

Arthur H. Compton Lecture Series: An Intro to Climate Systems Engineering

lecturers: Professor Emeritus Doug MacAyeal & Professor David Keith
November 8, 2025



	Speakers	Topics
Oct 4	Keith	Introductions. Climate in 4 Dimensions. Emissions are peaking. Adaptation. Climate in Context.
Oct 11	Archer	Carbon cycle and natural geochemical processes as basis to understand carbon removal.
Oct 18	Shaw	Scientific basis for predicting climate changes in response to emissions of greenhouse gases and aerosol pollution.
Oct 25	Cael	Carbon removal, including ocean alkalinity enhancement, land-based methods, bioenergy with carbon capture, and direct air capture with storage.
Nov 1	Keith	Sunlight Reflection Methods (SRM) Part 1: How to Reflect Sunlight, the history of SRM, and why stratospheric sulfur aerosols are most plausible now.
Nov 8	MacAyeal & Keith	MacAyeal on science of glaciers and interventions to prevent glacial melt. Keith on developing DAC technologies at Carbon Engineering, and lessons for cleantech.
Nov 15	Shaw & Keith	The climate responses to SRM, potential side effects, and what can be learned from past aerosol pollution, highlighting the limits and uncertainties of experiments.
Nov 22	Keith & Shaw	The future of climate systems engineering, and climate engineering in context.



Tsuchiya Koitsu, *Nikko Sacred Bridge*, 1937

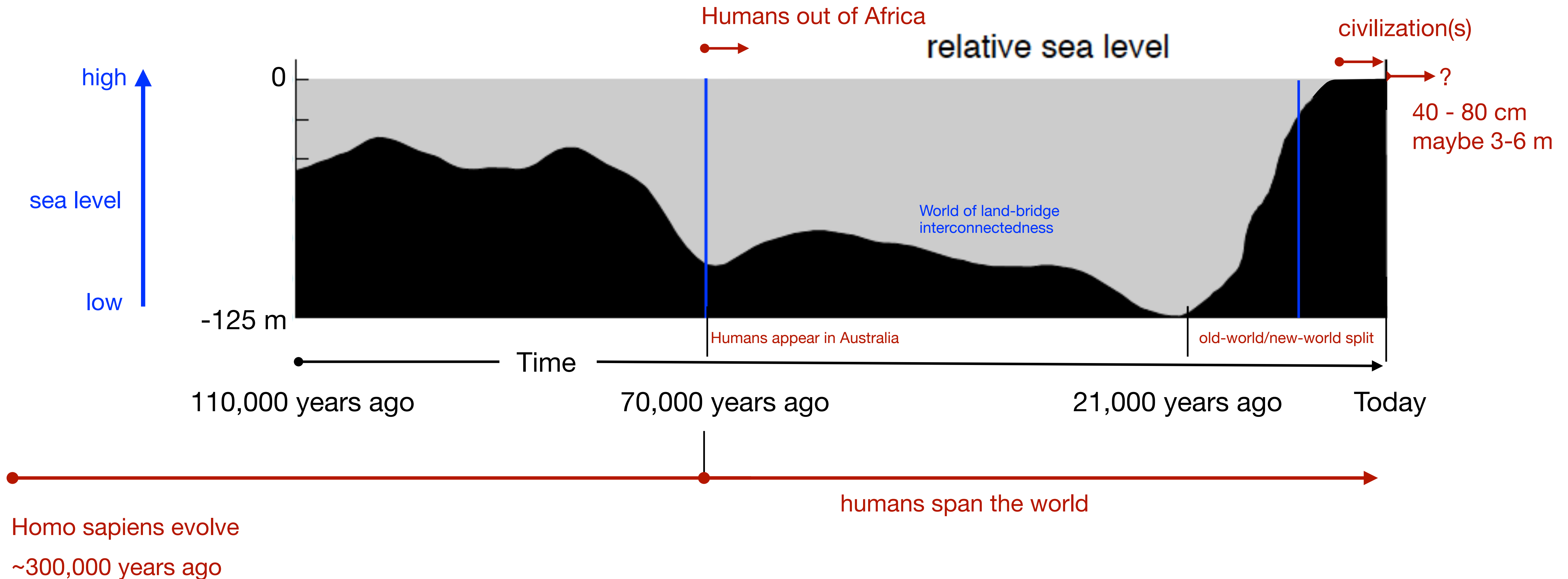
Geoengineering, a bridge to the future?

- Can **local** glacier intervention slow or reduce **global** sea-level rise

Outline

1. Sea-level rise (and fall) is a major consequence of climate change
2. An introduction to ice on Earth
3. Engineering ideas to avoid high-end sea-level rise
4. Nature's advice: accidental, natural examples of these ideas
5. Can engineering technology step-up to the task?

Humanity ***has*** lived with climate change...
Sea-level change has been our constant companion...



Earth has 3 basic types of ice:



floating sea ice

Nature's Solar Radiation Management (SRM) system...

indirect effect on sea level

Earth has 3 basic types of ice:



floating sea ice

Nature's Solar Radiation Management (SRM) system...



Sierra Nevada Mountain Landscape, Albert Bierstadt, 1868

Alpine snow and glaciers

Nature's water delivery service...

~ 25 cm of sea-level rise

Earth has 3 basic types of ice:



Continental ice sheets

Nature's Solar Radiation Management (SRM) system...

Nature's sea-level regulator...

70 meters of sea-level rise

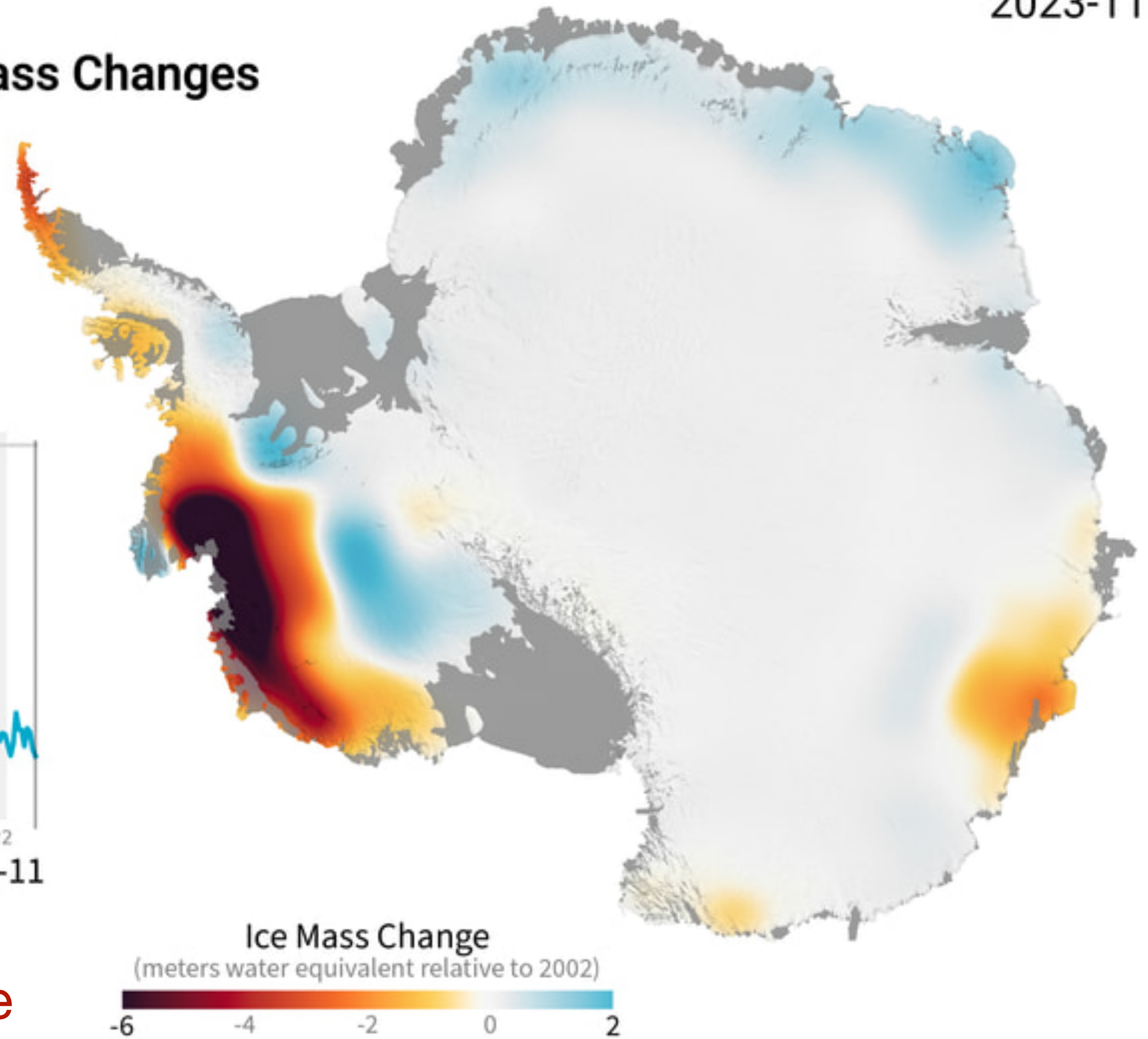
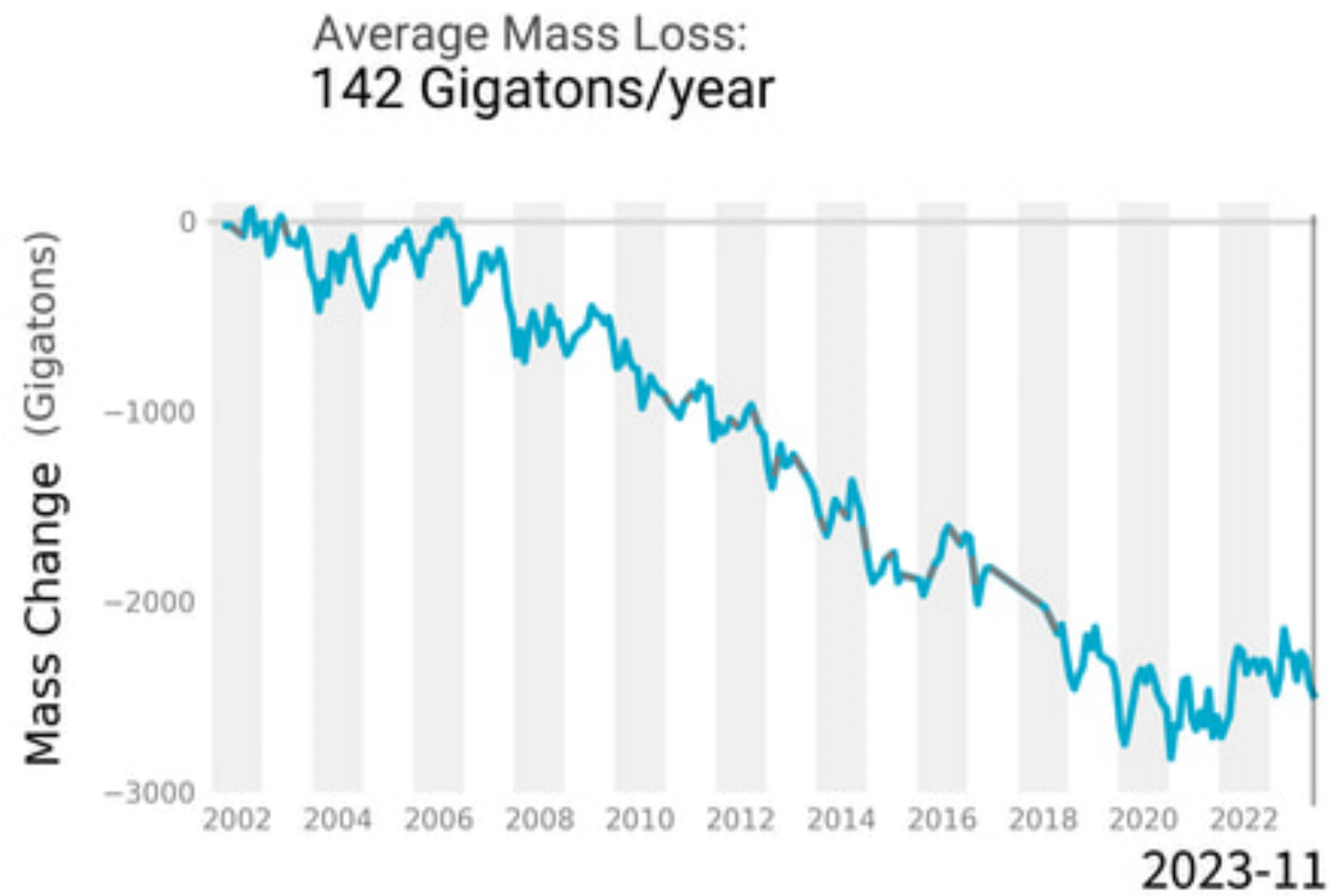
Nature's water delivery service...

Albert Bierstadt, 1868

Context:

Where is glacial ice likely to cause sea-level rise?

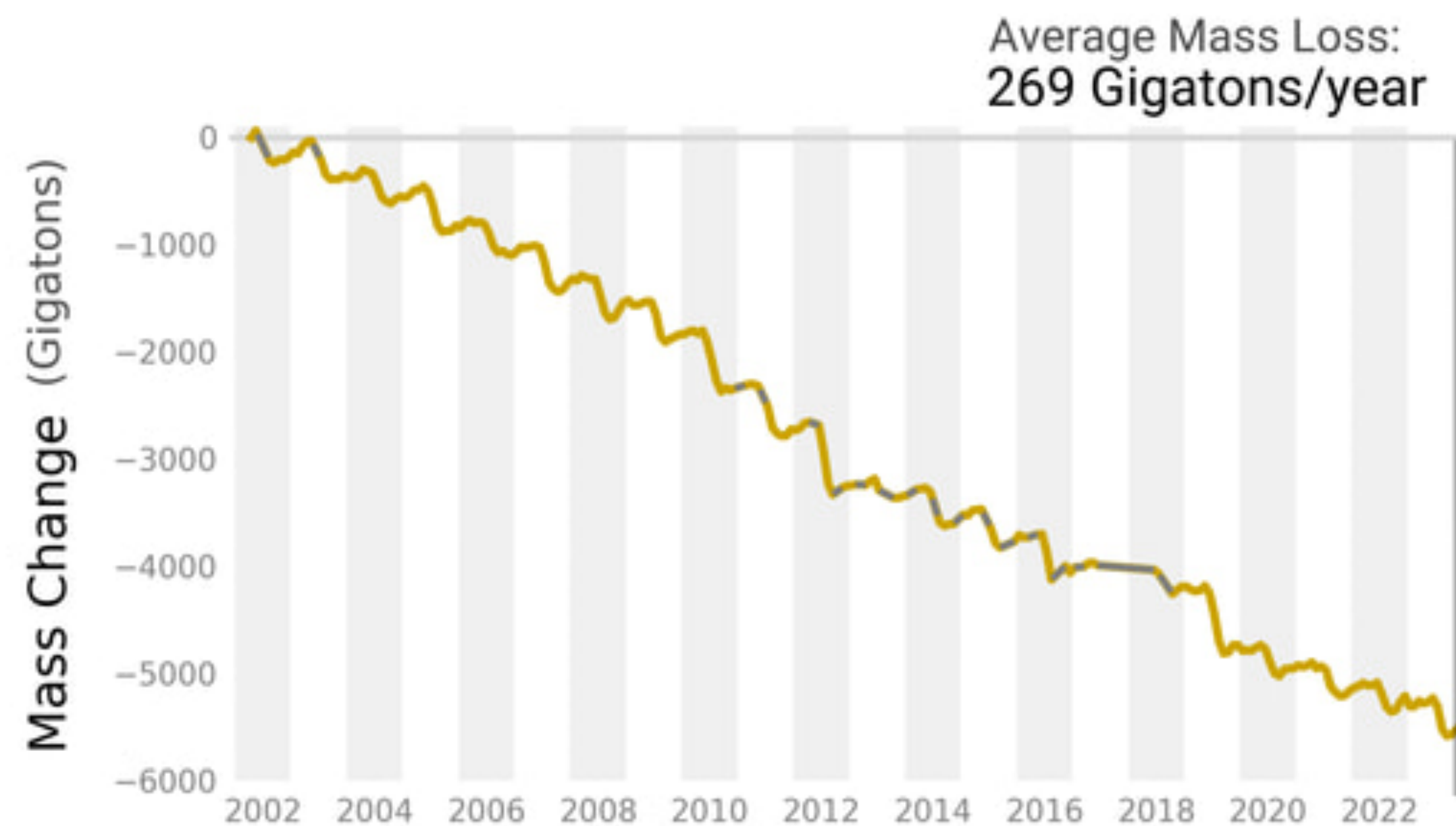
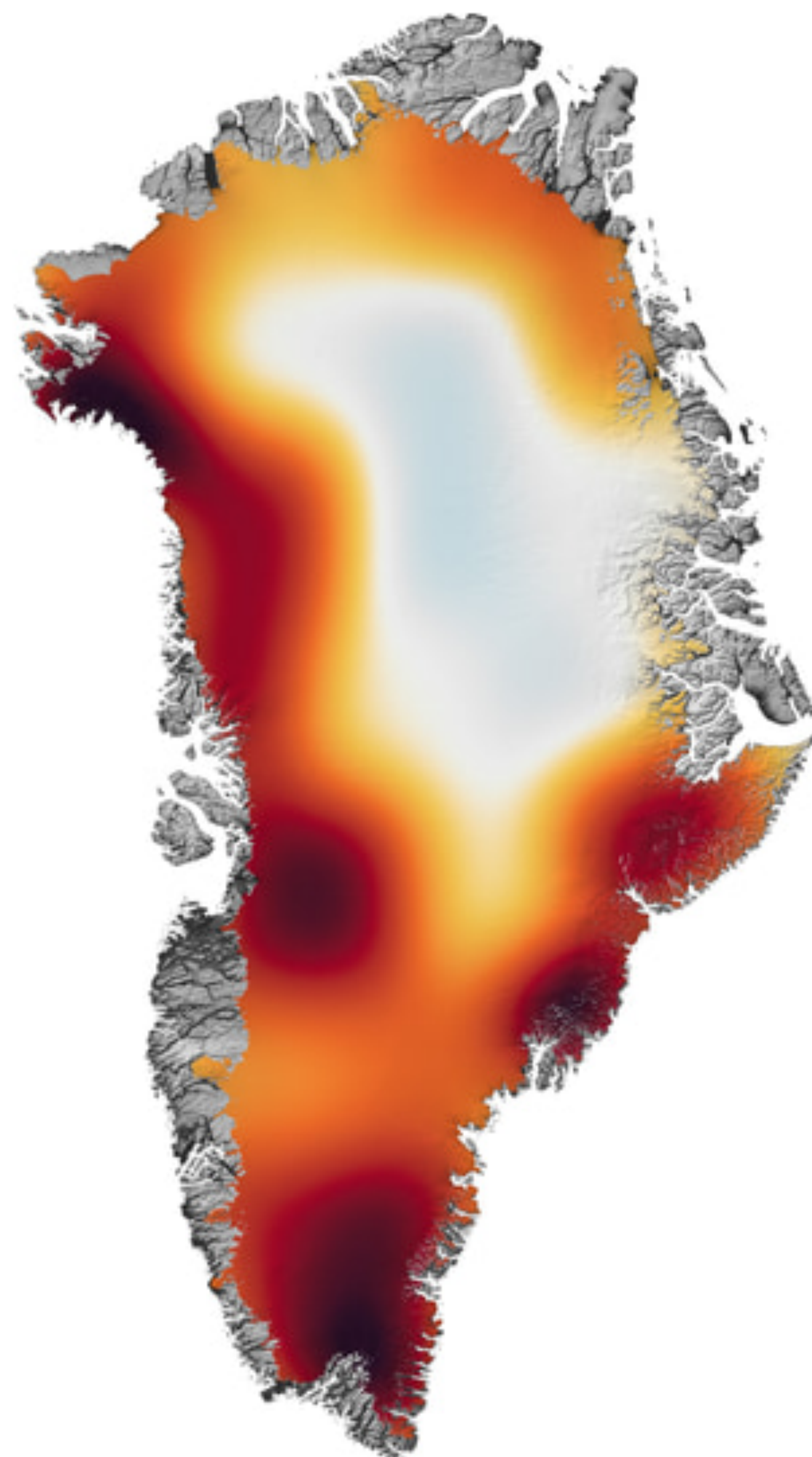
Observations of Antarctic Land Ice Mass Changes



350 Gt of ice = 1 cm sea-level rise

2023-11

GRACE AND GRACE-FO Observations of Greenland Land Ice Mass Changes



2023-11



350 Gt of ice = 1 cm sea-level rise

How does this work?

It's all about shape and stiffness...



The water-balloon analogy...

Like the balloon, ice-sheets reach high altitudes...

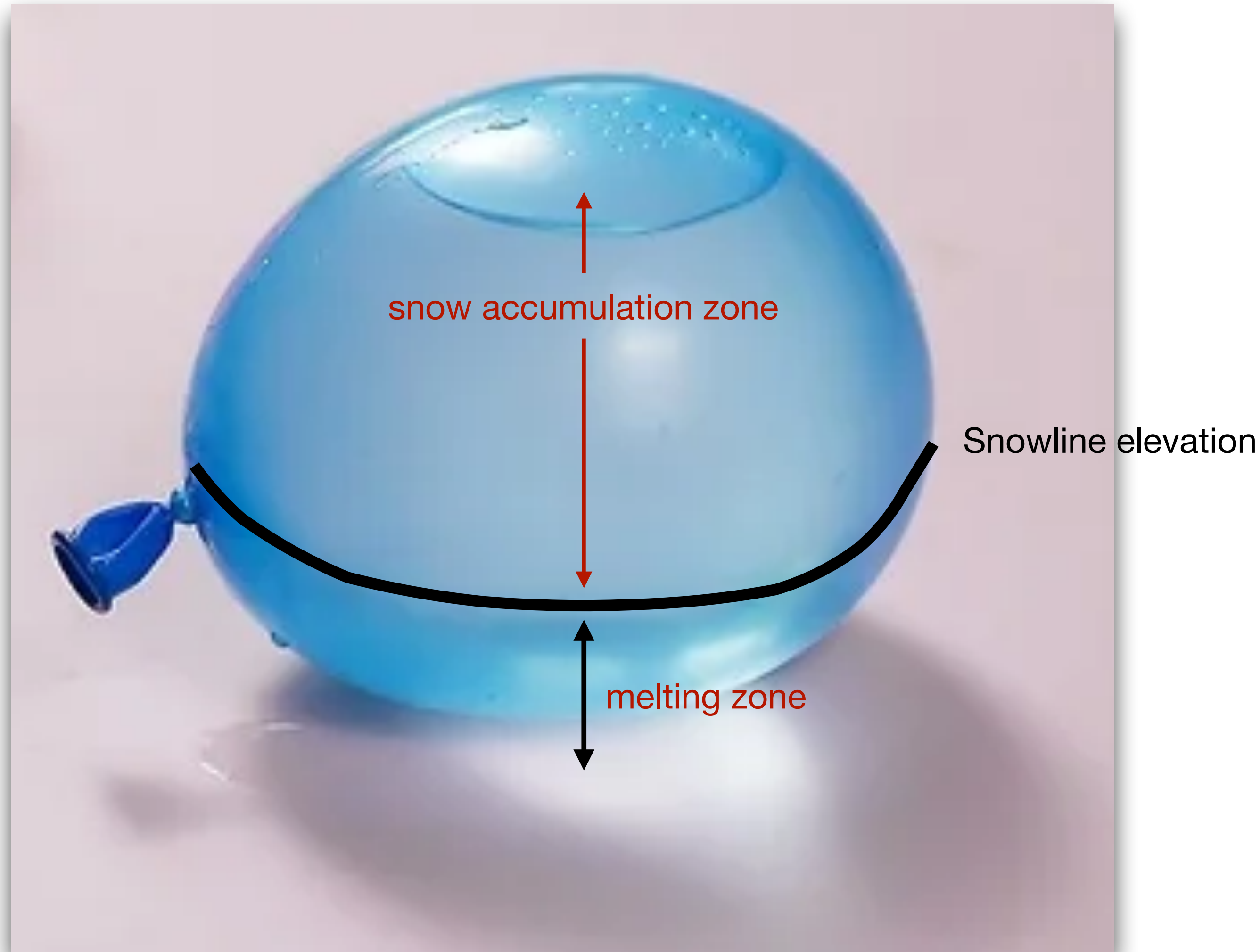


Snowline...



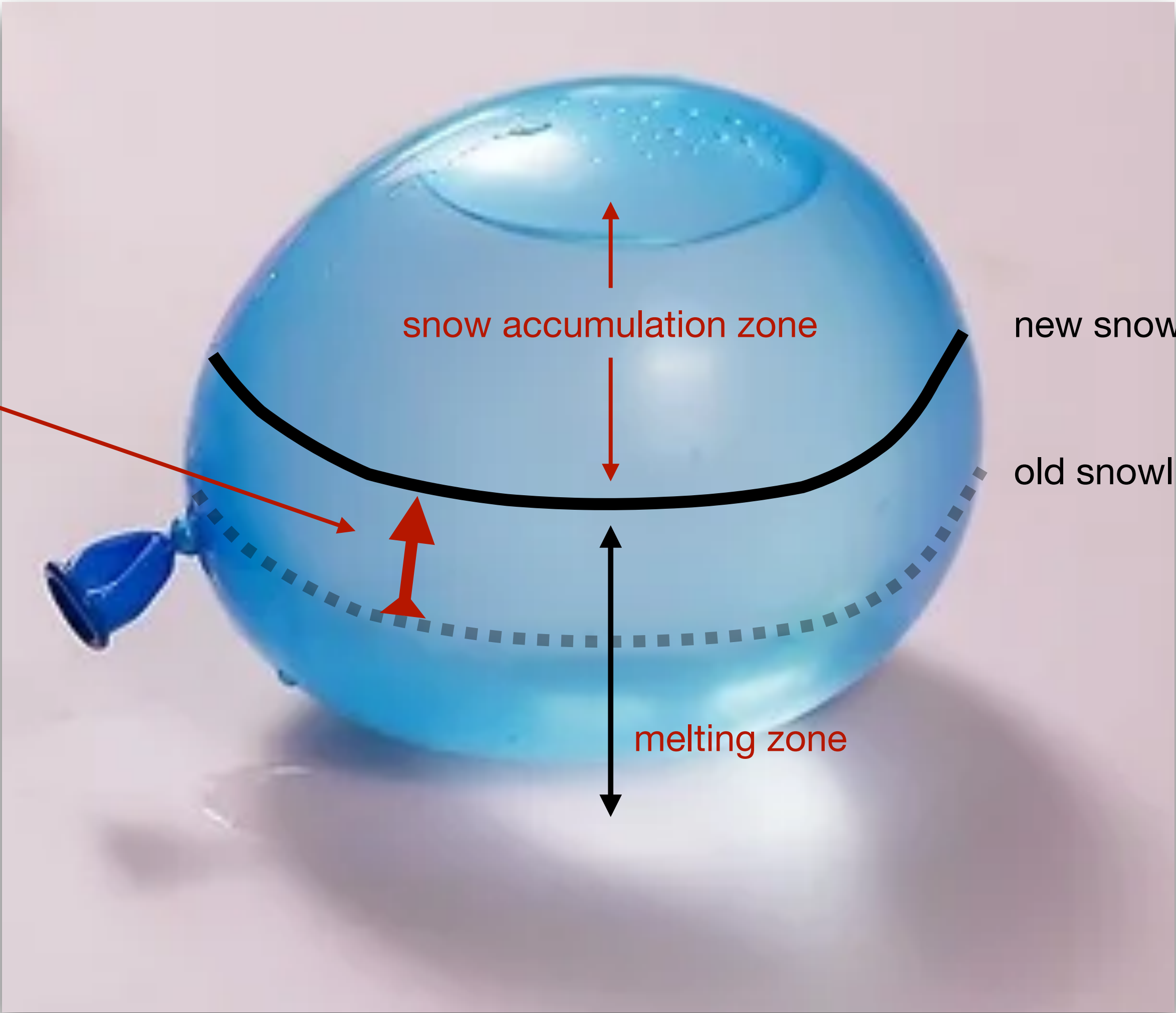
The snows of Kilimanjaro

Greenland:

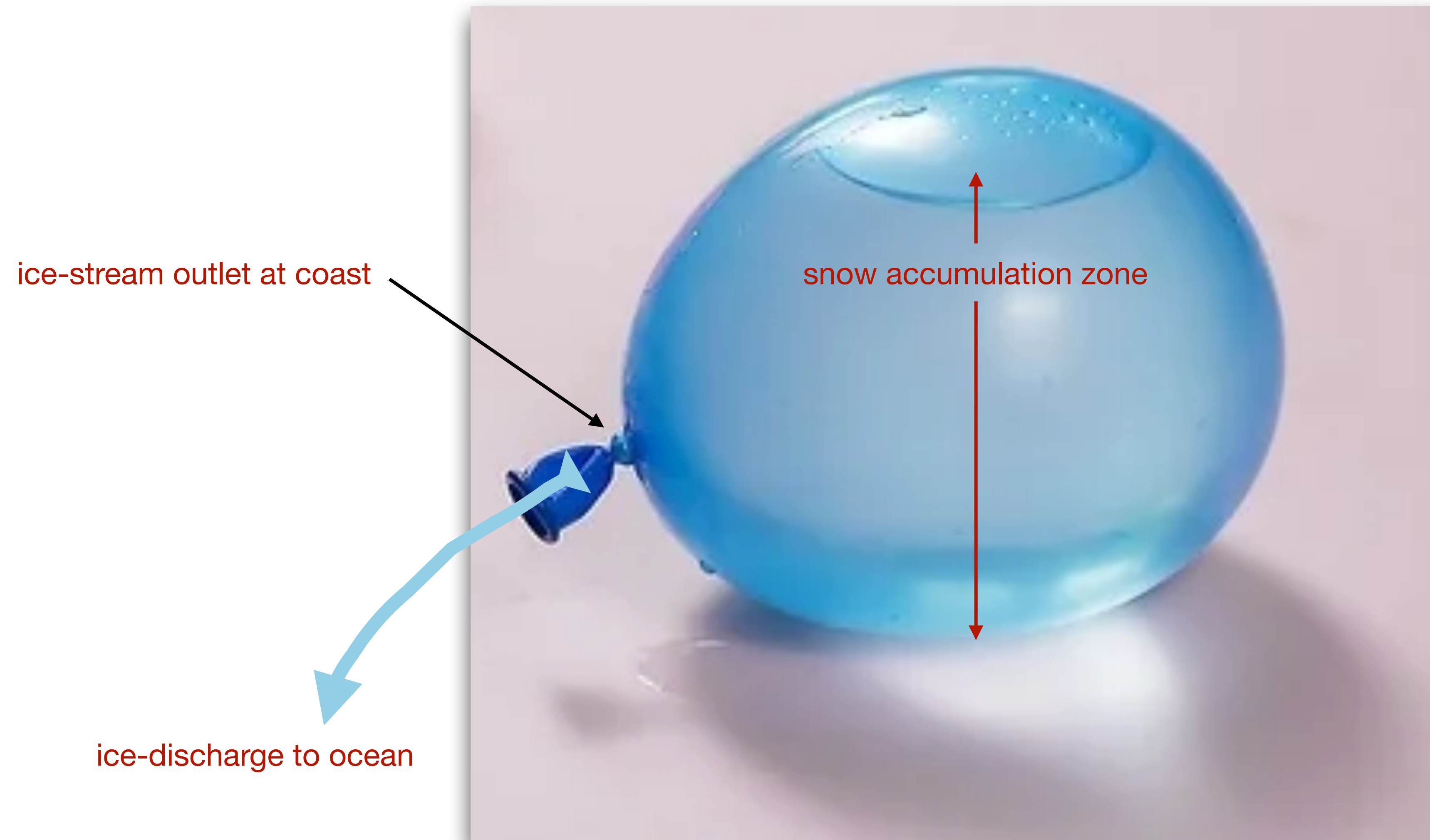


Greenland:

Global warming



Antarctica is way too cold!



Antarctic ice streams:

Global warming

(Ocean heat and waves
try to untie the knot)

snow accumulation zone

ice-discharge to ocean





An example of how the “knot” of an outlet glacier is untied by global warming.

Hecetoria Glacier in the Antarctic Peninsula

How will Humanity deal with sea-level rise?

- **There is about 350,000 km of coastline**
- **~ 650 million people live within 3 m of sea level**
- **Significant socio-economic infrastructure near sea level**
- **Wetlands that protect against storm surges**

There is no doubt that humans will respond with a myriad of individually optimized adaptations at a plethora of locations...

How will Humanity deal with sea-level rise?

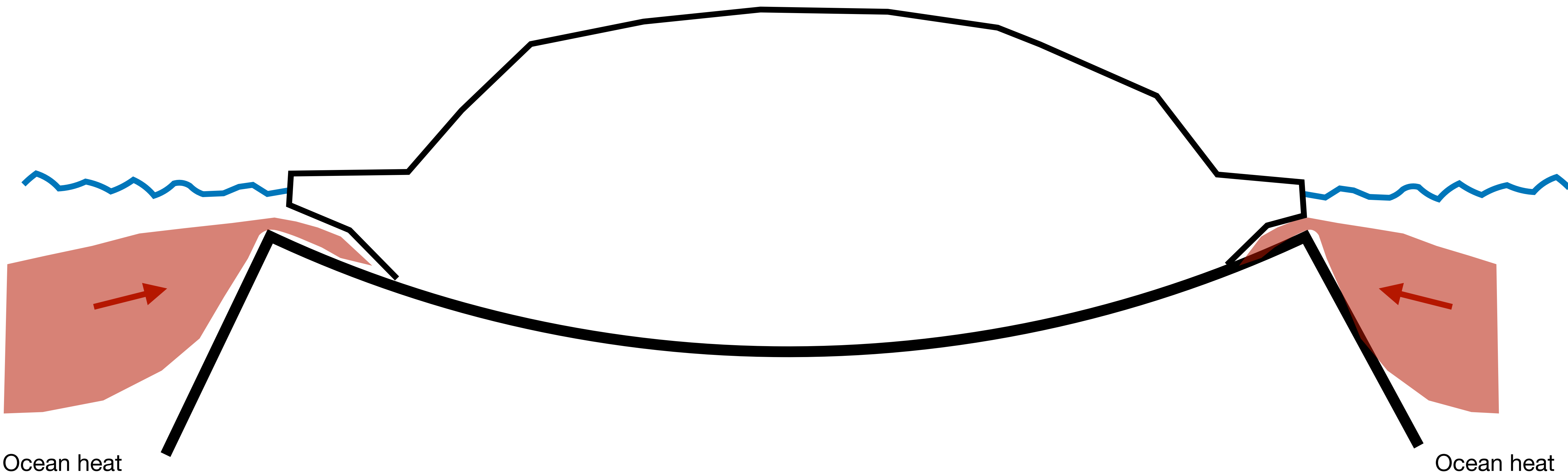
A **local** engineering response to Antarctica's "weak knot":

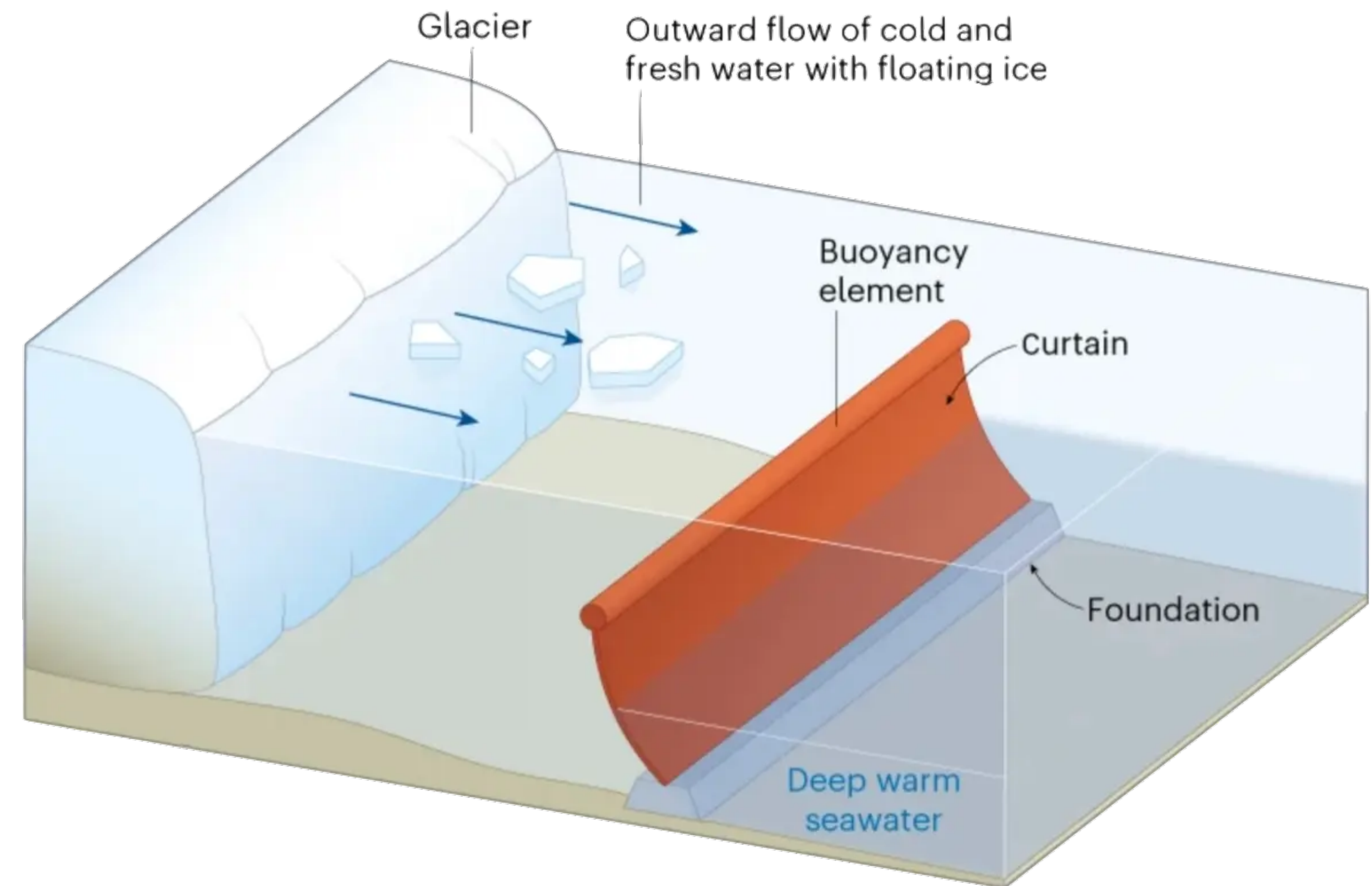
two approaches:

Protect the knot from the warming ocean
Tie the knot tighter

***But, what if there's a cooperative response that is focussed
at one location (or a few) at the ice sheet's most vulnerable points?***

Ocean heat comes in “low and hard”:





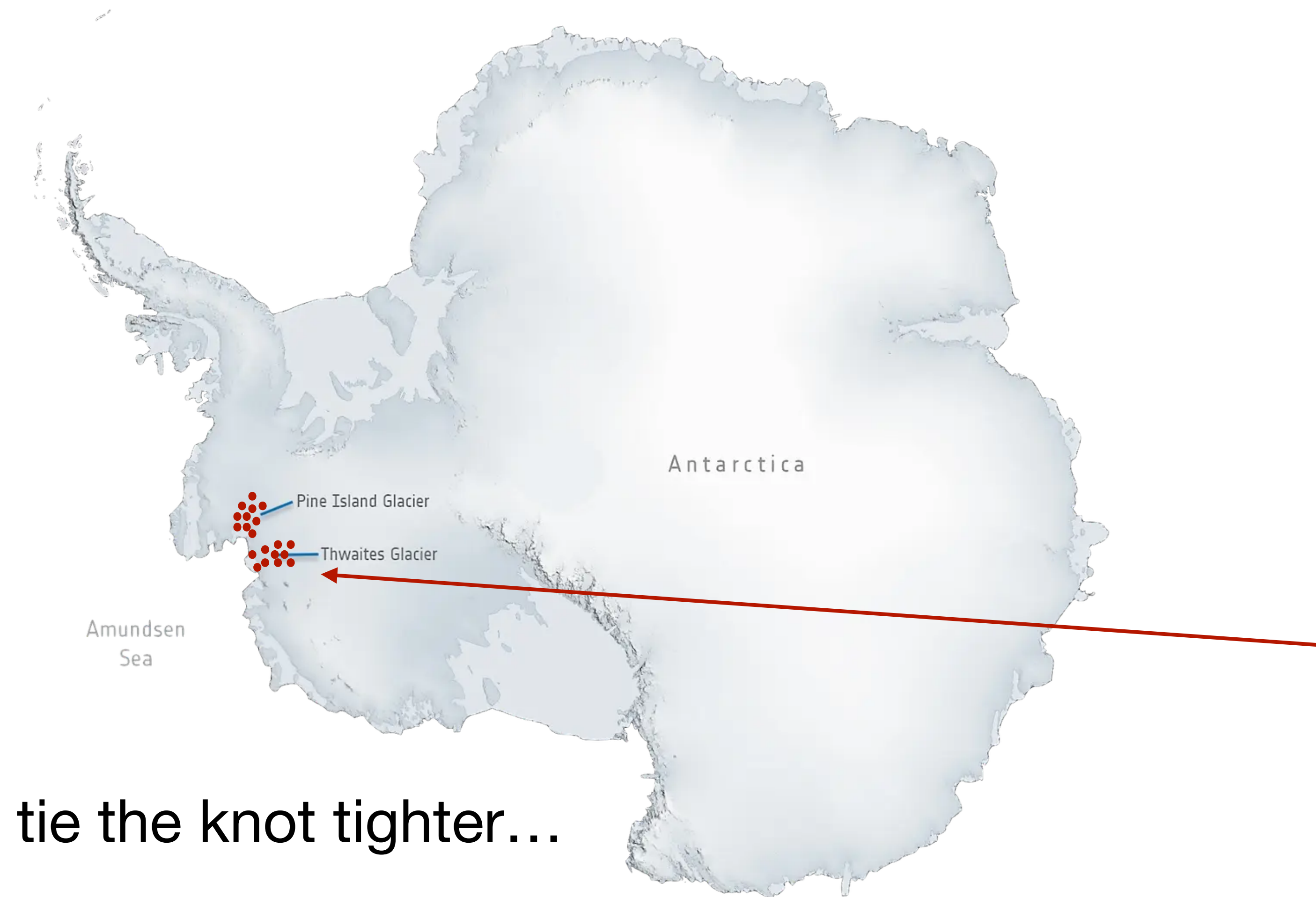
How will Humanity deal with sea-level rise?

A **local** engineering response to Antarctica's "weak knot":

two approaches:

- ✓ **Protect the knot from the warming ocean**
- ? **Tie the knot tighter**

But, what if there's a cooperative response that is focused at one (or a few) location at the ice sheets most vulnerable points?



tie the knot tighter...



Humans are good at pumping out fluids

How will Humanity deal with sea-level rise?

A **local** engineering response to Antarctica's "weak knot":

two approaches:

- ✓ **Protect the knot from the warming ocean**
- ✓ **Tie the knot tighter**

Do any of these methods obey the David Keith principle?

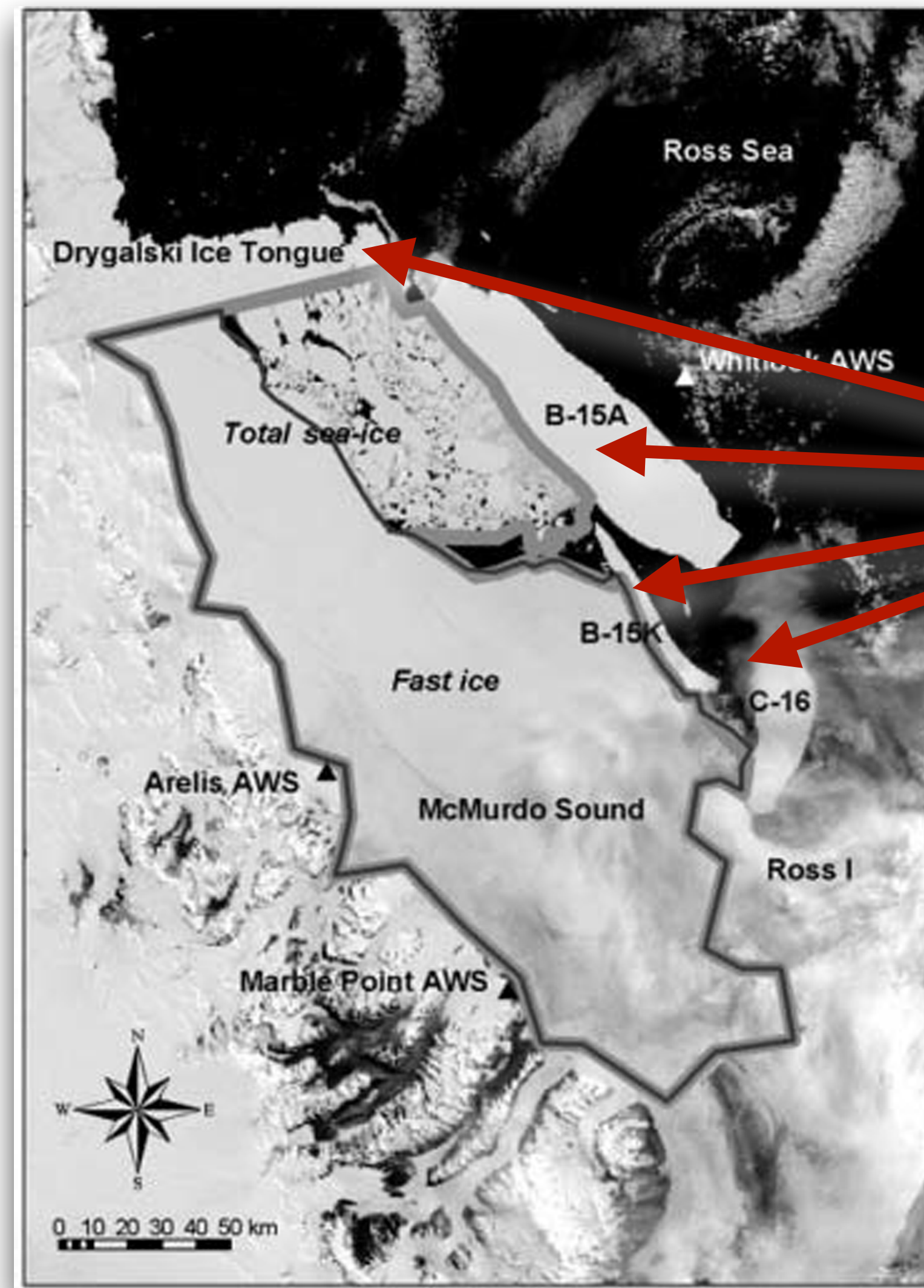
An old study I did of Earth's largest iceberg:



B15 blocked the Ross Sea because it ran aground

3-years of intense land-fast sea ice that normally melts

3 types of glacial geoengineering:

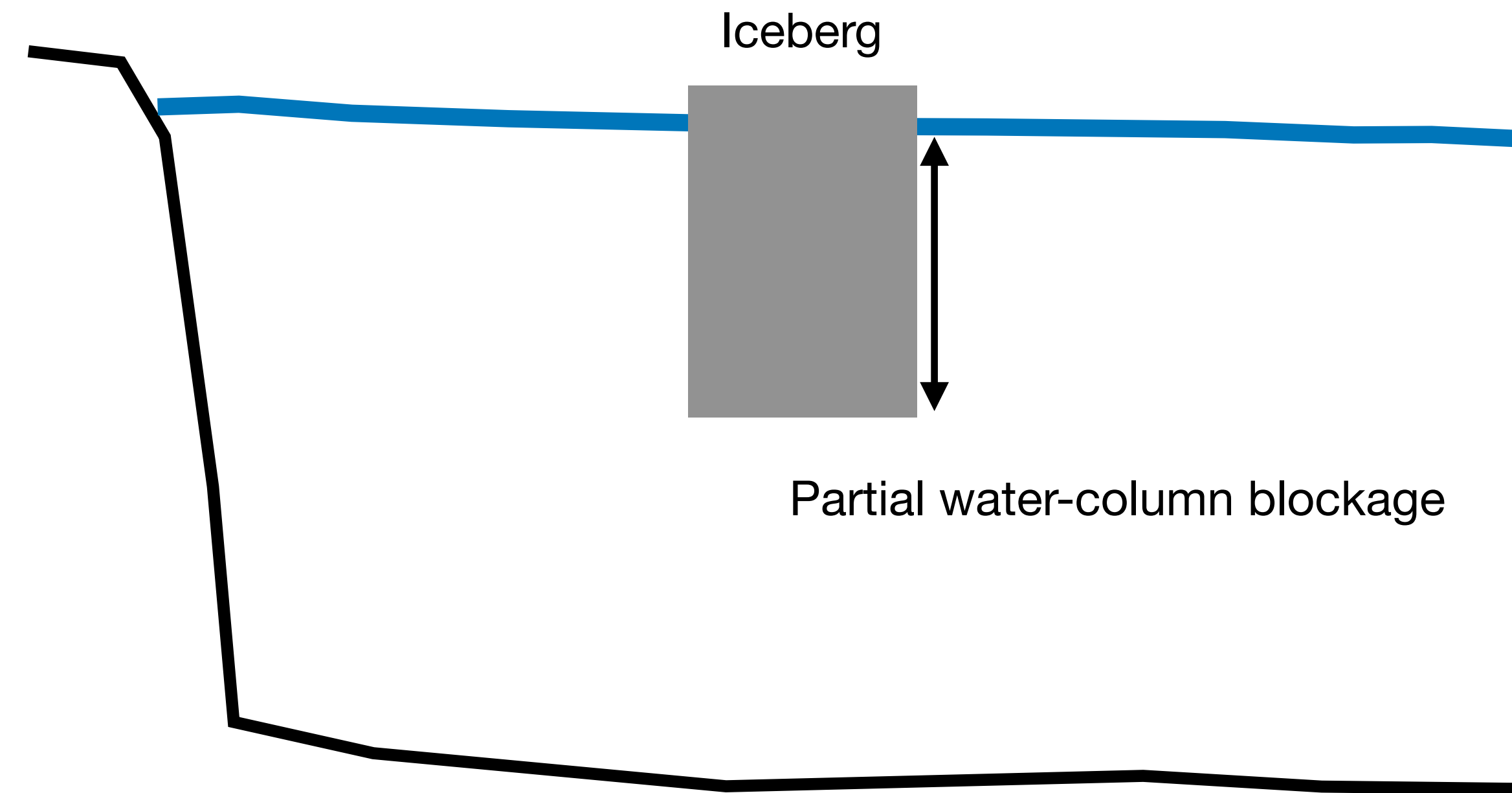
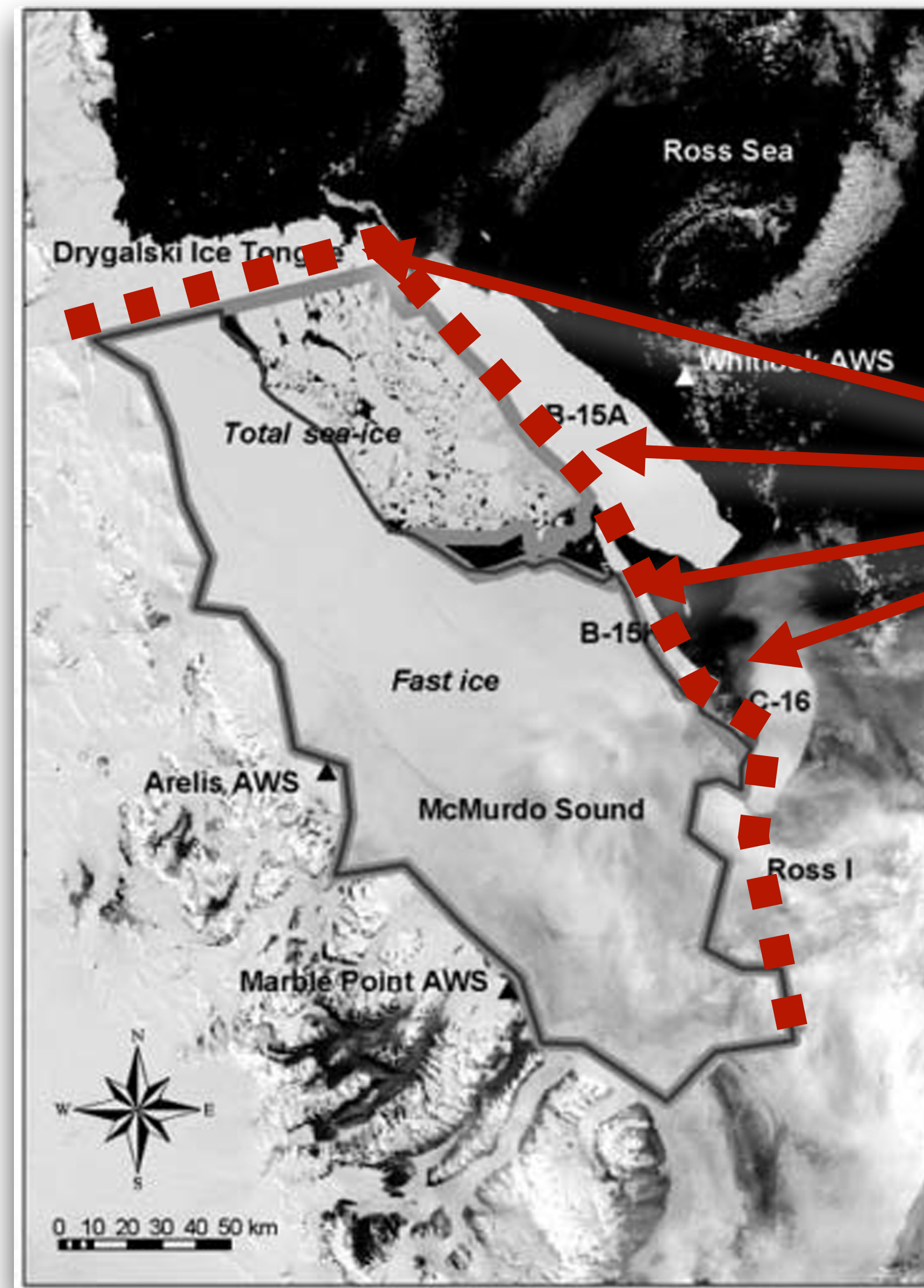


Accidental arrangement of icebergs

block the warm ocean currents

Icebergs: nature's barrier to ocean heat transport

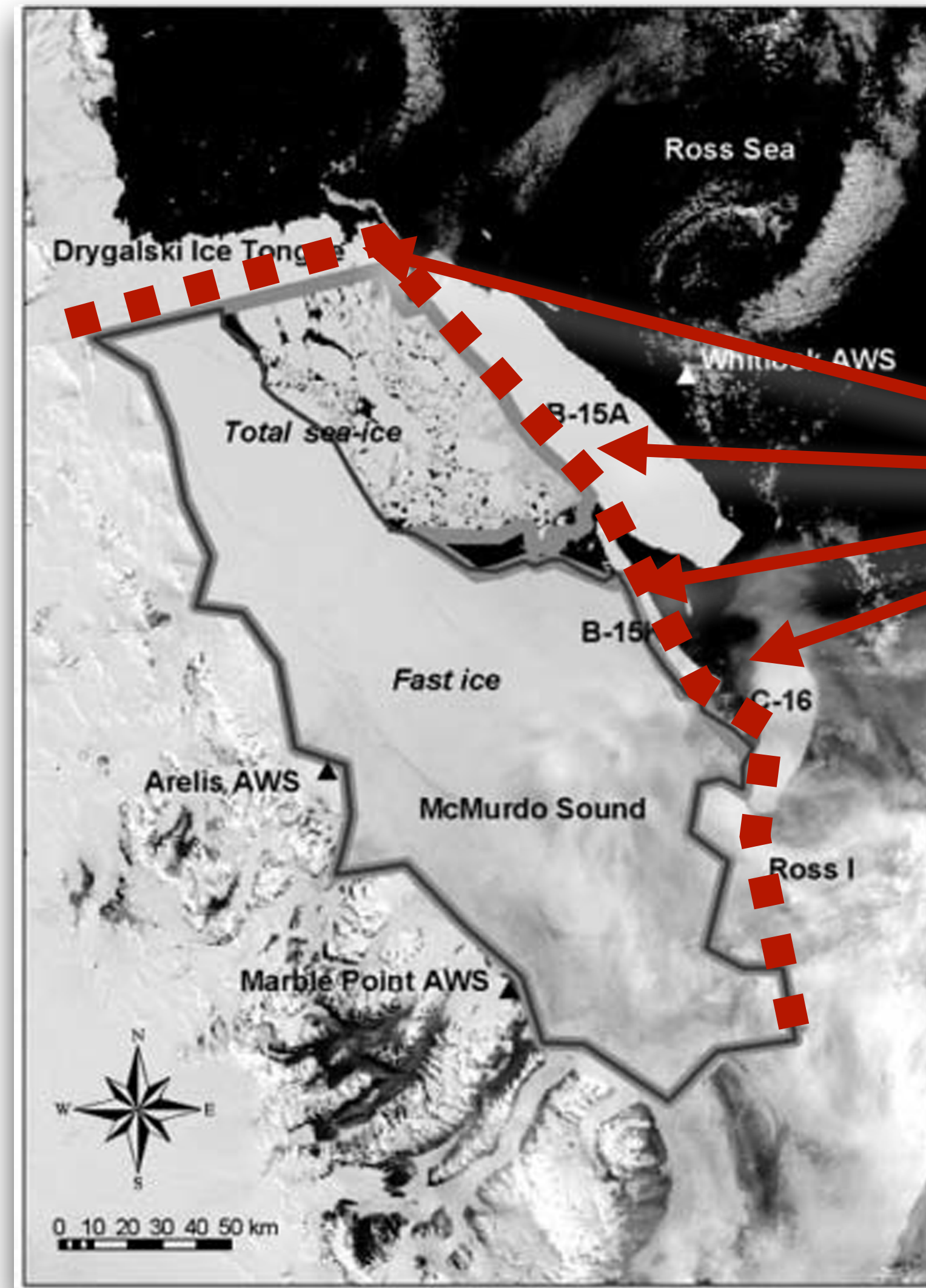
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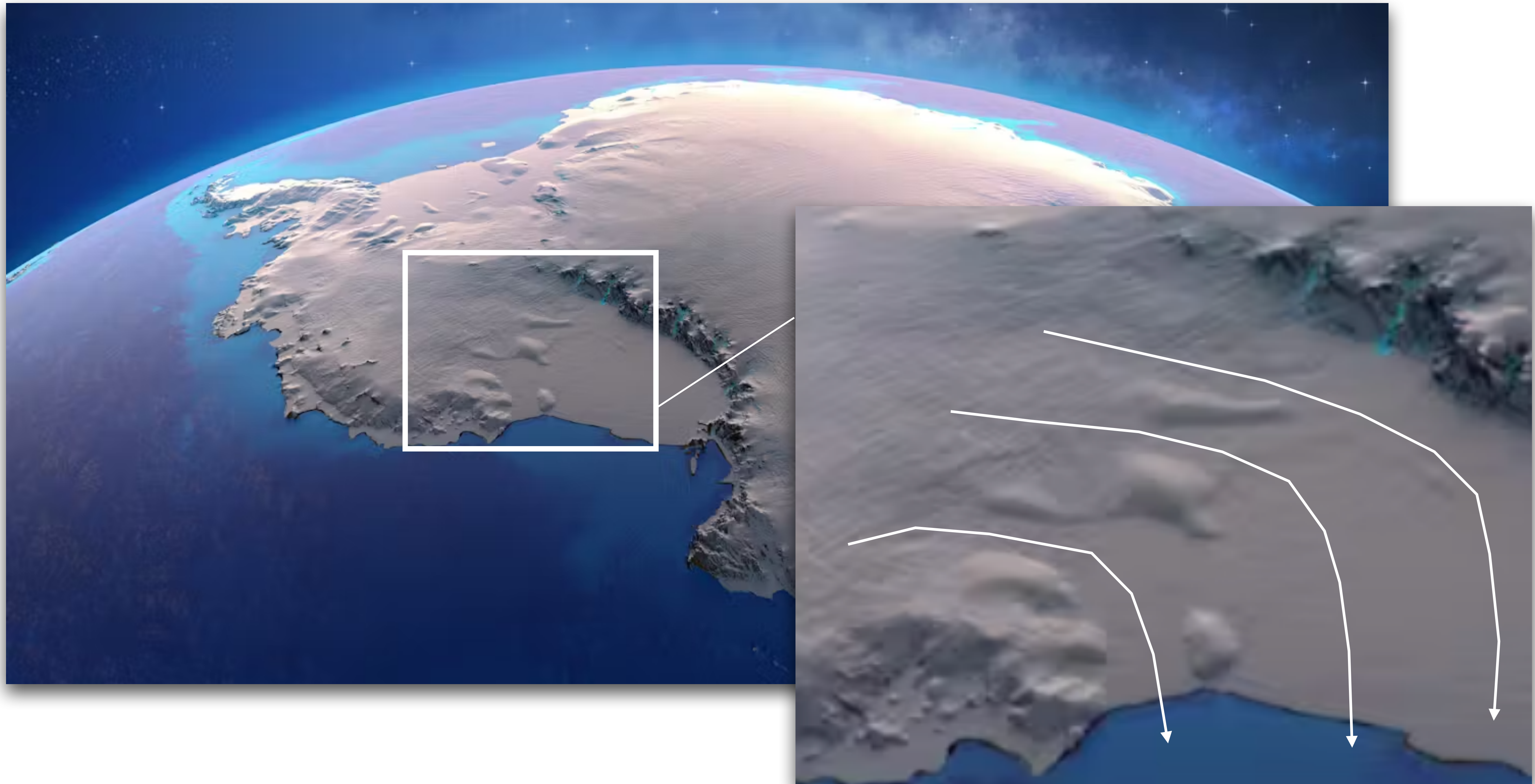


Nature's lesson!

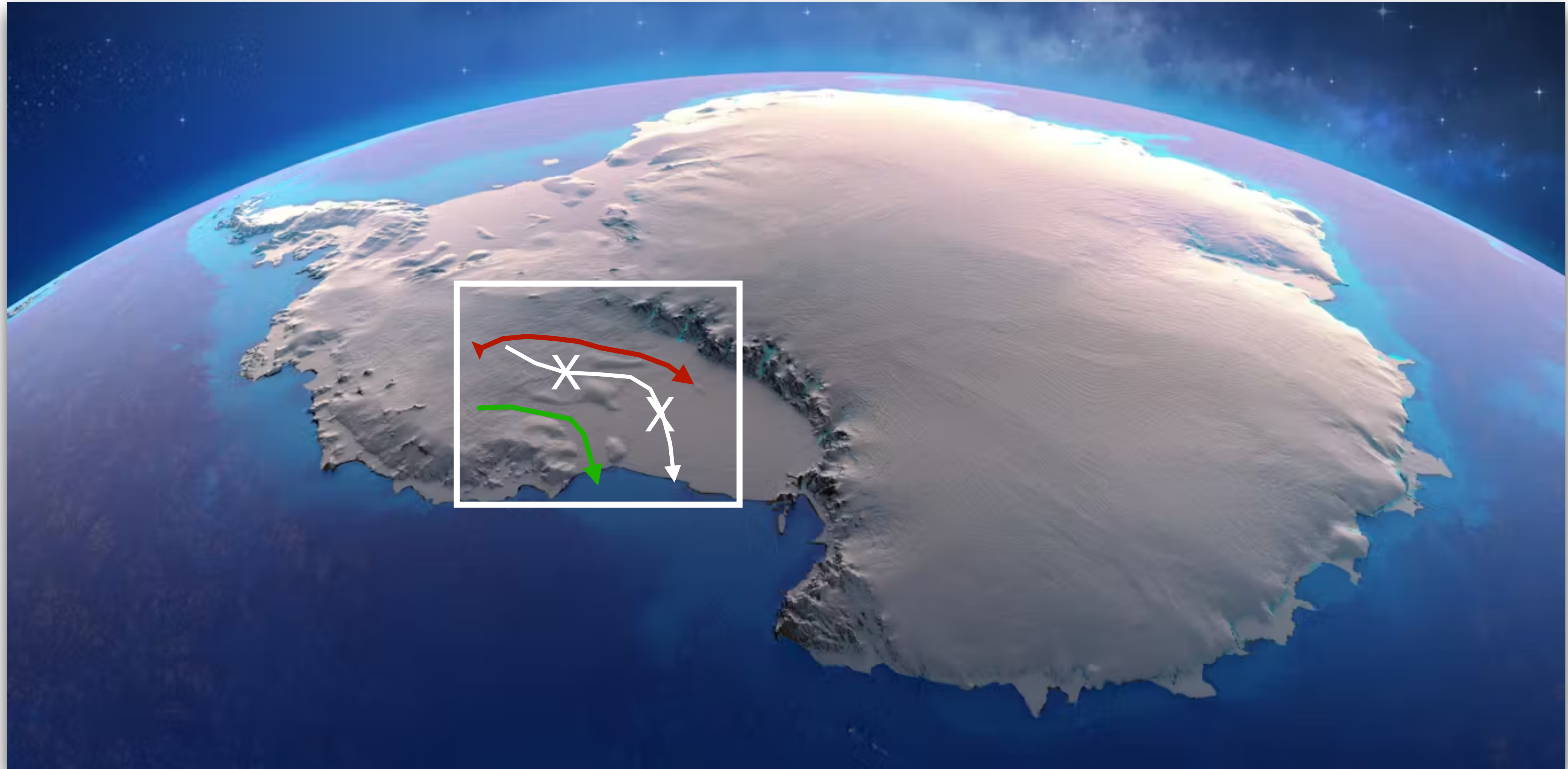
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Icebergs: nature's barrier to ocean heat transport

An old study I was involved in of Antarctica's ice streams:



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Kamb Ice Stream mysteriously “dead”...

Happened about 250 years ago due to “water piracy”

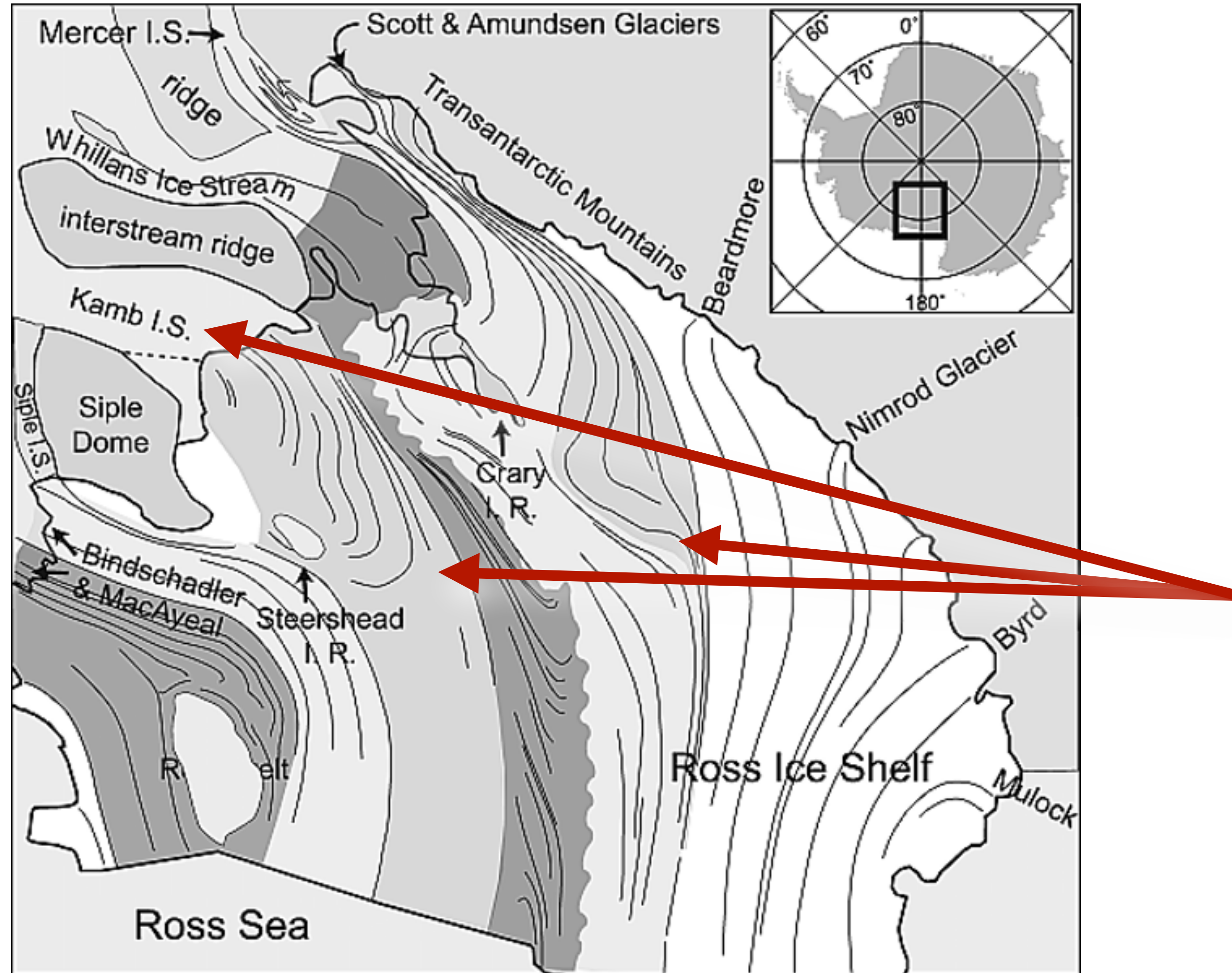
History of ice flow variation in medial moraines:



Sustina Glacier, Alaska



Shut-down of Kamb Ice Stream



- 160 years ago
- 10 years to shut down

Tie a knot in the ice flow

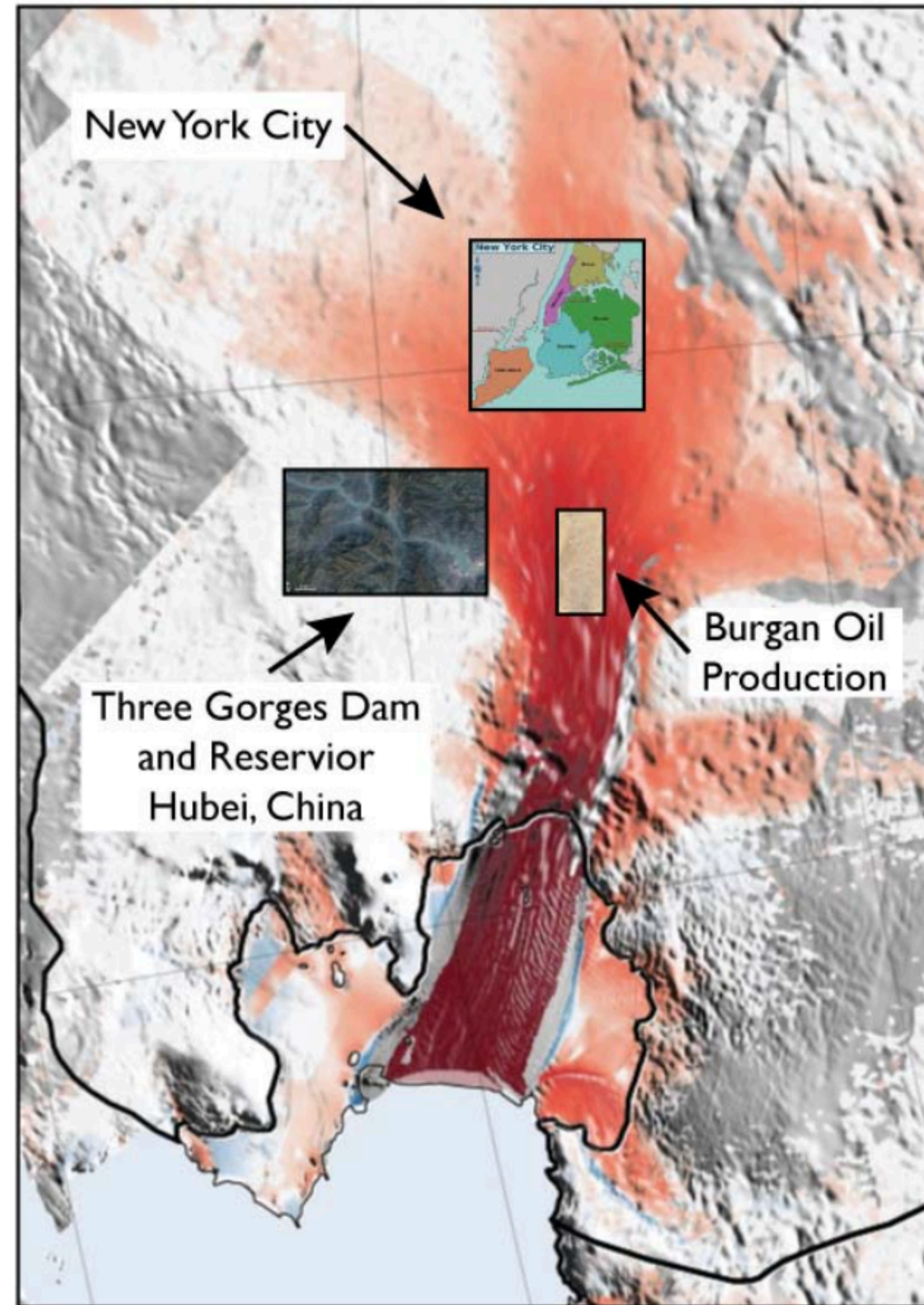
Subglacial water: nature's ice-sliding lubricant

Can engineering do this?

Drilling:

Oil fields, water projects, subway tunnels

Drilling:



Pine Island Glacier, comparison of scale

Curtains:

Anti-submarine curtains (nets)

RESTRICTED

ORDNANCE PAMPHLET 636A

DECLASSIFIED
Authority ND 348 865

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3/73:21-4

NET AND BOOM DEFENSES



RESTRICTED

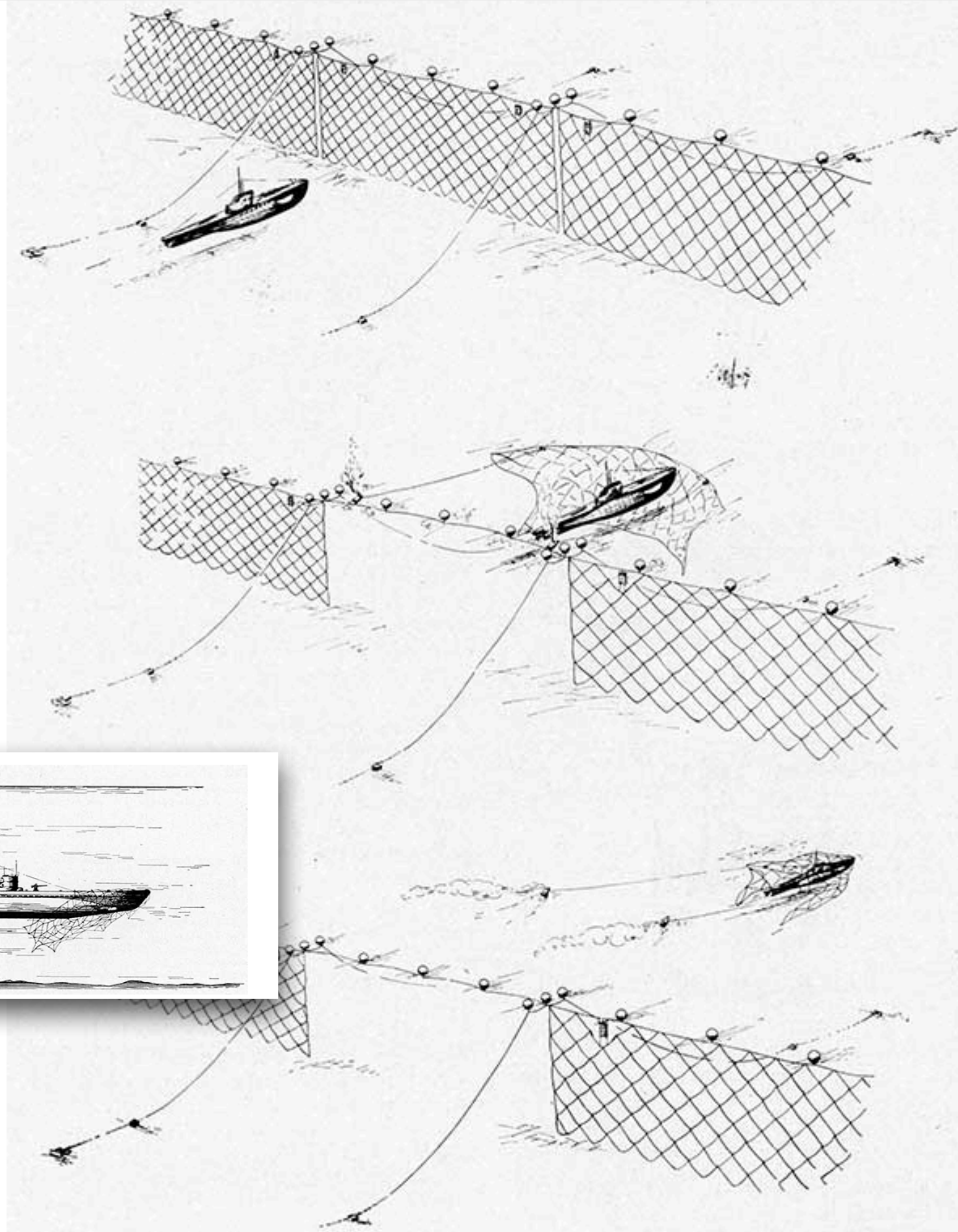
A BUREAU OF ORDNANCE PUBLICATION

27 JUNE 1944

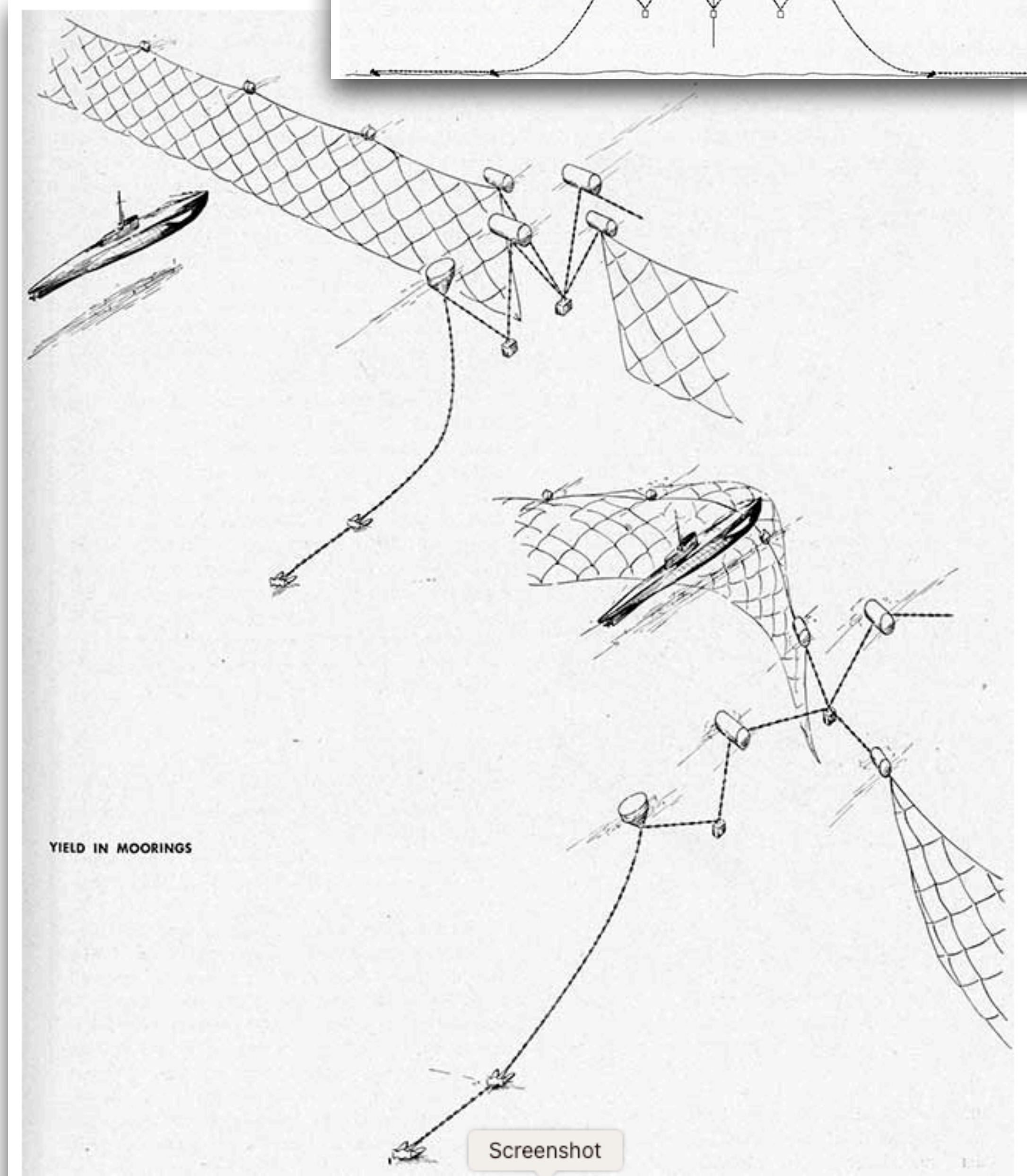
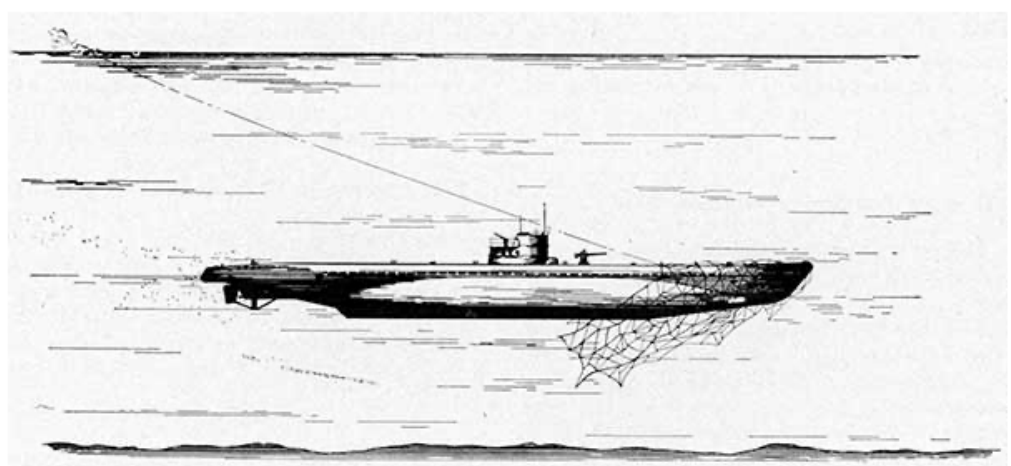
Revolution in Nets: An Unglamorous But Essential Phase of Naval Warfare
Author(s): Buford Rowland
Source: *Military Affairs*, Vol. 11, No. 3 (Autumn, 1947), pp. 149-158

The British Navy was outstanding in the development of nets and booms. From 1914 to 1918 it laid approximately 600 miles of nets in 85 harbors and bases. Engaged in rigging and maintaining these defenses were 360 officers, 4,222 men and 312 vessels.





ACTION OF INDICATOR NET



YIELD IN MOORINGS

Screenshot

US Net installations (WW2):

At Saipan, the *Keokuk* laid 10,000 feet of LISP-2 net in 3 hours and 35 minutes.

At Saipan, the team of the *Tuscana* (AKN) and the *Holly*, *Cinchona*, and *Chinquapin* (AN's) installed 7,373 yards of T-8 net in 19 days.

At Ulithi the *Tuscana*, *Sagittarius*, *Zebra* (AKN's) and the *Mastic*, *Cornel*, *Viburnum*, and *Winterberry* (AN's) installed 16,000 yards of T-8 net in 28 days.

At Kossul Passage, the *Zebra* (AKN) and the *Catalpa*, *Cliffrose* and *Winterberry* (AN's) installed 3,160 yards of T-8 net in 6 days.

At Okinawa the *Sagittarius* and *Tuscana* (AKN's) and the *Aloe*, *Mahogany*, *Chinquapin*, *Snowbell*, *Spicewood*, *Winterberry* and *Abele* (AN's) installed 10,680 yards of T-10 net in 19 days.

ADVANCED BASE TORPEDO NETS (T-8, T-9, T-10) INSTALLATIONS

<i>Base</i>	<i>Yards</i>
Guadalcanal	1,300
Tulagi	2,700
Espiritu Santo	5,000
Kwajalein	3,100
Eniwetok	8,800
Tinian	4,400
Saipan	9,800
Peleliu	1,000
Ulithi	23,300
Manus	9,000
Philippine Islands	8,500
Okinawa	13,500
Aleutians	30,000

SUMMARY

Approximately \$120,000,000 was spent in net and boom procurement from July 1, 1940, to August 14, 1945.

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