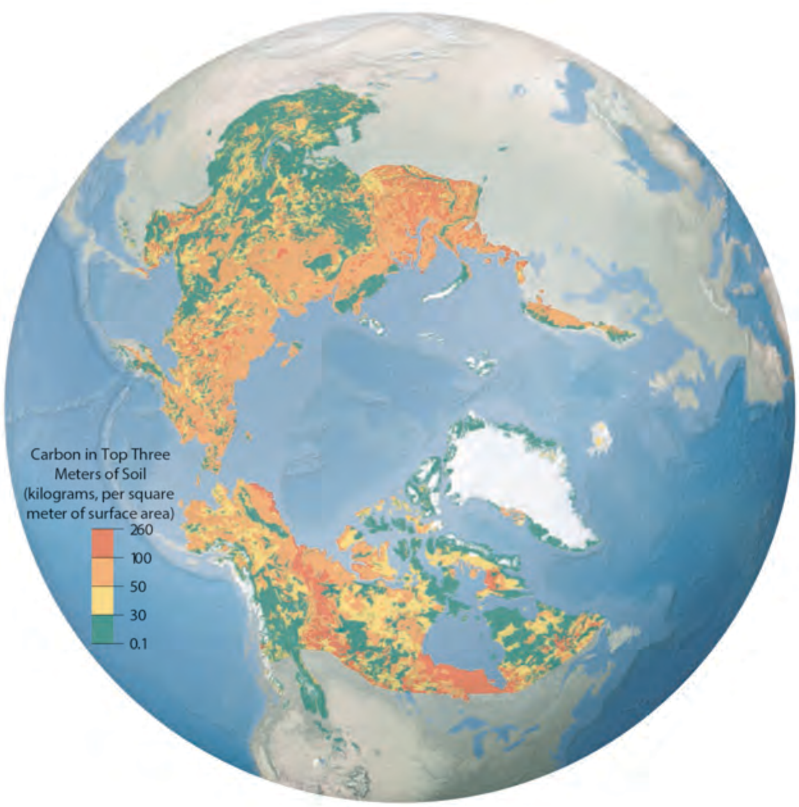
Climate Change and the Permafrost Carbon Feedback

THE ISSUE. As permafrost thaws in a warming climate, once-frozen organic carbon is broken down by soil microbes, releasing carbon dioxide and methane to the atmosphere. Release of these additional greenhouse gases to the atmosphere accelerates climate change and incurs additional societal costs for mitigation and adaptation.

WHY IT MATTERS. Sustained and substantial carbon release from the Arctic is a wildcard that could affect how fast climate change happens. While a large proportion of the modern increase in atmospheric carbon is due to human activities, the future trajectory of the atmosphere also depends on the response of land and ocean to climate change. A key societal question is whether there are *tipping points*: global carbon cycle surprises that will make climate change effects (sea-level rise, extreme weather, droughts, and impacts on agriculture) occur faster than currently projected by models. Permafrost carbon, the remnants of plants, microbes, and animals accumulated in perennially frozen Arctic soil over thousands of years, is a potential climate tipping point.

STATE OF KNOWLEDGE. Northern soils were known to have relatively large amounts of organic carbon, accumulating in frozen and waterlogged conditions. But it was only recently that carbon stored deeper in permafrost soils below the traditional 1-meter accounting depth was quantified. The latest circumpolar inventory represents a synthesis of measurements from hundreds of individual study sites that now includes an order of magnitude more data for deep soils (>1m). This comprehensive inventory places the amount of organic carbon stored in the northern permafrost region at 1,330-1,580 billion tons carbon, almost twice as much carbon as currently contained in the atmosphere (**Figure**). The upper 3m of northern permafrost zone soils contains carbon equal to 50% of the soil carbon found in ecosystems everywhere else, even though the permafrost region represents only 15% of the global soil area. Release of just a fraction of this frozen carbon as the greenhouse gases carbon dioxide and methane into the atmosphere would significantly increase the rate of global climate warming.



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The potential for soil carbon to decompose and be emitted to the atmosphere as greenhouse gases increases with warming and thawing of permafrost. The ultimate impact on climate depends on how much carbon is released, how fast, and whether as either carbon dioxide or methane. Given current rates of warming, an estimated 130-160 billion tons of permafrost carbon, could be released in the form of greenhouse gases—primarily carbon dioxide but with an important warming contribution from methane—during this century. Thus, emissions from thawing permafrost, in total equivalent to 61-75 ppm atmospheric carbon dioxide, could be similar to other fluxes from other environmental changes, such as deforestation, but far less than fossil fuel emissions. New plant growth is expected to offset only ~20% of this carbon release, but this offset could help to delay impacts on climate. Over this century and beyond, permafrost carbon emissions are likely to amplify warming caused by fossil fuel burning and other human activities incurring additional costs to society. Reduction of human emissions will help slow climate change and in turn will significantly reduce the amount of additional carbon emitted from permafrost into the atmosphere.

WHERE THE SCIENCE IS HEADED. Prediction of change in permafrost has focused mostly on gradual top-down thawing as a result of a warming climate. However, increasing evidence suggests that abrupt permafrost thaw may be the norm for many parts of the Arctic landscape. Abrupt permafrost thaw occurs when warming, or an ecosystem disturbance such as fire, causes ground ice to melt. Ice can comprise 50 to 80% of ice-rich permafrost ground, and the loss of its volume causes the ground surface to collapse. Loss of ground ice with thaw is an ecosystem disturbance that temporarily decreases plant carbon uptake while exposing more permafrost carbon to decomposition. Together, abrupt thaw disturbance acts to speed net carbon release to the atmosphere. Incorporating these abrupt thaw threshold events into models remain an important forefront for projecting the amount of permafrost carbon release, because emissions could be higher than are currently estimated.

FURTHER READING

Schuur, E. A. G., A. D. McGuire, C. Schädel, G. Grosse, J. W. Harden, D. J. Hayes, G. Hugelius, C. D. Koven, P. Kuhry, D. M. Lawrence, S. M. Natali, D. Olefeldt, V. E. Romanovsky, K. Schaefer, M. R. Turetsky, C. C. Treat, and J. E. Vonk. 2015. Climate change and the permafrost carbon feedback. *Nature* 520:171-179 doi:10.1038/nature14338