Rising global temperatures turn northern permafrost region into significant carbon source

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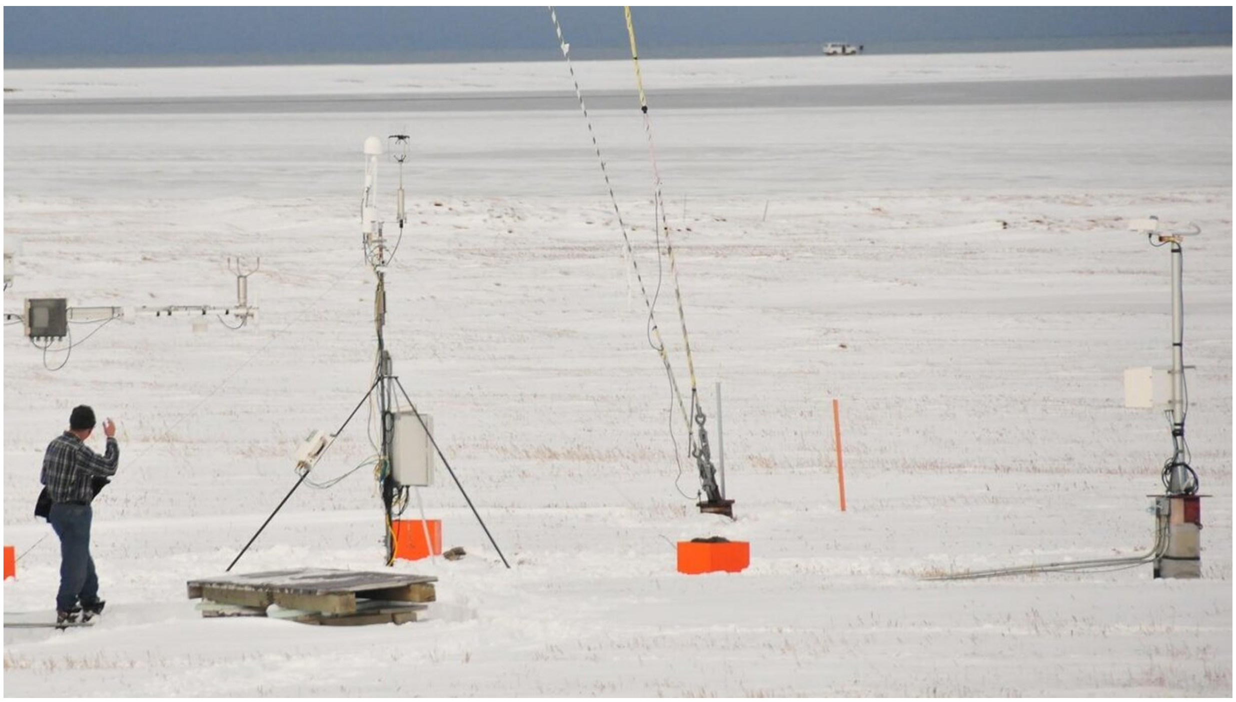

David Cook, a recently retired Argonne meteorologist, performs maintenance on an eddy correlation flux measurement tower, operated by the DOE-funded Atmospheric Radiation Measurement (ARM) program, in Utqiavik, Alaska. The tower exemplifies one of several types of instrumentation used to generate the data in this study. Credit: Argonne National Laboratory/Ryan Sullivan

Permafrost, the perennially frozen subsoil in Earth's northernmost regions, has been collecting and storing plant and animal matter since long before the last Ice Age. The decomposition of some of this organic matter naturally releases carbon dioxide (CO_2) into the atmosphere year-round, where it is absorbed by plant growth during the warmer months.

This region, called the northern permafrost region, is difficult to study, and experiments there are few and far between compared with those in warmer and less remote locations. However, a new synthesis that incorporates datasets gathered from more than 100 Arctic study sites by dozens of institutions, including the U.S. Department of Energy's (DOE) Argonne National Laboratory, suggests that as global temperatures rise, the decomposition of organic matter in permafrost soil during the winter months can be substantially greater than previously thought. The new numbers indicate a release of CO_2 that far exceeds the corresponding summer uptake.

Even more importantly, when modeling the carbon balance using the large collection of data, the scientists found that the CO_2 released by permafrost soil in the winter could increase 41 percent by 2100 if human-caused greenhouse gas emissions continue at their current rate.

The study, published in *Nature Climate Change* this past October, is the most comprehensive study on this phenomenon to date. It highlights the need for more research on the permafrost region's net CO_2 emissions, and it demonstrates the significant impact these emissions could have on the greenhouse effect and global warming.

The study brings together a combination of in-field measurements and laboratory-based studies—or soil incubations—like those performed at Argonne. To better understand how future warming might affect CO_2 emissions in permafrost regions, the Argonne scientists sampled a variety of permafrost soils and monitored CO_2 release at a range of laboratory-controlled temperatures above and below freezing that mimic typical Arctic conditions. The researchers wanted to identify how different soil properties or other factors influence the rate of decomposition and CO_2 release from frozen and thawing soils—information that could help improve climate and Earth system models.

"Climate and Earth system models often treat these winter permafrost CO_2 emissions as insignificant or even non-existent," said Roser Matamala, a scientist in Argonne's Environmental Science division and a contributor to the study. "But this study, with its large volume of data extending over multiple seasons, shows that winter respiration is substantial and significant. The study should convince modelers that this flux of winter-time carbon to the atmosphere can no longer be overlooked. It is not small, and it needs to be taken into account."

The northern permafrost region covers approximately 15 percent of the Earth's land area, extending from the Arctic Ocean's coastline through much of Alaska, northern Canada and northern Eurasia. The ever-frozen soil in these regions contains more carbon than humans have ever released, and roughly a third of the carbon stored in all of Earth's soil exists in this region.

During the summer, plants whose roots grow in thawed soil above the perennially frozen subsoil absorb CO_2 as they photosynthesize. At the same time, microbes release CO_2 into the atmosphere as they actively decompose soil organic matter. In the winter, when the surface soil and underlying permafrost are both frozen, the rate of decay and the amount of CO_2 returned to to the atmosphere drops significantly. Yet, a small amount of microbial activity continues to decompose some of the organic matter contained in thin, unfrozen water films surrounding soil particles, releasing smaller amounts of CO_2. For years, this balance was tipped toward greater absorption rather than release of CO_2, but this study indicates that the loss of CO_2 from permafrost soils to the atmosphere over the entire year is now greater than its uptake during the summer.

"Arctic soils have retained disproportionately large amounts of organic matter because frozen conditions greatly slow microbial decay of dead plant roots and leaves," said Argonne soil scientist and study contributor Julie Jastrow. "But just as food in the freezer compartment of a refrigerator will spoil faster than it would in a chest freezer, the temperature of seasonally frozen soils and permafrost affects the amount of microbial activity and decomposition."

According to the Argonne scientists, microbial activity can increase exponentially as rising global temperatures warm the permafrost to levels just below freezing. Even before permafrost thaws, the acceleration in microbial activity in permafrost soil causes acceleration of its CO_2 emissions.

Based on these results and upscaling across the Arctic, the authors estimate that about 1.7 billion metric tons of CO_2 are released during current winter seasons, but that only 1 billion metric tons would be taken up by photosynthesizers in the summer months.

Computer models also showed that if humans were to mitigate their own emissions even minimally, winter CO_2 emissions in the permafrost region would still increase 17 percent by 2100.

More information: Susan M. Natali et al, Large loss of CO_2 in winter observed across the northern permafrost region, *Nature Climate Change* (2019). DOI: 10.1038/s41558-019-0592-8

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