Risk management of climate thresholds and feedbacks: **Introduction and Synthesis**

This series of factsheets presents recent Met Office work and plans for future research around risks from thresholds in four components of the climate system: the Atlantic Meridional Overturning Circulation (AMOC); Ice Sheets; Tropical Forests, and Arctic Sea Ice, and from positive feedbacks in one: Permafrost. [1]

What are thresholds and feedbacks?

Thresholds occur when the processes that keep a system in a stable state are disrupted, causing runaway change. This can happen when positive feedbacks outweigh negative feedbacks. Negative feedbacks provide stability, reducing changes to the system. To use Greenland as an example, a thicker ice sheet tends to lose ice faster through glaciers flowing into the ocean; in a thinner ice sheet this happens more slowly. This restricts any change in size, helping to keep the ice sheet stable. Positive feedbacks drive instability. For example, melting of the Greenland ice sheet lowers the surface, bringing it in contact with warmer air, causing further melting (and if the ice sheet grows, the surface meets colder air, allowing further growth). A threshold or tipping point occurs when the positive feedbacks outweigh the negative feedbacks, causing runaway change until a new stable state is reached (e.g. complete loss of the ice sheet). Changes can occur rapidly and with little warning, potentially causing large socio-economic impacts.

Fig 1 shows an diagram of a climate tipping point using the example of the Atlantic Meridional overturning circulation (AMOC). The horizontal axis shows the amount of fresh water entering the North Atlantic through precipitation, rivers and ice melt. The vertical axis shows the possible strength of the AMOC. For small amounts of fresh water input, only a strong AMOC state is possible (red curve), whereas for large values only a weak or collapsed AMOC is possible (blue). In between, both strong and collapsed states are possible. In this theory, the present day AMOC is considered to be in a strong state. However, if the fresh water input were to increase beyond the 'tipping point' due to climate change, the AMOC would collapse into the weaker state (blue curve). Then, even if the climate change were reversed, the AMOC would return along the blue curve and would not recover to its strong state until freshwater input is reduced to well below the present day value. This phenomenon is known as 'hysteresis'.

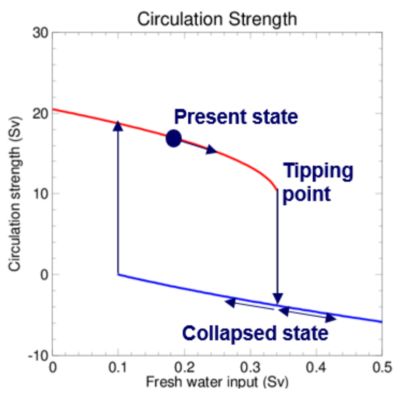

Figure 1 – Hysteresis and tipping points in the AMOC. Red shows the present state of the AMOC. After passing the tipping point, the AMOC collapses into the blue state.

Can thresholds occur in the real earth system?

Thresholds in ice sheets are well established, and thought the most likely to be crossed this century. In tropical forests, thresholds exist locally, but it is unclear how much forest loss would be irreversible. For Arctic sea ice, on the other hand, thresholds are thought unlikely. For the AMOC, the presence of a threshold, and whether it might be crossed due to human influence, is under active scientific debate. Palaeoclimate records show some evidence for real world thresholds, such as abrupt changes in temperature across central Greenland (e.g. Dansgaard-Oeschger cycles). These thresholds were not crossed by human influence - the causes of these changes and the conditions under which they occurred are different from those expected over the coming decades to centuries.

What are the challenges associated with understanding thresholds?

Crossing a threshold involves the earth system moving into a state that has different behaviour from that observable in the recent past. Therefore, even if earth system models are built to reproduce the current conditions realistically, this may tell us little about how well they can capture a threshold. Some known thresholds involve complex processes that are yet to be included in many recent generation models, e.g. forest fire. The main areas that could exhibit thresholds are also some of the most inaccessible regions of the globe. Interconnectivity between different tipping points has also been proposed, meaning that there could be a domino effect of tipping points (Fig 2). These issues make assessing the likelihood of crossing a threshold under different emissions scenarios challenging.

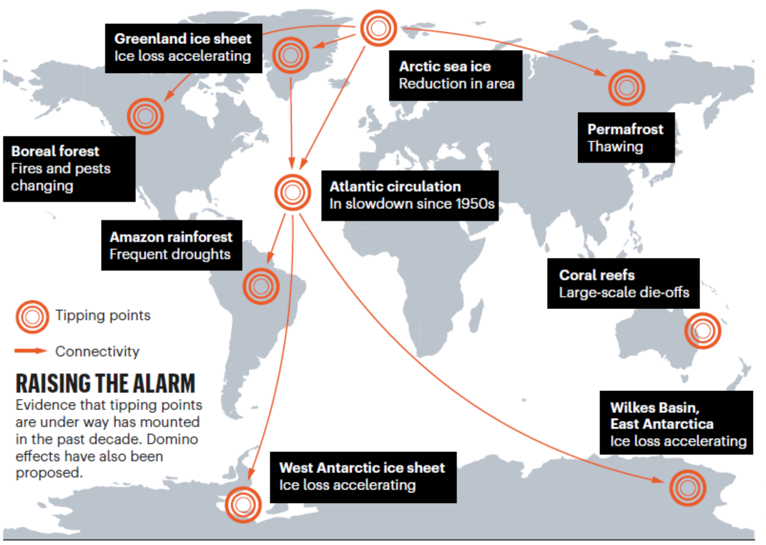

Fig 2 – Proposal of possible interconnectivity between tipping points in the climate system. (2)

What kind of advice does the Met Office plan to offer?

The Met Office aims to develop advice on three areas, which are potentially more tractable than estimating likelihood from climate projections. These are: the impacts of crossing a threshold; whether a threshold may be overshot temporarily before changes are irreversible ('temporary resilience'); and methods of early warning of a threshold based on observational monitoring. In the accompanying factsheets, many impacts are robust in nature, although their magnitude may be less certain. Some limited temporary resilience is expected for ice-sheets, the AMOC and tropical forests. This may allow more time to act on early warnings. In each case, however, the temporary resilience time decreases with larger overshoots. Elements of early warning systems exist. Shorter timescale warning for adaptation purposes is generally more robust than the longer lead time needed for mitigation action to avoid a threshold. Warning that a threshold is approaching is easier than estimating the proximity of the threshold.

What future work is planned?

Details for individual thresholds are given in the accompanying factsheets. Broadly, this involves adding new processes to earth system models (such as interactive ice sheets and forest fire), and work to quantify and understand processes relating to thresholds, with relevance to impacts, temporary resilience and early warning. For example, the recent evidence for threshold behaviour in the AMOC in a high resolution Met Office model provides an opportunity for developing improved policy advice. As part of the next Met Office Hadley Centre Climate Programme program the Met Office is also planning an opinion paper exploring what is needed for a robust early warning system.

References

1. Recent progress in understanding climate thresholds: ice sheets, the Atlantic meridional overturning circulation, tropical forests and responses to ocean acidification. Good et al. 2018; 2. Climate tipping points - too risky to bet against. Lenton et al. 2019.