You'd better watch out, you'd better not cry: Santa Claus is going to drown

Submission to the House Standing Committee on the Environment and Energy in respect of the Climate Change (National Framework for Adaptation and Mitigation) Bill 2020 and Climate Change (National Framework for Adaptation and Mitigation) (Consequential and Transitional Provisions) Bill 2020

Dr Bill Laing
Climate scientist & former Geological Consultant to the international mining industry

4 December 2020

Support I support the Climate Change Bill - as a former 50-year international geological consultant to the mining industry on all continents, and now as a climate scientist whose new empirical synthesis of Australia's climate, heating at a mean rate of 2.4 DPC (degrees per century) threatens, and is threatened by, the growing melting instability of our polar neighbour Antarctica.

Personal statement Sealevel rise is a sleeping giant. So far the world's oceans have risen, imperceptibly as far as 99% of people are concerned, a "mere" 7 centimetres. However around 2000, the West Antarctic, the storehouse of 50% of the world's fresh water, began a rapid melting phase which has the potential to create sealevel rise of several metres within the next couple of centuries. The world needs awakening out of our sealevel complacency. The Antarctic is out-of-sight out-of-mind to us; yet Australia is one of the founding nations who committed via ANARE in 1956, to understanding our polar neighbour. It is time we finished what we started. I have been working with the Townsville Local Marine Advisory Committee of the Great Barrier Reef Marine Park Authority, specifically on climate change in our region, and through this have realised the catastrophic threat Antarctic melting poses to the world.

Conscience vote: I ask that the decision by Parliamentarians be a conscience vote, to allow MPs to represent the views and voices of Australians in their electorate. In 2019 300,000 ordinary Australians went on strike, in the middle of a working Friday, to express their plea for action on climate change and to express their anger at politicians and the Federal Government for their failure to act on climate change. The Federal Government is manifestly not listening to their electorates, and it is about time we taught them.

FIRE WATER AIR
Solar Hydro Wind

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You’d better watch out, you’d better not cry: Santa Claus is going to drown

Key points:

- I am a Climate Scientist researching Australia’s and global climate.
- Sealevel rise is a sleeping giant. So far the world’s oceans have risen, imperceptibly as far as 99% of people are concerned, a “mere” 7 centimetres, and people are saying “ho hum what’s this about sealevels rising?”.
- This rise is geologically rapid, it is due to expansion of the oceans as our climate heats, and does not yet reflect the impact of already-commenced and accelerating melting of the Antarctic icecap, specifically the West Antarctic land icecap and intermingled sea icecap.
- This has the potential to create sealevel rise of several metres within the next couple of centuries.
- However in addition to the water volume from even peripheral melting of the Antarctic icecap, melting has recently been identified to contain at least 5 different tipping points: physicochemical changes which perpetuate, and often escalate, into a catastrophic unstoppable process.
- Sealevel rise will increase dramatically, in an up-stepping trajectory, unpredictably, and probably soon (within a century or two).
- The results may be catastrophic.

This Submission addresses the following aspects of the Bill:

1	√√	**Objectives and long-term emissions reduction commitment**
2	√√	**Why legislating Net Zero by 2050 and regular 5 year budgets is important**
3		**Guiding principles to be applied**
4	√√	**Risk and adaptation assessments for all sectors**
5	√	**Technology readiness assessment**
6		**Independent climate change Commission and skills needed on the Commission**

You'd better watch out, you'd better not cry: New understandings of the Arctic/Antarctica tell us that sealevel rise will increase dramatically, in an up-stepping trajectory, unpredictably, and probably soon

Dr Bill Laing
Climate scientist

26 November 2020

FIRE WATER AIR
Solar Hydro Wind

SANTA CLAUS IS GOING TO DROWN

CHORUS
You'd better watch out, you'd better not cry
You'd better not pout, I'm telling you why
Santa Claus is going to drown.

His polar home is melting, it'll be gone within a shake *(25 years!)*
The Arctic Circle's getting small so be good for goodness sake.

CHORUS
He's learning to swim and learning the price
Of taking his toys to people not nice
Santa Claus is going to drown.

The polar air is warming, at twice the global rate
The polar bears are warning that they'll be gone and it's too late.

CHORUS
He's making a list of people who dice
Of climate deniers who are really not nice
'Cause Santa Claus is going to drown.

He knows that he’s not sleeping, 'cause the nights are now too warm
He knows that burning coal's no good 'cause we all are going to burn.

CHORUS
You'd better watch out, you'd better not cry
You'd better not pout, I'm telling you why
Santa Claus is going to drown.

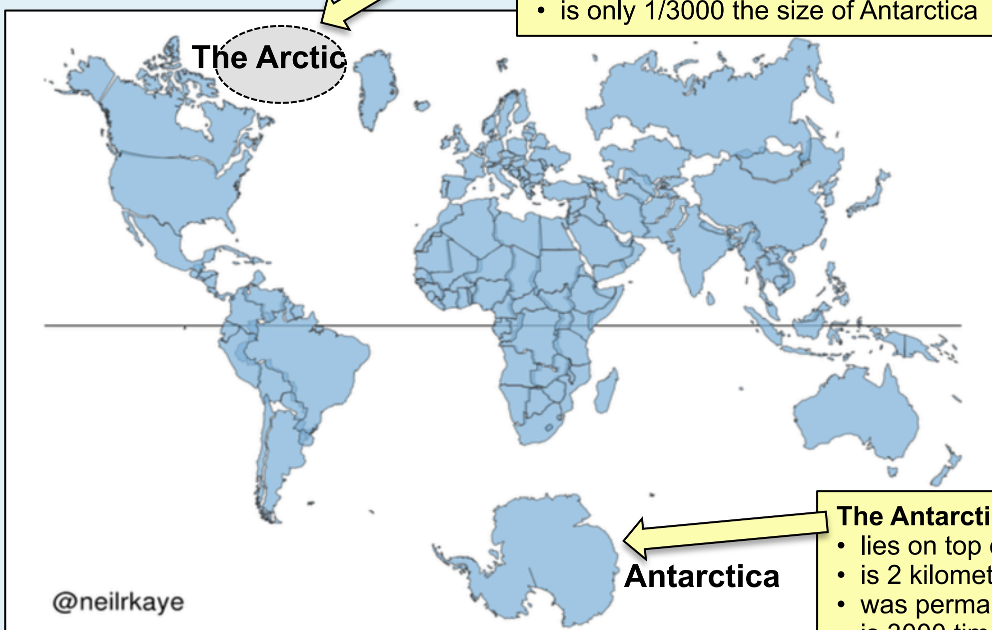
How important is the Antarctic for climate change?

Antarctica is a land continent, twice the size of Australia. Antarctica is the second-largest “country” on the planet.
The Antarctic contains 14 million square kilometres of icecap which is 2 kilometres thick = 30 million cubic kilometres
The Arctic is a floating ice sheet 10 million square kilometres, but only 1 metre thick = 10 thousand cubic kilometres
Antarctica contains 3000 times more ice than the Arctic

Antarctica is the last domino to fall: it lies furthest from the Earth’s industrial revolution in the northern Northern Hemisphere, it is disconnected from all other continents, and is the Earth’s biggest *cold sink* (heat capacity of ice = 2x water). Climate change appearing in Antarctica is most definitely the canary in the coalmine.

Antarctica is the latest, and the last, climate domino to fall. It lies furthest from the Earth’s industrial revolution in the northern Northern Hemisphere, furthest from the dominant carbon emissions in the northern hemisphere, it is disconnected from all other continents, and is the Earth’s biggest *cold sink* (heat capacity of ice = 2x water). Climate change manifesting, quite dramatically, in Antarctica, is the climate canary in the coalmine.

The Arctic ice *shelf*
- floats on the ocean
- is only 1-10 metres thick
- melts to ca 2 million kilometres2 and reforms each year
- is only 1/3000 the size of Antarctica



THIS MAP SHOWS COUNTRIES IN THEIR CORRECT SIZE
https://www.newsweek.com/true-scale-map-world-shows-how-big-countries-really-are-1183386

The Antarctic ice *cap*
- lies on top of the Antarctic land continent
- is 2 kilometres thick
- was permanent, until climate heating
- is 3000 times bigger than the Arctic
- melting would raise sealevel by ...metres

Polar ice-melting's contribution to sealevel rise: Antarctica

The Antarctic sheet is the globe's largest single mass of ice. It covers almost 14 million km^2 and contains 30 million km^3 of ice. Around 90% of the fresh water on the planet's surface is held in this area and if melted would raise sea levels by 58m.[130] The continent-wide average surface temperature trend of Antarctica is positive and significant at >0.05 °C/decade since 1957.[131]

The potential for major sea level rise depends mostly on a significant melting of the polar ice caps of Greenland and Antarctica, as this is where the vast majority of glacial ice is located. If all the ice on the polar ice caps were to melt away, the oceans of the world would rise an estimated 70 m (230 ft). Although previously it was thought that the polar ice caps were not contributing heavily to sea level rise (IPCC 2007), recent studies have confirmed that both Antarctica and Greenland are contributing 0.5 millimetres (0.020 in) a year each to global sea level rise.[157][158][159] The Thwaites Glacier alone, in Western Antarctica is "currently responsible for approximately 4 percent of global sea level rise. It holds enough ice to raise the world ocean a little over 2 feet (65 centimeters) and backstops neighboring glaciers that would raise sea levels an additional 8 feet (2.4 meters) if all the ice were lost."[160][144] Thwaites Glacier has been referred to as the weak underbelly of the West Antarctic Ice Sheet.[141] New satellite imaging data led to calculations of Thwaites Glacier "ice shelf melt rate of 207 m/year in 2014–2017, which is the highest ice shelf melt rate on record in Antarctica."[144]

The fact that the IPCC estimates (2007) did not include rapid ice sheet decay into their sea level predictions makes it difficult to ascertain a plausible estimate for sea level rise, but a 2008 study found that the minimum sea level rise will be around 0.8m by 2100.[161]

A 2019 study showed that Antarctica is losing ice six times faster than it was 40 years ago. Another study showed that two glaciers, Pine Island and Thwaites, are melting five times faster than "in the early 1990s".[147]

In February 2020 Esperanza Base in the Antarctic Peninsula reached a temperature of 18.3°, the hottest on record to date for continental Antarctica. In the past 50 years, temperatures in the Antarctic Peninsula have surged 5° and about 87% of the glaciers along the peninsula's west coast have retreated.[148][149][150] 10% of Antarctica's coastal glaciers are now in retreat.

https://en.wikipedia.org/wiki/Retreat_of_glaciers_since_1850

Over the past 50 years Antarctica has heated as follows (° per century = DPC):

Antarctic Peninsula	1.1
East Antarctica	1.0
West Antarctica	1.8
All Antarctica	1.2

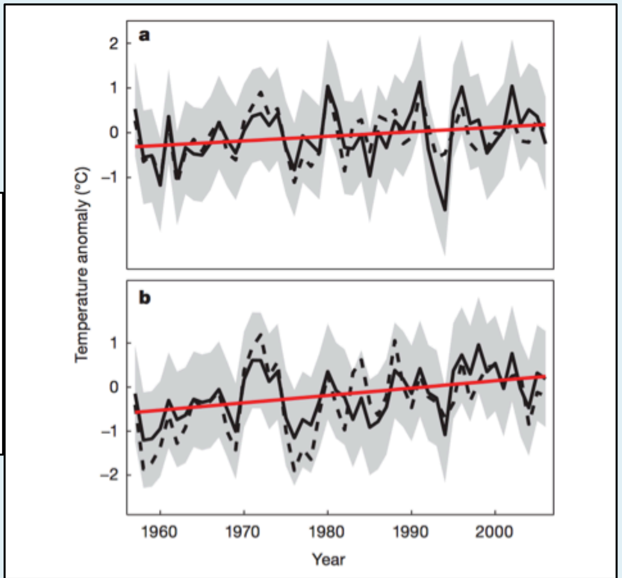


Figure 2 | Reconstructed annual mean Antarctic temperature anomalies, January 1957 to December 2006. a, East Antarctica; **b**, West Antarctica. Solid black lines show results from reconstruction using infrared satellite data, averaged over all grid points for each region. Dashed lines show the average of reconstructed AWS data in each region. Straight red lines show average trends of the T_{IR} reconstruction. Verification results for the continental mean of the T_{IR} reconstruction are RE = 0.34, CE = 0.31 and $r = 0.73$. Grey shading, 95% confidence limits.

https://docs.rwu.edu/cgi/viewcontent.cgi?article=1313&context=fcas_fp

Polar ice-melting's contribution to sealevel rise: Greenland + Canada

About 99% of all freshwater ice is in the great ice sheets of Antarctica and Greenland. These continuous continental-scale ice sheets, 3km or more in thickness, cap much of the polar and subpolar land masses. Like rivers flowing from an enormous lake, numerous outlet glaciers transport ice from the margins of the ice sheet to the ocean.[106]

Greenland

In Greenland, glacier retreat has been observed in outlet glaciers, resulting in an increase of the ice flow rate and destabilization of the mass balance of the ice sheet that is their source. **The net loss in volume and hence sea level contribution of the Greenland Ice Sheet has doubled in recent years from 90 km³ per year in 1996 to 220 km³ per year in 2005**.[121] Researchers noted that **the acceleration affected almost all glaciers south of 70N by 2005**. The period since 2000 has brought retreat to several very large glaciers that had long been stable, including Helheim, Kangerdlugssuaq, and Jakobshavn Isbræ, which jointly drain more than 16% of the Greenland Ice Sheet.

Helheim Glacier: Satellite images and aerial photographs from the 1950s and 1970s show the front of the glacier stationary for decades. **In 2001 the glacier began retreating rapidly**, and by 2005 the glacier had retreated a total of 7.2 km, accelerating from 20m per day to 35m per day during that 4 year period.[122]
Jakobshavn Isbræ: the fastest moving glacier in the world over the past half century, had been moving continuously at speeds of over 24m per day with a stable terminus since at least 1950. **In 2002 its 12km long floating terminus entered a phase of rapid retreat**, with the ice front breaking up and the floating terminus disintegrating and accelerating to a retreat rate of over 30m per day.[123]
Kangerdlugssuaq Glacier: flowing at 15m per day from 1988 to 2001 then **from 2001 measured flowing 267% faster at 40m per day** in the summer of 2005, and thinned by more than 100m.[124]

These findings show that models underestimate the sensitivity of Greenland glaciers to ocean warming and resulting ice sheet runoff. Hence, without better modelling, new observations suggest that **past projections of sealevel rise attribution from the Greenland Ice Sheet require upward revision**.[128]

According to one study, **in the years 2002–2019 Greenland lost** 4,550 gigaton of ice, 268 gigaton per year, on average. In 2019 Greenland lost **600 gigaton of ice in two months, contributing 2.2 mm to global sea level rise.**[129]

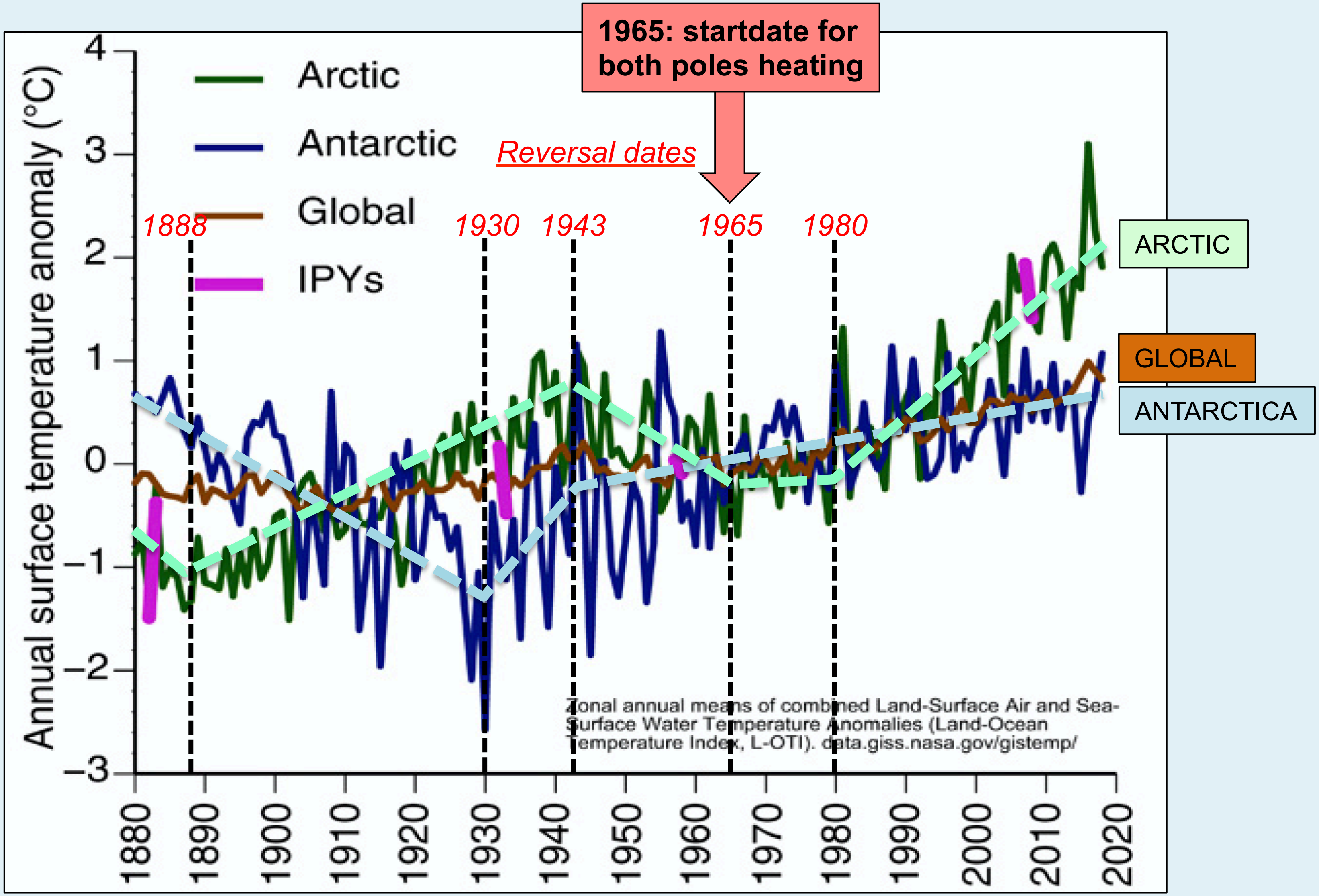
https://en.wikipedia.org/wiki/Retreat_of_glaciers_since_1850

Calculation: Greenland's melted 4,550 gigatonnes of ice since 2002 has contributed 16.5 mm to global sea level rise.

Canada

The Canadian Arctic islands contain the largest area and volume of land ice on Earth outside of Greenland and Antarctica[109][110] Glaciers in the Canadian Arctic were near equilibrium between 1960 and 2000.[111] Since this time, Canadian Arctic glaciers have experienced a sharp increase in mass loss in response to warmer summer temperature, losing 92 Gt per year between 2007 and 2009 .[112]

Heating graphs: Global - Arctic - Antarctic



Science Advances, 4 December 2019
https://advances.sciencemag.org/content/5/12/eaaw9883

Global heating scenarios: Linear → accelerating → tipping

1 LINEAR

We think Earth is here

Heating rate constant:

- Straight line
- Predictable
- Less dangerous

2 ACCELERATING

Earth is here

Heating rate increasing:

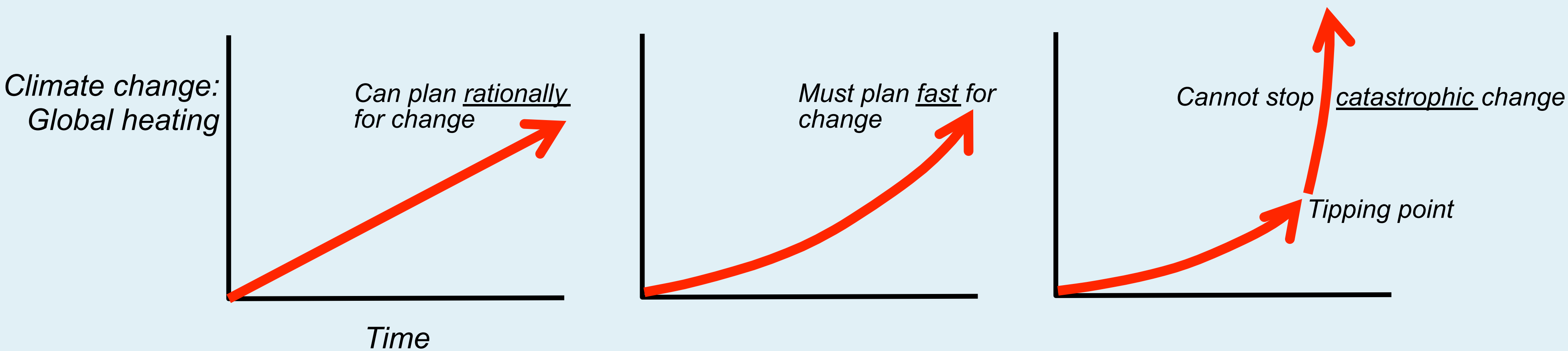
- Curved line
- Hard to predict
- More dangerous

3 TIPPING POINT

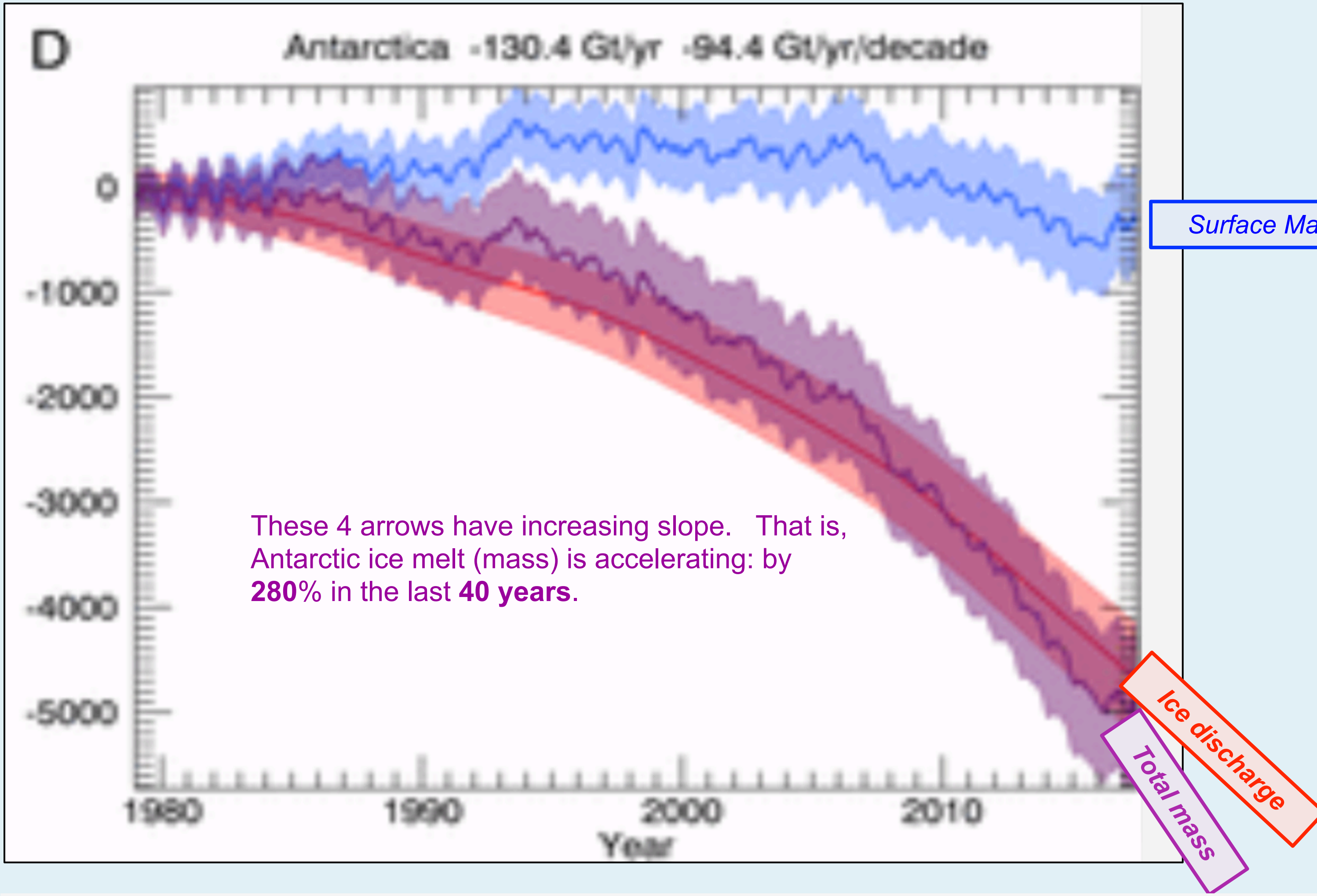
Is Earth actually here?

Heating is in unstable equilibrium:

- Broken line
- Impossible to predict
- Catastrophic

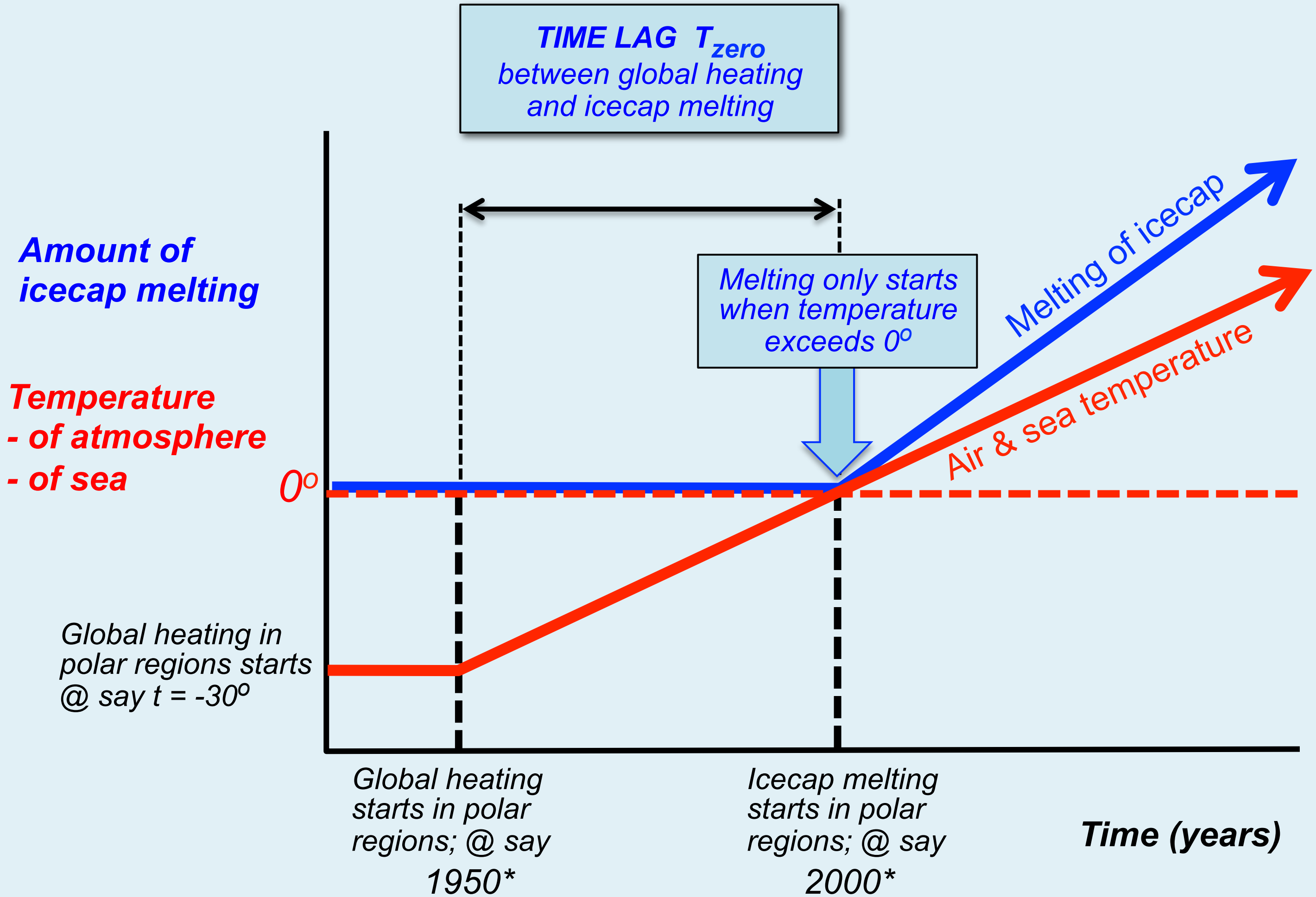


The bottom line: Antarctica is melting rapidly & accelerating



Time series of cumulative anomalies in SMB (blue), ice discharge (D, red), and total mass (M, purple) with error bars in billions of tons for (*D*) Antarctica, with mean mass loss in billions of tons per year and an acceleration in billions of tons per year per decade for the time period 1979 to 2017.

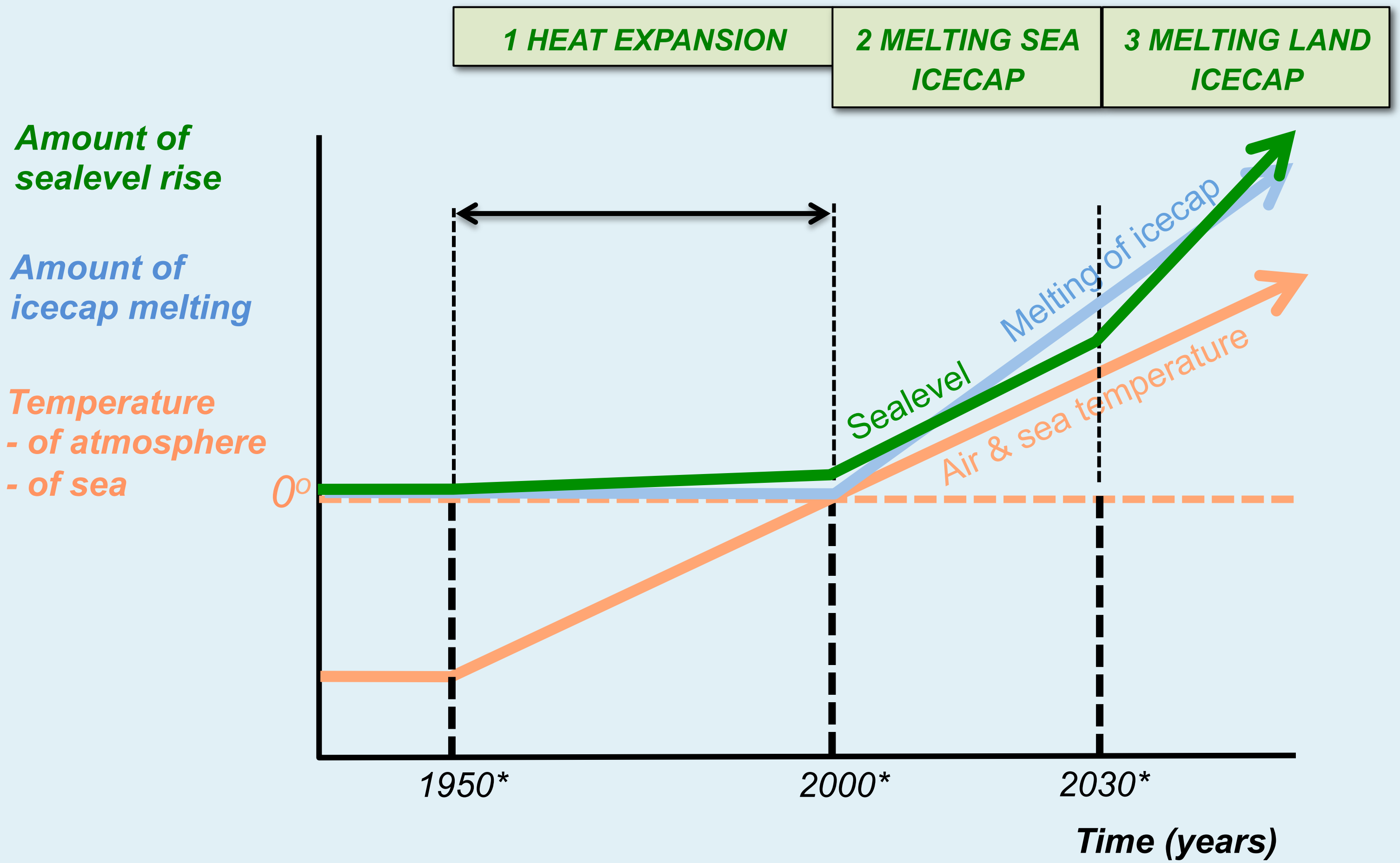
The trajectory of icecap melting: *a time lag after heating startdate*



The polar icecaps did not start melting when global heating started in the polar regions. There is a time lag. This is due to the initial temperatures of sea and air in the polar regions, at well below zero. It takes a number of decades for the ambient temperatures (sea and air) at any place (at the periphery of the Antarctic continent, where melting starts) to reach 0°. The time lag is termed T_{zero}. In this graph all parameters are given notional values, because they vary from place to place, and linear heating curves are used. The global data suggest that T_{zero} in the Arctic may be only ca 20 years, while the Antarctic, being combined sea and land ice, is larger at ca 50 years.

* Global heating started in the polar regions well before 1950, but this analysis is simplified to the start of significant heating.

The trajectory of sealevel rise: *three separate drivers*

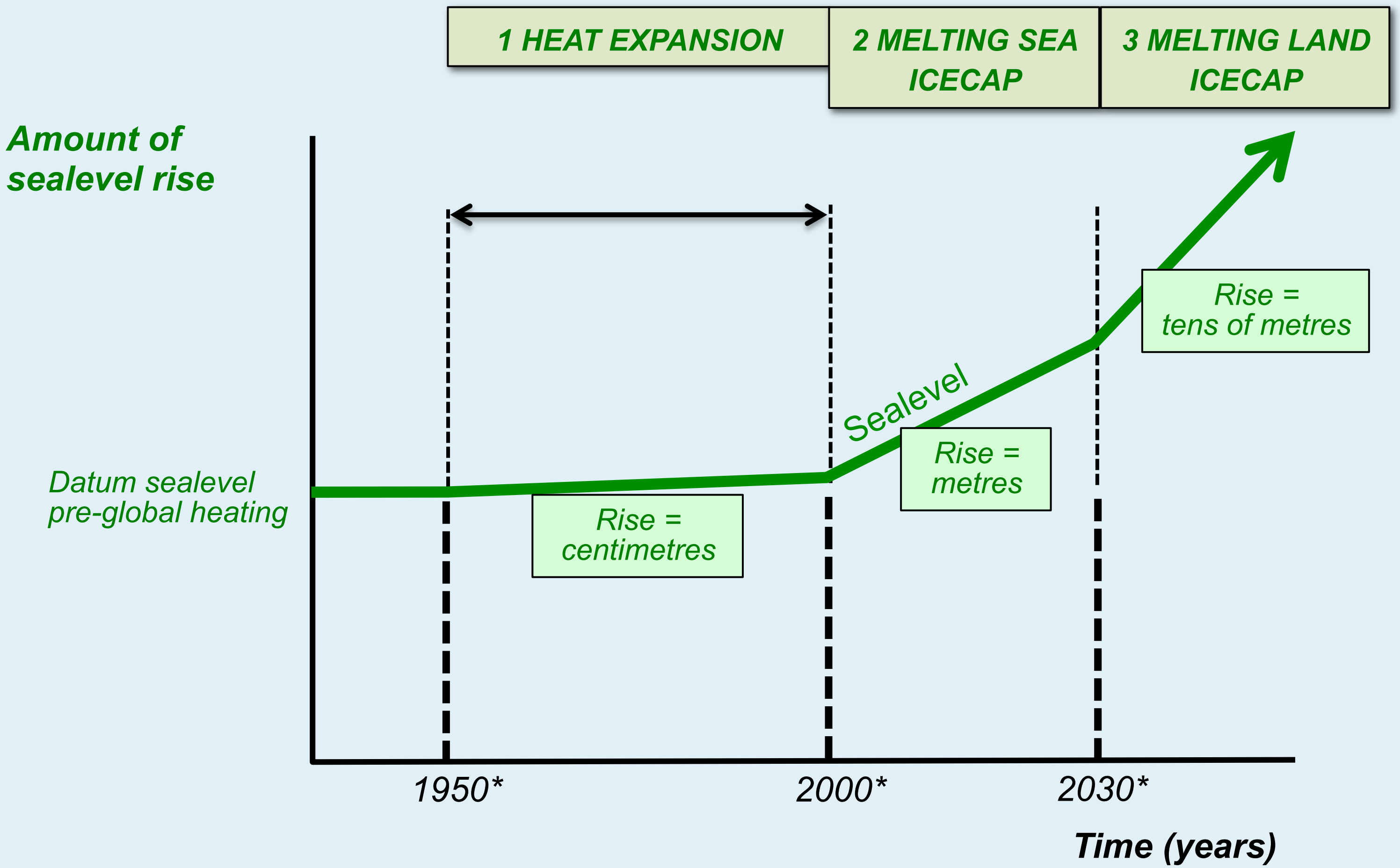


Phase 1 of sealevel rise is due to heat expansion of the warming oceans. There is no significant ice melt. Expansion continues through the subsequent phases, but is overshadowed in amount by icecap melt.

Phase 2 is due to the start of significant melting of the sea icecaps: the Arctic, and the floating Antarctic (large parts of West Antarctica).

Phase 3 is due to the start of significant melting of the land icecaps in Antarctica. West Antarctica, with thin land icecaps bounded by melting sea icecaps, sets the initial melting scene, and is followed later by East Antarctica with a thick (and surface-elevated) land icecap.

The trajectory of sealevel rise: *three distinct phases*



Phase 1, from heat expansion of the warming oceans, has produced the sealevel rise seen to date (augmented by the melting Arctic).

Phase 2, from significant melting of the sea icecaps, has begun. The Arctic is half-melted, and West Antarctica is pemanently losing sea icecap.

Phase 3, from significant melting of the land icecaps in Antarctica, has begun. There is permanent ice loss at vulnerable "spot" locations in West Antarctica and around the coast of East Antarctica.

The planet's ice: complex melting, complex sealevel rising

Each Earth ice reservoir is different: **Antarctica, Greenland, Arctic, mountain glaciers**.

The melting of each is different. There are three types.

TYPE 1 Polar continental icecaps ± ice shelfs (Types 1a and 1b)

Antarctica: On land and on sea. Complex geometry, above + below SL, thick (centre) to thin (edge), ice shelfs different again = Arctic but thick near land. Probably 5-6 different icebody types, none melting linearly, some melting smoothly bu exponentially, some melting with a singularity (a hiccup during melt history). *Complexity 10/10*

Greenland: Like Antarctica but without major ice shelfs, hence a bit simpler. *Complexity 6/10*

TYPE 2 Mountain glaciers

Mountain glaciers: Small but several thousand globally: no floating component, but local variations in controlling topography, altitude, controls on meltwater egress (direct into river or into tarns). *Complexity 8/10*

TYPE 3 Polar oceanic iceshelfs

Arctic**:** Simple, floating ice sheet; still non-linear as the melt rate is controlled by two factors - aerial conditions + underwater conditions - whose relative influence changes as the ice sheet gets thinner. Plus however these interact, with melting the Arctic surface area:volume ratio increases dramatically, *accelerating* the melt rate. *Complexity 3/10*

Scientists are still grappling to understand the dynamics of Type 1 Antarctica. This is critical because Antarctica contains the biggest ice volume of all. The melting of Antarctica hinges on a poorly known melting trajectory. This is definitely non-linear; definitely a cumulative combination of different trajectories for each icebody; and probably with one or more singularities.

Sealevel rise will have huge impacts on a large proportion of humanity: lifestyle & infrastructure disruption (existential for billions), insurance in wealthy nations, geopolitical boundary changes and consequent tensions/wars, etc etc.

The planet's ice: complex melting, complex sealevel rising

The melting of Earth's ice reservoirs is a complex affair, involving physicochemical interactions (a) External: between the ice mass and

- the Sun
- the land
- the sea
- the atmosphere**,**

and (b) Internal: the various components of the ice mass itself.

However the complexity can be broken into several dominant processes.

1. The surface area: thickness ratio of the ice mass.

2. The substrate: **l**and or sea**.** This creates the most complex situations of all, as complex physical factors come into play at the interface - a triple junction - between land, sea (water) and ice (on land or on water). Mutiple tlipping points are inherent in this complexity. The magnitude of the sea level rise which comes from melting icesheets, makes these tipping points possibly the most dangerous of all climate tipping points.

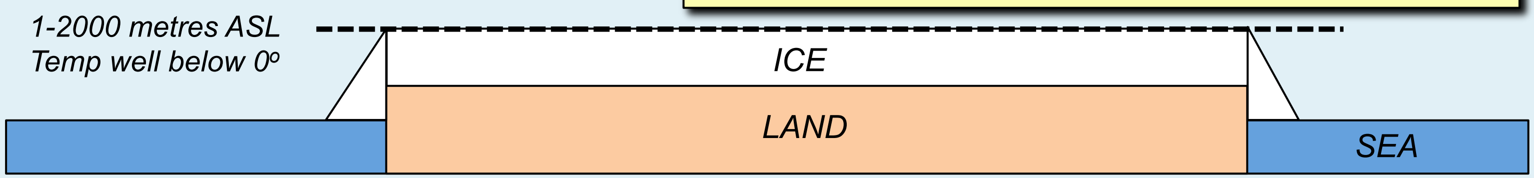
3. The altitude of the ice surface.

4. The decreasing albedo (reflectance) of the ice region as the ice melts and is replaced by the substrate, which is invariably darker, and commonly much darker (eg most rock, regrowing forest), than the original ice mass.

The planet's ice: 3 types of ice reservoir

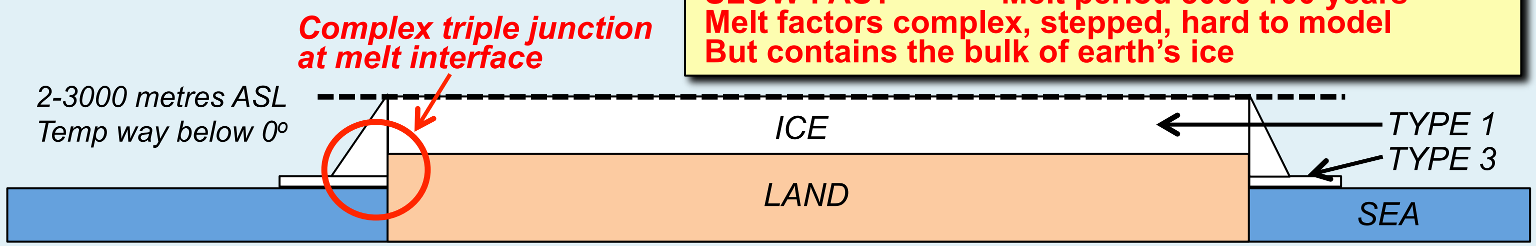
TYPE 1a Polar continental icecaps
Greenland

SLOW Melt period 5000 years*
Melt factors complex, stepped, hard to model
But contains much of earth's ice



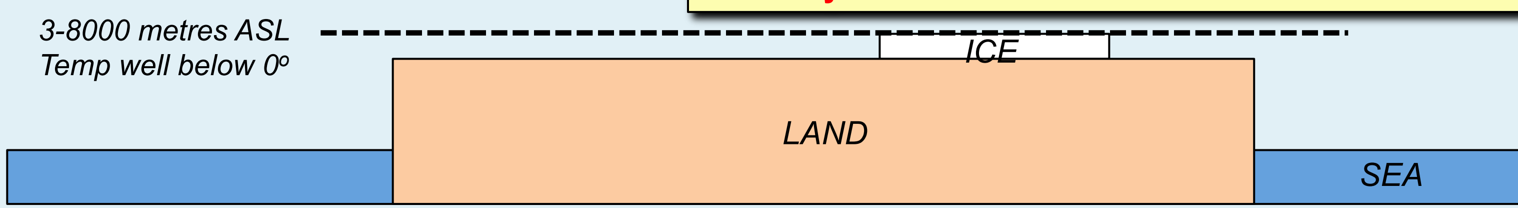
TYPE 1b Polar continental icecaps ± TYPE 3 ice shelfs
Antarctica

SLOW-FAST Melt period 5000-100 years*
Melt factors complex, stepped, hard to model
But contains the bulk of earth's ice



TYPE 2 Mountain glaciers
Temperate + polar mountains

MODERATELY FAST Melt period 500 years*
Contains a small % of earth's ice
A canary - cosmetic - the smallest reservoir



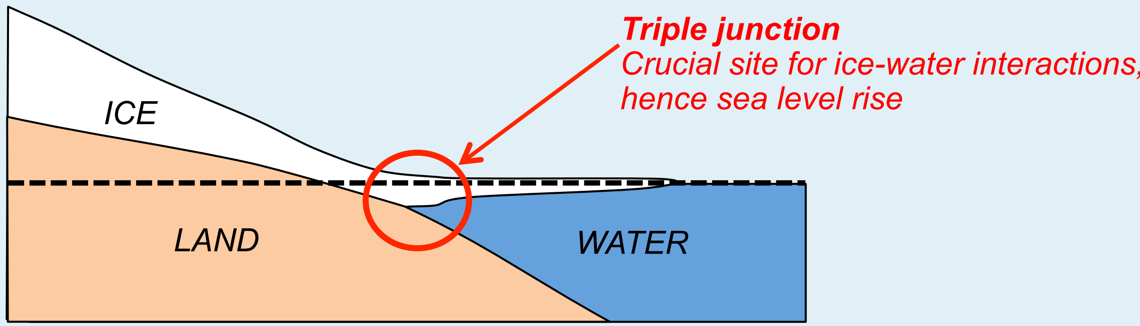
TYPE 3 Polar oceanic ice sheets
Arctic

FAST Melt period 50 years*
Contains a moderate % of earth's ice
Main role is N polar climate moderator

** Indicative*

Continental icecap breakdown: the general context

TYPE 1b
Polar continental icecaps + TYPE 3 ice shelfs
Antarctica



In 1978, the glaciologist John Mercer issued a warning in the scientific journal Nature. If people kept burning fossil fuels at the present rate, he wrote, then within 50 years they could set off the “rapid deglaciation” of West Antarctica. The process he identified - called “marine ice-sheet instability” - has haunted climate scientists for the past 4 decades.

Mercer’s problem begins with a simple fact: Ice floats in water. Many glaciers in West Antarctica have “wet feet,” as Dutton put it, meaning their front face sits in the water. Just like ice in a water glass, these glaciers want to float. But they don’t. The weight of the ice above the waterline keeps the entire glacier stuck to the seafloor. But as it gets farther from the ocean, the bedrock of West Antarctica slopes downhill. If the glacier were to start retreating, then more and more of its mass would fall below the waterline. Eventually, the mass above the waterline would no longer keep the glacier stuck to the seafloor. The glacier would float off its foundation, the ice floe behind it would quickly spill out into the sea, and the glacier would quickly become so many melting ice cubes. Once this process starts, it’s irreversible. It has never been observed—because we’ve never observed wrenching global climate change before. But since about 2006, more and more evidence has suggested that Mercer’s process is real and has happened in the past.

https://www.theatlantic.com/science/archive/2019/09/ipcc-sea-level-rise-report/598765/

Continental icecap breakdown: mechanisms & timeframes

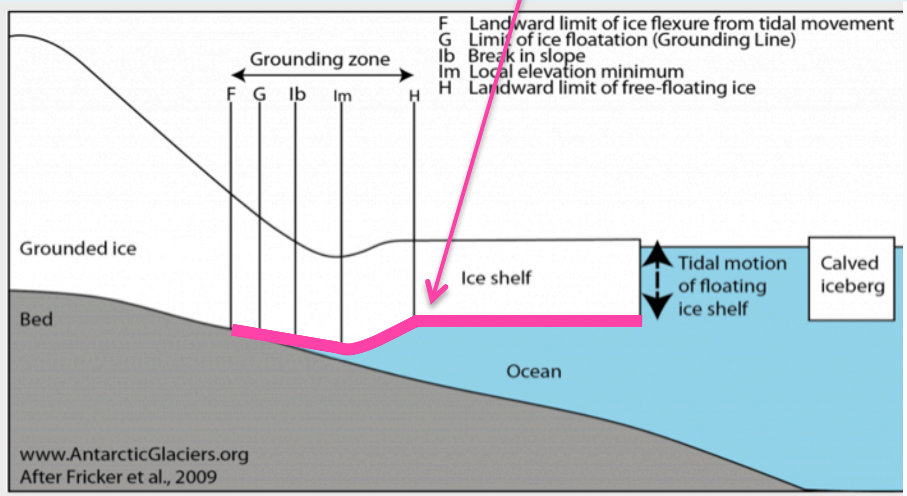
Photo

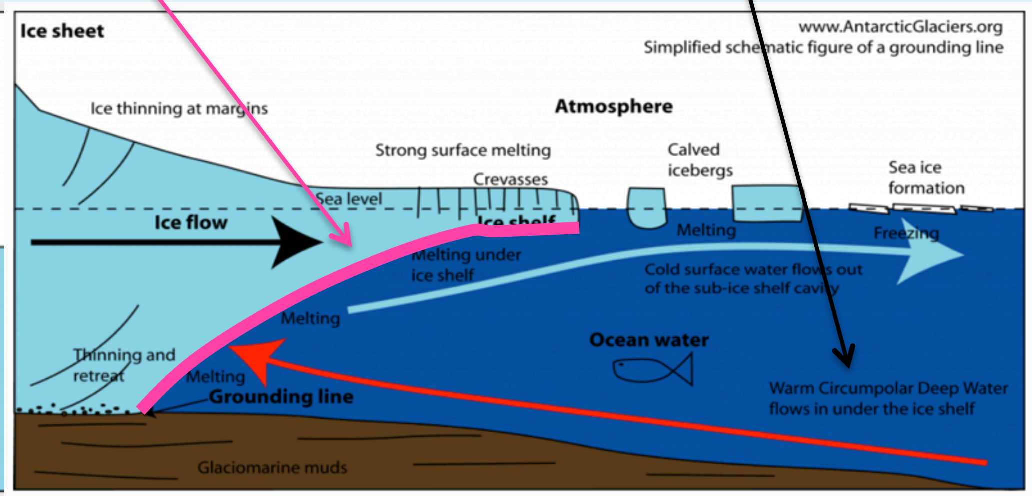
Almost all of Antarctica is covered in ice. Less than 1% its land area is ice free. This means that, across Antarctica, almost all glaciers end in the ocean, whereupon they calve icebergs. These glaciers can be grounded, or can end in floating ice tongues or larger ice shelves. These floating ice shelves move with the tide. They fringe 75% of Antarctica's coastline, collecting 20% of its snowfall over only 11% of its area. **Basal melt from ice shelves is the largest melting process in Antarctica**. Clearly, ice sheet-ocean interactions are extremely important for controlling ice sheet dynamics and rates of melting and recession.

Glaciers that end in the ocean have a point at which they start to float - their grounding line. The location of the grounding line is important, because mass loss from Antarctica is strongly linked to changes in the ice shelves and their grounding lines. Change in the grounding line can result in very rapid changes in glacier and ice-shelf behaviour**.**

Across the Antarctic Peninsula and West Antarctica, increased upwelling of the relatively warm Circumpolar Deep Water is melting ice at the grounding line. In the Amundsen Sea, this has resulted in glacier acceleration, thinning, and grounding line recession. Circumpolar Deep Water, which is a key component of the Antarctic Circumpolar Current, is able to reach the undersides of the ice shelves and the grounding line by flowing through deep submarine troughs. This has resulted in rapid grounding-line recession at Pine Island Glacier – up to 31 km from 1992 to 2011**.**

http://www.antarcticglaciers.org/glaciers-and-climate/ice-ocean-interactions/grounding-lines/





Antarctic ice loss: is not linear, and has tipping points

The West Antarctic is the largest single contributor to global sea level rise *Carbon Brief, 14 February 2020*

According to the recent special report on the ocean and cryosphere (2019) by the Intergovernmental Panel on Climate Change (IPCC), there are two main controls on how much global sea levels will rise this century:

1 Future human-caused greenhouse gas emissions
2 How warming affects the Antarctic ice sheet.

The IPCC says:

"Beyond 2050, uncertainty in climate change induced SLR [sea level rise] increases substantially due to uncertainties in emission scenarios and the associated climate changes, and the response of the Antarctic ice sheet in a warmer world."

Within the Antarctic ice sheet, the West Antarctic Ice Sheet will be the first to melt and create major SLR.

The three likely 'tipping points' of the West Antarctic ice sheet

The West Antarctic Ice Sheet has (at least) three known tipping points of SLR drivers (= the phenomenon is self-sustaining) or self-accelerating SLR drivers (the current rate is increasing, at an unknown rate):

1. MISI: Marine Ice Sheet Instability - a tipping point **Photo 1**
2. Melt rate in MISI - a self-accelerating driver **Photo 1**
3. MICI: Marine Ice Cliff Instability - a tipping point **Photo 1**

How close is the West Antarctic ice sheet to its three likely 'tipping points'?

Late last year, a large team of modellers assessed different studies of ice sheet response to the Paris climate target to keep global average warming "well below" 2C. The models all point in the same direction. Namely, that the threshold for irreversible ice loss in both the Greenland ice sheet and the WAIS is somewhere between 1.5C and 2C global average warming. And we are already at a bit more than 1C warming right now.

This 1.5-2C window is the key for the "survival of Antarctic ice shelves"

https://www.carbonbrief.org/guest-post-how-close-is-the-west-antarctic-ice-sheet-to-a-tipping-point

Antarctic ice loss: is not linear, and has tipping points

Antarctica is really two small continents covered by a single ice sheet: one is stable, the other is unstable

The cross section shows clearly the difference between the West and East Antarctic ice sheets. The East Antarctic Ice Sheet is grounded largely above sea level, whereas the West Antarctic Ice Sheet is mostly grounded well below sea level.

West Antarctica's situation makes it vulnerable to melting - and disappearance - by two different mechanisms.

Melting of West Antarctica by thermal erosion from beneath

Much of West Antarctica drains through glacers and ice shelves, which are now being heated from below by Circumpolar Deep Water. This has resulted in system imbalances, more intense melting, glacier acceleration and drainage basin drawdown. This is the "Weak Underbelly" of the West Antarctic Ice Sheet, which may be prone to collapse. Pine Island Glacier is currently thinning and the Amundsen Sea ice shelves are undergoing rapid basal melting, which means there is concern for the future viability of West Antarctic fringing ice shelves.

Melting of West Antarctica by sudden collapse of its ice sheet: the Marine Ice Sheet Instability (MISI) hypothesis Photo

In 1978, Mercer was one of the first to identify that rising temperatures could have catastrophic consequences in West Antarctica, triggering a collapse of the West Antarctic Ice Sheet. Evidence suggests that, in previous interglacials, the West Antarctic Ice Sheet completely disappeared, leading to sea levels about 5m higher than at present. This is because much of the West Antarctic Ice Sheet lies below sea level, making it a marine ice sheet. West Antarctica is currently the world's largest marine ice sheet, although they may have been common during the Last Glaciation, circa 18,000 years ago. Portions of the Greenland Ice Sheet and East Antarctic Ice Sheet are also marine, but occupy ocean shallower than West Antarctica.

Ice sheets whose grounding lines lie on ocean floor which deepens toward the continent - an anomalous situation termed a "reverse slope gradient" - are not stable. The West Antarctic Ice Sheet is currently stable, due to its buttressing ice shelves, and local regions where the ice sheet is not a "reverse slope gradient". However global heating could result in increased melting and recession at the West Antarctic grounding lines, over its large regions of reverse slope gradient. The receding glaciers would become grounded in deeper water and assume a greater ice thickness. In this situation, the ice sheet at the grounding line undergoes flotation, basal melting, increased iceberg production, and further retreat within a positive feedback loop.

This would result in a rapid melting of the West Antarctic Ice Sheet, triggering rapid sea level rise. This could be exacerbated by the melting of fringing ice shelves around the margin of the West Antarctic Ice Sheet. Removal of buttressing ice shelves around ice streams tends to result in glacier acceleration, thinning, and grounding line migration.

Recent numerical models predict a sea level rise of 3.3m if this event was to occur, in a timeframe of the next 200 years.

http://www.antarcticglaciers.org/glaciers-and-climate/ice-ocean-interactions/marine-ice-sheets/

Antarctic ice loss: is not linear, and is unstable

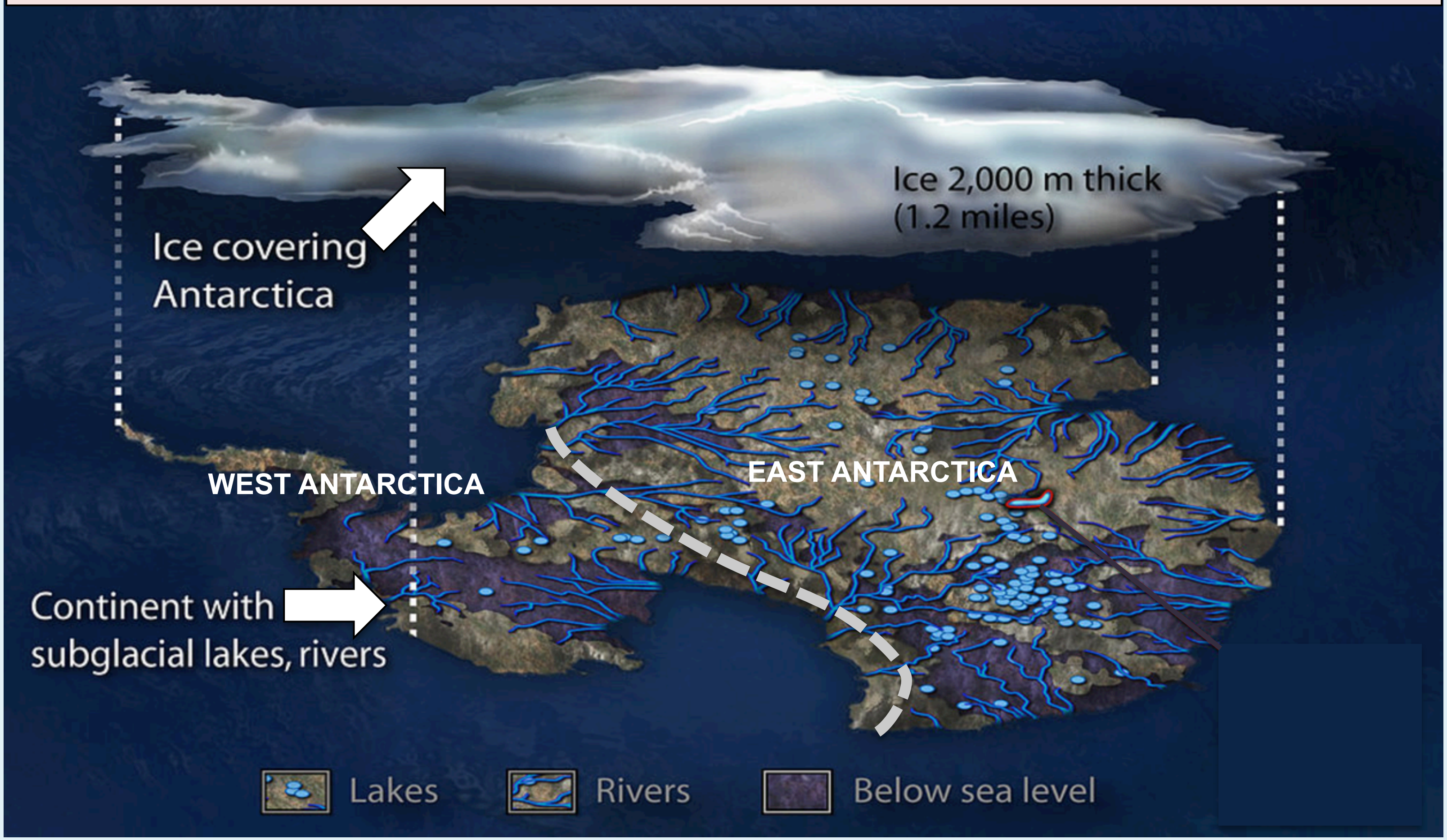
Photo

Marine ice sheet instability (MISI): "Basal" type *AntarcticGlaciers.org, 16 September 2014*

Research shows that Antarctica has major waterways between its ice and its basement. These waterways - lakes and rivers - contribute to the instability of the Antarctic icesheet as a whole, via helping to "float" the overlying icesheet, and in hydraulically "lubricating" the overlying glaciers, in ways analogous to the marine ice sheets surrounding the continental Antarctic ice sheet.

http://www.antarcticglaciers.org/glaciers-and-climate/ice-ocean-interactions/marine-ice-sheets/

3D map of Antarctica showing the water - not ice - regime at the base of the Antarctic ice sheet



Antarctic ice loss: is not linear, and is unstable

Photo

Marine ice sheet instability (MISI): “Edge” type

2017 research shows that icecap edges can be in unstable equilibrium - several tipping points - contingent on the icecap/seafloor configuration. Where the icecap edge overlies a seafloor basin, with the seafloor sloping back toward the icecapped continent (a “retrograde” seafloor), the whole edifice can be in permanent unstable equilibrium. This results in self-perpetuating (“runaway”) retreat via ad-nauseam repeated fracturing of the edge cliff, and calving of icebergs which float away from the Antarctic continent, northward, and melt.

2D diagrams showing the unstable fracturing-melting regime at the edge of the West Antarctic ice sheet

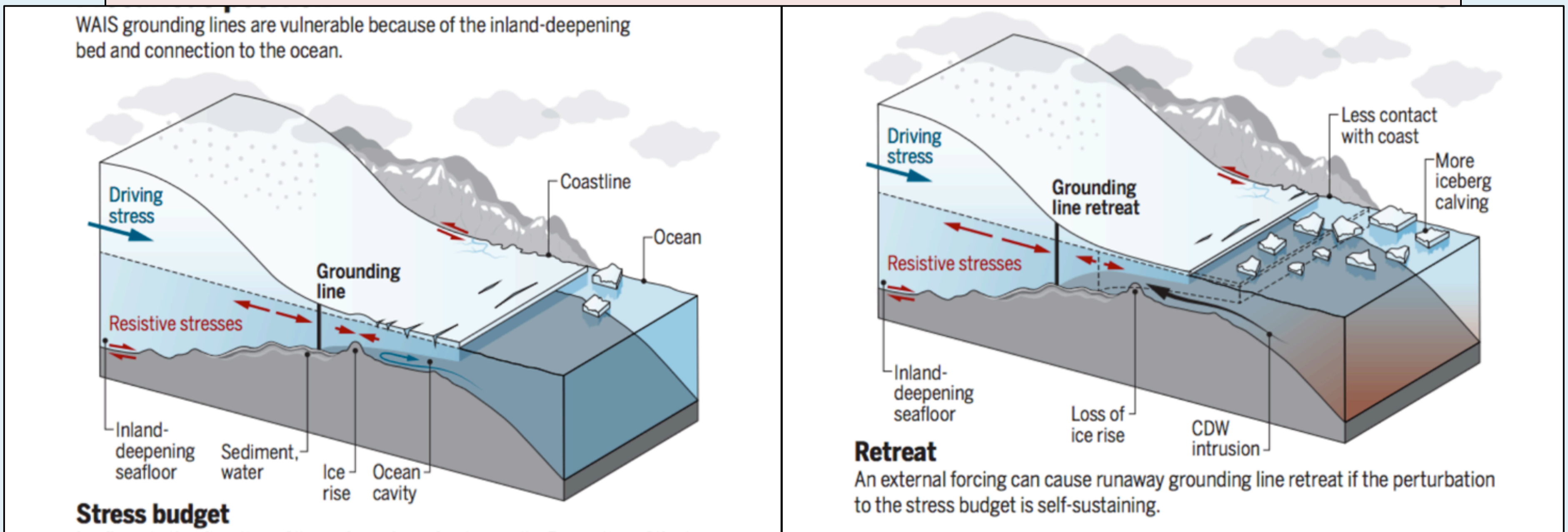


Diagram showing why the West Antarctic Ice Sheet is particularly susceptible to runaway grounding line retreat. Source: Hulbe (2017).

https://www.carbonbrief.org/guest-post-how-close-is-the-west-antarctic-ice-sheet-to-a-tipping-point

Antarctic ice loss: has tipping points which may be catastrophic

Photo

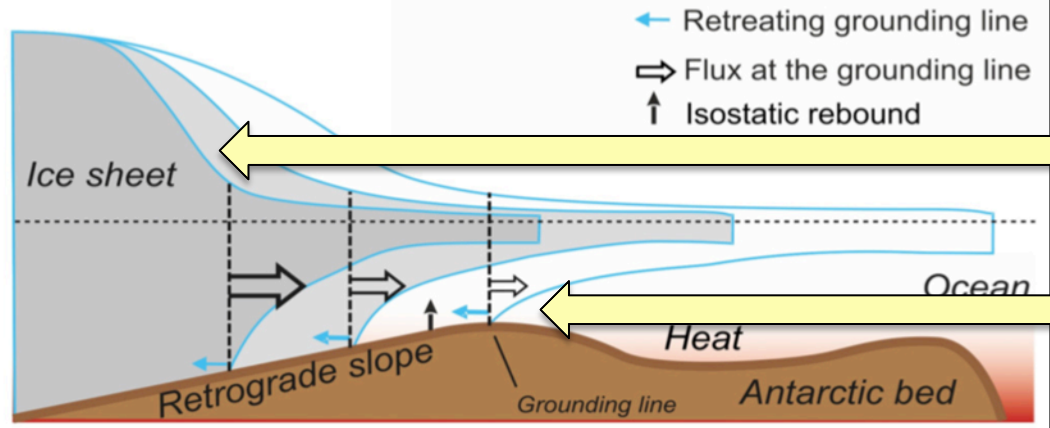


Illustration of Marine Ice Sheet Instability, or MISI. Thinning of the buttressing ice shelf leads to acceleration of the ice sheet flow and thinning of the marine-terminated ice margin. Because bedrock under the ice sheet is sloping towards ice sheet interior, thinning of the ice causes retreat of the grounding line followed by an increase of the seaward ice flux, further thinning of the ice margin, and further retreat of the grounding line. Credit: IPCC SROCC (2019) Fig CB8.1a

TIPPING POINT Type 1
Melt rate instability
Higher MISI melt rate - faster melting - steeper slope - faster retreat
FASTER MELT RATE IS SELF-ACCELERATING

TIPPING POINT Type 2
MISI - Marine Ice sheet instability: "Edge" type
Heating - Grounding line retreats - glacier floats - increases basal melting increases - iceberg calving increases
PROCESS IS SELF-SUSTAINING
ICE SHEET COLLAPSES VIA SUBMARINE PROCESSES

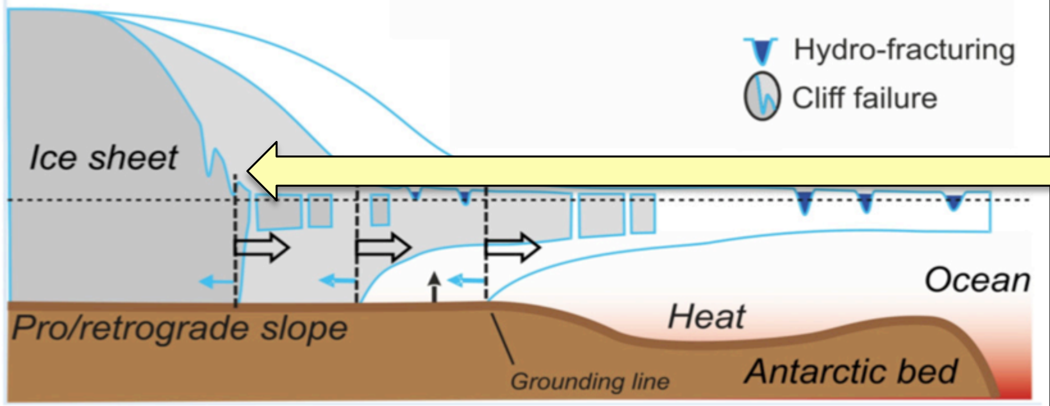
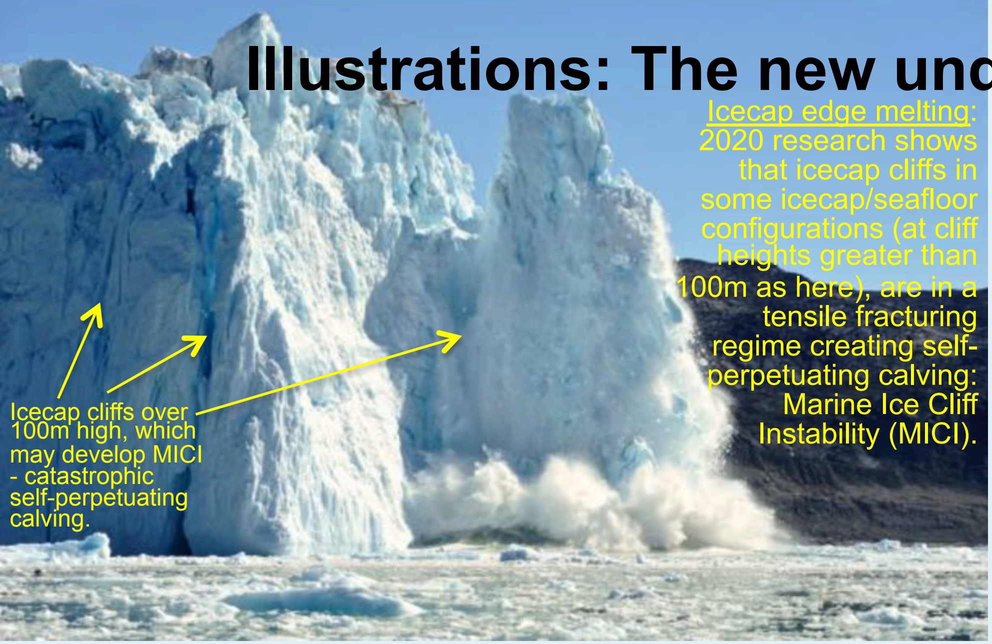


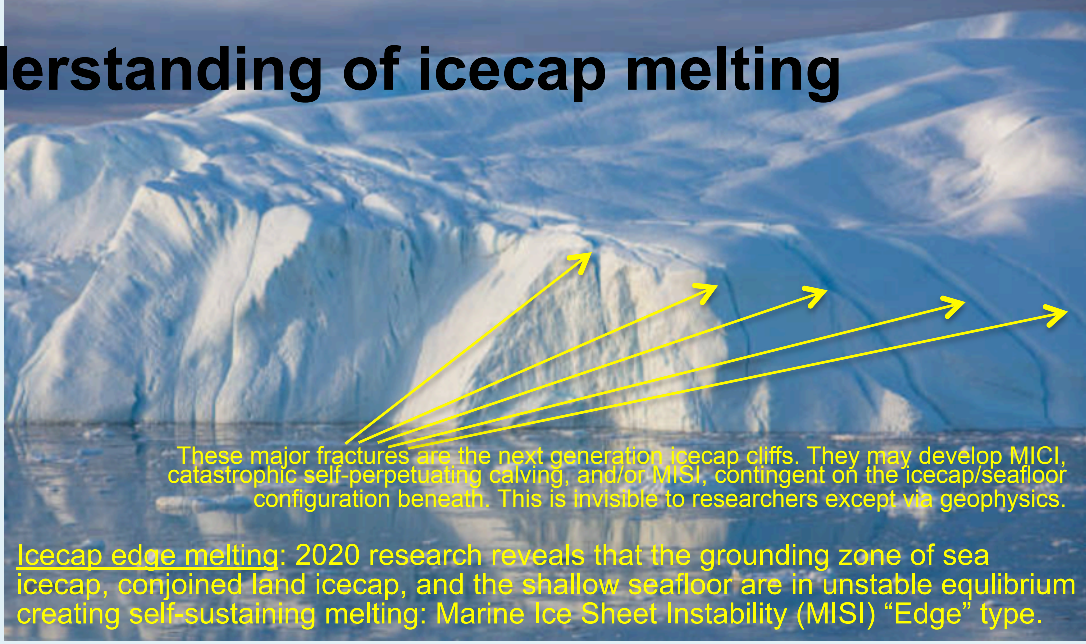
Illustration of Marine Ice Cliff Instability. If the cliff is tall enough (at least ~800m of total ice thickness, or about 100m of ice above the water line), the stresses at the cliff face exceed the strength of the ice, and the cliff fails structurally in repeated calving events. Credit: IPCC SROCC (2019) Fig CB8.1b

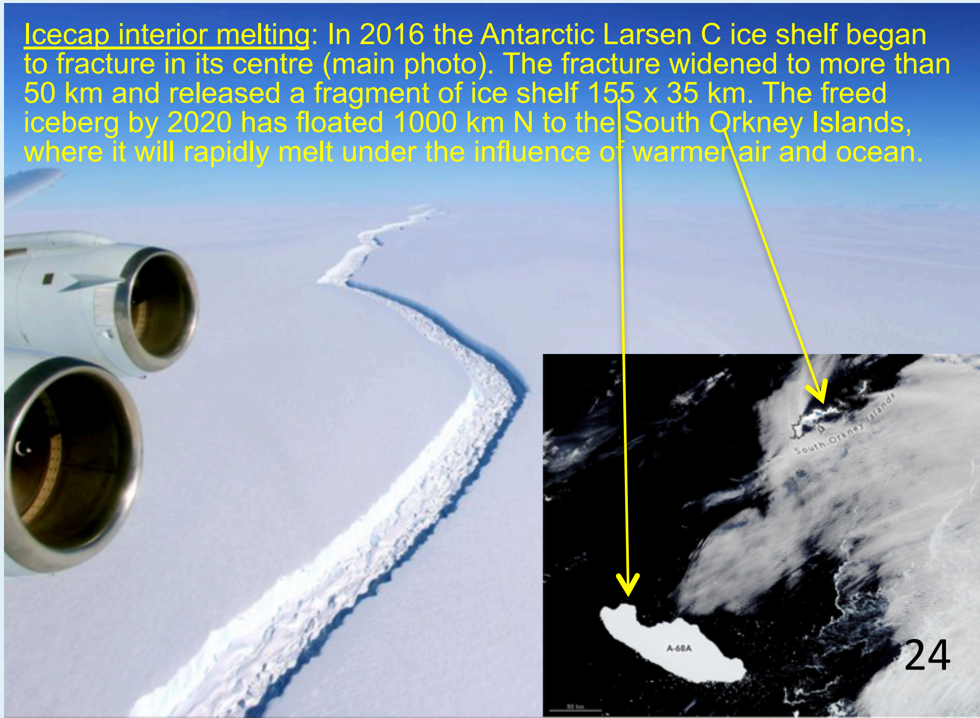
TIPPING POINT Type 3
MICI - Marine Ice Cliff Instability
Glacierfront cliffs >100m high will collapse - domino cliff collapse back up glacier (which is thicker away from ocean)
PROCESS IS SELF-SUSTAINING
GLACIER COLLAPSES VIA ATMOSPHERIC PROCESSES

https://www.carbonbrief.org/guest-post-how-close-is-the-west-antarctic-ice-sheet-to-a-tipping-point

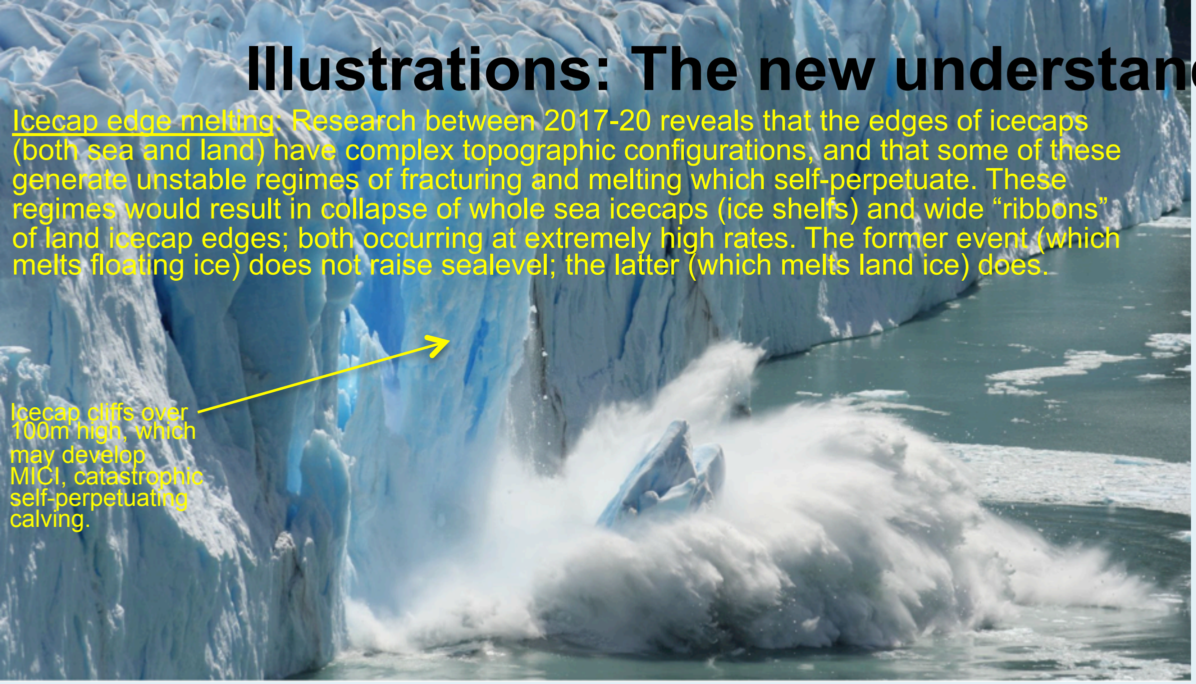
Illustrations: The new understanding of icecap melting





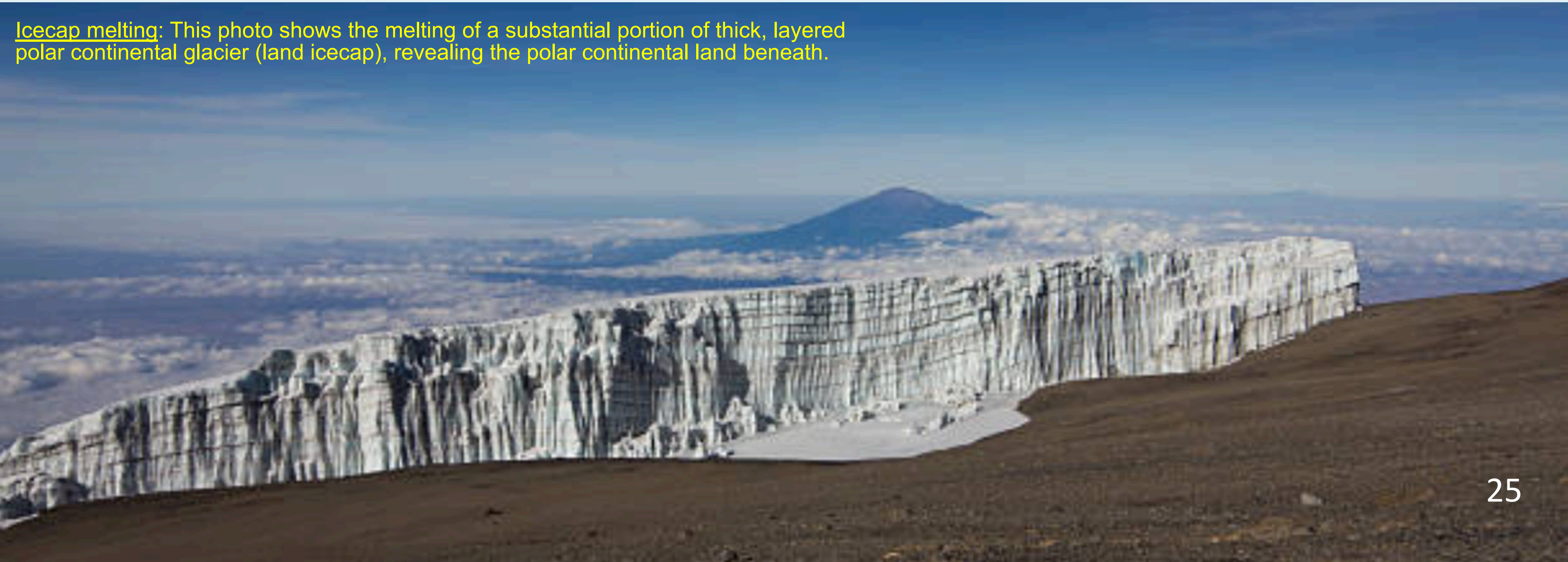


Illustrations: The new understanding of icecap melting



Icecap edge melting: Research between 2017-20 reveals that the edges of icecaps (both sea and land) have complex topographic configurations, and that some of these generate unstable regimes of fracturing and melting which self-perpetuate. These regimes would result in collapse of whole sea icecaps (ice shelfs) and wide “ribbons” of land icecap edges; both occurring at extremely high rates. The former event (which melts floating ice) does not raise sealevel; the latter (which melts land ice) does.

Icecap melting: The irreversibly melting Arctic sea icecap will be gone in 25 years. The unique species Ursus maritimus will be dramatically diminished.



Icecap melting: This photo shows the melting of a substantial portion of thick, layered polar continental glacier (land icecap), revealing the polar continental land beneath.

West Antarctic ice loss: how it happens & why so much

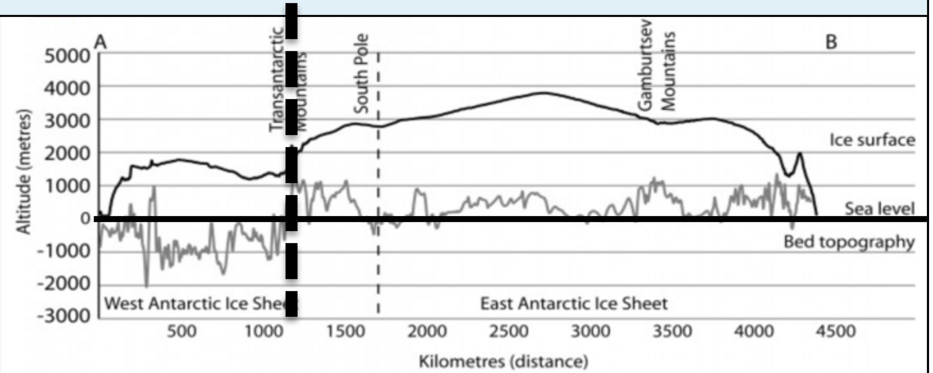
A new paper in the journal *Science* (April 30 2020) produces fresh satellite data from NASA, which provides a visual of Antarctica's rapidly melting ice. This delivers more detailed pictures of Antarctica's ice, showing how and where the ice is accumulating ice, showing how and where the ice is accumulating or melting rapidly.

Antarctica is really two small continents covered by a single ice sheet. The different behaviour of the ice sheets above these different land masses renders one of them stable, the other unstable.

https://cleantechnica.com/2020/05/01/antarctica-is-melting-like-never-before/

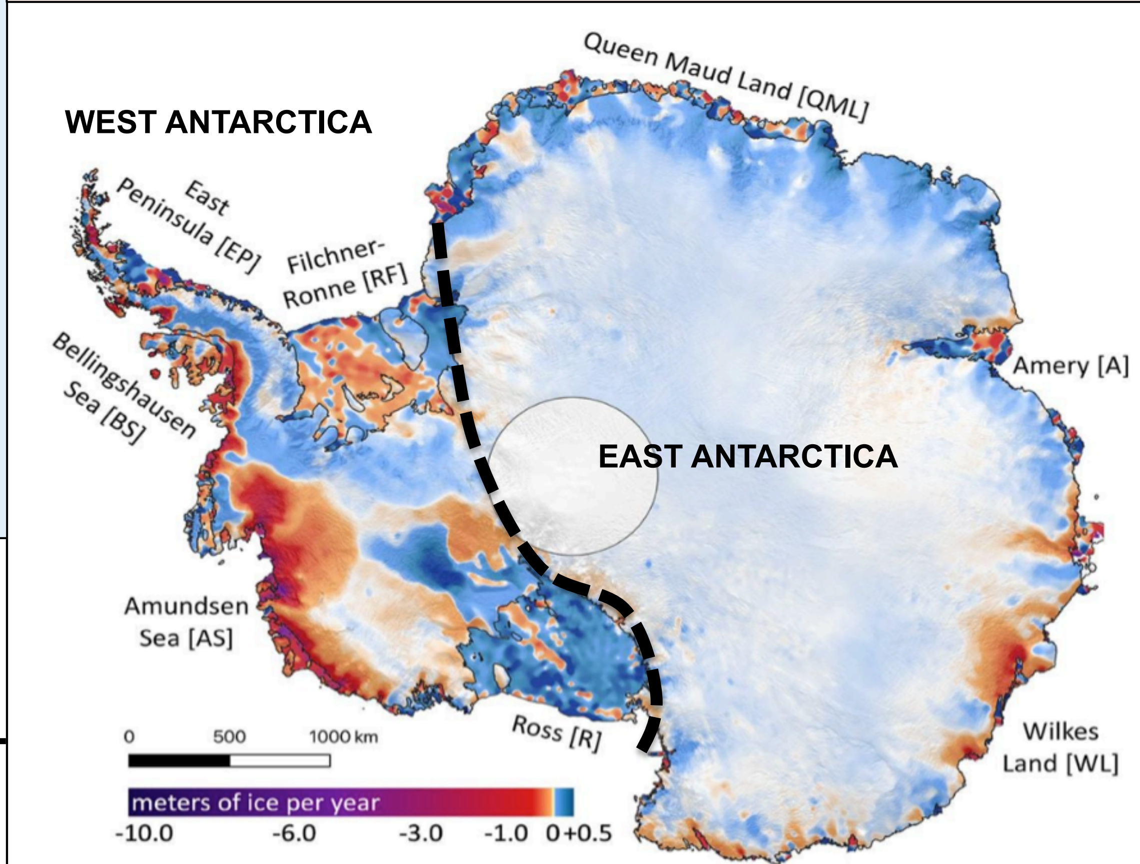
W Antarctica is 30% floating

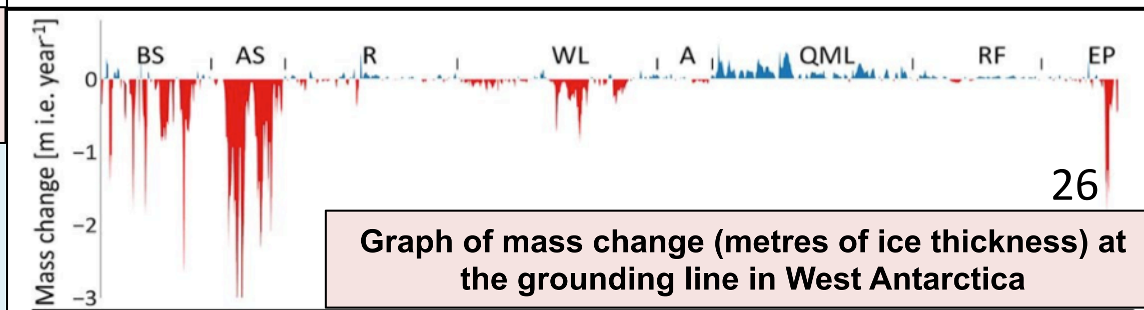
E Antarctica is continental



Cross section of Antarctica showing the continental basement ("bed") under East Antarctica vs the floating nature of much of West Antarctica

Map of mass change (metres of ice thickness) Antarctica 2003-2019

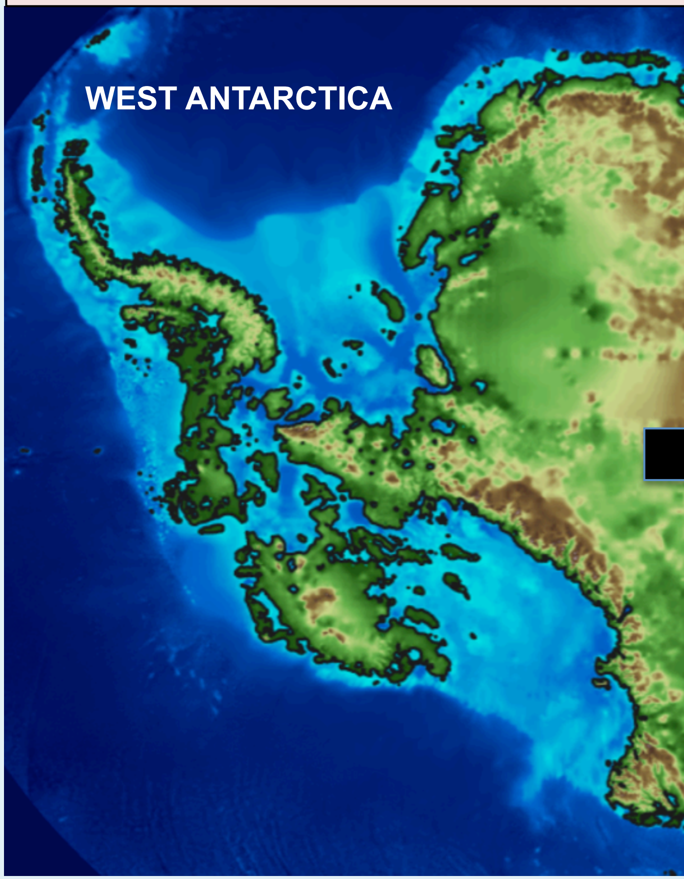




Graph of mass change (metres of ice thickness) at the grounding line in West Antarctica

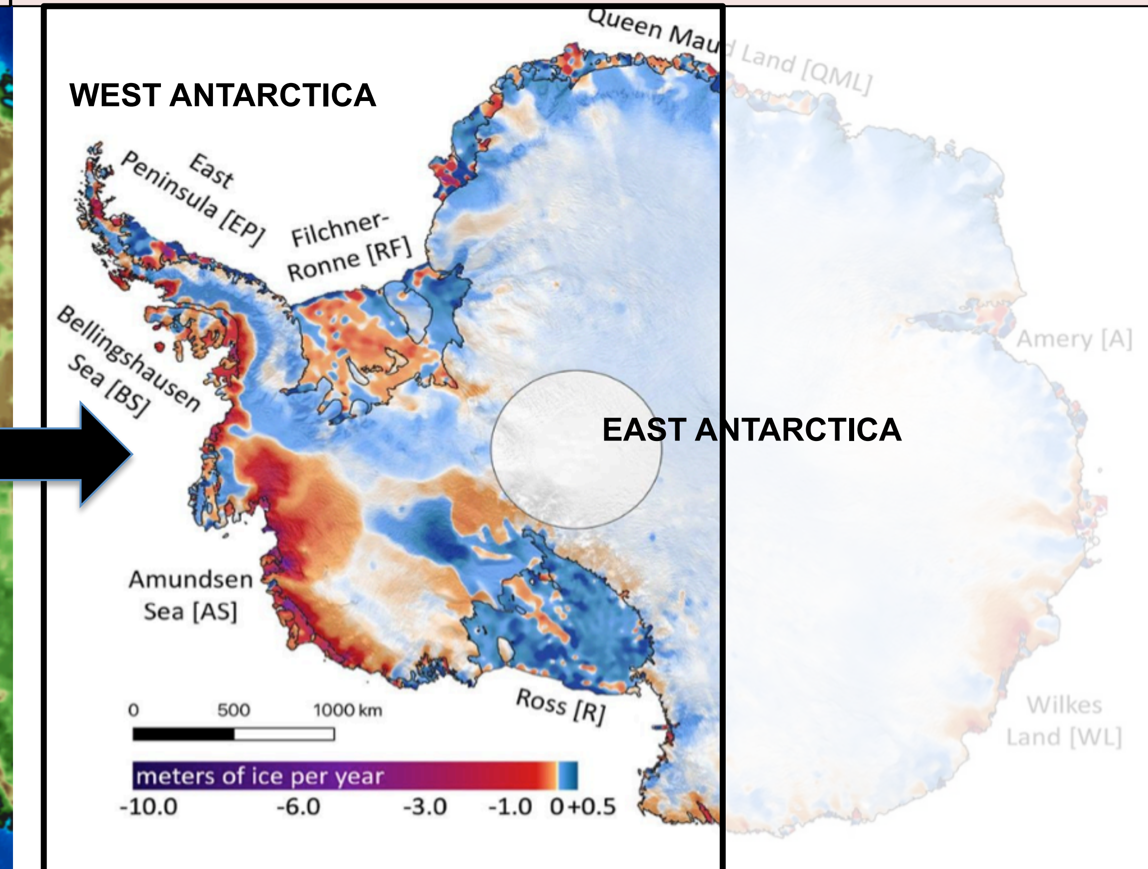
West Antarctic ice loss: how it happens & why so much

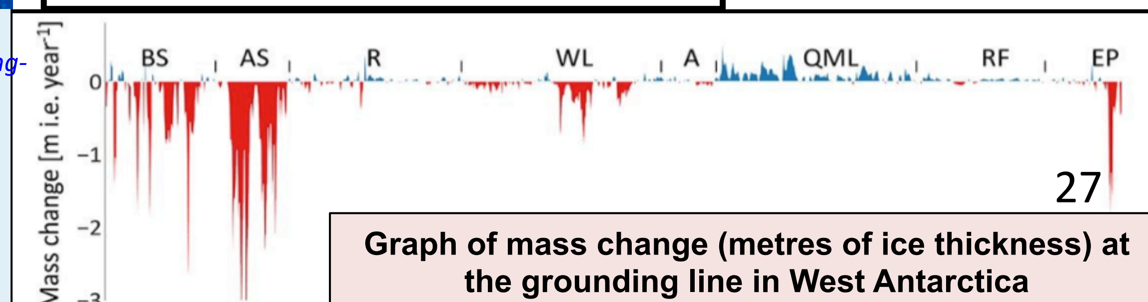
Map of West Antarctica, ice removed



https://cleantechnica.com/2020/05/01/antarctica-is-melting-like-never-before/

Map of mass change (metres of ice thickness) across Antarctica





Graph of mass change (metres of ice thickness) at the grounding line in West Antarctica

Melting of mountain glaciers

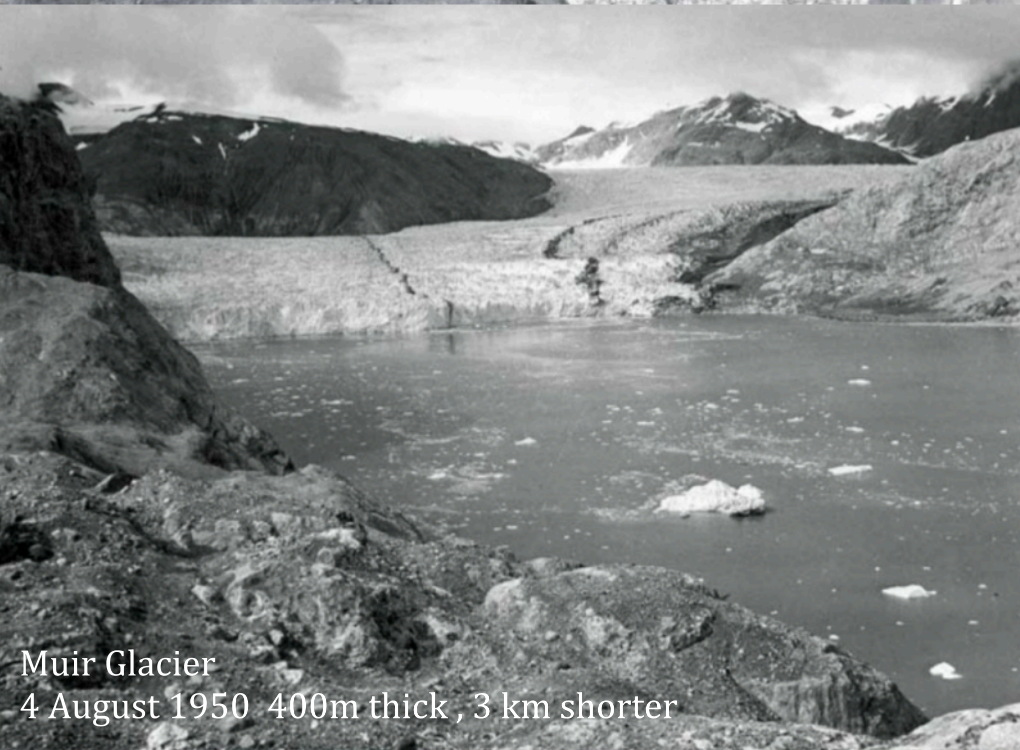

Muir Glacier
13 August 1941 700m thick

These 3 photos are taken from the same site, in the years shown, of the dramatic melting of the Muir Glacier, Alaska.

https://blogs.egu.eu/divisions/cr/2015/10/30/image-of-the-week-63-years-of-the-muir-glaciers-retreat/

Glaciers in the Swiss Alps are retreating faster than a few decades ago. In 2009 a Swiss survey of 89 glaciers found **76 retreating, 5 stationary, 8 advancing**, from where they had been in 1973. Even if we significantly curb emissions, **more than a third of the world's remaining glaciers will melt before 2100**.

https://www.worldwildlife.org/pages/why-are-glaciers-and-sea-ice-melting


Muir Glacier
4 August 1950 400m thick , 3 km shorter


Muir Glacier
31 August 2004 0 m thick, 13 km shorter

Antarctica and sealevel rise: summary of the latest research

If warming exceeds 2°C, Antarctica's melting ice sheets could raise seas 20 metres in coming centuries *The Conversation, 3 October 2019*

At the current rate of global emissions we may be back in the Pliocene by 2030 and we will have exceeded the 2°C Paris target. One of the most critical questions facing humanity is how much and how fast global sea levels will rise. The recent special report on the world's oceans and cryosphere by the IPCC states that **glaciers and polar ice sheets continue to lose mass at an accelerating rate**, but the contribution of polar ice sheets, in particular the Antarctic ice sheet, to future sea level rise remains difficult to constrain.

If we continue to follow our current emissions trajectory, the median (66% probability) **global sea level reached by the end of the century will be 1.2 metres higher than now**, with two metres a plausible upper limit (5% probability). But of course climate change doesn't magically stop after the year 2100.

Most of the sea-level rise during the Pliocene came from Antarctica's ice sheets. The melting of the Greenland ice sheet would have contributed at most five metres to the maximum 25 metres of global sea-level rise.

Of critical concern is that over 90% of the heat from global warming to date has gone into the ocean. Much of it has gone into the Southern Ocean, which bathes the margins of Antarctica's ice sheet.

Already, we are observing warm circumpolar deep water upwelling and entering ice shelf cavities in several sites around Antarctica. **Along the Amundsen Sea coast of West Antarctica, where the ocean has been heating the most, the ice sheet is thinning and retreating the fastest. One third of Antarctica's ice sheet - the equivalent to up to 20 metres of sea-level rise - is grounded below sea level and vulnerable to widespread collapse from ocean heating.**

A tipping point in the Antarctic ice sheet may be crossed if global temperatures are allowed to rise by more than 2℃. This could result in large parts of the ice sheet being committed to melt-down over the coming centuries, reshaping shorelines around the world.

https://theconversation.com/if-warming-exceeds-2-c-antarcticas-melting-ice-sheets-could-raise-seas-20-metres-in-coming-centuries-124484?gclid=EAIaIQobChMI_7269eqX6gIVFR4rCh0RGQOYEAAYASAAEgISrPD_BwE

The planet's oceans and ice: status end-2019

The Oceans We Know Won't Survive Climate Change
United Nations–led Intergovernmental Panel on Climate Change (IPCC) The Atlantic, 25 September 2019

Climate change's effects seem to be speeding up in the oceans and sea levels.

The seas are now rising at a pace "unprecedented over the last century," the IPCC warns.

- The rate of global sea-level rise was 2.5 times faster from 2006 to 2016 than it was for nearly all of the 20th century.
- In the Antarctic ice sheet, the rate of mass loss has tripled relative to the previous decade. In Greenland, it's doubled over the past decade.

The oceans act like a massive sponge in the planetary system, and they have so far absorbed most of the warmth trapped by greenhouse gases.

- Since 1993, the rate of ocean warming has more than doubled.
- Marine heat waves - when the ocean becomes so hot that it can kill plants and animals - happen twice as frequently now.
- Marine heat waves have grown in intensity, duration, and size.

This is prompting invisible bonfires to break out across the ocean's most pristine environments. Tropical coral reefs contain most of the ocean's biodiversity. They are the so-called rainforests of the ocean, yet they are dying more surely than the Amazon.

- Almost all warm-water coral reefs are projected to suffer significant losses of area and local extinctions, even if global warming is limited to 1.5^{o}C.
- From 2016 to 2018, half the coral in the Great Barrier Reef died.

It will take at least 15 years to recover - and given the pace and spread of marine heat waves, it probably never will. A child born today in Australia may never know the Great Barrier Reef as an adult. That is not a hyperbolic statement; that is an assessment of the facts.

Even beyond reefs, life is fleeing the tropical ocean.

- Since the 1950s, entire populations of fish and seafloor creatures have moved toward the poles at a rate of up to 80 kilometres a decade. This is an incredible figure when you consider that it is unplanned, unorganized, and unhabitual. The population is relocating itself all at once.

Sealevel rise in Australia 1

Rising tide: Dealing with sea-level rise when private property is at stake

Around 10 years ago, upon retirement, Dr Brett Stevenson started spending less time in Sydney and more in a house he owned in a town 200 kilometres south – the beginnings of the classic Australian sea change. The region he came to is called the Shoalhaven, the kind of place where if someone says they live a stone's throw from the coast they're probably not exaggerating. Nearly every town there starts adjacent to a beach or clings to the edge of an estuary – evidence of the Australian ethos that the closer we live to the coast, the better. Stevenson wanted to contribute to his new community, so he volunteered to sit on some of the local council's natural resources and coastal management committees. He'd spent more than a decade working in policy for the New South Wales department of the environment, and before that with the state's Environmental Protection Authority, and he had academic qualifications in science (including a doctorate for research into the NSW coast), so he thought he might have something to offer.

Like every other local government around the Australian coastline, Shoalhaven City Council has spent much of the past decade trying to figure out what to do about that wickedest of problems: 85 per cent of us live in proximity to the coast, and as the climate warms and sea levels rise, bringing bigger tides and more frequent storms, the ocean is coming for many of our homes. Local councils – being the ones that decide where and how we build – are the first responders to this critical challenge. In 2015, Shoalhaven councillors solved the problem by voting to plan for a future in which sea-level rise will not be so bad after all: an alternative reality, where Shoalhaven remains unscathed from the worst impacts of climate change.

Stevenson witnessed this decision-making process unfold and still can't quite believe what he saw. "It was just bizarre," he says. The council had commissioned an expert report, and then tossed most of it out, taking the advice of an American climate-change denial advocacy organisation backed by the fossil-fuel industry, and the advice of a group of property owners whose land value was impacted by the expert report's findings. "It was horrifying," says Stevenson. "I mean, it was just crap policy."

Even by Australian standards, last summer was one of weather extremes. As record-breaking rain was falling in northern Queensland, sending crocodiles up trees in the suburbs of Townsville, bushfires were burning alpine heathlands in Tasmania that hadn't burnt in centuries, and drought-stricken towns in New South Wales were running out of drinking water. In the midst of this, a couple of reporters from Guardian Australia ventured into a flood-ruined street in Townsville, where locals were still clearing the debris, and asked a man named Mark the question that was on many people's minds that summer: Is climate change making floods more extreme? "If anyone mentions that, I'll punch 'em," Mark replied.

Who could blame him? For a nation of coast-dwellers, climate change is much more than an inconvenient truth; it is upending.

https://www.themonthly.com.au/issue/2019/october/1569374459/bronwyn-adcock/rising-tide?utm_medium=email&utm_campaign=The%20Monthly%20Today%20-%20Tuesday%2021%20July%202020&utm_content=The%20Monthly%20Today%20-%20Tuesday%2021%20July%202020+CID_12e4b8e3d7a4e9bc2b04695699a124af&utm_source=EDM&utm_term=THE%20Monthly

Sealevel rise in Australia 2

Rising tide: Dealing with sea-level rise when private property is at stake *Monthly Essay, October 2019*

In 2009, when Australia still had a federal department of climate change, a comprehensive national assessment quantified the scale of the problem we face. It found that if sea levels continue to rise at the rate suggested by current modelling, somewhere between 157,000 and 247,600 individual residential buildings are at risk of inundation by the end of the century.

David Hanslow, a scientist with the NSW Office of Environment and Heritage, recently co-published research into urban development around the 186 estuaries and major rivers in the state. He found that if sea levels were to rise by half a metre – which is projected to happen around 2050 – then 23,700 properties will be exposed to tidal inundation, and if they rise by the projected 0.9 of a metre by 2100, then 50,700 properties are exposed. However, if a storm surge coincides with a tidal inundation – an event that would push water levels even higher – those figures would rise to 51,600 and 74,700.

Recent work by the University of Melbourne's Dr Georgia Warren-Myers found that in the City of Port Phillip, which includes the suburbs of St Kilda and South Melbourne, a sea-level rise of half a metre combined with a storm surge would expose 33 per cent of all properties in that local government area to inundation.

The NSW government directed councils to plan for a sea-level rise of 0.4 metres by 2050 and 0.9 metres by 2100 – projections that came from assessments by the International Panel on Climate Change (IPCC).

*Since this essay went to press, the latest IPCC report released in September 2019 confirmed that global mean sea level is rising and accelerating. The most likely range of sea-level rise is now projected to be between 0.61m and 1.10m by 2100. Extreme sea-level events (serious storm surges) that have occurred once a century in the past will take place once a year by 2050 in some parts of the world, particularly in the tropics.

https://www.themonthly.com.au/issue/2019/october/1569374459/bronwyn-adcock/rising-tide?utm_medium=email&utm_campaign=The%20Monthly%20Today%20-%20Tuesday%2021%20July%202020&utm_content=The%20Monthly%20Today%20-%20Tuesday%2021%20July%202020+CID_12e4b8e3d7a4e9bc2b04695699a124af&utm_source=EDM&utm_term=THE%20Monthly

State of proposed Antarctic Marine Parks

News from international Antarctic meeting *Tim Jarvis, 5 November 2020*

2020 marks the 200th anniversary since the first sighting of Antarctica!

This week the Antarctic Treaty nations around the world met to discuss whether or not they'll support the proposal for this desperately-needed marine park. Three marine park proposals were on the agenda: the **East Antarctic, Weddell Sea** and **Antarctic Peninsula** Marine Parks. Global disruption and travel restrictions due to Covid meant that this year's meeting of the Antarctic nations had to take place by video-conference, and over a much shorter period of time. This meant it wasn't possible to consider the marine park proposals properly. **The Marine Parks didn't get over the line this year.**

Many of the nations signed a pledge declaring the urgent need to create the network of marine parks across the Southern Ocean - home to some of our most special marine life and one of the fastest warming regions on Earth. Norway and Uruguay joined forces with Australia, France and the EU as new co-sponsors of the **East Antarctic** Marine Park. And Australia continued to demonstrate our strong leadership on Antarctic protection by becoming a co-sponsor for the Antarctic's **Weddell Sea** Marine Park.

Australia's leadership will be essential to drive the diplomatic push needed over the next year to secure the full backing of the **26 Antarctic nations.** The Australian Government has made Antarctic protection a priority, and together we must keep up the momentum to get these marine parks over the line.

Tim Jarvis AM

Antarctic Explorer and Environmental Scientist

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