Making Sense of "Tipping Points"

Tipping Points: Part 2 - Potential Ice Sheet Collapse

What are the potentials for

Greenland and Antarctic Ice Sheet Collapses?

As we started our look at tipping points last time, in CSSG-2.10, we saw: in the cryosphere, six Earth system tipping points are identified, including large-scale tipping points for the **Greenland Ice Sheet (GIS) and the West Antarctic and East Antarctic Ice Sheets (WAIS and EAIS)**.

And, we noted that the study (https://global-tipping-points.org/) articulated our current status:

The picture is dynamic - here we see ice melting (the brownish-reddish tones), but there is actually a little (less than half a meter, the blue shading) increasing thickness in the higher and colder regions.

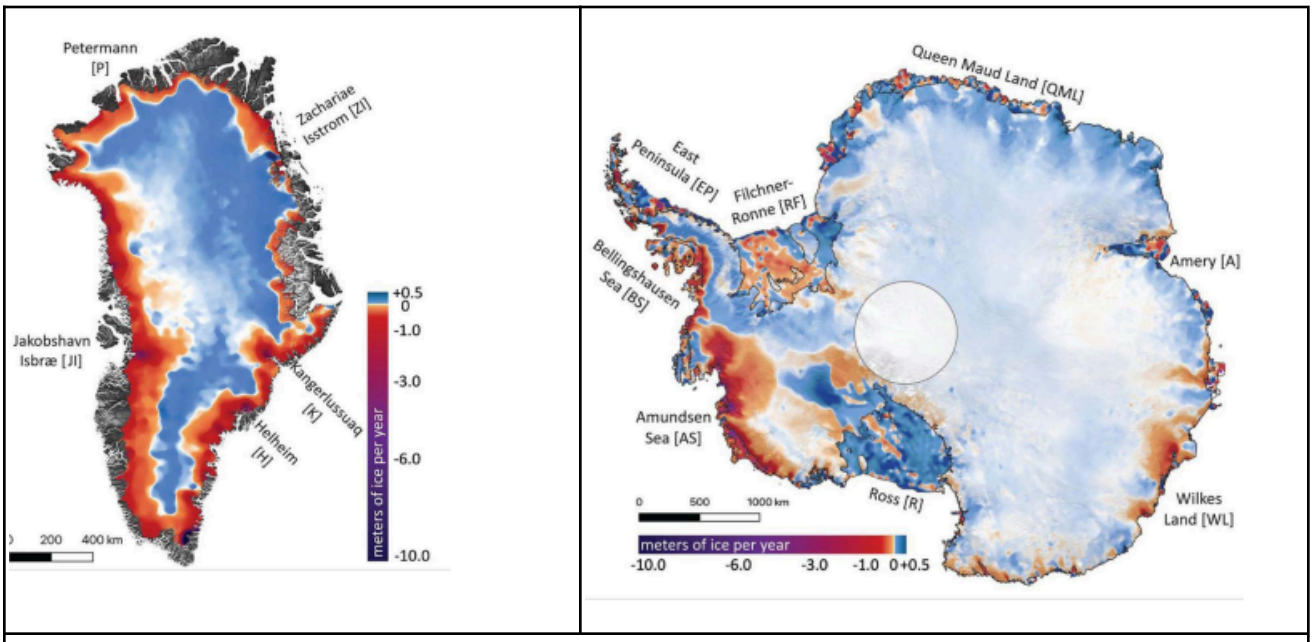

Figure 1.2.4: Observed mass change of Greenland and Antarctic ice sheets. Mass change (mass loss in red, mass gain in blue) between 2003 and 2019 for Greenland and Antarctica, given in metres of ice equivalent per year (from Smith et al., 2020).

Approximate "Cheat Sheet":

1 meter → 3 feet **1 degree Celsius (°C)** → 2 degree Fahrenheit (°F)
ppm = parts per million **CO_2** = Carbon Dioxide
1 tonne = 1000 kilograms = 2205 pounds **1 gigatonne (1 Gt)** = 1 billion tonnes
1 trillion tonnes (1Tt) = 1000 gigatons

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The maps below show an unsurprising view of the **Greenland below the ice**, but a wildly-different imagining of **Antarctica!** All that blue-green shading in Antarctica is the **ice sheet grounding below sea level**! Basically, as the ice sheet formed over millennia, the continent was pushed down under its weight so that much of it is far below sea level. The ground is flexible and will rebound over time as the ice melts.

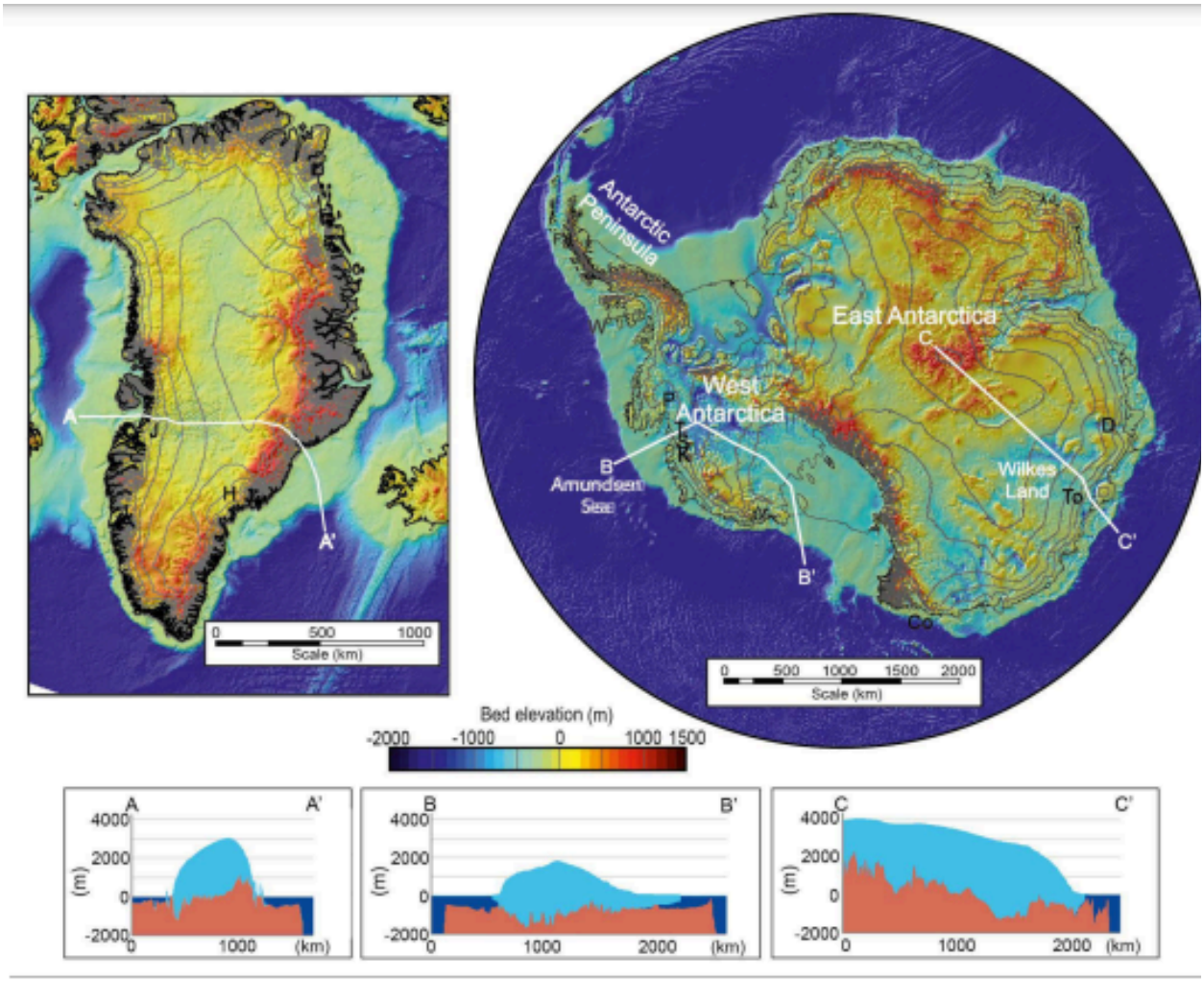

Figure 1.2.3: Greenland and Antarctic ice sheets. Given is the bedrock topography of the GrIS (left, based on Bamber et al., 2013) and the Antarctic Ice Sheet (middle and right, based on Fretwell, 2013) alongside cross sections marked in the maps by white lines. In marine ice sheet sectors (blue-green shading in the maps) the ice sheet rests on a bed submerged below sea level.

So, let's take a look at the main drivers of the potential collapse of these two regions, both caused by global warming.

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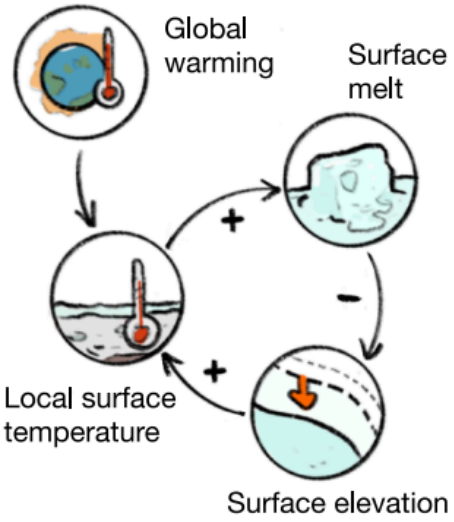
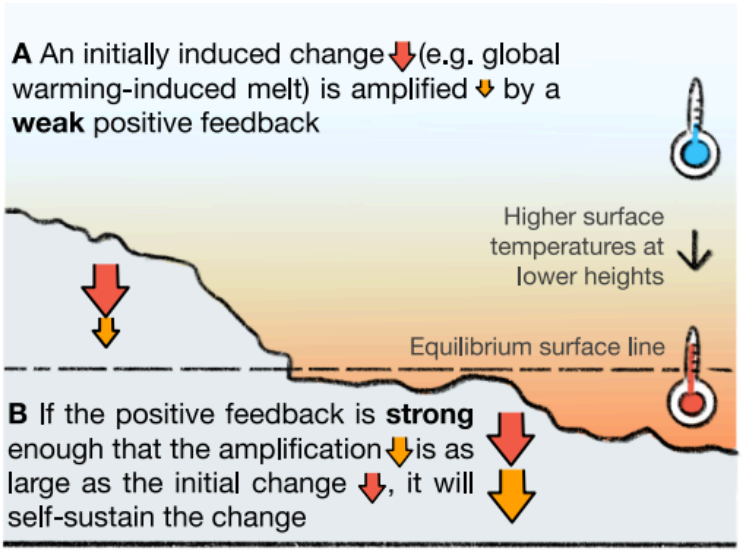
Greenland Ice Sheet COLLAPSE DRIVER

Although I find this graphic pretty awkward, I couldn't find a better one quickly. Global warming most directly impacts the Greenland Ice Sheet (away from the edges) by melting the surface, **lowering its elevation**. Lower air is warmer, and this means more warming and more melting.





You can see this effect below. The smooth snow is above the warmer atmosphere; below this, melting and riverlettes are seen:

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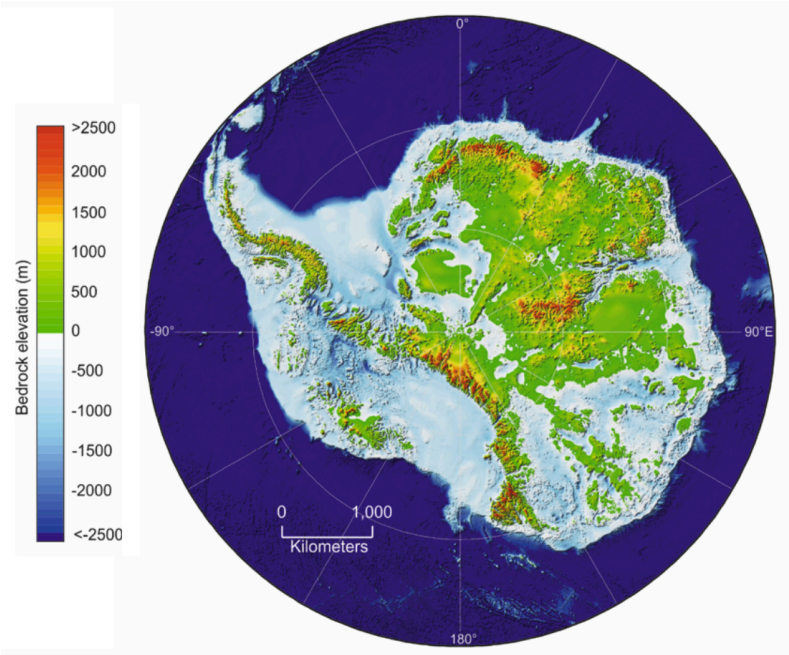
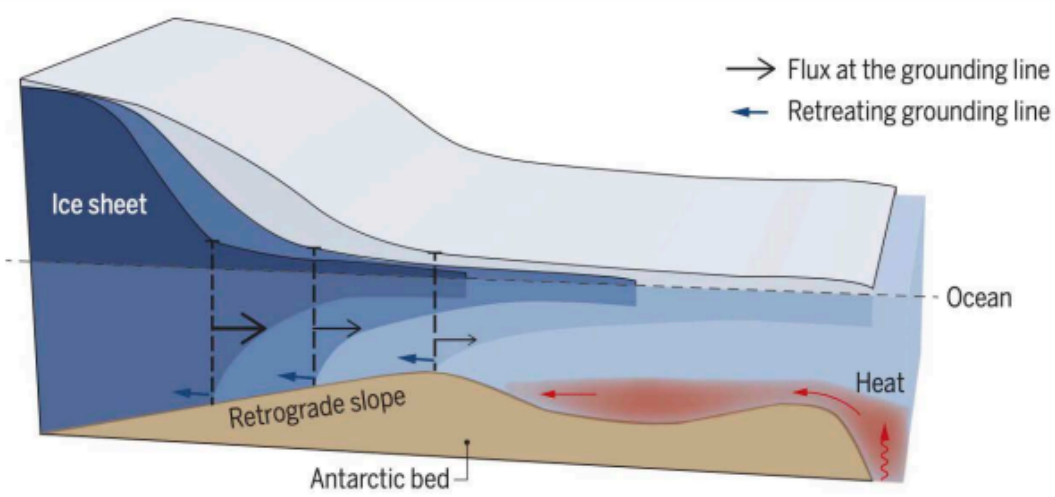
Antarctic Ice Sheet COLLAPSE DRIVER

The surface-elevation melting effect is less dominant in Antarctica, because, being at the pole, the air is colder. Instead, it's the below-sea level melting which makes it more vulnerable.



https://www.carbonbrief.org/explainer-nine-tipping-points-that-could-be-triggered-by-climate-change/



This is one of various ways the warmer ocean water can encroach on the ice from below.

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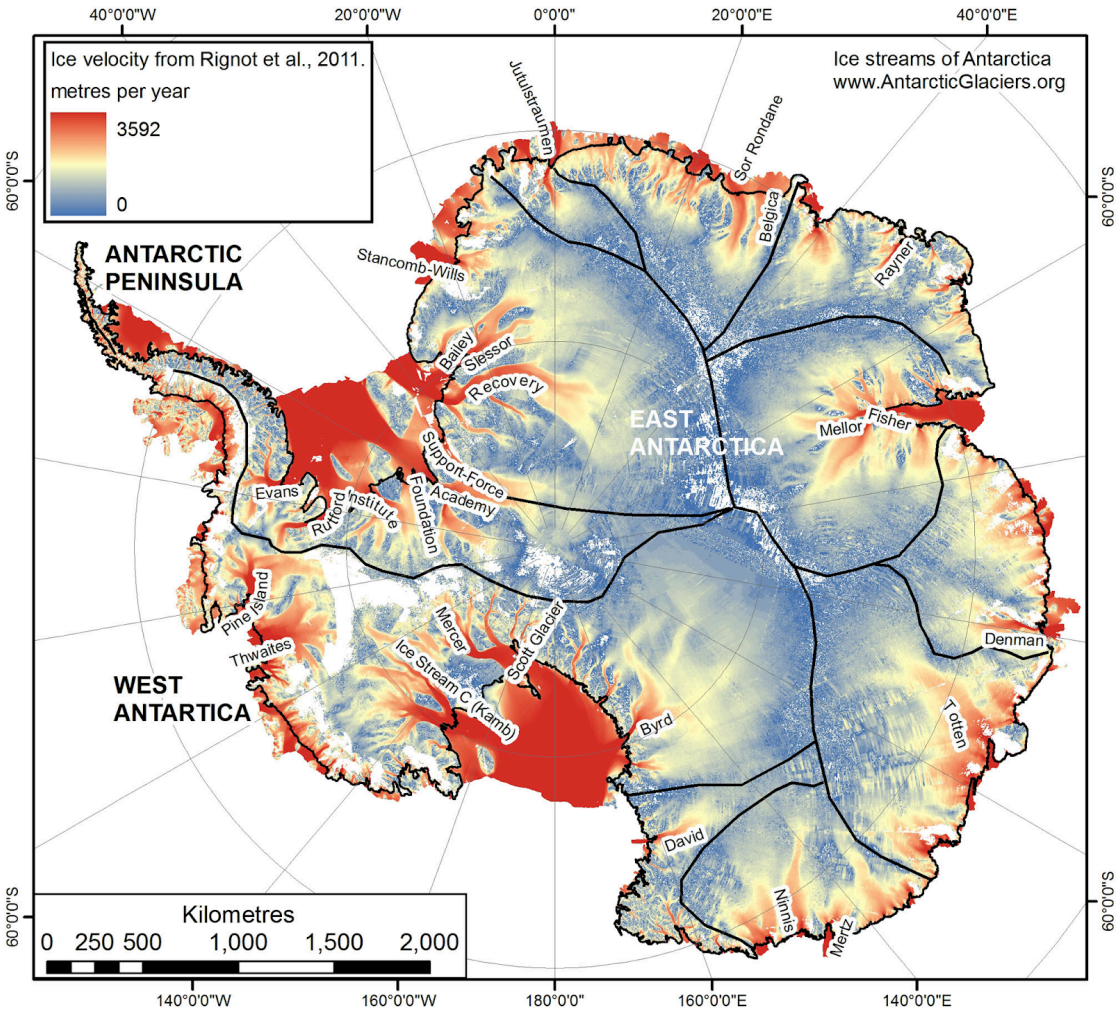
The main attack is from the warming ocean waters which can directly access the ice below sea level. As a result, the ice sheet can move forward more rapidly into the sea, by motion of its glaciers.



You probably have heard of the so-called "Doomsday Glacier". This is the Thwaites Glacier. It and its neighbor, the Pine Island Glacier, empty into the Amundsen Sea (just below the Antarctic Peninsula on this graphic by the "West Antarctica" label).

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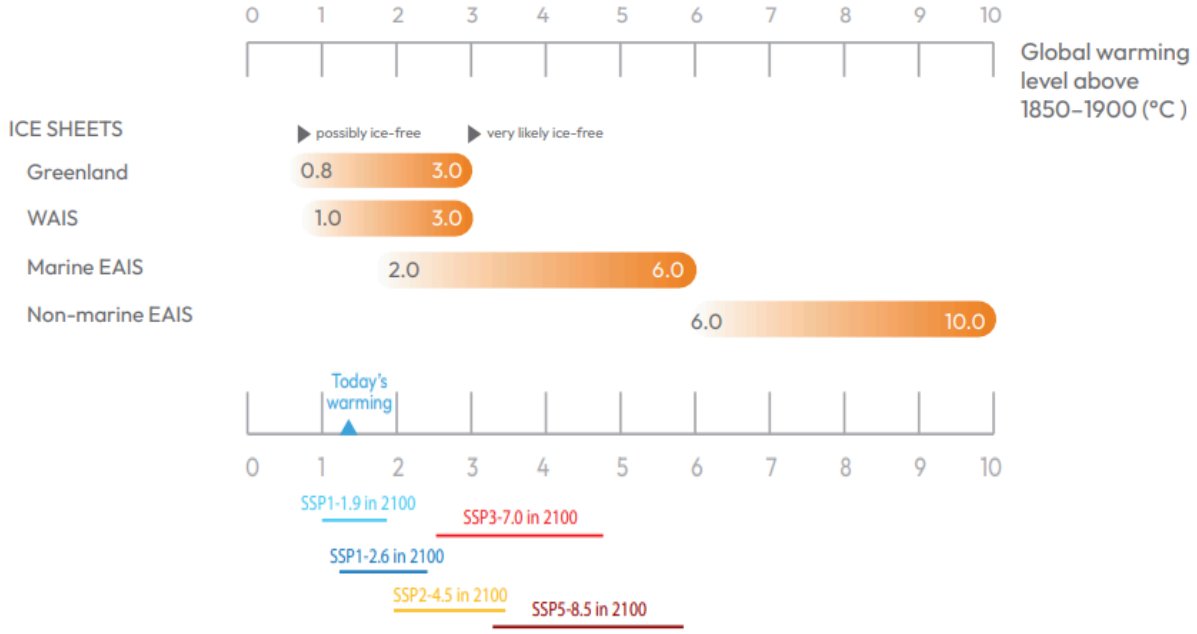
The Report referenced at the top goes into numerous studies which have indicated that these are indeed ripe for "TIpping Points". The ancient paleo records, recent measurements of changes, and complex computer modeling all point in that direction. Last time, we noted some summary conclusions:

> **Already, at today's 1.2°C global warming**, we cannot rule out that some systems may already have passed tipping points, including the ice sheets of Greenland [total 7m sea level rise potential over centuries to millennia] and West Antarctica [3m].
>
> **At 2°C global warming and beyond**, several more systems could tip, including subglacial basins in East Antarctica [19m], and irreversible collapse of the Greenland and West Antarctic ice sheets is likely to become locked in.

These conclusions are made more specific in the following chart, which shows the **lower temperature collapse of the Greenland Ice Sheet (GIS)** and the **West Antarctic Ice Sheet (WAIS)**. In addition, at perhaps higher temperatures, the **Eastern Antarctic Ice Sheet (EAIS)** will behave in two fundamentally different ways: the **"Marine EAIS" [19m]** is grounded on rock which is itself below sea level (!) and the **"Non-Marine EAIS" [34m]** is the great ice dome on an above-sea-level foundation. For context, we are very much on target to exceed 3 ºC warming.



The "SSP" bars immediately above reference IPCC scenarios varying from very aggressive action against global warming up to "business as usual" increases in emissions.

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Punchlines

Because the words "Tipping Point" can have an intuitively emotional response before any real understanding is developed, it's important to keep a little more complete picture in mind:

Projected "Tipping Point"- Collapse of the:	Best Estimate of how soon might Irreversibility be reached?	Dominated by	What's the Ultimate Impact?	How Long till the Ultimate Impact is Reached?	How much Impact this Century? (Per IPCC)
Greenland Ice Sheet (GIS or GrIS)	About **1.5 ^{0}C** warming - we'll almost surely pass that this decade. **Above 2 ^{0}C**, cannot be stopped	**Atmospheric Warming ->** Surface melting -> **melt-elevation feedback** -> melt-albedo feedback -> surface melt	**- 7 meters** of Sea Level rise - **Disruption of global ocean circulation** - Substantial shifts in atmospheric circulation patterns	Centuries to millennia	More melting and more snow because of warming? -> **ocean circ disruption.** Perhaps 1.2 meters SL rise from GIS and 2 meters SL in combination with WAIS, affecting 480 million people
West Antarctic Ice Sheet (WAIS)	**1 - 3 ^{0}C** warming - we are on target to exceed 3 ^{0}C this century	**Atmospheric Warming -> Ocean warming and circulation changes**: Ocean-induced melting at the underside of the floating ice shelves	**- 3 - 5 meters** of Sea Level rise - Disruption of global ocean circulation - Substantial shifts in atmospheric circulation patterns	Centuries to millennia	
Marine East Antarctic Ice Sheet (EAIS)	**2 - 6 ^{0}C** warming - we are on target to exceed 3 ^{0}C this century	**Ocean warming and circulation changes**: Ocean-induced melting at the underside of the floating ice shelves	**- 19 meters** of Sea Level rise - Disruption of global ocean circulation - Substantial shifts in atmospheric circulation patterns	Centuries to millennia	
Non-marine East Antarctic Ice Sheet (EAIS)	**6-10 ^{0}C** warming		**- 34 meters** of Sea Level rise - Disruption of global ocean circulation - Substantial shifts in atmospheric circulation patterns	Centuries to 10,000 years	