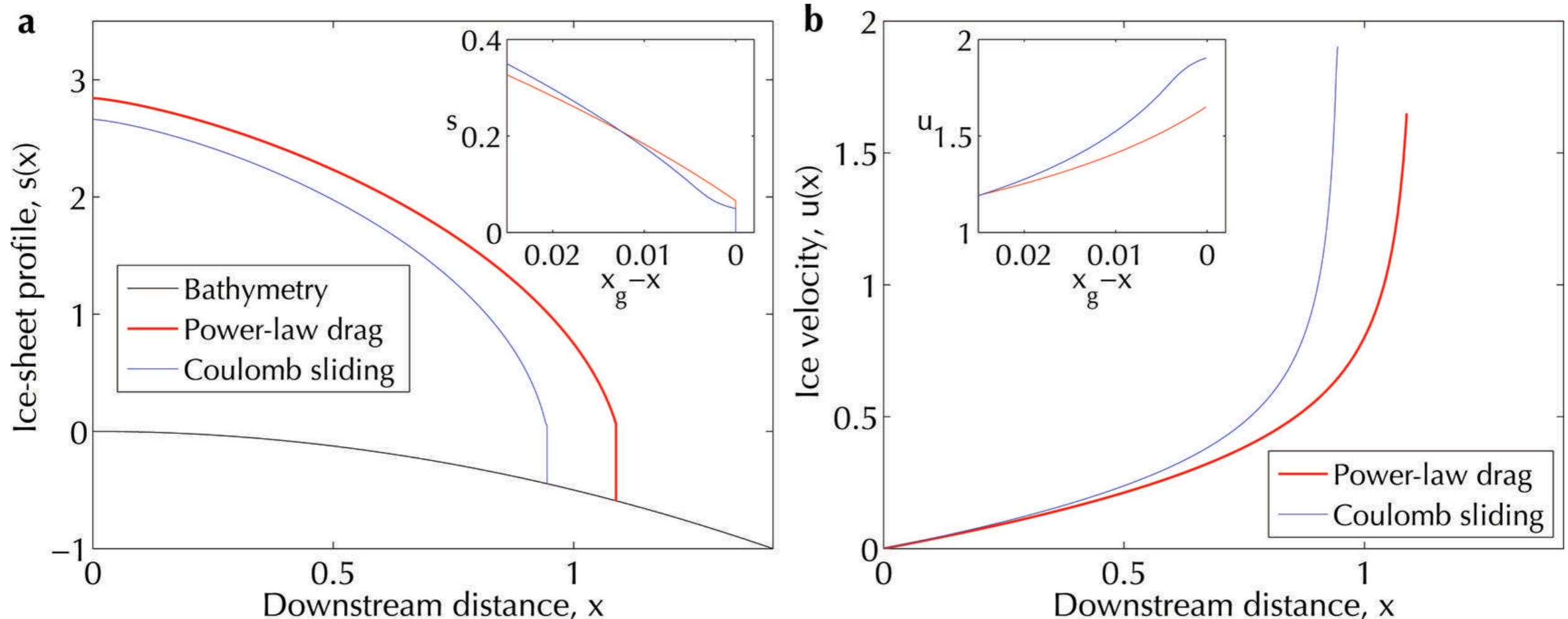


What else plays a role in marine ice sheet stability?



Sediment deposition in front of grounding line can possibly cause grounding line advance (long time scales)

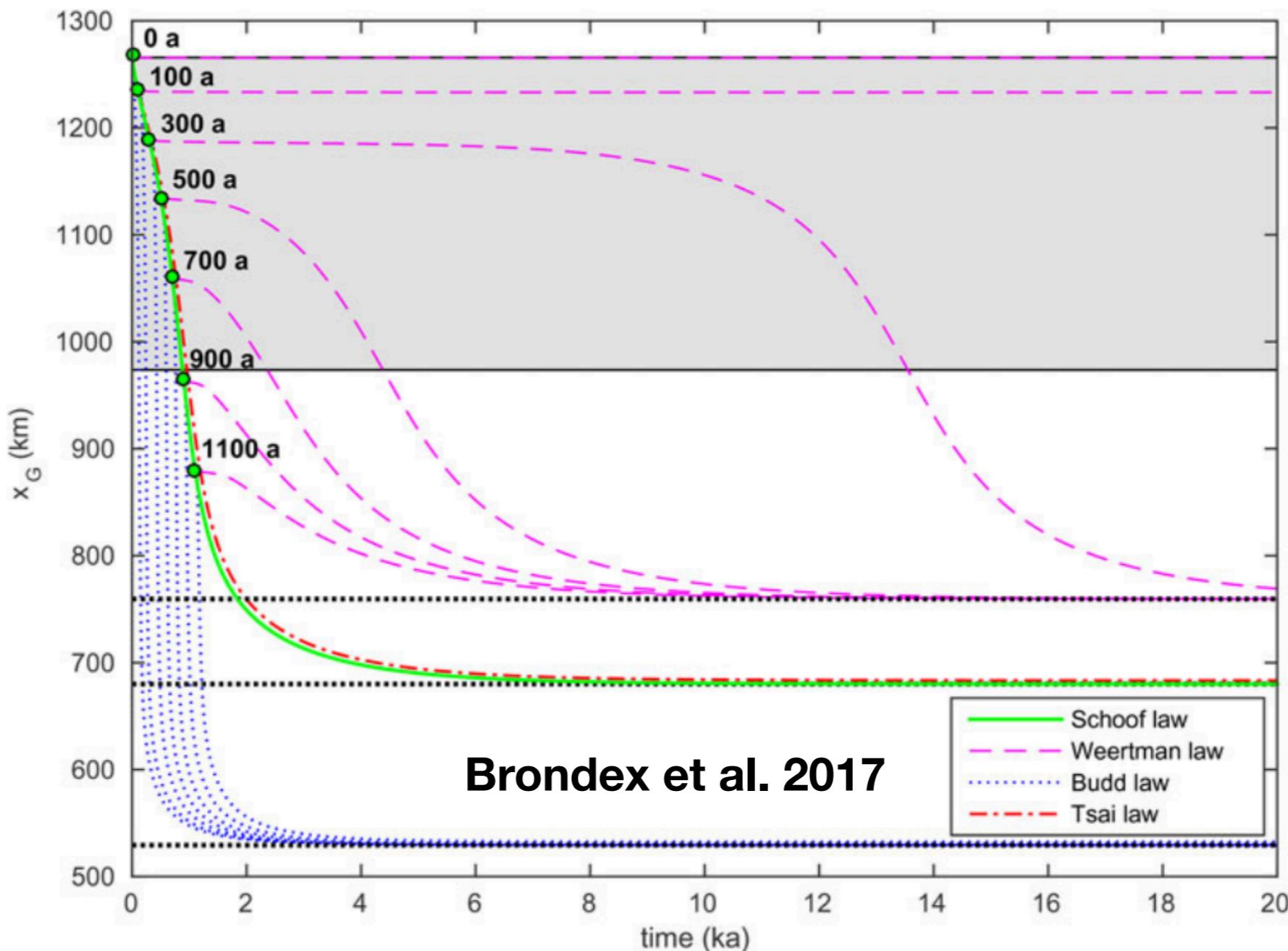
What else plays a role in marine ice sheet stability?



Tsai et al. 2015

Plastic sliding near the grounding line leads to higher grounding line flux, a smaller ice sheet, greater potential for instability

What else plays a role in marine ice sheet stability?



Type of bed friction law affects stability and rate of retreat of grounding line

So what determines the stability of marine ice sheets?

- Back to the board!
 - Linear stability analysis theory
 - Analyzing grounding lines
 - Python demo