ESS 203 - Glaciers and Global Change

Friday March 12, 2021.

Outline for the day

- Last Wednesday's highlights: *Jennifer Lomeli*
- Today's highlights (written report only): *Caroline Wills*

- Marine Ice-Sheet Instability MISI
- Marine Ice-Cliff Instability MICI
- Ice in the Future

Course/Instructor Evaluations

I expect you have received course-evaluation requests from IAS (UW Instructional Assessment Surveys).

These evaluations help us to improve our teaching and to design courses to be more effective, and they allow you to pass forward your insights to future students.

We hope you will participate in 3 anonymous surveys, to assess:

1. Ed’s contributions (lectures, and the course as a whole).

   https://uw.iasystem.org/survey/239461

2. Seth’s contributions (Labs and lecture).

   (see your email or ask Seth for the link)

3. Jessica’s contributions (Lectures and your group projects).

   (see your email or ask Jessica for the link)

We know that is takes time to complete not 1, but 3 surveys, and we (and future students) all appreciate your time and contributions ☺

Thanks!

The surveys will be open until Friday next week Mar 19, 2021 at 11:59pm.

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2. Seth's contributions (Labs and lecture).
   https://uw.iasystem.org/survey/239460
3. Jessica's contributions (Lectures and your group projects).
   https://uw.iasystem.org/survey/239444

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Is the Antarctic Ice Sheet Doomed?

- Marine Ice Sheet Instability
- Marine Ice Cliff Instability

Nature 271, 321-325. (1978)

West Antarctic ice sheet and CO_2 greenhouse effect: a threat of disaster

Thinner WAIS could float!

J. H. Mercer

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

If the global consumption of fossil fuels continues to grow at its present rate, atmospheric CO_2 content will double in about 50 years. Climatic models suggest that the resultant greenhouse-warming effect will be greatly magnified in high latitudes. The computed temperature rise at lat 80° S could start rapid deglaciation of West Antarctica, leading to a 5 m rise in sea level.

ATMOSPHERIC carbon dioxide traps some of the long-wave radiation emitted by the Earth's surface (principally near 15 µm wavelength), thereby tending to warm the troposphere. This so-called greenhouse effect has long been suspected[1,2] but only recently, as the implications of a continuation of the current near-exponential growth of industrial CO_2 production have been realised, have many come to fear a disastrous climatic warming in the rather near future. In a recent report on the climatic effects of energy production, Revelle *et al.*[3] conclude that industrial civilisation may soon have to decide whether or not to make the tremendous investment of capital and effort needed to change over from fossil fuels to other sources of energy. Bolin[4], in hearings before the

If so, the actual doubling time for atmospheric CO_2 content is likely to be nearer 50 than 200 years.

Many attempts have been made to estimate by climatic modelling the average global rise in temperature that would result from a doubling of atmosphere CO_2 content. The figures obtained have ranged from 0.7 K to 9.6 K, and Schneider[7] has critically examined the models in an attempt to clear up the confusion created by these widely different estimates. He points out that some of the models give unrealistic results because they compute an equilibrium condition for the Earth's surface rather than for the Earth–atmosphere system as a whole. He stresses the advantages of radiative–convective models, which take into account vertical motions of the atmosphere and latent heat transport, and he compares the radiative–convective models of Rasool and Schneider[8], who had computed an average global temperature rise of 0.8 K, with that of Manabe and Wetherald[9] who had computed a rise of 2.3 K, later revising this to 2.9 K. He estimates that, using the most refined input of feedback mechanisms that is possible with present knowledge, globally-averaged temperatures would rise about 1.9 K. But, because some feedback mechanisms may have been improperly modelled, some (especially those involving changes in cloud cover and cloud

Hughes − Weak-underbelly letter
(*J. Glaciology*, 1981)

"Possible collapse of the West Antarctic Ice Sheet by surges of Thwaites and Pine Island Glaciers …"

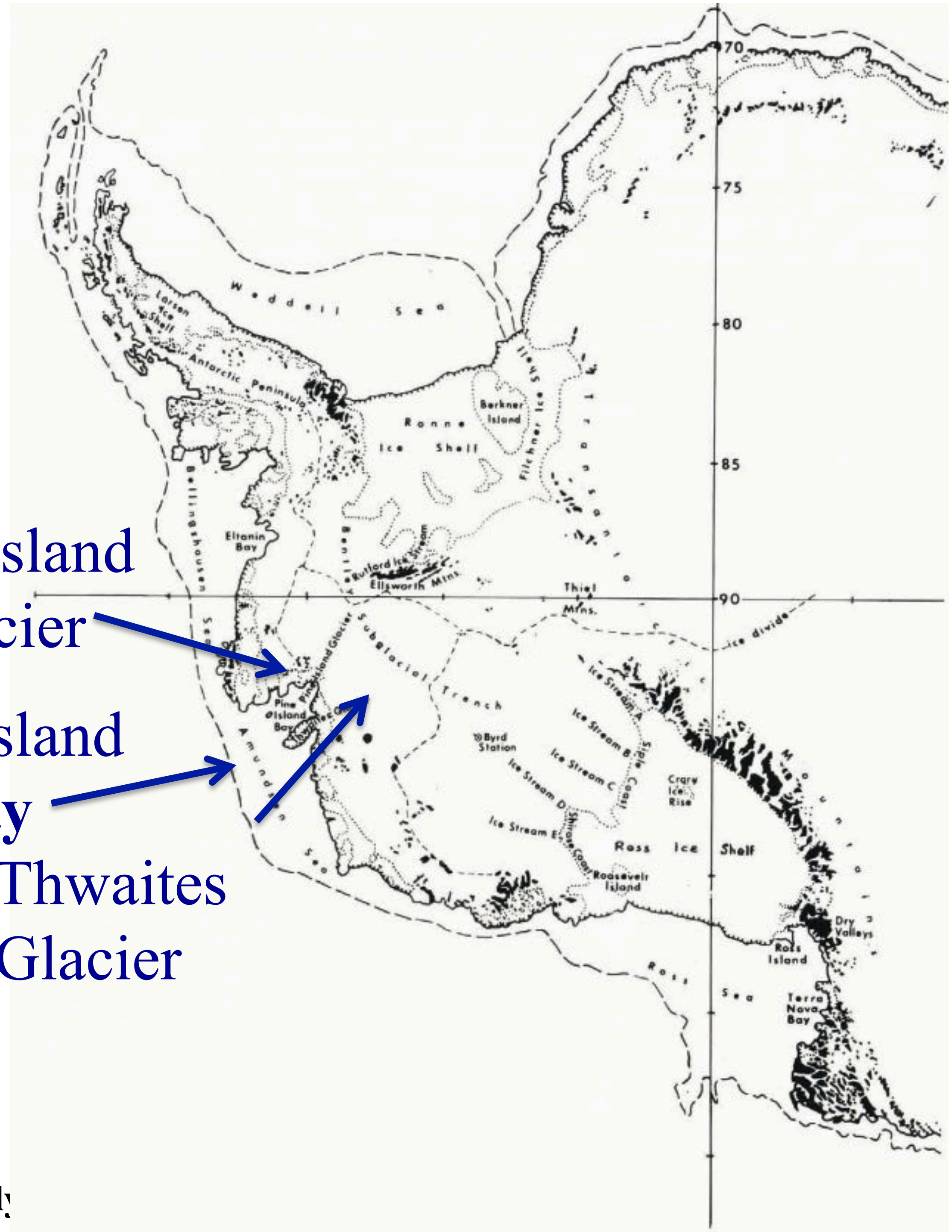
"A brief history of the development of the concept that Pine Island Bay may be the weak underbelly of the West Antarctic ice sheet is in order. … AAAS *[publishers of Science]* and *DOE [US Dept of Energy]* … sponsored a workshop … in April 1980 … to formulate a science plan that would "elucidate the research that might establish once and for all the likelihood and time frame of collapse of the grounded ice in West Antarctica".

2021 – we are still working on that …

Hughes, T. (1981), The weak underbelly of the West Antarctic ice sheet, *J. Glaciol.*, *27*(97), 518–525

Hughes – Weak underbelly letter (1981)

(1981 graphics)



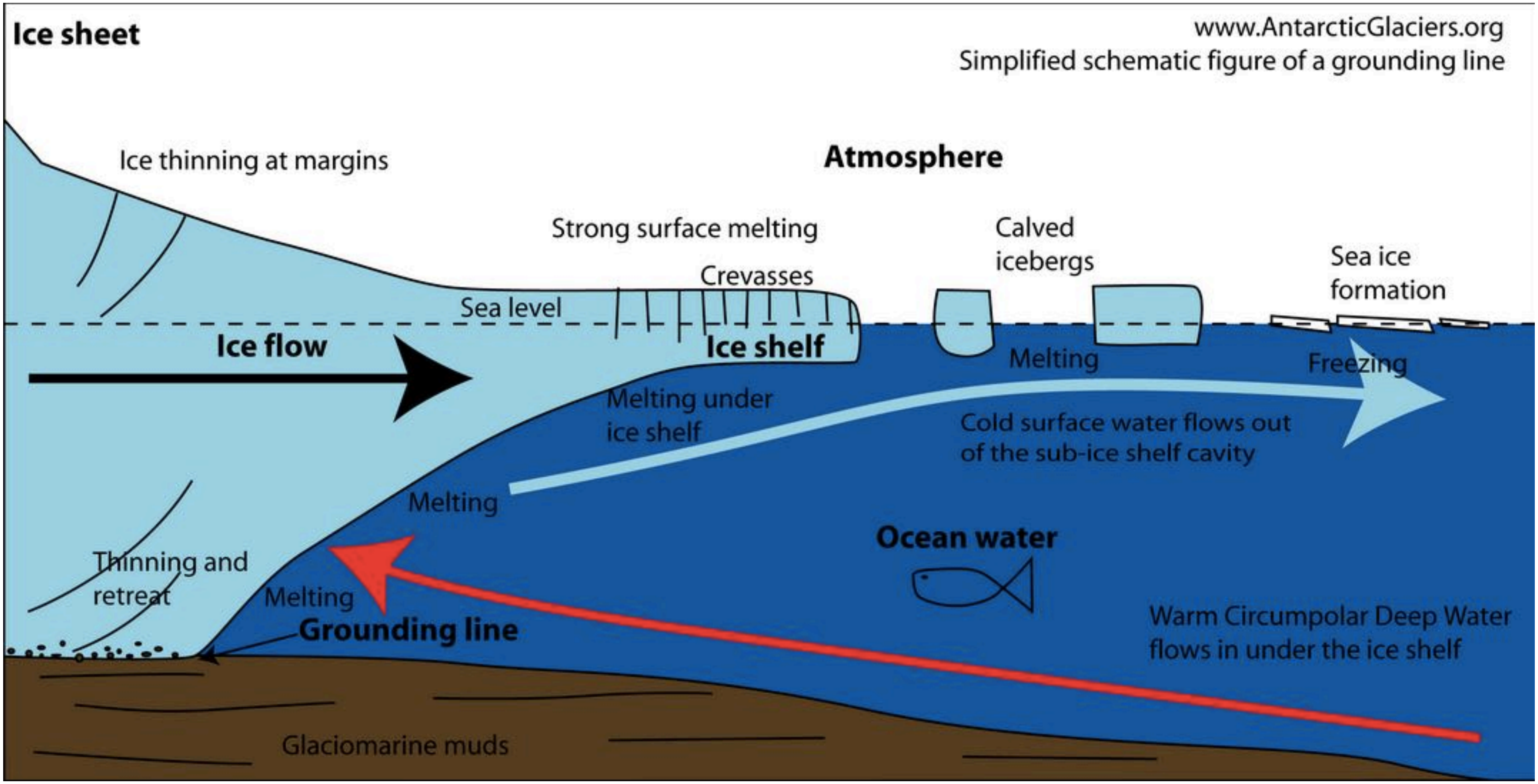
Pine Island Glacier

Pine Island Bay

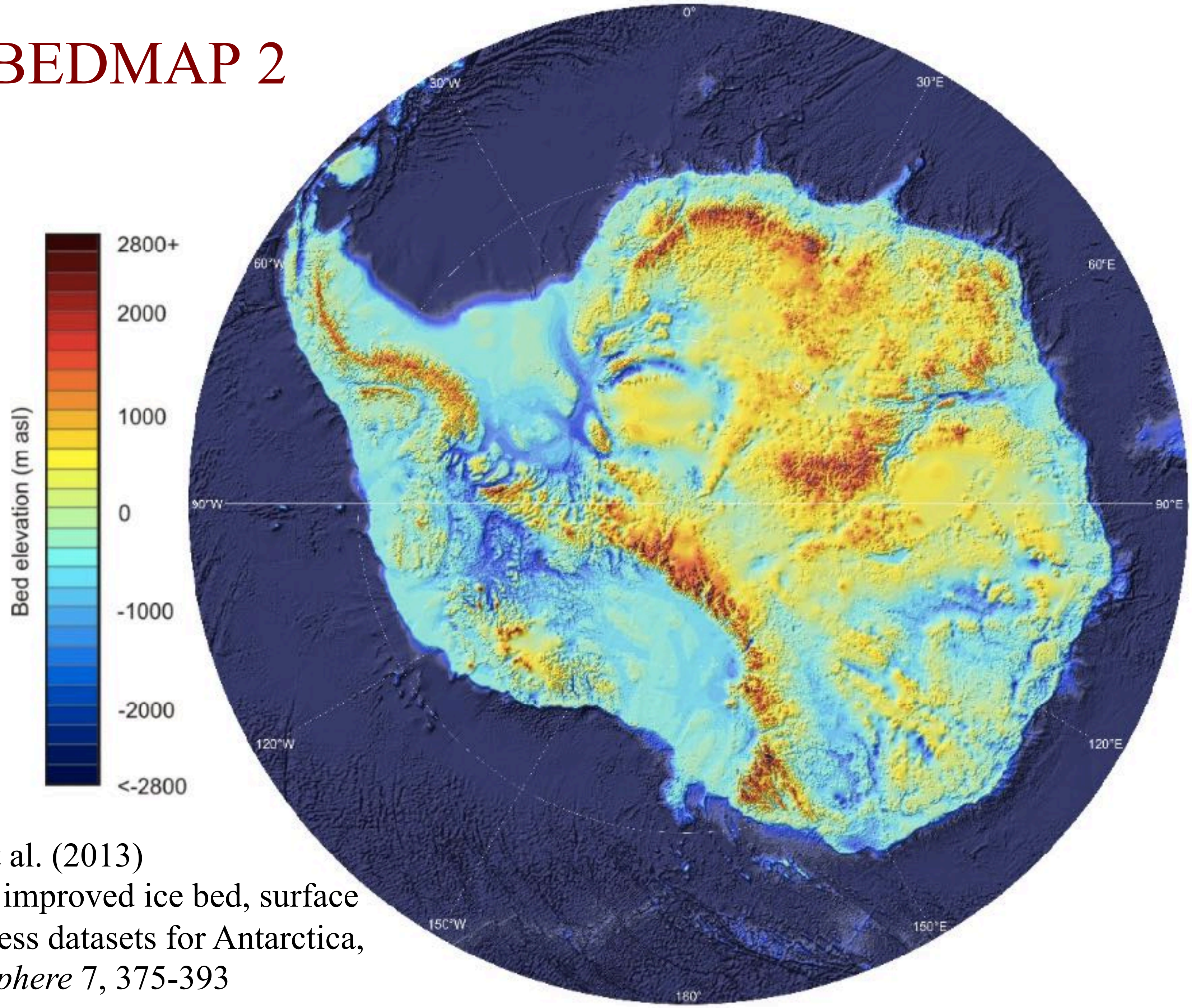
Thwaites Glacier

Hughes, T. (1981), The weak underbell

Ice Shelf Processes

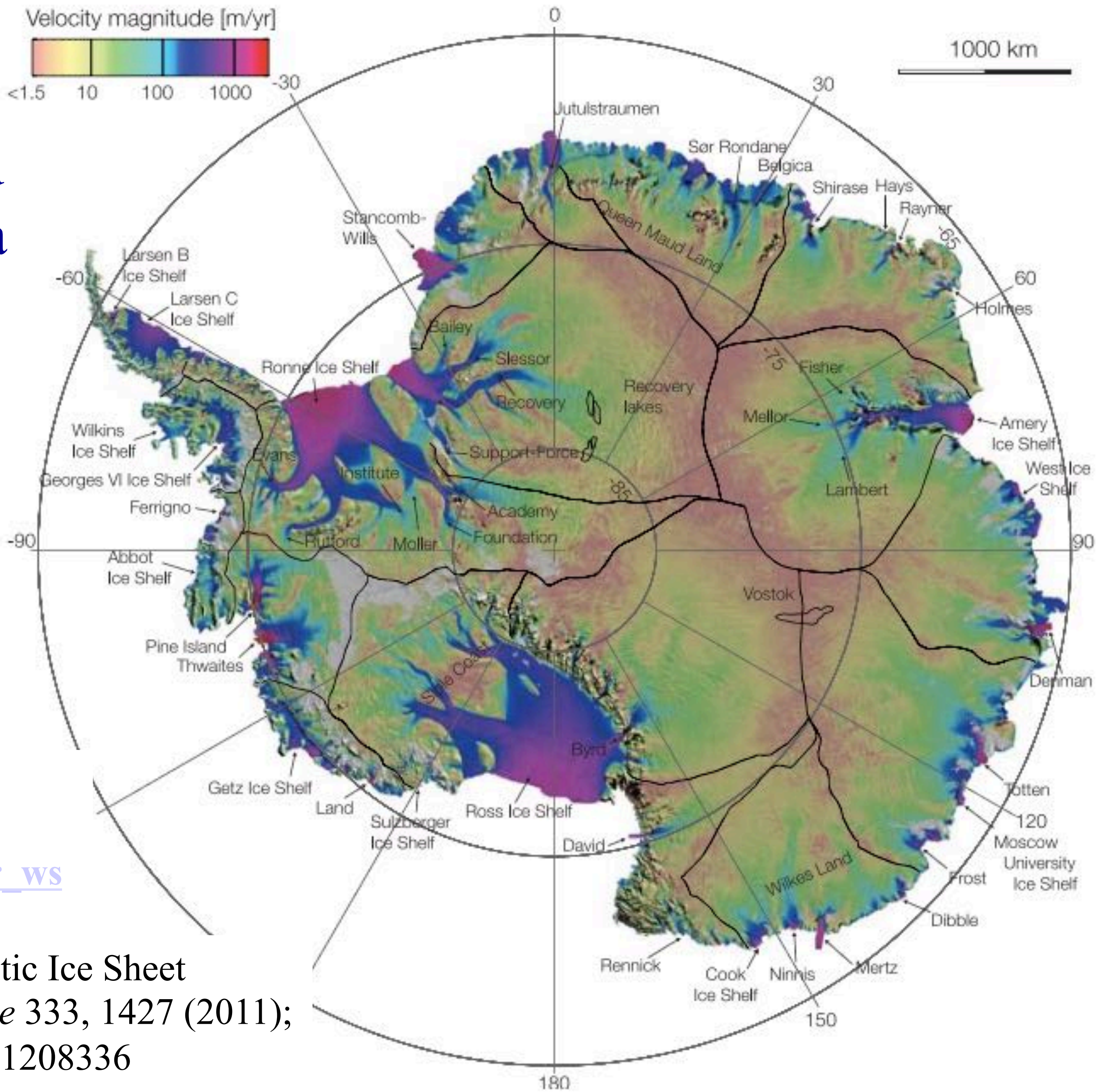


BEDMAP 2



Fretwell et al. (2013)
Bedmap2: improved ice bed, surface and thickness datasets for Antarctica, *The Cryosphere* 7, 375-393

Surface speed in Antarctica



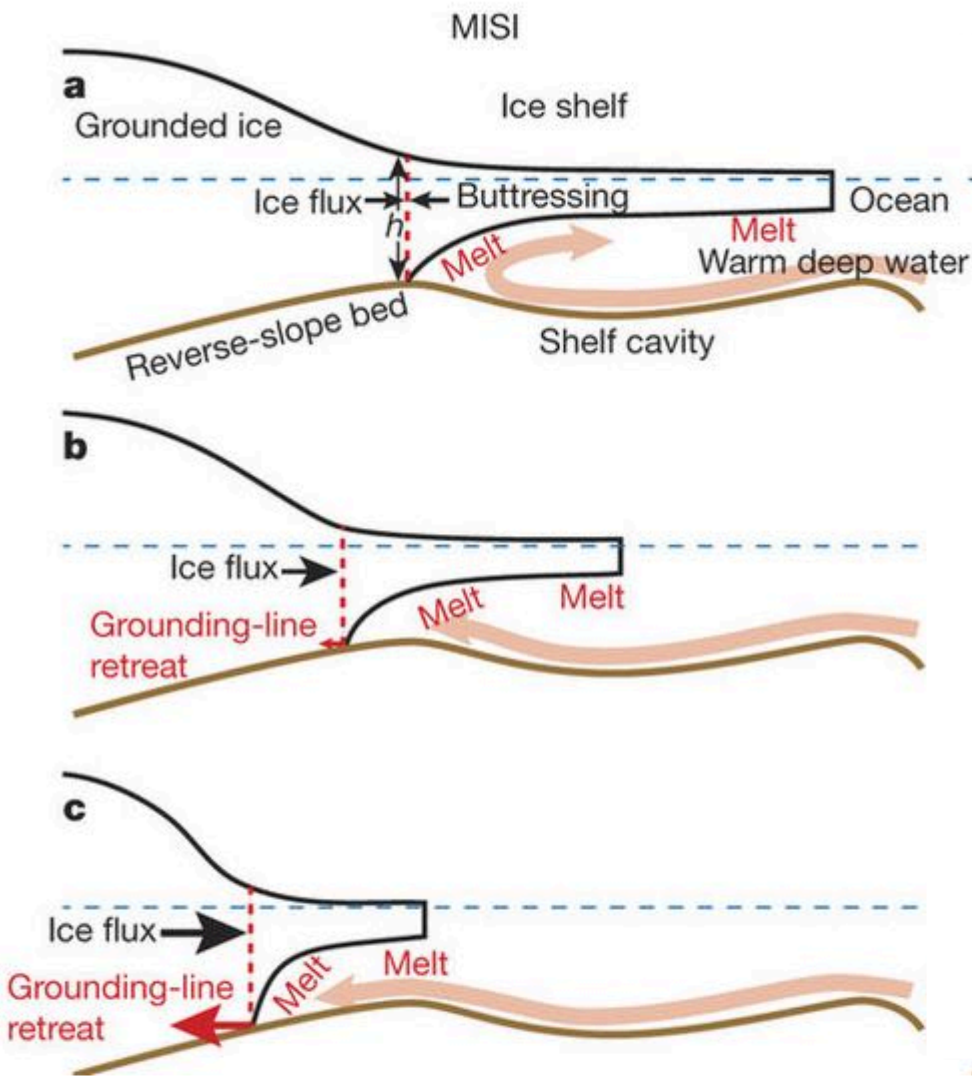
https://www.youtube.com/watch?v=KIDO0C8r_ws

Ice Flow of the Antarctic Ice Sheet
E. Rignot *et al. Science* 333, 1427 (2011);
DOI: 10.1126/science.1208336

Ice flux into the sea can now be calculated from ice thickness and flow speed.

- Asking how long it would take to drain a glacier catchment is now possible …
- But what if the flow speeds up (a lot) …?

Marine Ice Sheet Instability (MISI)



A grounding line in a marine ice sheet can be unstable on a retrograde (back-sloping) bed.

- Slight thinning of the ice at the grounding line (for any reason) can lift up the ice, causing grounding line retreat.
- Loss of bed friction can cause the ice to flow faster, leading to stretching.
- Stretching makes the ice thinner, more susceptible to floating, and grounding line retreats further …
- Meanwhile, warm ocean water can penetrate farther under the ice …

DeConto, R.M. and D. Pollard (2016). Contribution of Antarctica to past and future sea-level rise. *Nature* 532, 591-597.

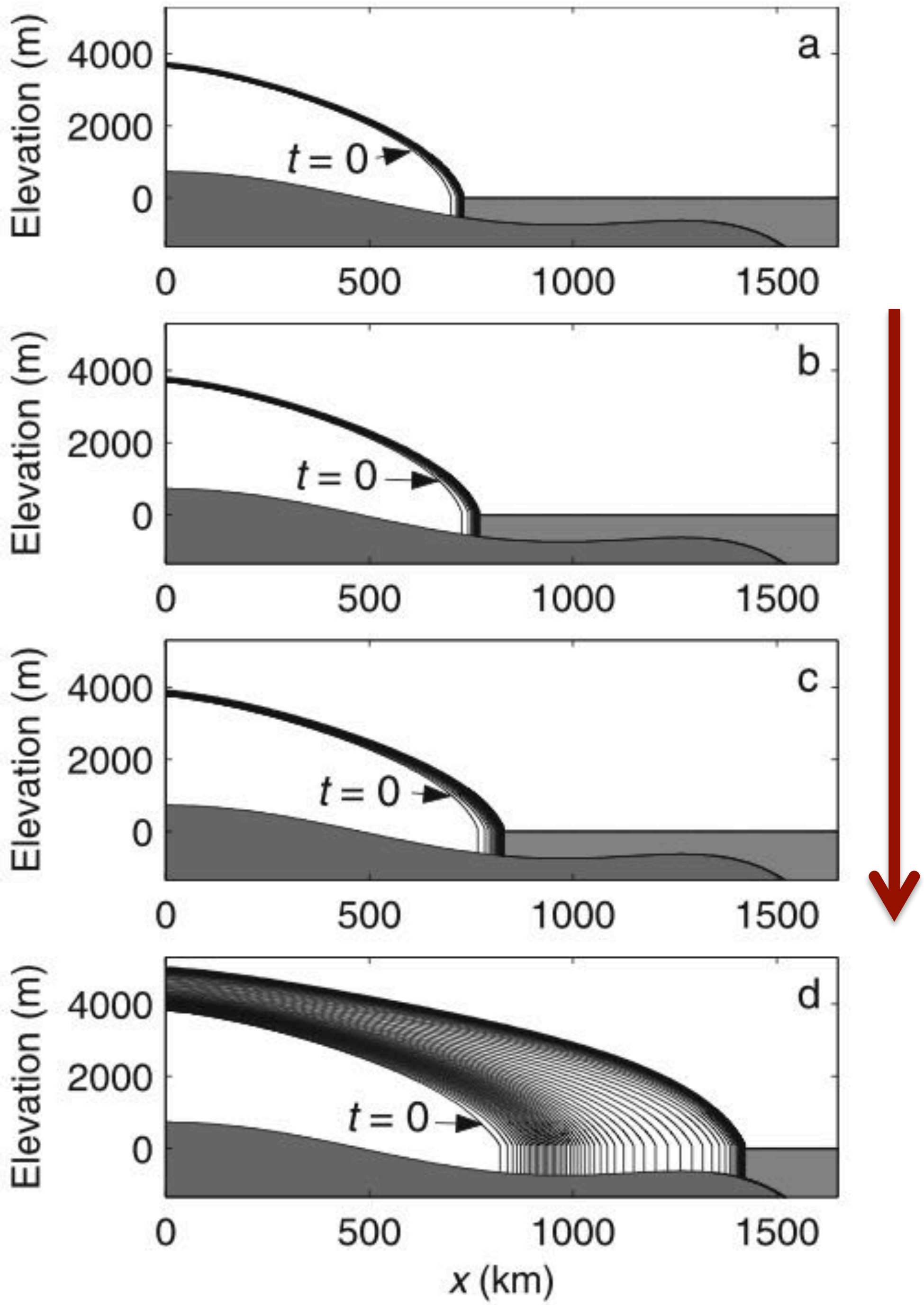
Christian Schoof

Glaciologist at UBC in Vancouver

Computer model of grounding line stability on prograde *vs* retrograde bed slopes

Frames (a) through (d) show grounding-line response to a series of small increases in accumulation, then (e) through (h) show response a series of small decreases.

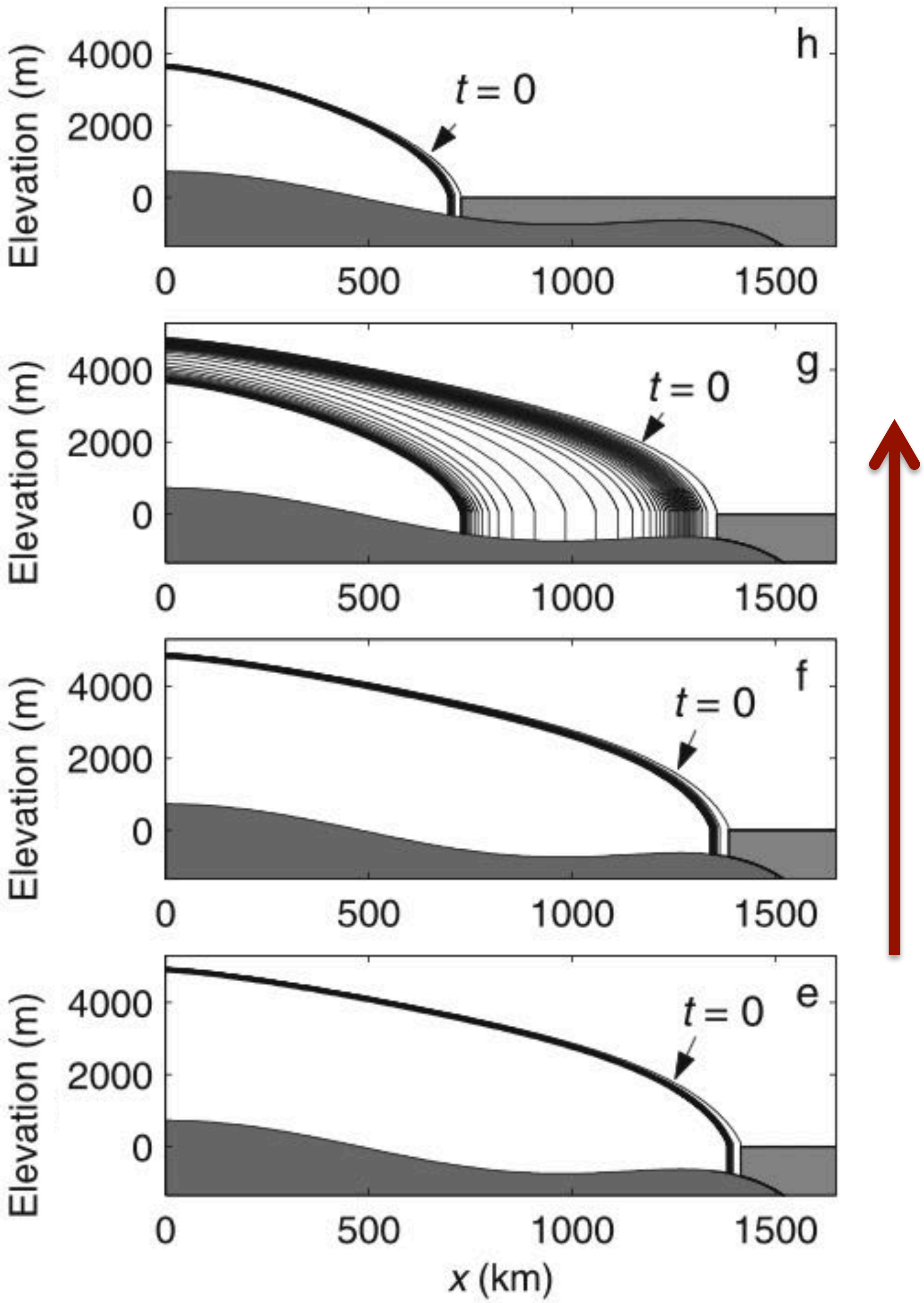
Schoof, C. 2007. Ice sheet grounding line dynamics: Steady states, stability, and hysteresis. *J. Geophysical Research* 112 F03S28, doi:10.1029/2006JF000664



Panels are sequential, and in each panel, profiles are shown at equal times after *t*=0 in that panel.

(a-c) Small incremental increases in snowfall cause small incremental advances down a prograde bed slope.

(d) Subsequent small incremental increase in snowfall causes large unstable advance over retrograde bed slope. Advance stops only when grounding line is again on a prograde bed slope.

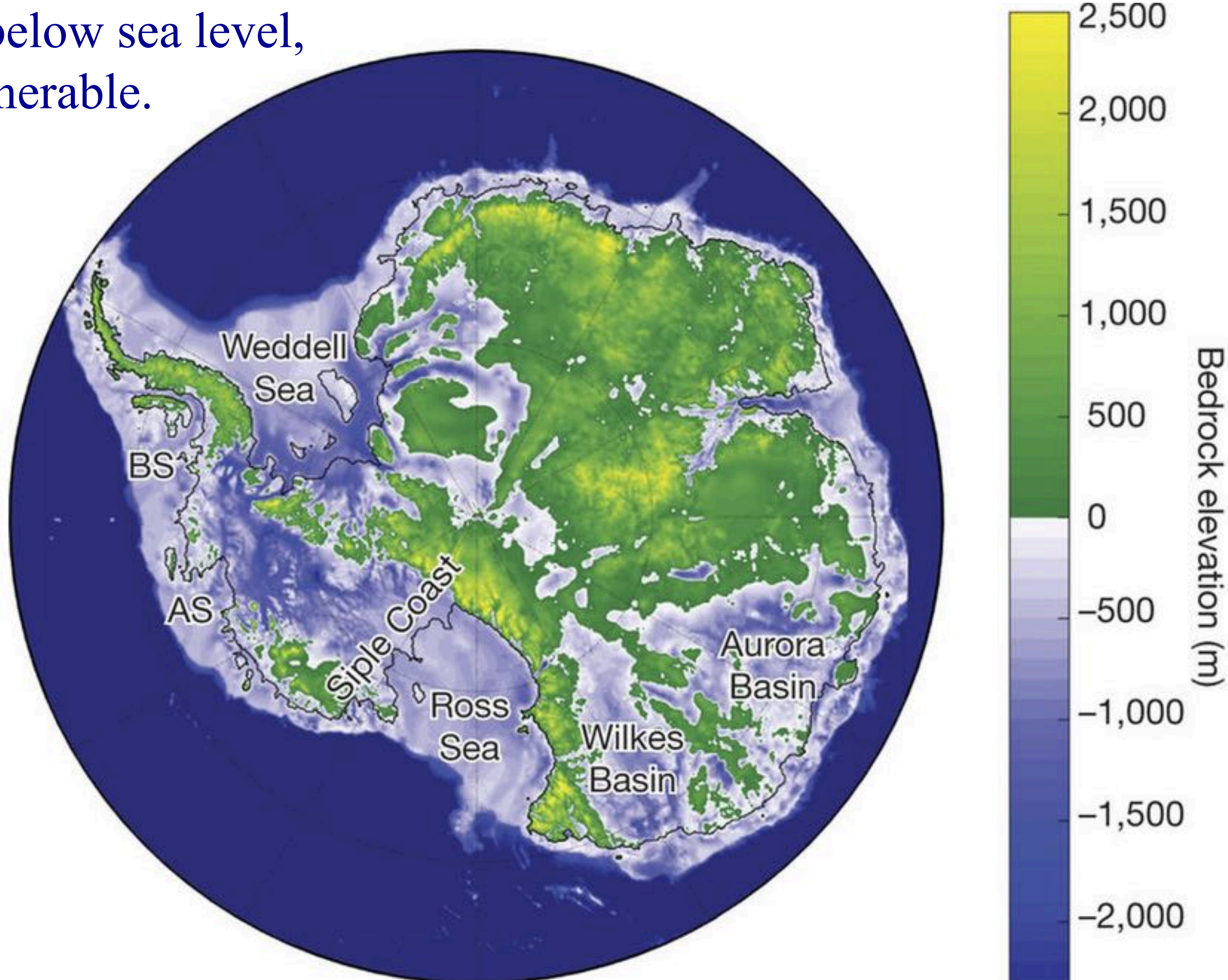


(h) Small incremental decrease in snowfall again causes small retreat up prograde bed slope.

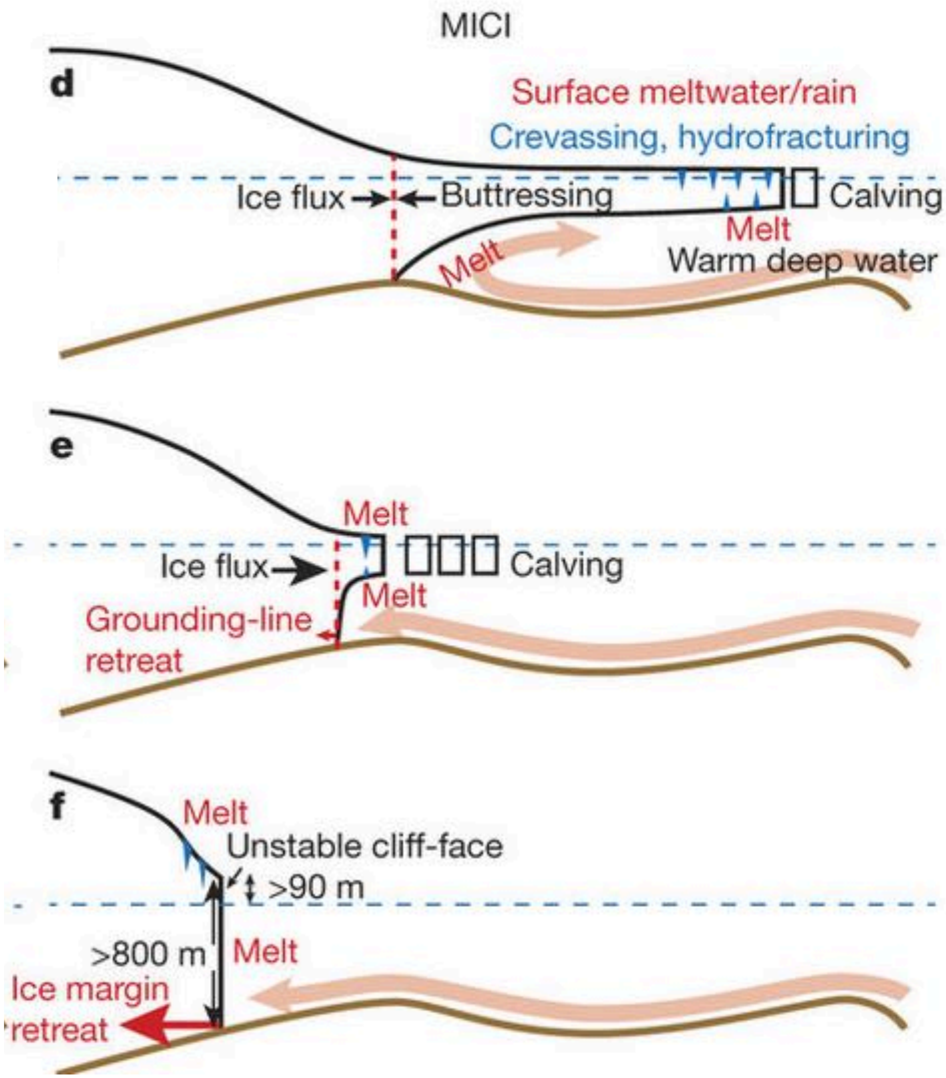
(g) Small incremental decrease in snowfall causes unstable retreat for a large distance down retrograde bed slope.
Retreat stops only when grounding line is again on prograde bed slope.

(e-f) Small incremental decreases in snowfall then cause small incremental retreats back up prograde bed slope.

Many areas in Antarctica have beds below sea level, and are vulnerable.



Marine Ice Cliff Instability (MICI)



It gets worse …

- Ice cliffs standing higher than 120 meters above the water level have never been seen.
- Ice is just not strong enough to support taller cliff faces.
- When a cliff face collapses, the ice near the front gets thinner.
- the ice is more likely to float and to flow faster than it would with a high cliff.
- This compounds the MISI, and retreat is predicted to be even faster.

DeConto, R.M. and D. Pollard (2016). Contribution of Antarctica to past and future sea-level rise. *Nature* 532, 591-597.

ARTICLE

doi:10.1038/nature17145

Contribution of Antarctica to past and future sea-level rise

Robert M. DeConto[1] & David Pollard[2]

Polar temperatures over the last several million years have, at times, been slightly warmer than today, yet global mean sea level has been 6–9 metres higher as recently as the Last Interglacial (130,000 to 115,000 years ago) and possibly higher during the Pliocene epoch (about three million years ago). In both cases the Antarctic ice sheet has been implicated as the primary contributor, hinting at its future vulnerability. Here we use a model coupling ice sheet and climate dynamics—including previously underappreciated processes linking atmospheric warming with hydrofracturing of buttressing ice shelves and structural collapse of marine-terminating ice cliffs—that is calibrated against Pliocene and Last Interglacial sea-level estimates and applied to future greenhouse gas emission scenarios. Antarctica has the potential to contribute more than a metre of sea-level rise by 2100 and more than 15 metres by 2500, if emissions continue unabated. In this case atmospheric warming will soon become the dominant driver of ice loss, but prolonged ocean warming will delay its recovery for thousands of years.

31 MARCH 2016 | VOL 531 | NATURE | 591

DeConto, R.M. and D. Pollard (2016) Contribution of Antarctica to past and future sea-level rise. *Nature* 532, 591-597.

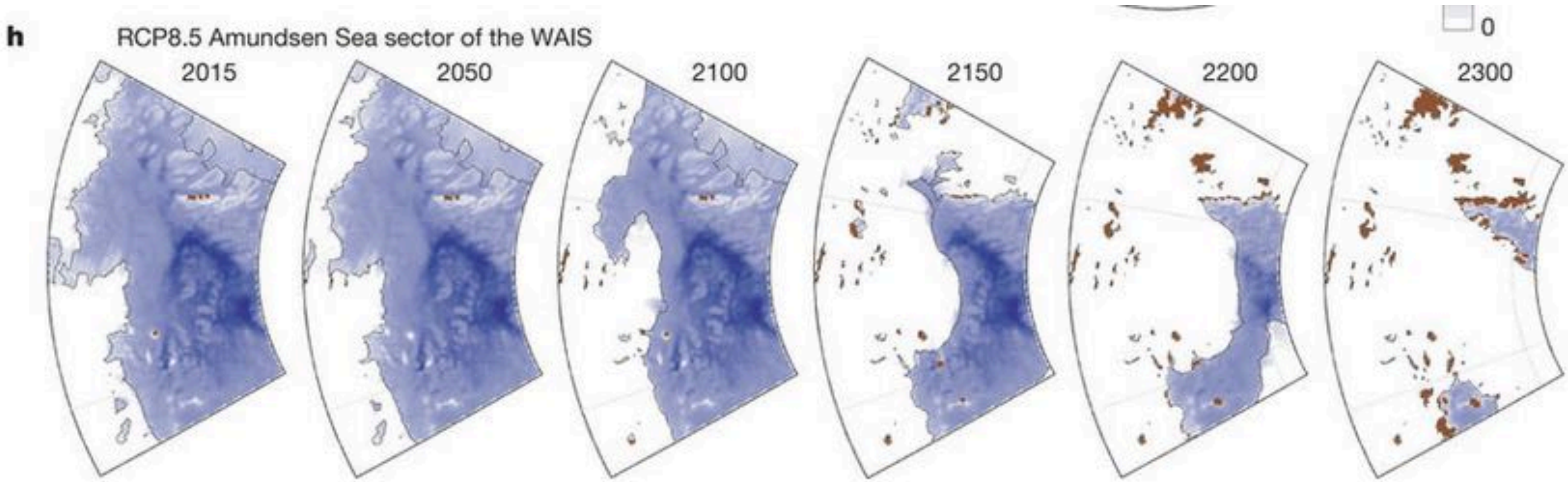
DeConto and Pollard (2016) included MISI and MICI

In their Supplementary Information section they included videos of the ice sheet behavior under various IPCC CO_2 forcing histories, and various ice-sheet physics assumptions.

https://www.nature.com/articles/nature17145#supplementary-information

DeConto, R.M. and D. Pollard (2016). Contribution of Antarctica to past and future sea-level rise. *Nature* 532, 591-597.

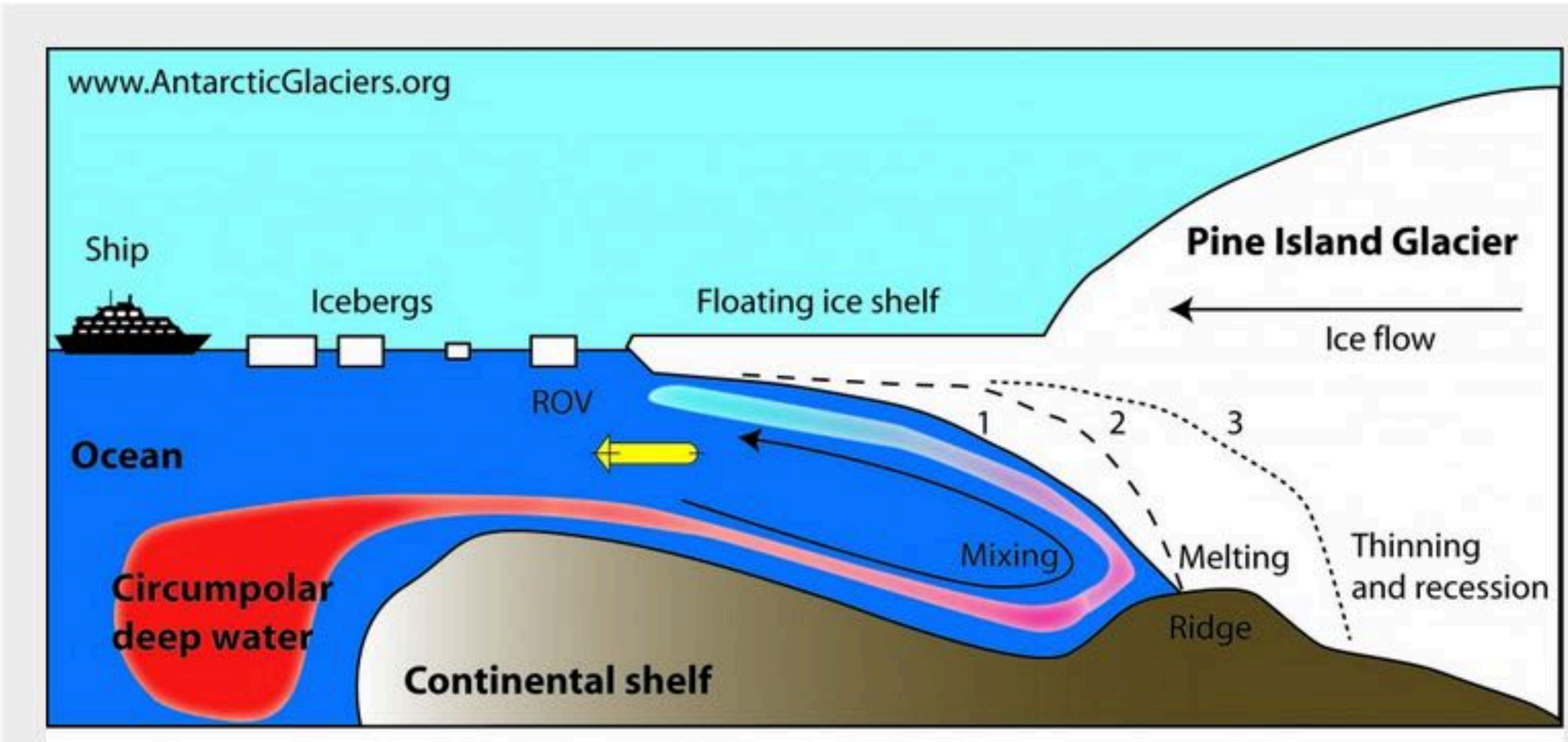
DeConto and Pollard (2014)



Snapshots of ice in Amundsen Sea sector at 50-year intervals for an aggressive greenhouse-gas emission history (RCP8.5)

DeConto, R.M. and D. Pollard (2016). Contribution of Antarctica to past and future sea-level rise. *Nature* 532, 591-597.

Meanwhile other scientists continue to investigate the role of warm ocean water on the continental shelf



http://www.antarcticglaciers.org/2014/05/west-antarctic-ice-sheet-collapsing/

AGU PUBLICATIONS

2017

Geophysical Research Letters

RESEARCH LETTER

10.1002/2017GL072910

Key Points:
- Thwaites Glacier likely to continue losing mass at a similar rate over the next decades
- Grounding line retreat governed

Continued retreat of Thwaites Glacier, West Antarctica, controlled by bed topography and ocean circulation

H. Seroussi[1], Y. Nakayama[1], E. Larour[1], D. Menemenlis[1], M. Morlighem[2], E. Rignot[1,2], and A. Khazendar[1]

"The Amundsen Sea sector is experiencing the largest mass loss, glacier acceleration, and grounding line retreat in Antarctica. Enhanced intrusion of Circumpolar Deep Water onto the continental shelf has been proposed as the primary forcing mechanism for the retreat. ··· Bed topography controls the pattern of grounding line retreat, while oceanic thermal forcing impacts the rate of grounding line retreat. The importance of oceanic forcing increases with time as Thwaites grounding line retreats farther inland."

Questions for Curious Scientists

Explain to a nonscientific family member whether there may be a risk of sea level rise from melting West Antarctica.

- How much might sea-level rise?
- Over what time frame?
- What factors matter?

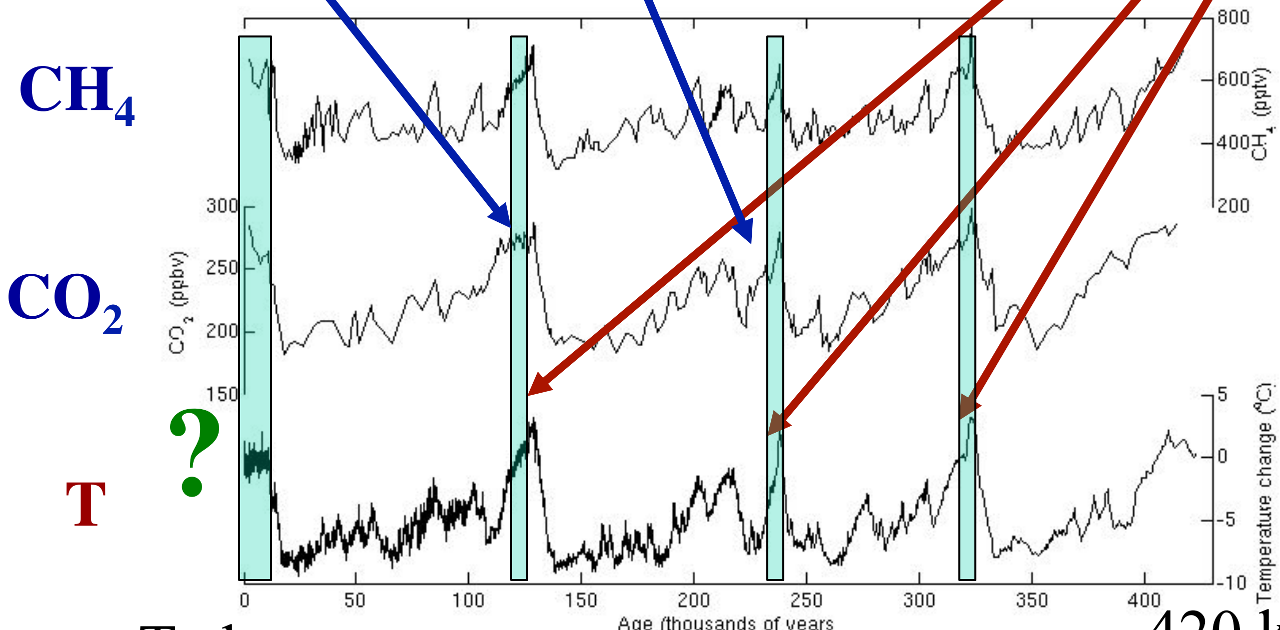
https://docs.google.com/document/d/1GBh9fJSBOiuGBM7lC10xA32G4vZ4CNW9C18Hq8V3kyQ/edit

Ice in our future?

How Long are Interglacials?

- "Typically" 10-15 ka (at least the last 3 were …)
- Temperatures start declining after a few ka
- CO_2 is high at interglacial termination, then holds steady or declines …

Vostok
ice core



Today

420 ka in the past

⟸ **Time**

Future of Ice?

How much ice can humans expect in the future?

10 years	Significantly less	Almost certainly
100 years	A lot less ice	Fairly certain
1000 years	Less?	Uncertain
10,000 years	More ice? Less ice?	New glacial Long interglacial (low eccentricity)

What do the Answers depend on?

10-100 years (your future)

- Political decisions
- Fossil fuel usage → Greenhouse Gases

1000 years

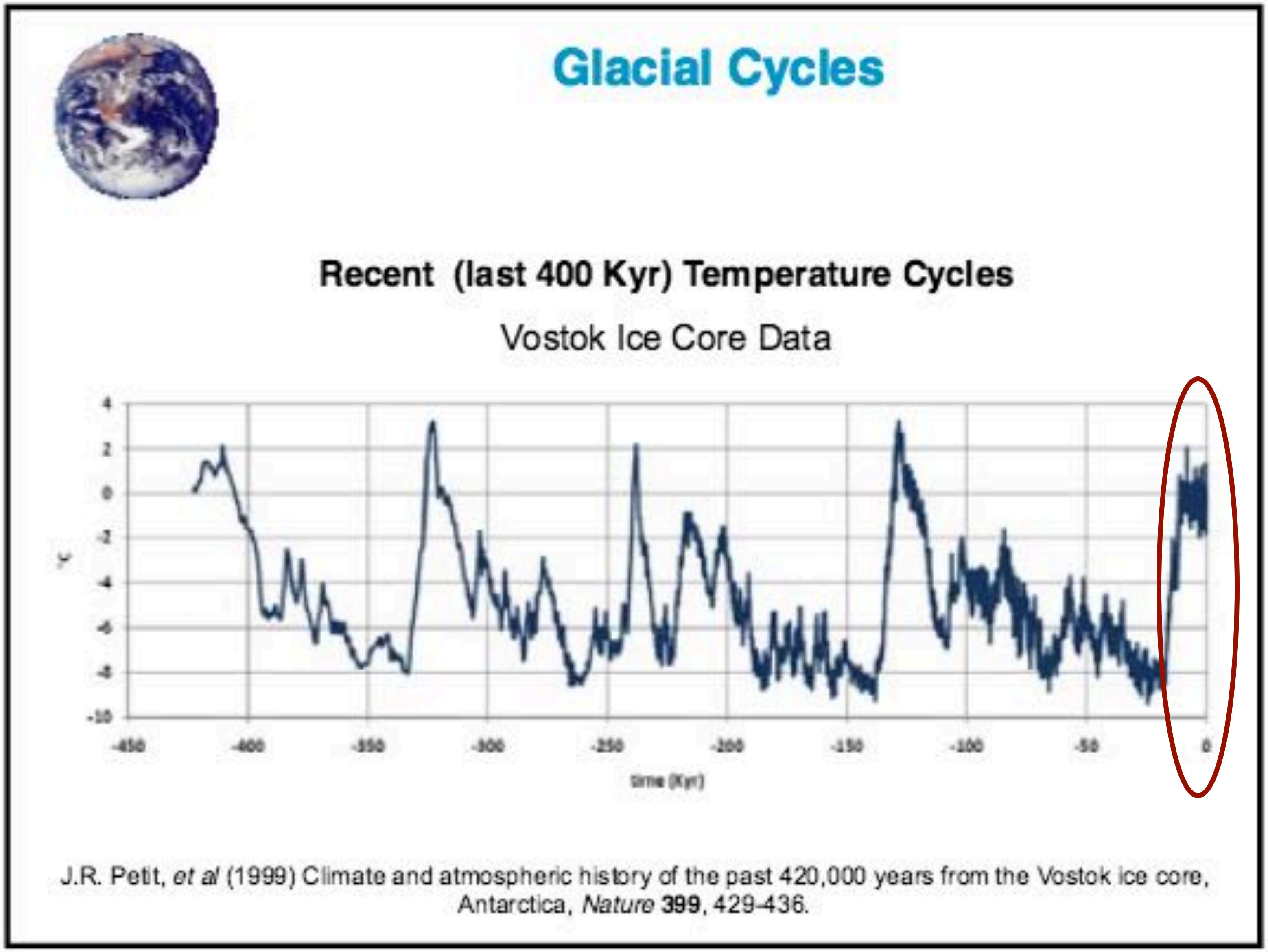
- Politics – Long-term fuel and energy policies
- Culture – Land-use ethics
- Earth-system response – CO_2 uptake in oceans

10,000 years

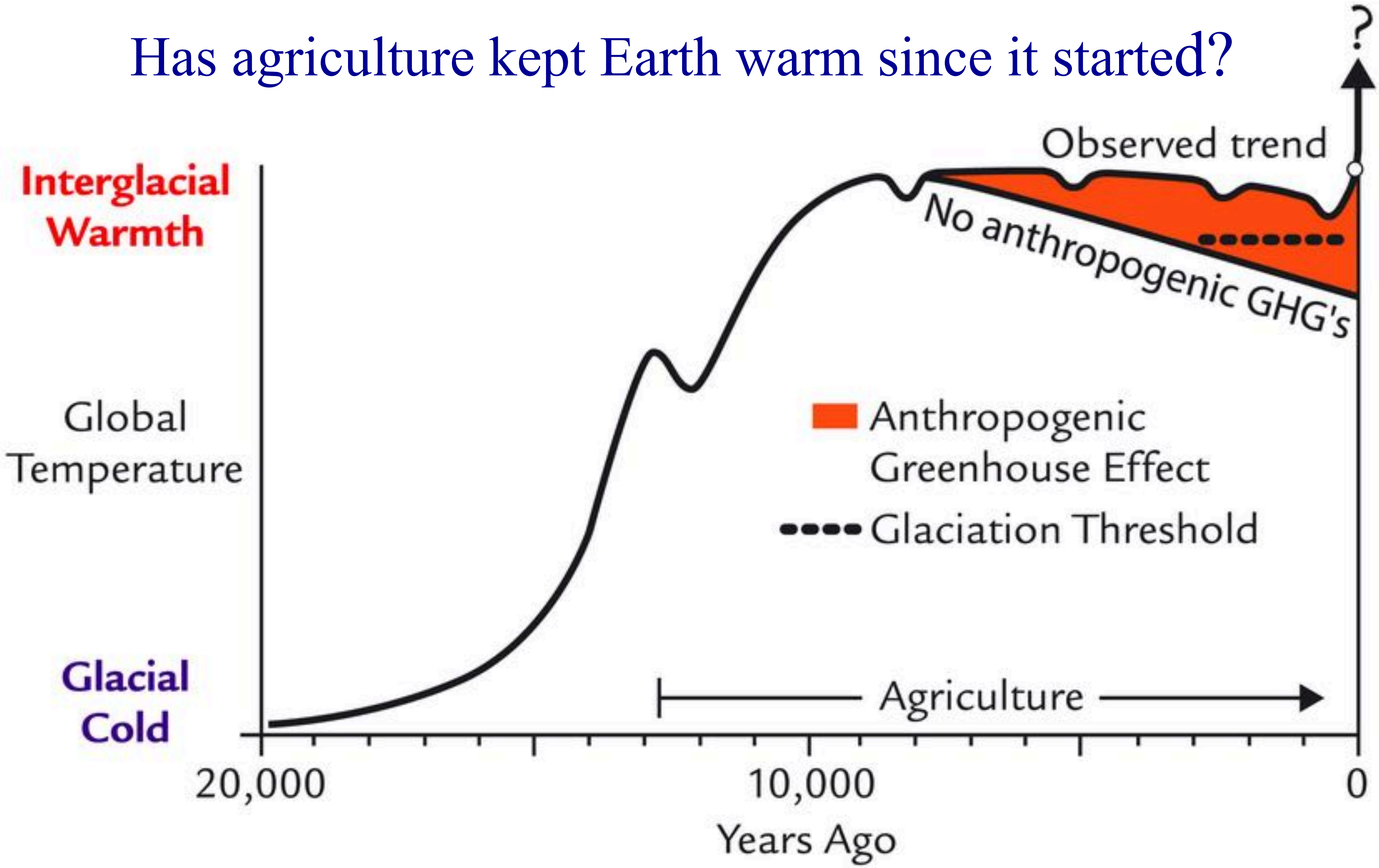
Orbital variations – eccentricity, precession

- Earth system response - CO_2 uptake in oceans

Why does the Holocene last so long?

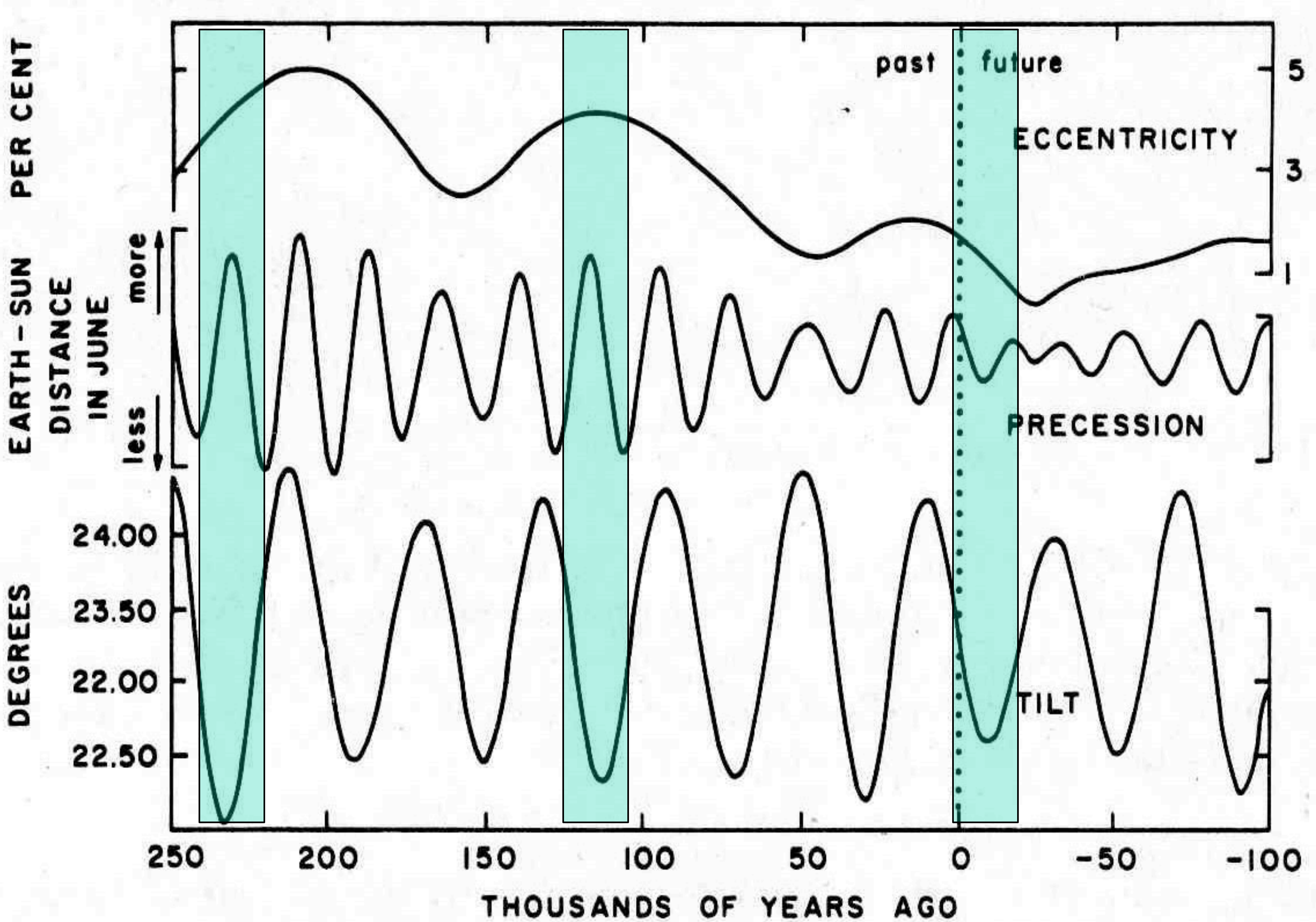


Has agriculture kept Earth warm since it started?



Ruddiman, W. F., et al. (2016), Late Holocene climate: Natural or anthropogenic?, *Rev. Geophys.*, 54, doi:10.1002/2015RG000503

What orbital conditions do we need to start an ice age?



We are approaching low obliquity, but with low eccentricity Earth is *not* far from the sun in northern summer.

What Have We Achieved in ESS 203?

Learning Objectives

- Understand how glaciers ***can change*** Earth in the past, present, and future.
- Understand how glaciers and ice sheets ***can record*** changes in Earth's past.
- Appreciate how scientists communicate their ideas.
- Appreciate how Curious Scientists can understand our complex world by formulating simple questions.
- Appreciate how powerful your thinking can be when you use quantitative estimates to understand processes going on around you.
- Did we get there?
- What other things you have learned?

Final thoughts?

Ode to the Ice

Ice, our ruthless enemy,
reflecting sunlight, cooling the ice-age world,
melting, damming rivers, flooding towns,
breaking bridges, creating scablands,
flooding our beaches and harbors.

Ice, our faithful friend,
reflecting sunlight in a warming world,
watering dry places in summer,
teaching us about our past.

Ice, alas, our faithless friend,
leaving us to our folly
as the heat cranks up,
just when we need it most.

(Anon.)

Have a great break!