Future Climate Change

EES 2110

Introduction to Climate Change

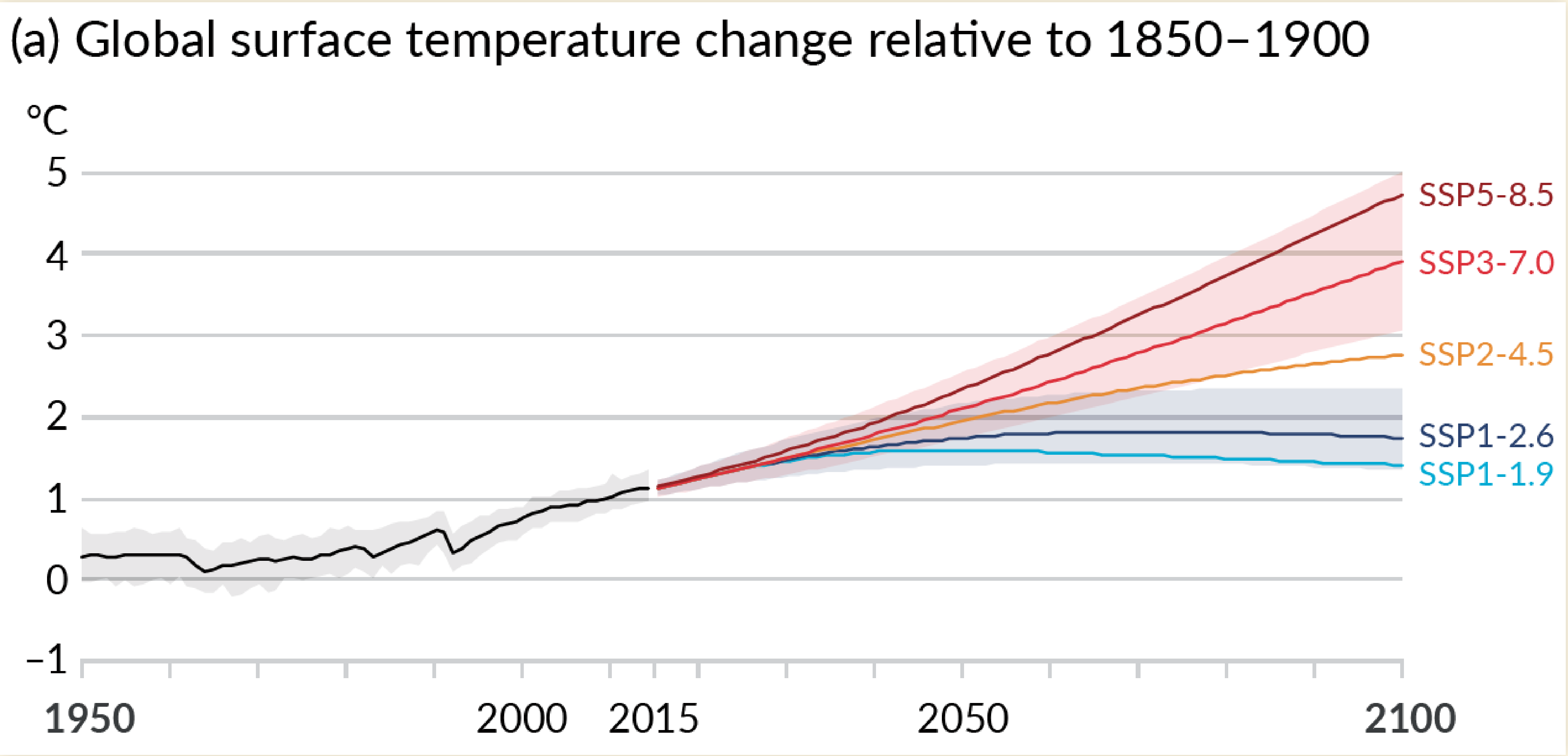
Jonathan Gilligan

Class #27: Monday, March 20 2023

Future Temperature Change

Future Temperature Change

- Projected temperature change through 2100:



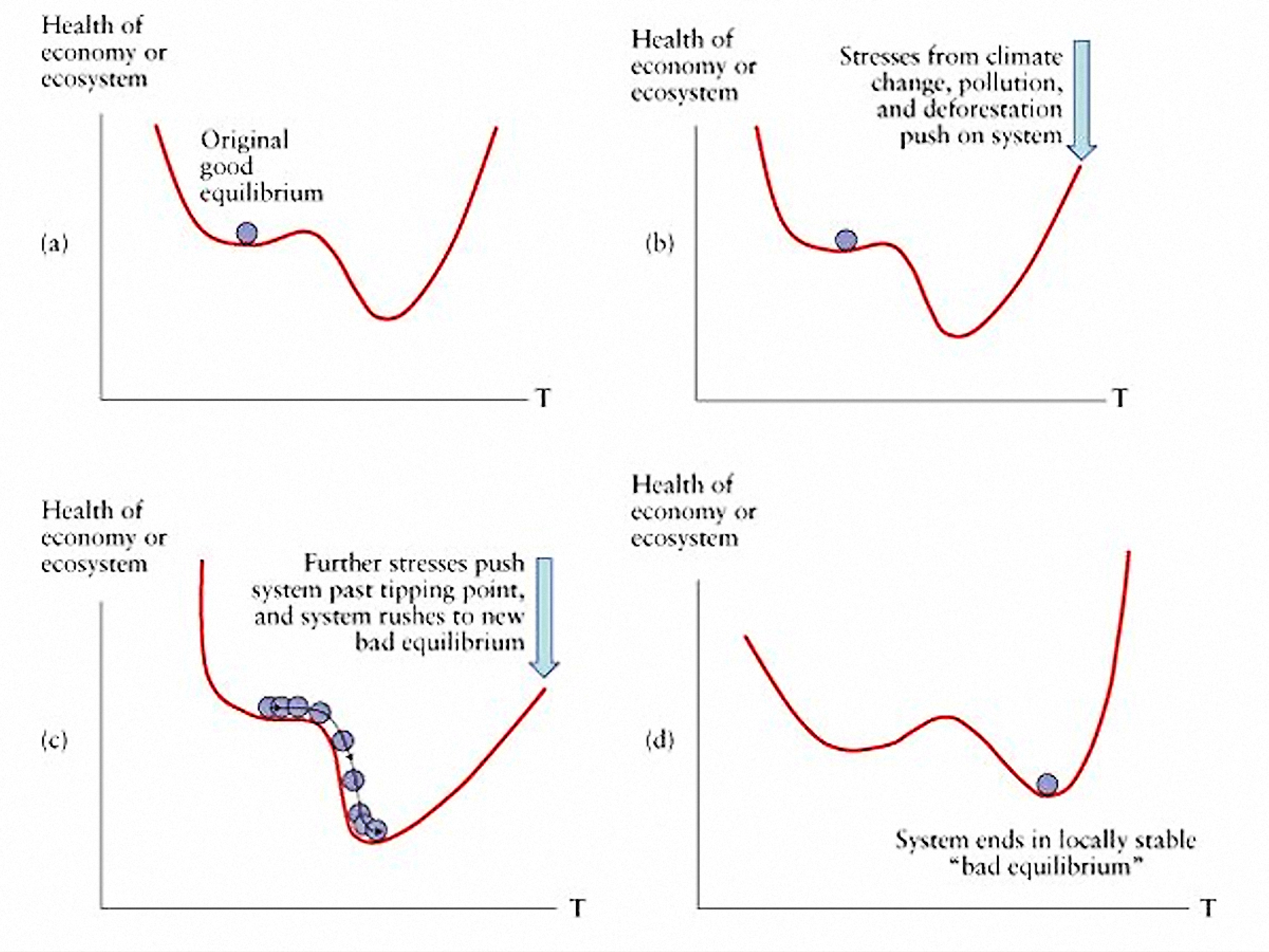
  - Greatest uncertainty is future greenhouse gas emissions
  - Worst case (SSP5-8.5) is very unlikely
  - Most likely without major policy changes: 4.5–7.0
  - With aggressive action to quickly reduce emissions: 1.9–2.6

Tipping points

What we know about tipping points

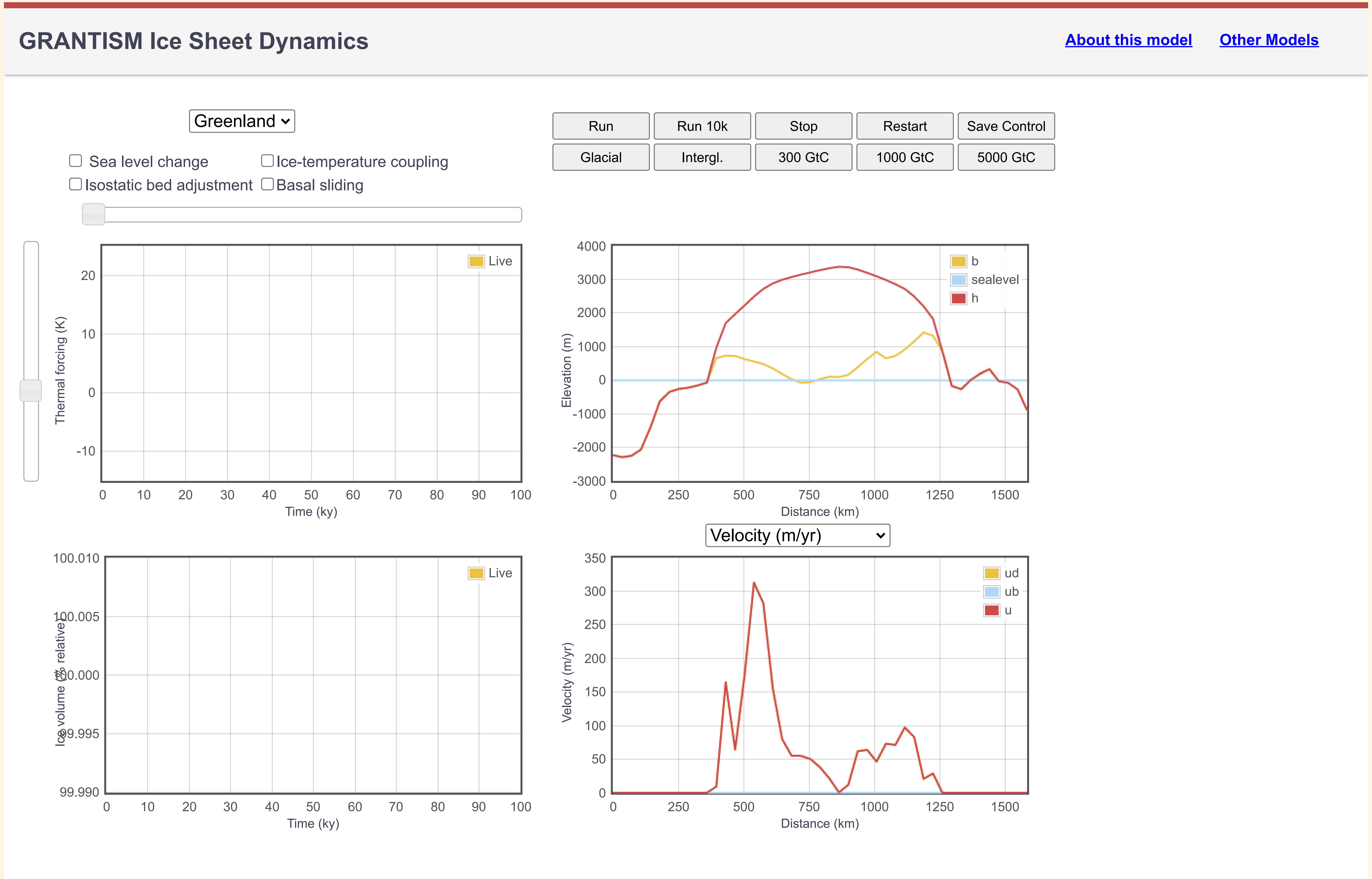
- Very hard to predict them.
- *Climate Casino*: important tipping points:
  - Ice sheet melting
  - Coral reefs
  - Tropical rain Forests
  - Runaway greenhouse gas release
  - Slowdown of ocean conveyor belt circulation
  - …

Bistability & Tipping Points

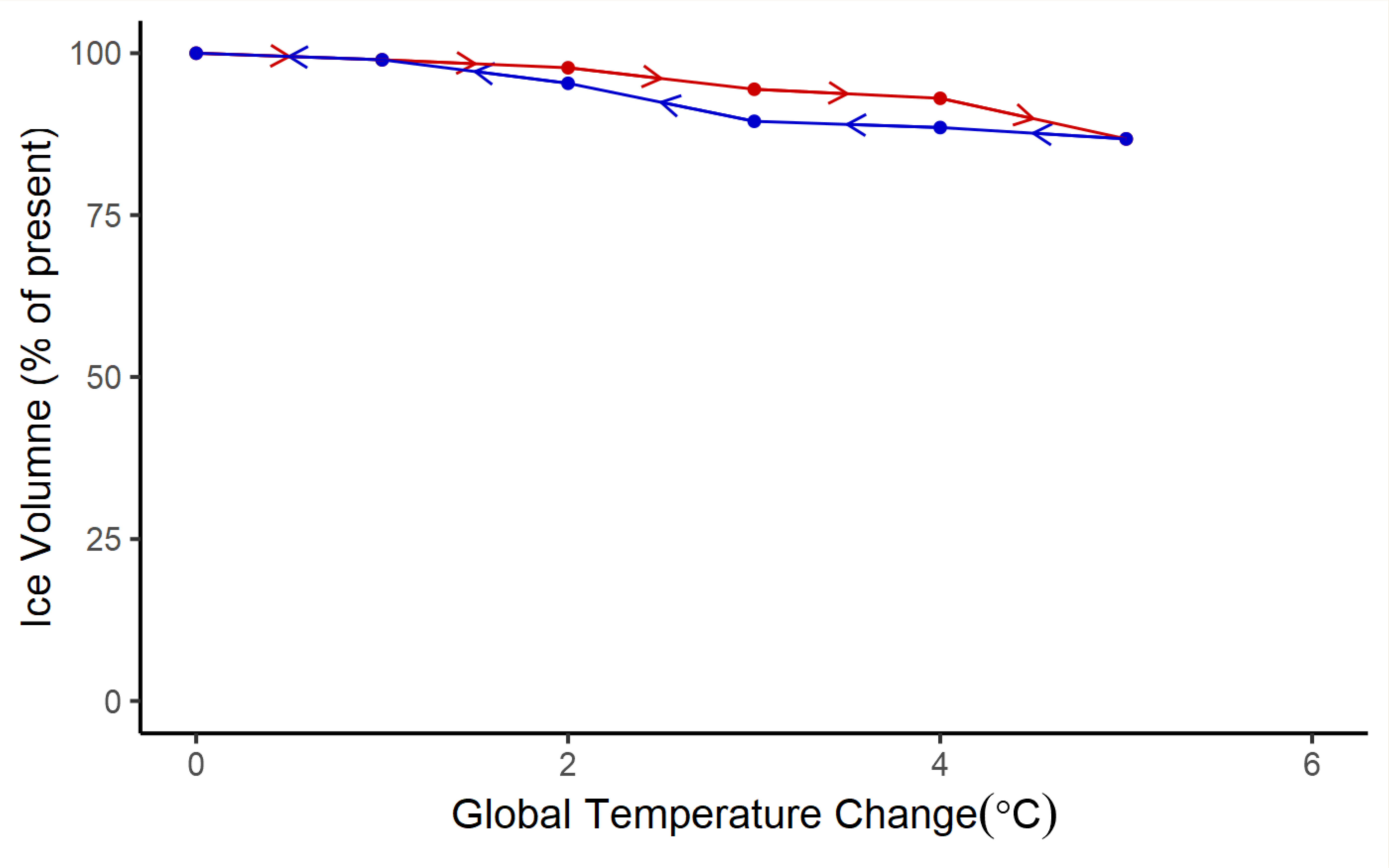


Hysteresis and Tipping Points

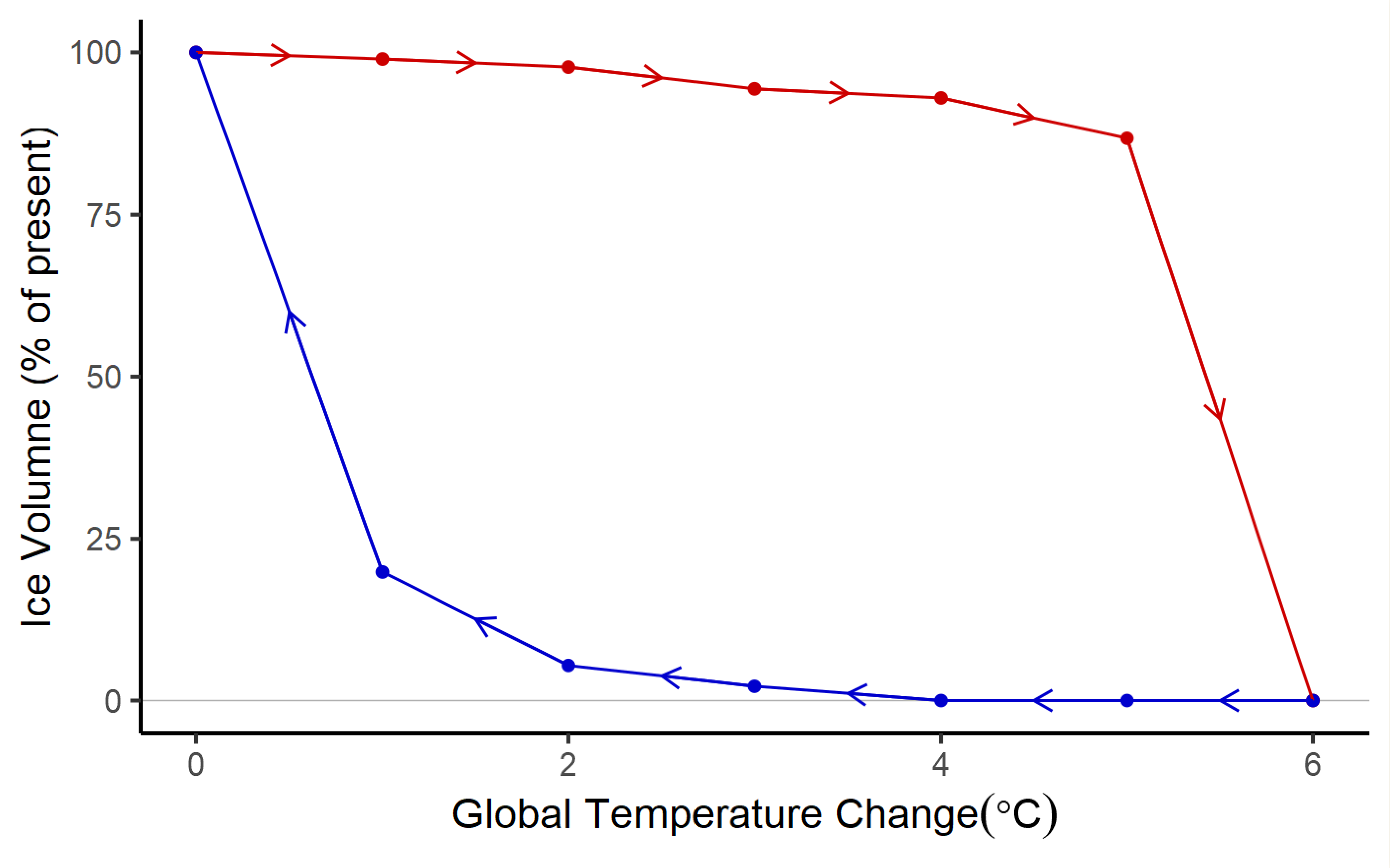
GRANTISM Model



Hysteresis:
Temperature and Ice Sheets



Hysteresis:
Crossing Tipping Point



Principles of Tipping Points

- Ordinary positive feedbacks amplify changes
  (hot → hotter, cold → colder).
  - Small positive feedbacks amplify but the *system remains stable*.
- If positive feedbacks are too strong they become *self-perpetuating*.
  - Secondary forcing from feedback creates *unstoppable change*.
- If feedback *strengthens with warming*:
  - Tipping point: feedback becomes strong enough
    to continue warming independent of external forcing.
- **Not all positive feedbacks have tipping points.**
- **Hard to predict** when a positive feedback might go from *amplifying* to *runaway* (tipping point).

Where are they?

- *Climate Casino*: No big danger of fast tipping points if warming stays less than 3°C
- But, recent research finds that West Antarctic Ice Sheet has already crossed irreversible tipping point.

2019 Scientific Paper

Comment

Climate tipping points — too risky to bet against

Timothy M. Lenton, Johan Rockström, Owen Gaffney, Stefan Rahmstorf, Katherine Richardson, Will Steffen & Hans Joachim Schellnhuber

The growing threat of abrupt and irreversible climate changes must compel political and economic action on emissions.

Politicians, economists and even some natural scientists have tended to assume that tipping points[1] in the Earth system — such as the loss of the Amazon rainforest or the West Antarctic ice sheet — are of low probability and little understood. Yet evidence is mounting that these events could be more likely than was thought, have high impacts and are interconnected across different biophysical systems, potentially committing the world to long-term irreversible changes.

Here we summarize evidence on the threat of exceeding tipping points, identify knowledge gaps and suggest how these should be plugged. We explore the effects of such large-scale changes, how quickly they might unfold and whether we still have any control over them.

In our view, the consideration of tipping points helps to define that we are in a climate emergency and strengthens this year's chorus of calls for urgent climate action — from schoolchildren to scientists, cities and countries.

The Intergovernmental Panel on Climate Change (IPCC) introduced the idea of tipping points two decades ago. At that time, these 'large-scale discontinuities' in the climate system were considered likely only if global warming exceeded 5 °C above pre-industrial levels. Information summarized in the two most recent IPCC Special Reports (published in 2018 and in September this year)[2,3] suggests that tipping points could be exceeded even between 1 and 2 °C of warming (see 'Too close for comfort').

If current national pledges to reduce greenhouse-gas emissions are implemented — and that's a big 'if' — they are likely to result in at least 3 °C of global warming. This is despite the goal of the 2015 Paris agreement to limit warming to well below 2 °C. Some economists, assuming that climate tipping points are of very low probability (even if they would be catastrophic), have suggested that 3 °C warming is optimal from a cost–benefit perspective. However, if tipping points are looking more likely, then the 'optimal policy' recommendation of simple cost–benefit climate-economy models[4] aligns with those of the recent IPCC report[2]. In other words, warming must be limited to 1.5 °C. This requires an emergency response.

Ice collapse

We think that several cryosphere tipping points are dangerously close, but mitigating greenhouse-gas emissions could still slow down the inevitable accumulation of impacts and help us to adapt.

Research in the past decade has shown that the Amundsen Sea embayment of West Antarctica might have passed a tipping point[3]: the 'grounding line' where ice, ocean and bedrock meet is retreating irreversibly. A model study shows[5] that when this sector collapses, it could destabilize the rest of the West Antarctic ice sheet like toppling dominoes — leading to about 3 metres of sea-level rise on a timescale of centuries to millennia. Palaeo-evidence shows that such widespread collapse of the West Antarctic ice sheet has occurred repeatedly in the past.

The latest data show that part of the East Antarctic ice sheet — the Wilkes Basin — might be similarly unstable[3]. Modelling work suggests that it could add another 3–4 m to sea level on timescales beyond a century.

The Greenland ice sheet is melting at an accelerating rate[3]. It could add a further 7 m to sea level over thousands of years if it passes a particular threshold. Beyond that, as the elevation of the ice sheet lowers, it melts further, exposing the surface to ever-warmer air. Models suggest that the Greenland ice sheet could be doomed at 1.5 °C of warming[3], which could happen as soon as 2030.

Thus, we might already have committed future generations to living with sea-level rises of around 10 m over thousands of years[3]. But that timescale is still under our control. The rate of melting depends on the magnitude of warming above the tipping point. At 1.5 °C, it could take 10,000 years to unfold[3]; above 2 °C it could take less than 1,000 years[6].

An aeroplane flies over a glacier in the Wrangell St Elias National Park in Alaska.

FRANS LANTING/NAT. GEO. IMAGE COLLECTION

Researchers need more observational data to establish whether ice sheets are reaching a tipping point, and require better models constrained by past and present data to resolve how soon and how fast the ice sheets could collapse.

Whatever those data show, action must be taken to slow sea-level rise. This will aid adaptation, including the eventual resettling of large, low-lying population centres.

A further key impetus to limit warming to 1.5 °C is that other tipping points could be triggered at low levels of global warming. The latest IPCC models projected a cluster of abrupt shifts[7] between 1.5 °C and 2 °C, several of which involve sea ice. This ice is already shrinking rapidly in the Arctic, indicating that, at 2 °C of warming, the region has a 10–35% chance[3] of becoming largely ice-free in summer.

> "The clearest emergency would be if we were approaching a global cascade of tipping points."

Biosphere boundaries

Climate change and other human activities risk triggering biosphere tipping points across a range of ecosystems and scales (see 'Raising the alarm').

Ocean heatwaves have led to mass coral bleaching and to the loss of half of the shallow-water corals on Australia's Great Barrier Reef. A staggering 99% of tropical corals are projected[2] to be lost if global average temperature rises by 2 °C, owing to interactions between warming, ocean acidification and pollution. This would represent a profound loss of marine biodiversity and human livelihoods.

As well as undermining our life-support system, biosphere tipping points can trigger abrupt carbon release back to the atmosphere. This can amplify climate change and reduce remaining emission budgets.

Deforestation and climate change are destabilizing the Amazon — the world's largest rainforest, which is home to one in ten known species. Estimates of where an Amazon tipping point could lie range from 40% deforestation to just 20% forest-cover loss[8]. About 17% has been lost since 1970. The rate of deforestation varies with changes in policy. Finding the tipping point requires models that include deforestation and climate change as interacting drivers, and that incorporate fire and climate feedbacks as interacting tipping mechanisms across scales.

With the Arctic warming at least twice as quickly as the global average, the boreal forest in the subarctic is increasingly vulnerable. Already, warming has triggered large-scale insect disturbances and an increase

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T. Lenton *et al.*, Nature **575**, 592 (2019).

More recent papers:

PERSPECTIVE

The quiet crossing of ocean tipping points

Christoph Heinze[a,b,1], Thorsten Blenckner[c], Helena Martins[d], Dagmara Rusiecka[a,b], Ralf Döscher[d], Marion Gehlen[e], Nicolas Gruber[f], Elisabeth Holland[g], Øystein Hov[h,i], Fortunat Joos[j,k], John Brian Robin Matthews[l], Rolf Rødven[m], and Simon Wilson[m]

C. Heinze, *et al.* (2021). PNAS **118**. https://doi.org/10.1073/pnas.2008478118

REVIEW ARTICLE
https://doi.org/10.1038/s41561-021-00790-5
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Past abrupt changes, tipping points and cascading impacts in the Earth system

V. Brovkin, *et al.* (2021). Nature Geoscience, **14**, 550. https://doi.org/10.1038/s41561-021-00790-5

Environmental Science & Technology
pubs.acs.org/est
Article

Multiple Climate Tipping Points Metrics for Improved Sustainability Assessment of Products and Services

Serena Fabbri,* Michael Z. Hauschild, Timothy M. Lenton, and Mikołaj Owsianiak

S. Fabbri, S. *et al.* (2021). Environ. Sci. & Technol., **55**, 2800. https://doi.org/10.1021/acs.est.0c02928

Economic impacts of tipping points in the climate system

Simon Dietz[a,b,1], James Rising[c], Thomas Stoerk[b], and Gernot Wagner[d]

Significance

Tipping points in the climate system are one of the principal reasons for concern about climate change. Climate economists have only recently begun incorporating them in economic models. We synthesize this emerging literature and provide unified, geophysically realistic estimates of the economic impacts of eight climate tipping points with an emphasis on the social cost of carbon, a key policy input.

S. Dietz *et al.*, (2021). PNAS, **118**. https://doi.org/10.1073/pnas.2103081118

scientific reports

OPEN

Multiple climate change-driven tipping points for coastal systems

Patrick L. Barnard[1], Jenifer E. Dugan[2], Henry M. Page[2], Nathan J. Wood[3], Juliette A. Finzi Hart[1], Daniel R. Cayan[4], Li H. Erikson[1], David M. Hubbard[2], Monique R. Myers[5], John M. Melack[6] & Sam F. Iacobellis[4]

P. Barnard *et al.* (2021). Scientific Reports **11**, 15560. https://doi.org/10.1038/s41598-021-94942-7

RESEARCH ARTICLE SUMMARY

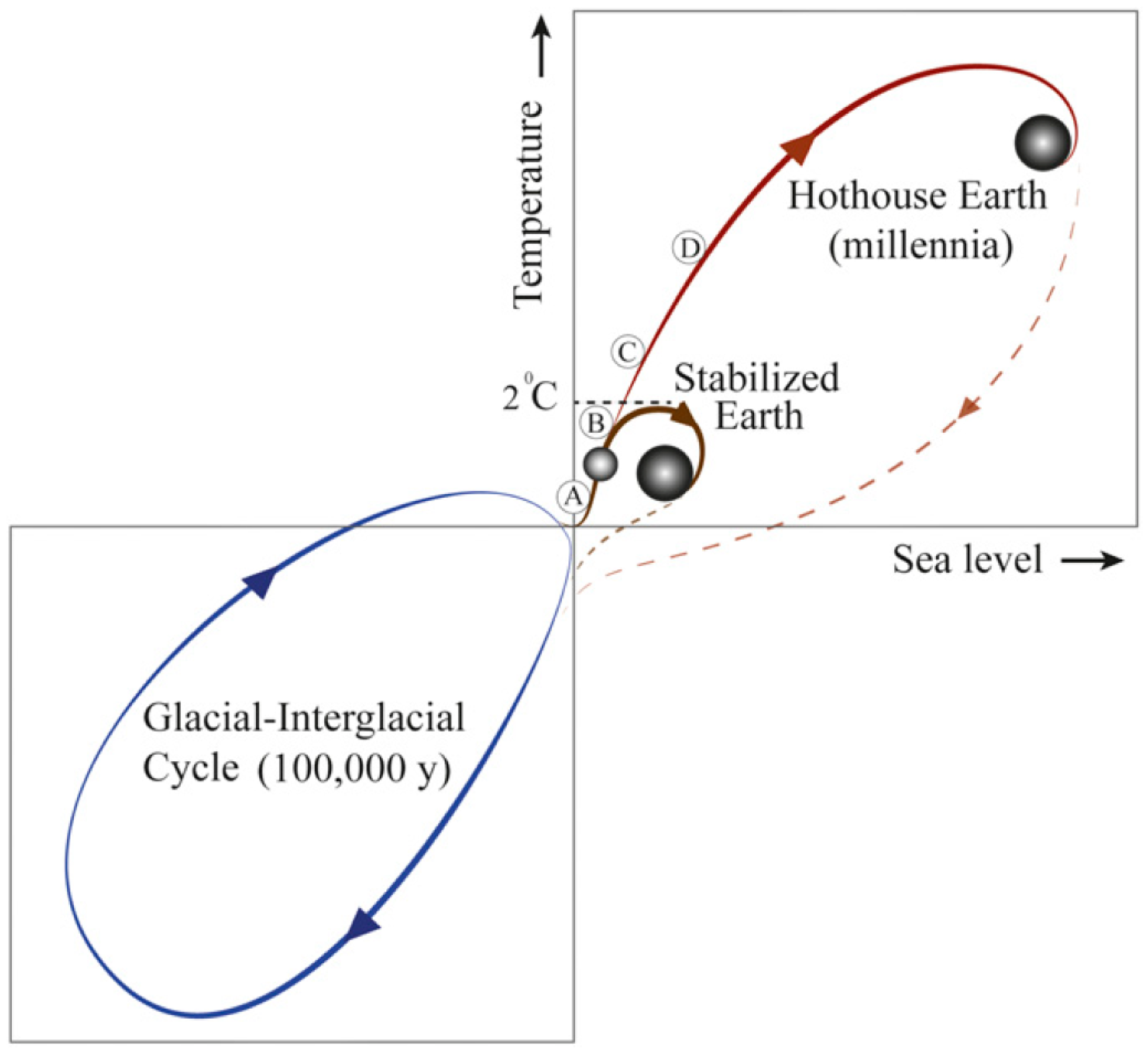
CLIMATE CHANGE

Exceeding 1.5°C global warming could trigger multiple climate tipping points

David I. Armstrong McKay*, Arie Staal, Jesse F. Abrams, Ricarda Winkelmann, Boris Sakschewski, Sina Loriani, Ingo Fetzer, Sarah E. Cornell, Johan Rockström, Timothy M. Lenton*

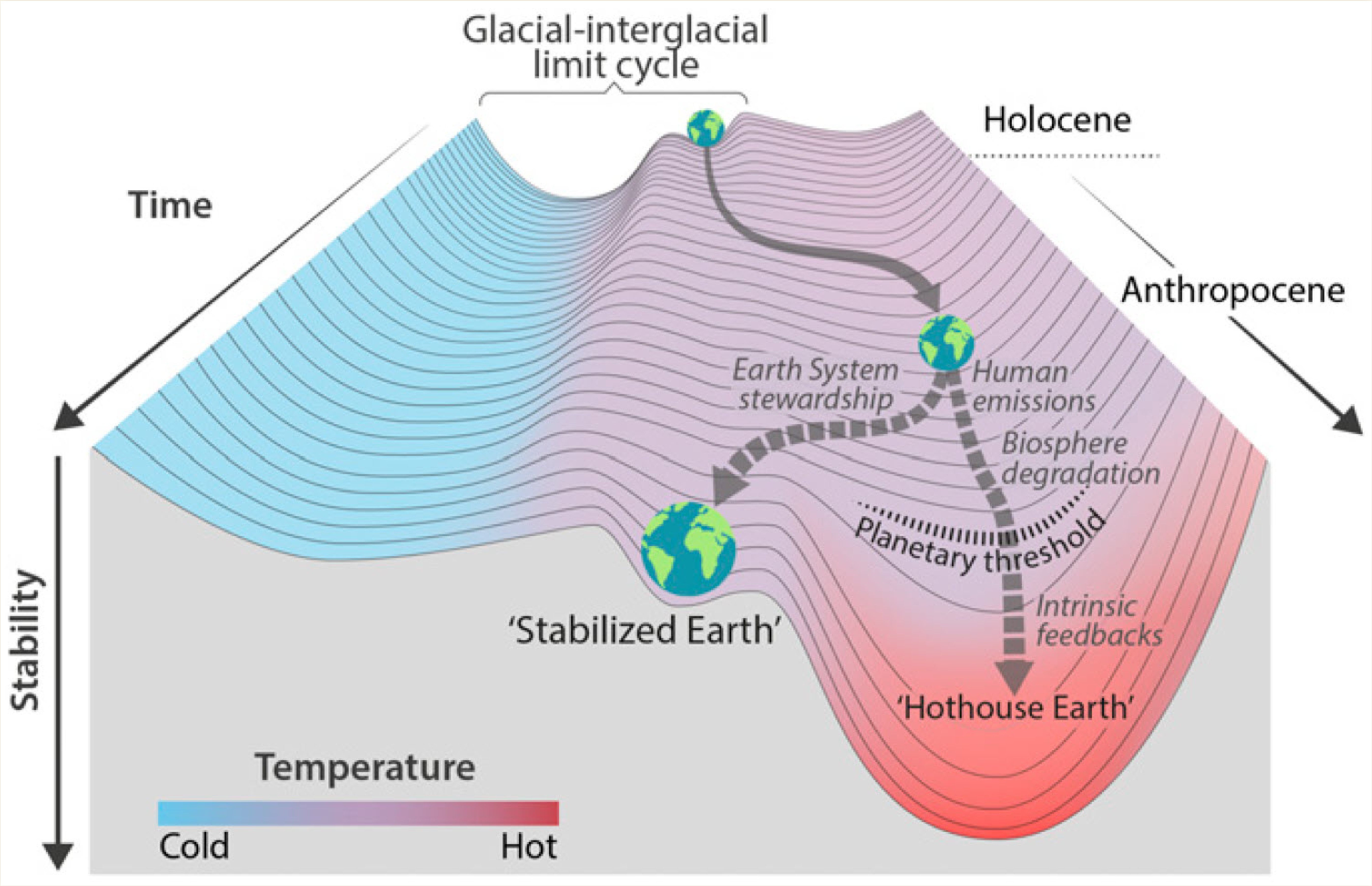
D.I. Armstrong McKay *et al.* (2022). Science **377**, 1171. https://doi.org/10.1126/science.abn7590

Tipping Points and Earth's History



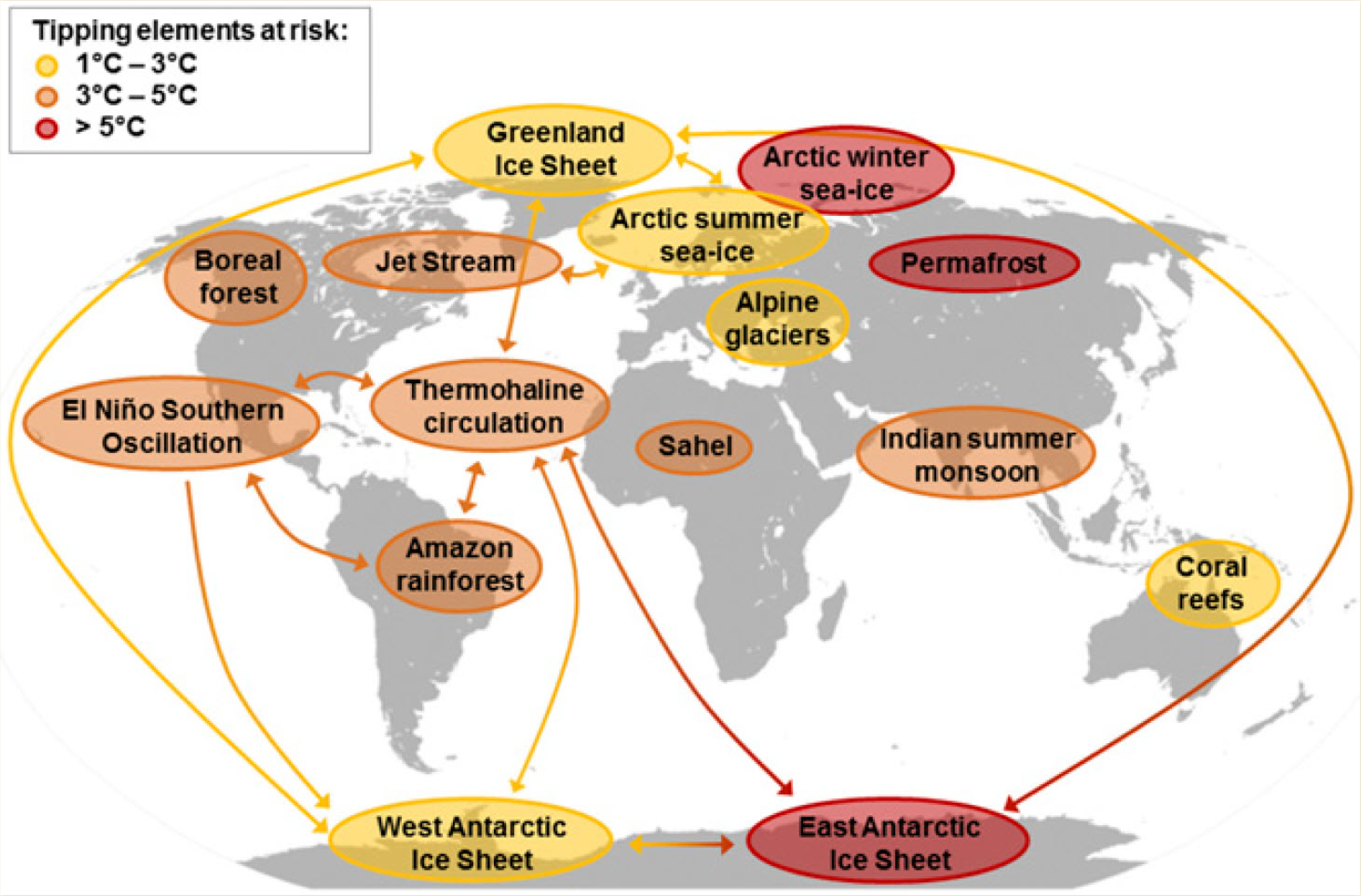
W. Steffen *et al.* (2018). PNAS **115**, 8252. https://doi.org/10.1073/pnas.1810141115

Dynamics of Tipping Points



W. Steffen *et al.* (2018). PNAS **115**, 8252. https://doi.org/10.1073/pnas.1810141115

Details of Tipping Points



W. Steffen *et al.* (2018). PNAS **115**, 8252. https://doi.org/10.1073/pnas.1810141115

Lessons from Earth’s Climate History

Abrupt Changes and Tipping Points in the Past

REVIEW ARTICLE
https://doi.org/10.1038/s41561-021-00790-5

nature geoscience

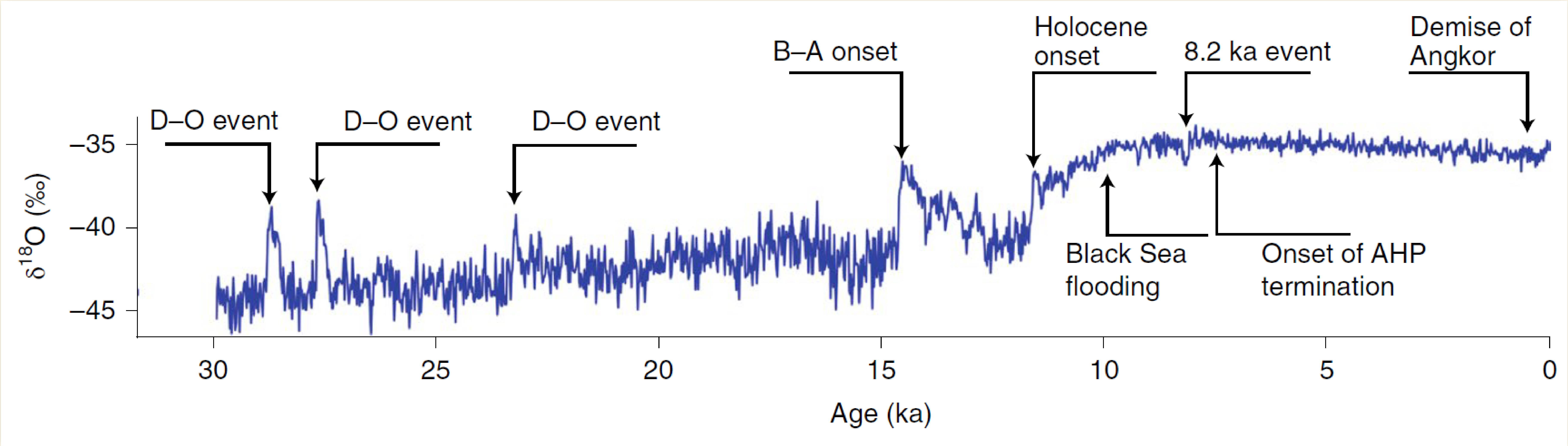
Check for updates

Past abrupt changes, tipping points and cascading impacts in the Earth system

Victor Brovkin[1,2], Edward Brook[3], John W. Williams[4], Sebastian Bathiany[5], Timothy M. Lenton[6], Michael Barton[7], Robert M. DeConto[8], Jonathan F. Donges[9,10], Andrey Ganopolski[9], Jerry McManus[11], Summer Praetorius[12], Anne de Vernal[13], Ayako Abe-Ouchi[14], Hai Cheng[15], Martin Claussen[1,16], Michel Crucifix[17], Gilberto Gallopín[18], Virginia Iglesias[19], Darrell S. Kaufman[20], Thomas Kleinen[1], Fabrice Lambert[21], Sander van der Leeuw[22], Hannah Liddy[23], Marie-France Loutre[24], David McGee[25], Kira Rehfeld[26], Rachael Rhodes[27], Alistair W. R. Seddon[28], Martin H. Trauth[29], Lilian Vanderveken[17] and Zicheng Yu[30,31]

The geological record shows that abrupt changes in the Earth system can occur on timescales short enough to challenge the capacity of human societies to adapt to environmental pressures. In many cases, abrupt changes arise from slow changes in one component of the Earth system that eventually pass a critical threshold, or tipping point, after which impacts cascade through coupled climate-ecological-social systems. The chance of detecting abrupt changes and tipping points increases with the length of observations. The geological record provides the only long-term information we have on the conditions and processes that can drive physical, ecological and social systems into new states or organizational structures that may be irreversible within human time frames. Here, we use well-documented abrupt changes of the past 30 kyr to illustrate how their impacts cascade through the Earth system. We review useful indicators of upcoming abrupt changes, or early warning signals, and provide a perspective on the contributions of palaeoclimate science to the understanding of abrupt changes in the Earth system.

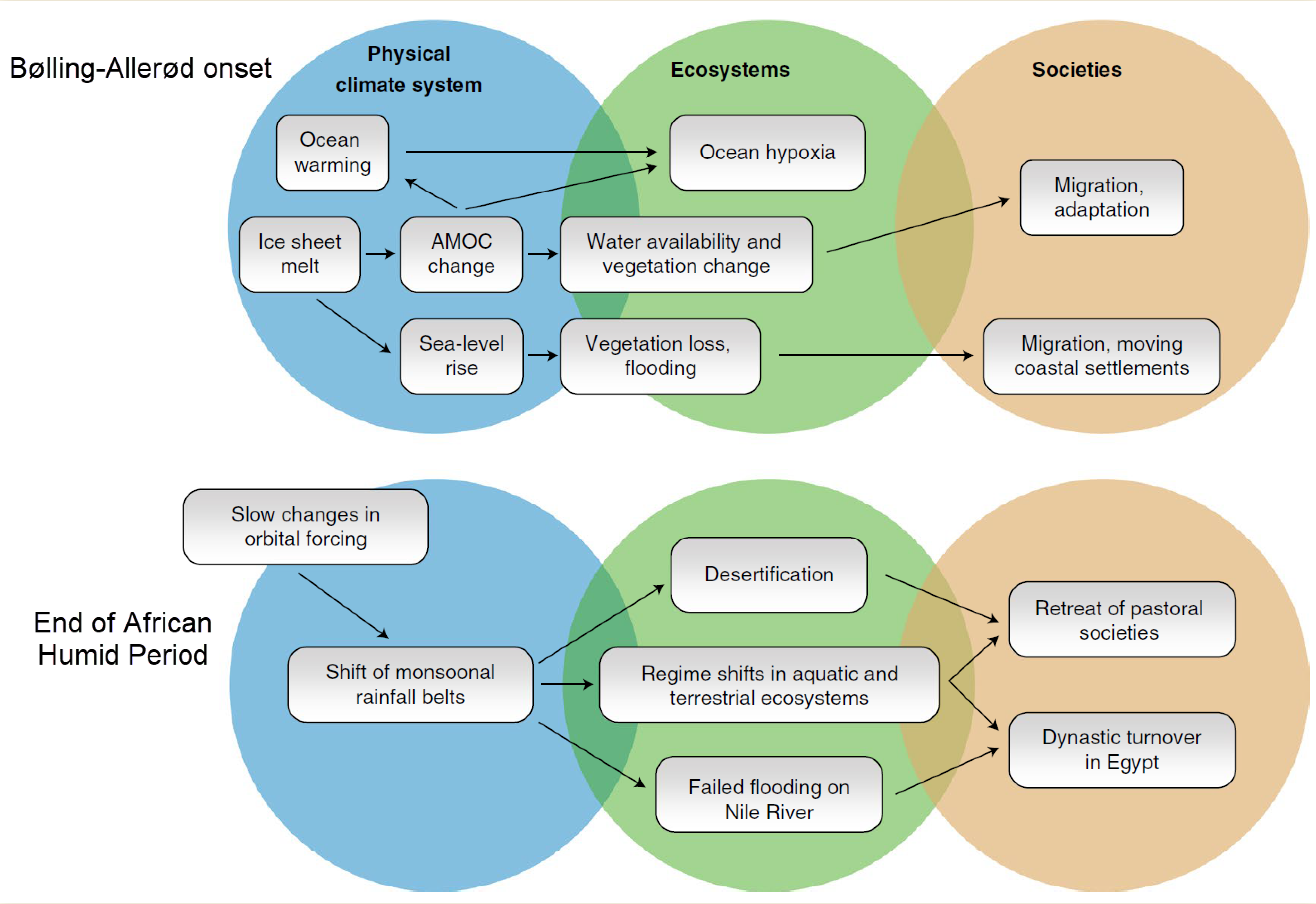
Abrupt Change in Earth's Past



V. Brovkin *et al.* (2021). Nature Geoscience **14**, 550. https://doi.org/10.1038/s41561-021-00790-5

- D-O: Dansgaard-Oeschger event.
  - Sudden temperature change caused by changes in Atlantic ocean currents
- B-A: Bølling-Allerød event.
  - Sudden warming, just before the Younger Dryas cooling
- AHP: African Humid Period.
  - Around 15,000–5,500 years ago. North Africa, including Sahara desert, was wet and green.

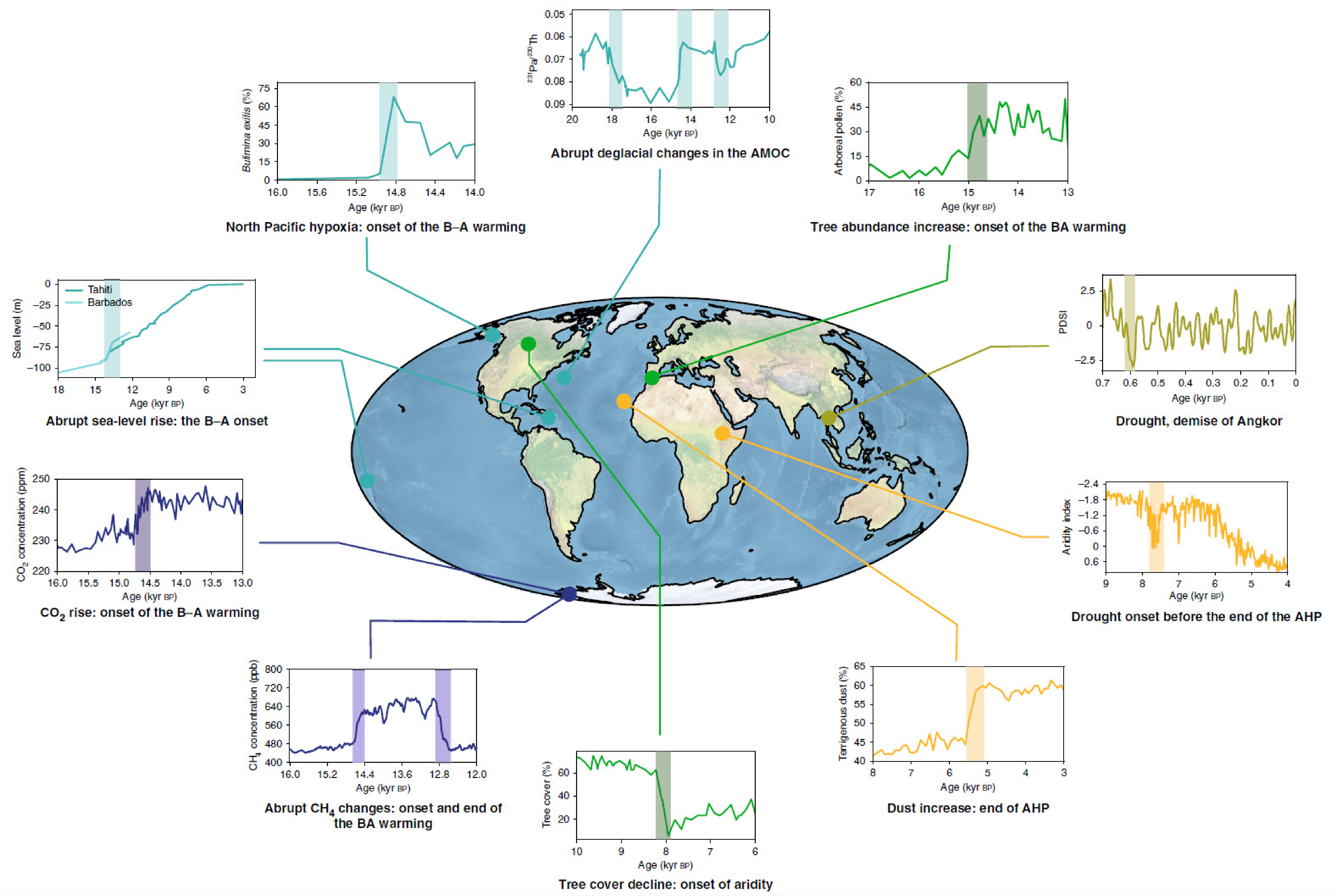
Cascades of Changes



V. Brovkin *et al.* (2021). Nature Geoscience **14**, 550. https://doi.org/10.1038/s41561-021-00790-5

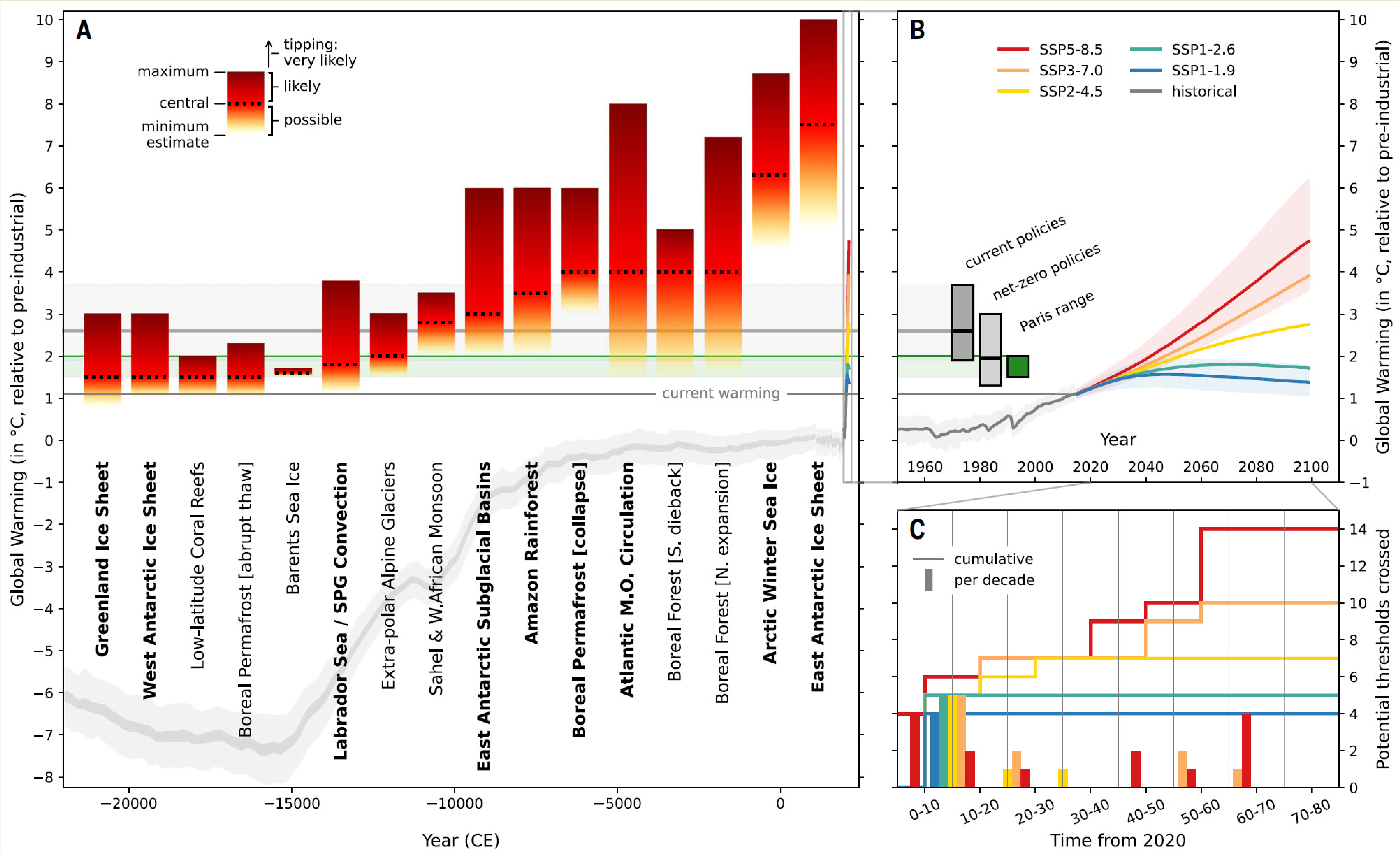
- Don't worry about details.
  - The important thing is the concept of cascading changes

Mapping Climate Cascades



V. Brovkin *et al.* (2021). Nature Geoscience **14**, 550. https://doi.org/10.1038/s41561-021-00790-5

Possible Thresholds for Future Tipping Points



D.I. Armstrong McKay *et al.* (2022). Science **377**, 1171. https://doi.org/10.1126/science.abn7950