AVOID 2

Can we avoid dangerous climate change?

What are climate 'tipping points' and how likely are they?

Evidence from ice core and sediment records shows that in the past, Earth's climate has reached critical thresholds, triggering abrupt and rapid change. Whilst the reasons behind such 'tipping points' are not always clear, evidence from climate models shows that they could be reached again as the planet warms in response to greenhouse gas emissions. However, this risk cannot yet be assessed precisely, neither can the full impacts of any resulting large-scale climate changes. However, whilst it is difficult to account for their likelihood in models and associated costs in policy, it is clear that the chance of triggering any such events would be reduced through greenhouse gas emission reductions.

What are tipping points?

Tipping points are critical thresholds at which large-scale Earth system processes may respond to changes in the climate. They can occur abruptly and can have perceived 'on/off' characteristics. The AVOID 2 research programme has reviewed scientific evidence for tipping points, published since the IPCC 5th Assessment Report.

Evidence from climate models

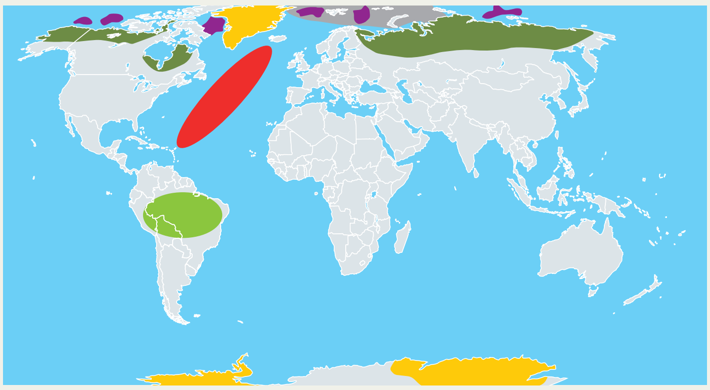
There has been substantial progress in understanding the risks and consequences of tipping points. Figure 1 shows some of the latest evidence from climate models of the occurrence of tipping points under climate change scenarios.

Despite recent advancements it remains difficult for climate models to simulate all the large-scale processes involved and the consequences of tipping points simulated by different models can be diverse.

Models consider tipping points to have a low, or very low probability though only inasmuch as they can define the likelihood of such events. Regardless of this it is known that the risk of reaching a tipping point increases with the level of global warming, thus the chance of such events can be reduced by limiting greenhouse gas emissions.

While tipping points represent substantial risks when considered individually there is also a possibility that different systems reaching a tipping point will interact with other parts of the climate system. For example, freshwater from the melting of the Greenland ice sheet could slow down aspects of Atlantic circulation affecting the climate of Europe and the Amazon, but there has been relatively little research on such complex scenarios. The next generation of Earth system models, which better consider Earth system processes, may provide further clarity.

Figure 1: Summary of new results on tipping points since the IPCC 5th Assessment Report and the magnitude of their impacts where they have been quantified. RCP8.5 is a high emissions future scenario that reaches 5°C by 2100.



Carbon release from soils due to melting permafrost
This release could be effectively *irreversible* over the near term but amounts and rates of release are highly uncertain, e.g. between 0.5 to 50% of carbon in the upper soil of northern polar regions could be released by the end of the century under a high emissions pathway (RCP8.5).

Collapse of the West & East Antarctic Ice Sheets (WAIS & EAIS) and Greenland Ice Sheet
WAIS and EAIS collapse could result in eventual sea level rise contributions of 3.3m and 4-5m respectively (for comparison, the IPCC range of sea level rise under RCP8.5 by 2100 is 0.52-0.98m). The global-mean warming threshold for *irreversible* Greenland Ice Sheet loss has been estimated to be 0.8-3.2 °C (best estimate 1.6 °C) above pre-industrial, if this magnitude of warming is sustained for thousands of years.

Methane (25 times stronger greenhouse gas than CO_2) release from the sea bed
Releases by global warming would be *irreversible* and enhance warming. This process is not yet included in the IPCC models, so detailed projections of the effect are not included in climate change projections and, if they occurred, would be additional to projected warming.

Ocean acidification
Large (>150%) increases in ocean acidity are projected by the end of the century under a high emissions pathway (RCP8.5). Unless CO_2 emissions are rapidly reduced, large areas of the Arctic Ocean will become corrosive to unprotected shelled organisms within a couple of decades, and the Southern Ocean will follow soon afterwards. There are also risks to productivity of fisheries and aquaculture.

Loss of Arctic sea ice
Nearly ice-free Arctic summers (i.e. less than 1 million km^2 of ice, compared with around 5 million km^2 in 2014) are possible by mid century under a high emissions pathway (RCP8.5).

Loss of tropical forests
New climate model simulations suggest that loss of much of the Amazon rainforest is unlikely to happen due to climate change alone; e.g. land-management and land-use change are other important factors.

Collapse of the Atlantic Meridional Overturning Circulation flow (AMOC)
Europe and the Amazon have been identified as two areas that could be most affected by AMOC collapse, with impacts including increases in winter storms and large reductions in vegetation respectively.

Evidence from the past

We can also turn to evidence from the past to demonstrate that tipping points are possible, and to understand their nature. Although care needs to be exercised when drawing a link between the pre-historic climate and the present day, there is compelling evidence from the past of rapid changes in Earth's climate.

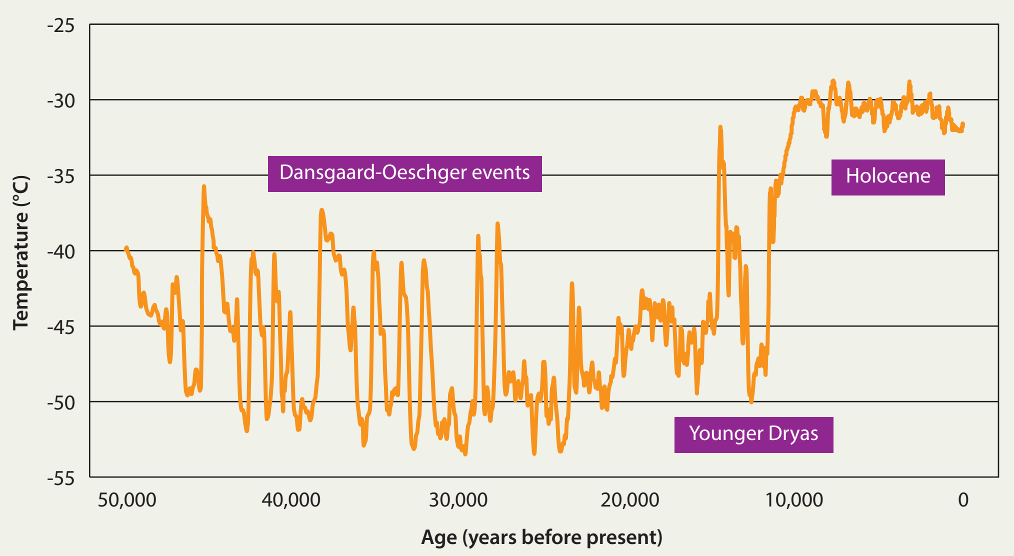
For example:

- **Rapid warming by 5-10°C in a few decades in Central Greenland** ('Dansgaard–Oeschger events' - Figure 2). These abrupt and dramatic changes, which may be due to changes in ocean currents, occurred multiple times over the past 49,000 years.
- **Cooling 14,500 years ago ('Younger Dryas'), followed by rapid warming by 5-10°C over a few decades** (Figure 2). Whilst the cause is uncertain, abrupt changes like this may have occurred due to the Atlantic Meridional Overturning Circulation (AMOC) switching between phases perceived to be 'on' and 'off' states, affecting sea temperatures.
- **Mass ice loss measurements from a major glacier on the West Antarctic Ice Sheet** (WAIS) during the early Holocene (8,000 years ago), when there was sustained warming around 2°C above pre-industrial temperatures. The rapid thinning that occurred for over 25 years is comparable to the present-day rate (which, for the WAIS as a whole, contributes 0.3mm per year to sea level rise).
- **55 million years ago, global temperatures increased by 5-8°C** over about 10,000 years, possibly due to large enhancements of atmospheric methane released from the sea bed.

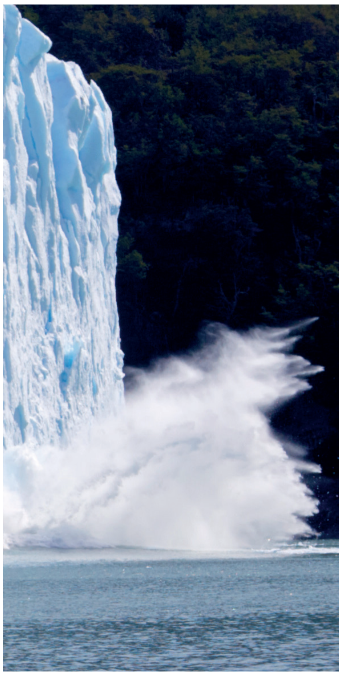
Implications of tipping points for policy

The difficulties of accurately estimating the likelihood of tipping points combined with their occasional 'on/off' nature, and the high potential damages they would cause if they are triggered, means it is hard to account for them in policy. A key component of preparing for this may be the deployment of global early warning systems. These should combine risk assessment, scientific prediction, careful warning formulation, effective communication and an appropriate response capability.[1]

Figure 2: Central Greenland temperature in the last 49,000 years, derived from ice core records.



Note: Produced using data from Alley (2000) *Quaternary Science Reviews* 19: 213-226.



[1]Lenton (2011) *Nature Climate Change* 1: 201-209.

Read more

AVOID 2 report A5: *An updated view of tipping points and the relevance for long-term climate goals* available on our website *www.avoid.uk.net*.