Dangerous climate thresholds

Evidence suggests the Earth's climate has reached critical thresholds in the past, triggering abrupt change. Climate models suggest such thresholds could be reached again as the Earth warms from increasing greenhouse gas emissions. So what do we understand about the current risks?

What are the thresholds of the climate system?

Arctic sea ice

Climate models suggest the Arctic could see ice-free[1] summers by mid-century[2] under a high emissions scenario. However some estimates indicate this could occur as early as the 2030s[3], though this is considered less likely. As ice melts, it exposes the darker ocean below which absorbs more solar radiation than the reflective white ice, resulting in further warming and more ice-melt, and so on. This is one reason why the Arctic is warming so rapidly and has potential for future abrupt change. Potential impacts of such abrupt change include:

- changes to northern hemisphere weather patterns;
- socio-economic changes (e.g. new shipping routes);
- loss of Arctic wildlife habitats.

Changes in ocean circulation

Current understanding suggests it is very likely that North Atlantic Ocean circulation will weaken but is "very unlikely" to undergo abrupt change before 2100. However, the likelihood of collapse increases on longer timescales if greenhouse gas emissions remain high. Weakening and eventual collapse could lead to a cooling of the northern hemisphere with more winter storms in Europe and changes in summer rainfall[4].

New Met Office Hadley Centre research suggests that an abrupt change in Atlantic Ocean circulation would not only lead to widespread northern hemisphere cooling, but also affect global plant productivity. Over Europe, plant productivity reduces over the spring and summer growing season in response to the cooler temperatures and lower year-round rainfall, with potential implications for crop growth. A longer dry season over parts of the Amazon rainforest is also found, which increases the chance of forest degradation.

Can we develop an early warning system for a potential collapse?

Separate research shows that if fresh water input from melting ice sheets exceeds a critical value the weakening of the Atlantic circulation is effectively irreversible even if the fresh water input later stops. Work is now underway to understand what controls this response and look at ways of developing an early warning system of how close Atlantic Ocean circulation is to collapse.

Permafrost

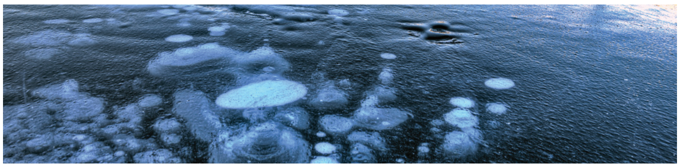
Permafrost soils in the high northern latitudes are the largest single store of carbon, most of which is currently frozen and inert. It is expected that under a warming climate permafrost regions will thaw releasing greenhouse gases into the atmosphere. Recent Met Office research suggests thawing permafrost soils could result in extra warming of up to 0.2 °C by 2100[5] although some estimates suggest this could be even higher[6]. This loss of carbon is likely to be irreversible over timescales of hundreds to thousands of years as the accumulation of such carbon stores takes a long time.

Tropical and boreal forests

Over the 21st century, climate change is unlikely to cause large-scale forest dieback on its own, however a transition from mature forest to low-biomass vegetation may occur in the Amazon in response to drought and other stresses such as logging[7]. As the climate changes, there are both opportunities and threats to tree growth. For example, in northern boreal forests increasing temperatures and higher concentrations of CO_2 could stimulate growth. However, reduced soil moisture levels and increased vulnerability to fire, drought, pests and diseases are considerable threats.

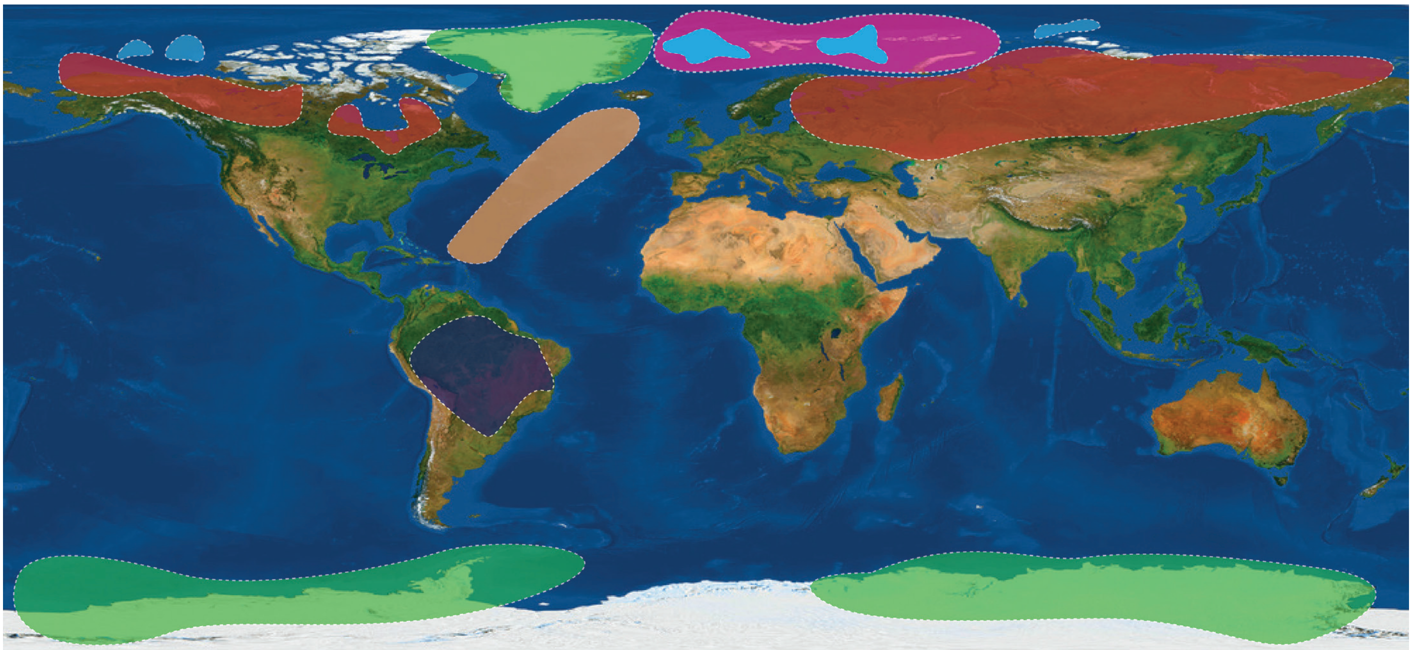
Ice sheets

Greenland and the Antarctic contain enough ice to raise global sea level by more than 65 metres if they were to completely melt. Melting of the Greenland ice sheet may become irreversible if temperatures rise by about 1.6 °C above pre-industrial levels, but complete melt would take many hundreds of years. New evidence suggests ice loss from Greenland has increased in recent years and that partial irreversible loss of the West Antarctic Ice Sheet has likely already begun and East Antarctica and northeast Greenland are potentially more sensitive to climate change than first thought[8]. Recent research shows the potential for rapid collapse of the west Antarctic ice sheet, contributing up to a metre of additional sea level rise by 2100 and more than 15 metres by 2500 under a low mitigation climate change scenario[9].

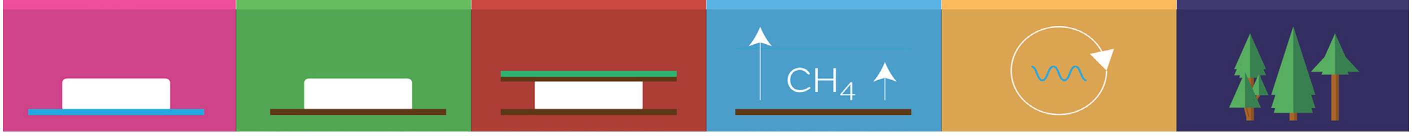


Methane release from the seabed

Methane, a powerful greenhouse gas, is the second largest contributor to climate change after carbon dioxide. Large amounts of it are stored in underwater sediments in an ice-like solid known as a clathrate (or methane hydrate). It has been leaking from these stores for the past 3000 years and continued ocean warming will very likely enhance these emissions[10]. However rising sea levels could make the hydrates more stable[11]. It is unlikely that abrupt widespread release of methane will occur this century[12], however if that was to happen the methane release would be irreversible on multi-millenial timescales. Large uncertainty remains regarding how much methane will be released from these sources this century.



ARCTIC SEA ICE	ICE SHEET	PERMAFROST (frozen ground)	METHANE RELEASE FROM SEABED	ATLANTIC OCEAN CIRCULATION	TROPICAL RAINFOREST
SEASONAL DISAPPEARANCE LIKELY IN 21ST CENTURY	PARTIAL COLLAPSE LIKELY ON MILLENNIAL TIMESCALES	SIGNIFICANT SURFACE THAW PROJECTED IN 21ST CENTURY	CATASTROPHIC RELEASE VERY UNLIKELY	COLLAPSE VERY UNLIKELY IN 21ST CENTURY	TRANSITION POSSIBLE IN 21ST CENTURY
REVERSIBLE	IRREVERSIBLE	IRREVERSIBLE	IRREVERSIBLE	UNKNOWN	UNKNOWN
IMPACTS: HABITAT LOSS; CHANGES IN N. HEMISPHERE CLIMATE	IMPACTS: SEA LEVEL RISE, ACCELERATED WARMING AND ASSOCIATED IMPACTS	IMPACTS: ACCELERATED WARMING AND ASSOCIATED IMPACTS	IMPACTS: ACCELERATED WARMING AND ASSOCIATED IMPACTS	IMPACTS: CHANGES IN N. HEMISPHERE CLIMATE	IMPACTS: ACCELERATED WARMING & REGIONAL IMPACTS



Map showing location of different parts of the climate system that show threshold behaviour, with an overview of their potential for abrupt change, reversibility and impacts.

[1]Less than 1 million km2 [2]IPCC AR5 WG1 SPM [3]Jahn, A et al. 2016. How predictable is the timing of a summer ice-free Arctic? Geophysical Research Letters. [4]Jackson, L et al. 2014. "Climate impacts of a slowdown of the AMOC in a high resolution GCM". Met Office Hadley Centre Climate Programme (MOHCCP) 2012-2105 Deliverable B7. [5]Wiltshire, A et al. 2014. "Quantifying the impacts of advanced Earth-system feedbacks on atmospheric carbon dioxide and methane". MOHCCP 2012-2015 Deliverable D10. [6]Good, P et al. 2017. "Recent progress in understanding of ice sheets, the Atlantic meridional overturning circulation, tropical forests and responses to ocean acidification", submitted to Climate Dynamics. [7]IPCC AR5 WG2 Chapter 4. [8]Good, P et al. 2017. "Recent progress in understanding of ice sheets, the Atlantic meridional overturning circulation, tropical forests and responses to ocean acidification", submitted to Climate Dynamics. [9]DeConto and Pollard. 2017. Contribution of Antarctic to past and future sea-level rise. Nature 531, 591-597, doi:10.1038/nature17145. [10]Berndt, C et al. (2014), "Temporal constraints on hydrate-controlled methane seepage off Svalbard", Science, Vol. 343/6168, pp. 284-287, http://dx.doi.org/10.1126/science.1246298. [11]IPCC AR5 WG1 Chapter 12. [12]Kretschmer, K et al. (2015), "Modeling the fate of methane hydrates under global warming", Global Biogeochemical Cycles, Vol. 29/5, pp. 610-625, http://dx.doi.org/10.1002/2014GB005011