Factsheet 6 of 6
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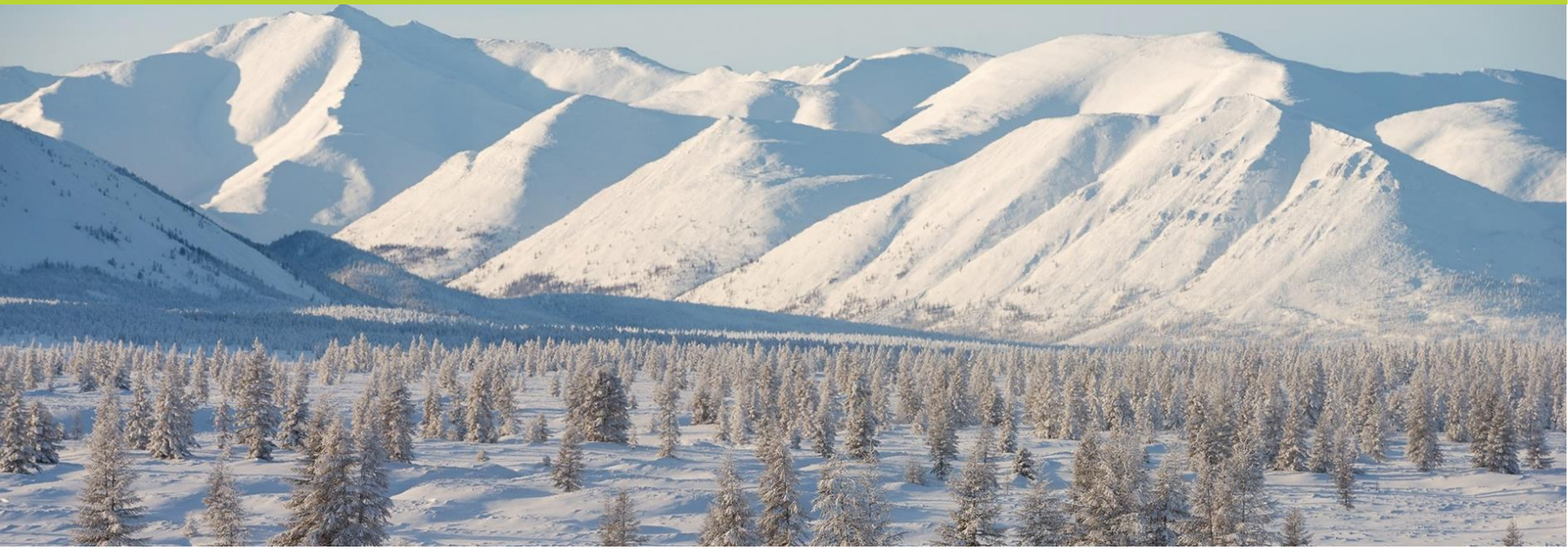
Risk management of climate thresholds and irreversible change: **Permafrost**



Global warming will be amplified by carbon released from thawing permafrost. This is irreversible but has no specific large-scale threshold.

What is the nature of the irreversible change?

Arctic soils contain large amounts of inert carbon, buried up to thousands of years ago, and locked up in frozen permafrost. Once permafrost soil has warmed enough to thaw, decomposition of soil carbon increases significantly. This releases carbon in the form of carbon dioxide and methane – both greenhouse gases, driving further global warming[1, 2, 3]. The release of carbon from permafrost thaw is irreversible on human timescales, because even if the temperature reduces and permafrost re-freezes, the mechanisms for burying carbon take place very slowly[3]. This means that a greater reduction in human greenhouse gas emissions would be required to reverse global warming. However, some permafrost carbon release may be offset by increased carbon storage by vegetation.

Borehole observations show that permafrost has warmed over recent years (Fig. 1) suggesting that the release of permafrost carbon may already be occurring at some locations. In addition, there is some evidence to suggest that the Arctic may no longer be a net sink of carbon[4].

Permafrost conditions and properties vary with location and soil depth. This means that different locations require different amounts of warming before the local threshold for thaw is reached. Therefore, the total amount of permafrost carbon released to the atmosphere will increase steadily as the world warms, with no large-scale threshold.

The active layer is the uppermost part of permafrost, which thaws during summer and re-freezes during winter. Gradual decomposition of permafrost carbon occurs when the active layer becomes deeper.

In some areas, thawing soil can cause the land surface to collapse, forming a thermokarst landscape. This may well occur more frequently under climate change[5]. Such abrupt thaw has the potential to release more methane than gradual thaw, leading to greater climate warming[6]. About half of below-ground carbon is stored in thermokarst landscapes[7]. However, it is very difficult to predict the sudden collapses of land that can lead to thermokarsts, so this process is not typically represented in models.

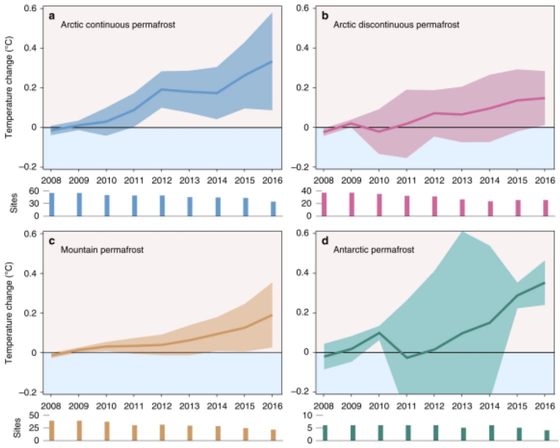


Figure 1. Changing permafrost temperatures calculated from boreholes near a depth where there is no seasonal cycle in the soil temperature.[8]

What impacts might be expected if a threshold were crossed?

Northern soils hold twice as much carbon as is currently contained by Earth's atmosphere[4], with approximately 1000 Gt of carbon is in the top 3 m of soil[9]. As the climate continues to warm and permafrost thaws, model projections suggest that 5-15% of the permafrost carbon pool may be released as either carbon dioxide or methane during the current century, contributing to further global warming[10]. This could cause an additional warming of between 0.2 and 12% of the change in global temperature by 2100[11]. In terms of mitigation targets, this could reduce our remaining carbon budget for limiting warming to 1.5°C by 10%[12] (Fig. 2). If global temperatures reach 2°C, permafrost emissions will be 60-100 Gt C greater than if warming is limited to 1.5°C.

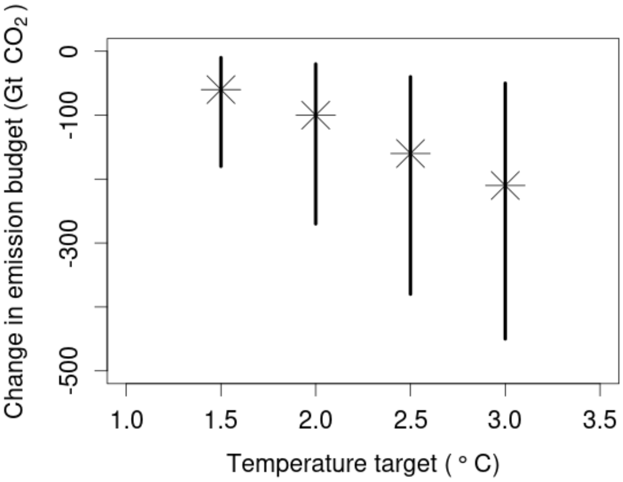


Figure 2. Reduction in emission budget caused by permafrost carbon release, for different global warming temperature avoidance targets.[11]

However, recent research suggests that these might be underestimates as these projections do not simulate thermokarst processes[6]. Abrupt permafrost thaw from thermokarst could double the global warming associated with permafrost carbon release[5].

The proportion of carbon released as carbon dioxide or methane is uncertain. This is important as methane is a more powerful greenhouse gas than carbon dioxide. Further release of greenhouse gases may also occur if fire frequency increases.

Thawing permafrost also causes regional impacts, affecting the sustainability of northern communities. These include subsidence, in which the land slumps, affecting manmade infrastructure and forests[13, 14]. Human health can also be affected[15], by processes such as the release of mercury from thawing permafrost[16].

Can some permafrost carbon release be avoided?

If temperatures are stabilised or reduced, further deepening of the active layer can be stopped, preventing some release of permafrost carbon. However, some carbon release may continue, contributing to further global warming, due to irreversible thermokarst landscape damage[10].

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

It is important to estimate how much permafrost carbon would be released for a given level of global warming. This would require estimates of the amount and distribution of organic carbon stored in permafrost, and long-term monitoring of soil temperatures and carbon emissions. Currently, permafrost properties and carbon emissions are only monitored at a few locations, via boreholes and flux towers. These need to be maintained and extended over the coming decades. Emissions are hard to monitor and may not be representative of other locations. Thermokarst landscape changes are currently not predictable.

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

Work is ongoing to improve the representation of permafrost in the UK community's land-surface scheme, JULES. These improvements will be incorporated into a future version of the UK global earth system model, UKESM. In addition, JULES, coupled with a simplified climate model[10] can be used to address policy-relevant questions such as how permafrost carbon impacts carbon budgets. It can also be used to quantify how other processes, such as the impact of fire, and nutrient limitations to vegetation growth, contribute to the overall feedback.

References – Met Office papers in **bold**
[1]Schuur et al., (2008) Vulnerability of Permafrost Carbon to Climate Change: Implications for the Global Carbon Cycle; **[2]Comyn-Platt et al., (2018) Carbon budgets for 1.5 and 2°C targets lowered by natural wetland and permafrost feedbacks**; [3]Schaefer et al., (2014) The impact of the permafrost carbon feedback on global climate; [4]NOAA, (2019) Arctic report card; [5]Turetsky et al., (2019) Permafrost collapse is accelerating carbon release; [6]Turetsky et al., (2020) Carbon release through abrupt permafrost thaw; [7]Oldefelt et al., (2016) Circumpolar distribution and carbon storage of thermokarst landscapes; [8]Biskaborn et al., (2019) Permafrost is warming at a global scale; [9]Hugelius et al., (2014) Estimated stocks of circumpolar permafrost carbon with quantified uncertainty ranges and identified data gaps; [10]Schuur et al., (2015) Climate change and the permafrost carbon feedback; **[11]Burke et al., (2017) Quantifying uncertainties of permafrost carbon-climate feedbacks**; **[12]Gasser et al., (2018) Path-dependent reductions in CO_2 emission budgets caused by permafrost carbon release**; [13]Melvin et al., (2017) Climate change damages to Alaska public infrastructure and the economics of proactive adaptation; [14]Hjort et al., (2018) Degrading permafrost puts Arctic infrastructure at risk by mid-century; [15]D'Costa et al., (2011) Antibiotic resistance is ancient; [16]Schuster et al., (2018) Permafrost stores a globally significant amount of mercury.