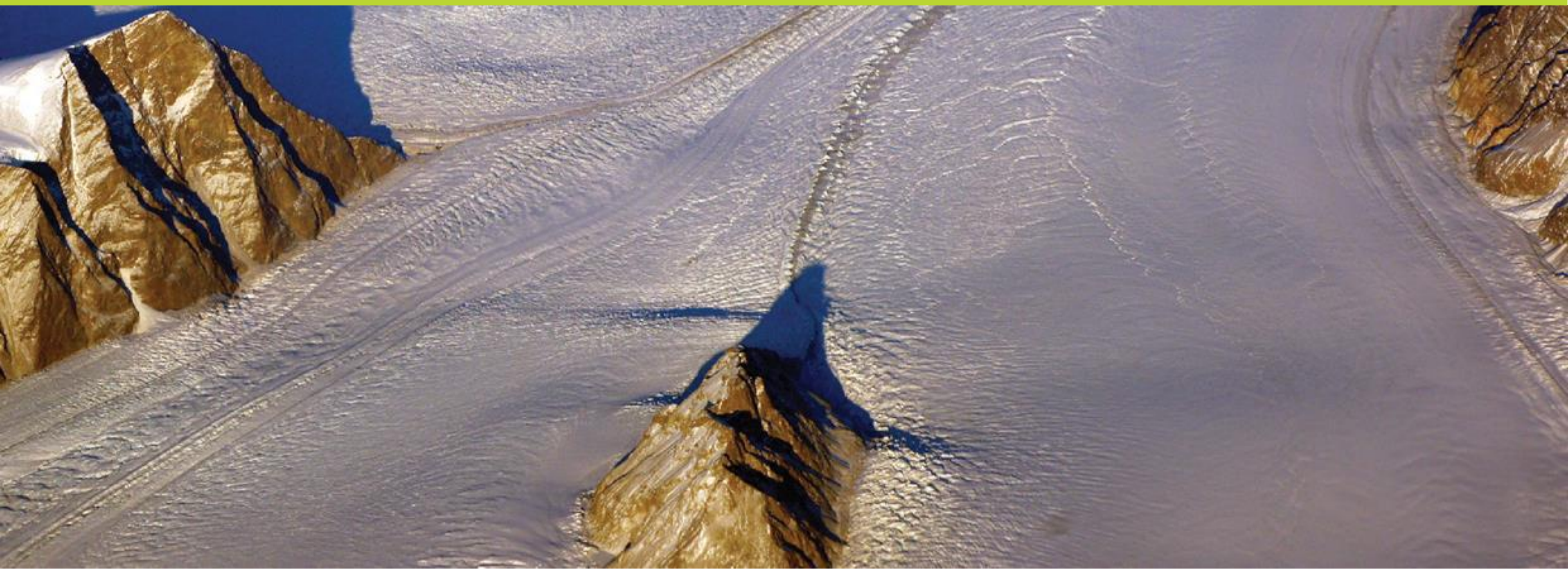
Risk management of climate thresholds and irreversible change: Ice Sheets



What is the nature of the threshold?

Ice sheets have been found to exist in different equilibrium states, and if they melt beyond a certain threshold, they may collapse into a no-ice state[1]. Different thresholds exist, because there are a range of different feedbacks over the Greenland and Antarctic ice sheets. For example, the albedo-temperature positive feedback is important for both the Greenland and Antarctic ice sheets. Bare ice absorbs more solar energy than snow covered ice, so as the summer snowline retreats more solar energy is absorbed, accelerating warming and further ice melt and snowline retreat. The dominant feedback for an ice sheet depends partly on whether it loses mass mostly through surface melting, or by calving of glaciers into the ocean. Both ice sheets are currently losing mass, Greenland at twice the rate of Antarctica (Fig. 1).

Greenland: Since 2009, mass loss from the Greenland ice sheet has occurred mostly through surface melting[2], and this will continue into the future. When melting on the surface of the ice sheet exceeds the snowfall, the ice becomes thinner and the surface lower. As air is warmer at lower altitudes, this causes melting to increase, in a process known as the melt-elevation positive feedback. Once more than 10% of the ice is lost, the change may be irreversible even if temperatures return to pre-industrial levels, leading to an alternate intermediate stable state with less mass in the ice sheet[3]. This will cause irreversible sea-level rise.

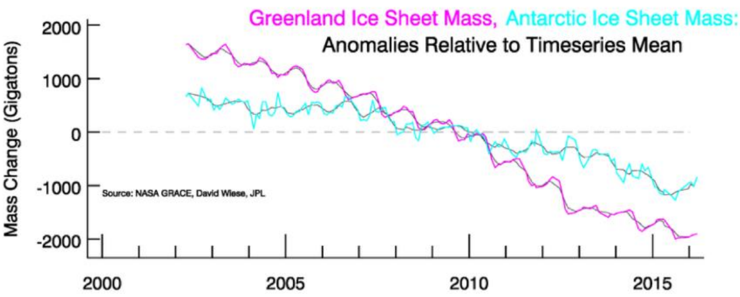


Figure 1. Changes in the mass of the Greenland and Antarctic ice sheets from the satellite gravity mission GRACE. Source: NASA GRACE, David Wiese, JPL

Antarctica: The Antarctic ice sheet is colder than Greenland, so most mass loss occurs through glacier calving. Here, a positive feedback called marine ice sheet instability is expected to occur. This feedback arises from the way in which bedrock below sea level slopes under much of the West-Antarctic and part of the East-Antarctic ice sheets. When the ice sheet, melted by the ocean, retreats back past a certain point on the bedrock, the ice flows faster and more ice is lost as icebergs (Fig. 2)[4].

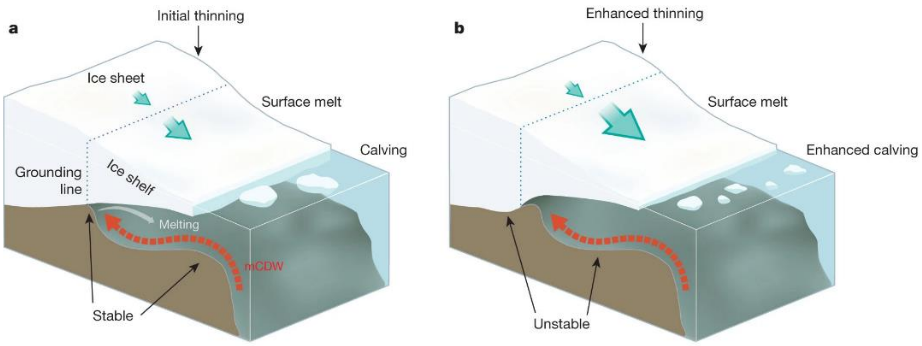


Figure 2. Marine ice sheet instability occurs when the edge of the ice sheet rests on bedrock that deepens inland, as shown in panel b). A warming ocean melts the ice, causing the ice sheet edge to retreat. This exposes a greater depth of ice to loss into the ocean, driving further retreat.[11]

What impacts might be expected if a threshold were crossed?

Greenland: Meltwater from the Greenland ice sheet is causing global sea levels to rise at a rate of 0.7 mm per year. In the future, this could eventually rise to as much as 5 mm per year[5]. If near-complete loss of the ice sheet were to occur, this would cause a sea level rise of 7 m and take between one to four thousand years, but partial irreversible melt is also possible.

Antarctica: The West Antarctic ice sheet could decline irreversibly over a few centuries, causing a total global sea level rise of about 3 m. However, the timescale of the ice sheet collapse is uncertain as the bedrock topography may contain several ridges that would delay the retreat. The East Antarctic ice sheet is much larger, but is more stable, and may partially retreat over a few thousand years.

If a threshold is crossed, are the changes irreversible?

Greenland: There is some temporary resilience during which the ice sheet decline may be reversed[5, 6] due to the time taken for ice to melt. This is on the scale of decades to centuries, decreasing with larger overshoots. However, if 10-20% of the ice sheet melts, it may be unable to recover[3].

Antarctica: Once the threshold is crossed, the loss of the West Antarctic ice sheet, and associated 3 m sea-level rise, cannot be stopped, even if climate is rapidly returned to pre-industrial conditions.

How likely is such a threshold to be crossed?

Greenland: Under some scenarios, such as the high-emissions RCP 8.5 scenario, the ice melt threshold is expected to be crossed by 2100. Some studies show that the threshold may not be reached if global warming is restricted to 2°C above pre-industrial levels[7, 8] but the threshold could be lower than this.

Antarctica: The threshold for West Antarctica is likely be crossed by 2200, though it could be earlier[1]. An enhanced knowledge of the bedrock would improve projections from model simulations[9].

What are the prospects for early warning and what long-term observing systems need to be maintained?

Greenland: Early warning of the threshold is provided by satellite altimetry of the surface height and surface melt area from satellite passive microwave observations. If the area of melt expands to routinely encompass 50% or more of the ice sheet, then the surface height will inevitably reduce. If repeated observations show a reduction in areas of growth combined with an increase in areas in which surface elevation is sinking, then it is likely that the threshold is approaching. Such observations need to be maintained for several decades prior to a threshold being reached.

Antarctica: Satellite altimetry and imagery can determine if the ice sheet is retreating. A sustained retreat around the West Antarctic ice sheet, combined with knowledge of the bedrock slopes, will be an early warning of imminent collapse. Such systems will need to be maintained for many decades (50+ years).

What future research is planned at the Met Office Hadley Centre?

Future work at the Met Office will involve the inclusion of a dynamic ice sheet in the global climate model allowing the timescales of ice sheet collapse under various scenarios of future climate change can be investigated.

References – Met Office papers in **bold**
[1]**Robinson et al., (2012) Multistability and critical thresholds of the Greenland ice sheet;** [2]Enderlin et al., (2014) An improved mass budget for the Greenland ice sheet; **[3]Ridley et al., (2010) Thresholds for irreversible decline of the Greenland ice sheet;** [4]Arthern et al., (2017) The sensitivity of West Antarctica to the submarine melting feedback; **[5]Ridley et al., (2005) Elimination of the Greenland ice sheet in a high CO climate;** [6]Applegate et al., (2015) How effective is albedo modification in preventing sea-level rise from the Greenland ice sheet; [7]Vizcaino et al., (2015) Coupled simulations of Greenland Ice Sheet and climate change up to AD 2300; [8]Gregory et al., (2004) Threatened loss of the Greenland ice sheet; [9]Sun et al., (2014) Dynamic response of Antarctic ice shelves to bedrock uncertainty; [10]https://ukesm.ac.uk/interactive-ice-sheets-ukesm1/. [11]Hanna et al., (2013) Ice-sheet mass balance and climate change.