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Lightning threatens permafrost

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Thawing Arctic permafrost, and release of its stored carbon, is a known amplifier of global warming. Now research suggests an increase in Arctic lightning could speed up the permafrost's demise.

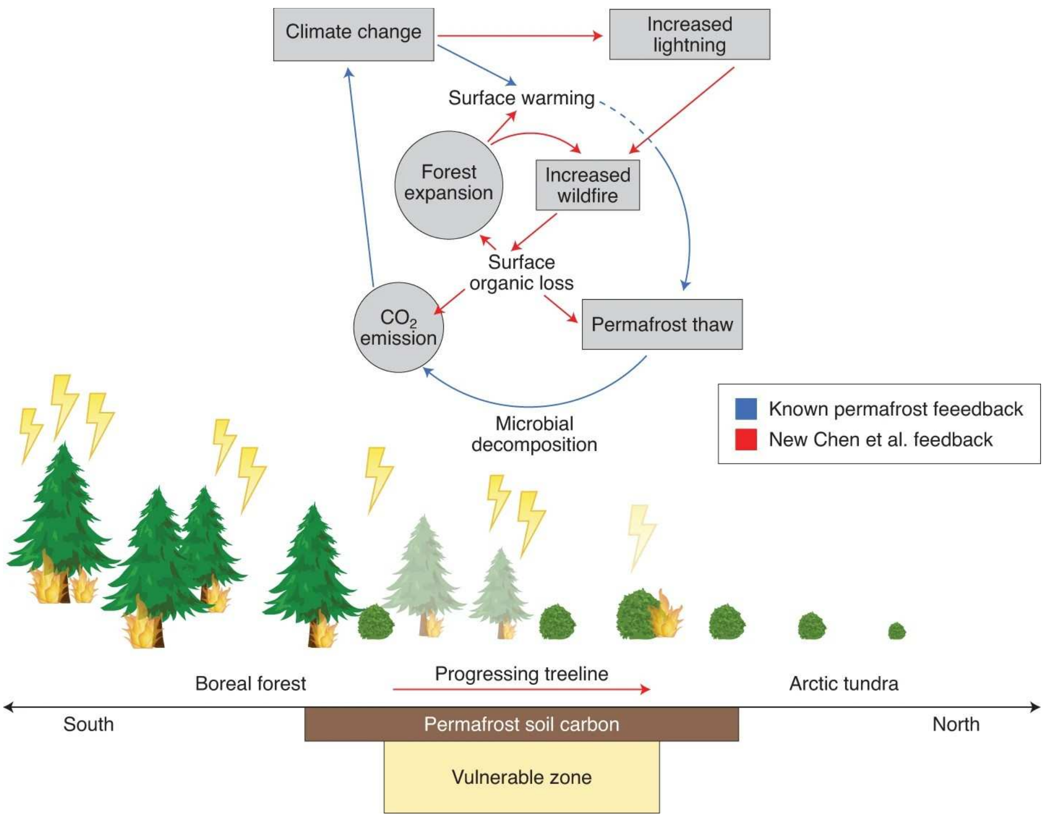

Figure 1: Top schematic shows the well-known climate feedback of warming, permafrost thaw and emission (blue arrows) alongside the additional positive feedbacks identified by Chen et al.[3] of lightning and wildfires (red arrows). This is illustrated (bottom) with lightning increases driving wildfires, which lead to vegetation change exemplified by the northward expansion of the treeline. The net result is a loss of stored soil carbon not offset by the relatively small increase in the aboveground carbon store.

Lightning has played a key role in recent major North American boreal forest wildfires occurring close to the Arctic treeline[1]. These wildfires can emit substantial amounts of carbon as well as modify the regional ecology[1], raising concern of how climate change could alter lightning and these associated impacts. However, it remains unclear how global lightning will change[2]. Writing in

Nature Climate Change, Yang Chen and colleagues increase confidence in the Arctic lightning response[3], finding a more than doubling of lightning flashes could be expected by the end of the century. The authors lay out a fundamental climate feedback of lightning, wildfires and permafrost thaw, with potential large carbon release, which is not well represented in current climate models (Fig. 1).

Lightning arises from convection driving the formation and collision of ice particles in a storm[2]. The full complexity of this process cannot currently be represented in global climate models. Instead, researchers use empirical relationships of observed lightning against representative features of storms (for example, convective energy, cloud-top height or upward motion of ice particles) to model lightning[2]. Applying these models to understand the climate change response of lightning is challenging, as the features closest to the underlying charging theory (that is, cloud-ice particle motions) often have the least confidence in prediction of their climate change response. However, for the Arctic at least, increasing lightning activity is a consistent feature of past predictions, even if it has not been robustly quantified until now.

Globally, humans are the main cause of wildfire ignition, but the Arctic differs in that lightning is the predominant cause of ignition[1]. The need to understand these driving processes became evident last year when scientists estimated that wildfires in the Arctic Circle emitted 244 $MtCO_2$ (ref. [4]), equal to almost half of Canada's annual emissions. In addition, such fires can burn off the surface organic material that insulates the underlying permafrost and clear the way for potential changes in vegetation composition. In doing so, a link is made between lightning activity, permafrost carbon stores and forest ecology[1].

Chen et al. provide the first lightning scheme developed specifically for the Arctic. It is based on the convective energy and precipitation of storms. Application to future climate with a 3.7 °C global mean temperature rise shows a likely range of increase in lightning over permafrost regions of 74–150% by the end of the century. This is about three times higher than most previous estimates of global or USA responses of lightning to global warming. Recent research[5] supports this finding by showing a three times stronger response of Arctic lightning to warming in the last decade than the global average. In part, this may be because the Arctic is warming much faster than the global average. Nevertheless, it should not be assumed that lightning responds directly to temperature. Recent work over the lightning hotspot of Africa exhibits a weak response of lightning to warming[6].

The study by Chen et al. uses multiple climate models, but all face the same limitation of approximating convection. Recently, the value of using higher resolution models which begin to explicitly represent deep convection has been shown[6]. Such models are one way to further increase confidence in results for the Arctic. Use of a high-emission scenario and a single lightning model in the Chen et al. study[3] will need to be expanded upon to confirm these initial findings. Additionally, while the authors calculate the lightning change per degree of warming to be 40% K^{-1} over Arctic tundra, more simulations are required to improve robustness. Global and regional model intercomparison projects will need to account for the processes Chen et al. present for accurate predictions. To date, these have limited themselves to a lightning scheme based on cloud-top height[7]. The new results[3] discussed here should provide impetus to develop the lightning schemes.

The impact of increased lightning is considered against lightning–wildfire feedbacks, calculating the present-day annual average burned area per lightning flash. Tundra regions have a lower ratio than boreal forest. Applying the ratios with two different methods of estimation gives an increase in burned area of 158% and 570%, with the larger estimate arising when considering a vegetation feedback. The proposed vegetation feedback sees increased wildfires driving a northward expansion of boreal forest, which, partly due to species composition, exhibits a greater burned-area-to-lightning-flash ratio. There is scope to more explicitly model vegetation feedbacks, but the authors provide useful first estimates of the effect. Furthermore, the authors hypothesize that through increased burning of surface organic material, insulation of permafrost will decrease and carbon stores will be more rapidly released to the atmosphere. The potential northward expansion of tree species, which absorb more sunlight (decrease albedo) compared to the current tundra surface, will likely enhance regional surface warming and further drive permafrost thaw. This lightning–wildfire–vegetation feedback mechanism with permafrost is yet to be fully incorporated into global climate models.

The work by Chen et al.[3] provides useful estimates of many steps in the feedback, notably the expected increase in Arctic lightning and burned area from wildfires. These directly relate to understanding the relevance of climate change to recent wildfire events in North America[1] and Siberia[4]. Furthermore, the work greatly encourages development of climate models to reliably estimate lightning–wildfire feedbacks that could be vital to understanding the response of permafrost thaw and associated carbon release[8].

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