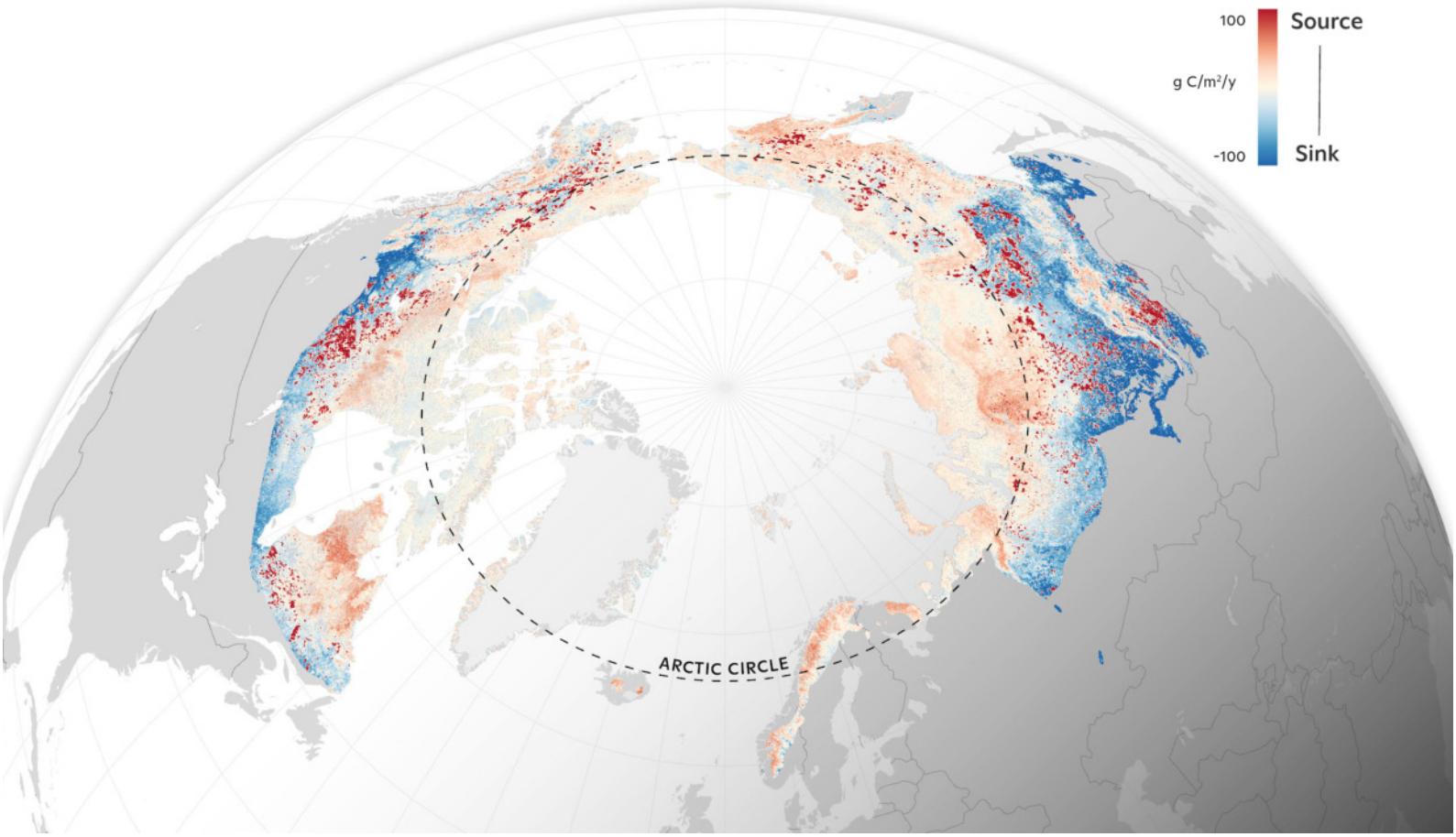
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Woodwell Climate Research Center

PERMAFROST PATHWAYS

Carbon budget warming-induced emissions

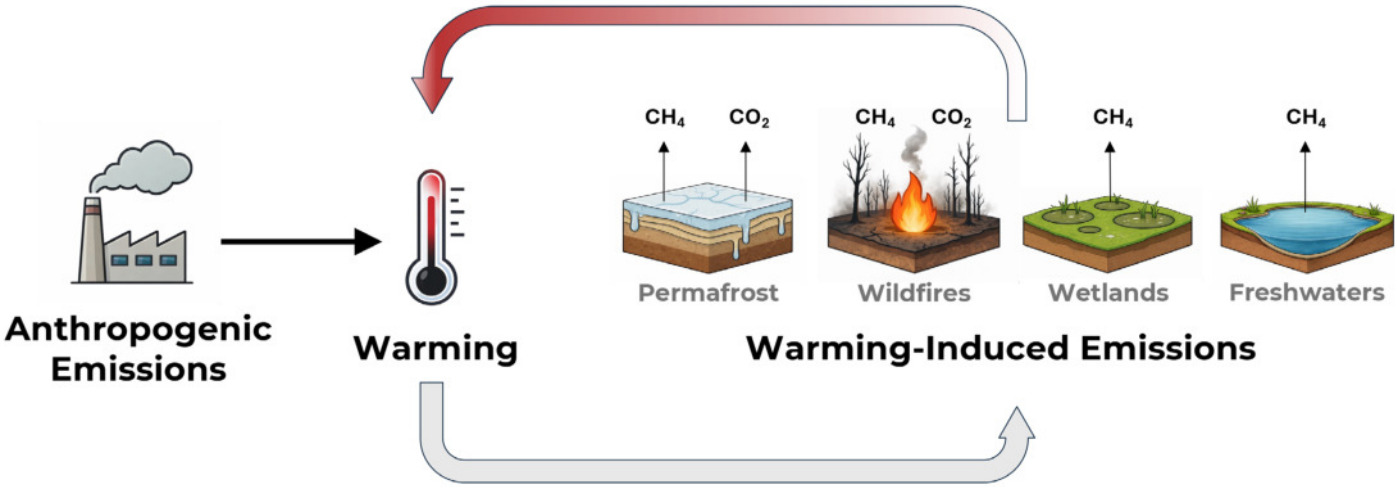
Emissions from warming ecosystems—like thawing frozen soil (permafrost thaw), wetlands, and wildfires—will likely shorten the remaining time to Paris temperature targets by 20–25% and make returning below 1.5°C more difficult. Learn about warming-induced emissions (WIE) and the recommended policy actions.



While the Arctic has been a carbon sink for thousands of years—storing more carbon than it releases—new research led by Permafrost Pathways scientists at Woodwell Climate found that one-third of the Arctic tundra is now a carbon source. / data sources: Virkkala et al. 2024, van Wees et al. 2022; map by Greg Fiske

The problem

The planet is heating up due to humans burning fossil fuels. How much the Earth warms in response to anthropogenic GHG emissions depends on climate feedbacks, processes that amplify or dampen the climate system's response to warming. Many of these feedbacks (e.g. water vapor, ocean carbon uptake) are well-represented in the climate projections in IPCC assessment reports, however, warming-induced emissions (WIE) are generally not. WIE are the additional GHGs released from natural sources (permafrost, wetlands, wildfires, freshwaters, etc.) as temperatures rise. While WIE amplify warming, they are among the biggest blind spots in climate models and policies. Not fully accounting for WIE means potentially underestimating projected future warming and overestimating the remaining carbon budget.



Cycle of warming-induced emissions. / illustration by Danielle Potocek

WIE, an international policy issue

Carbon emissions (both carbon dioxide and methane) from intensifying wildfire regimes and permafrost thaw, including fire-induced thaw, will reduce the remaining global carbon budget—the amount of carbon to overshoot the now expected 1.5°C, and the amount of carbon that remains before reaching 2°C. Global policy frameworks, like the Paris Agreement, rightly focus primarily on anthropogenic emissions as the main contributor for climate change. However, warming-induced emissions are (1) not fully accounted for yet may substantially reduce the remaining carbon budget, (2) making the goal of limiting temperature increases harder to achieve, and (3) possibly a target for mitigation. With exceedance of 1.5°C now unavoidable, it is critical to limit peak warming and overshoot duration to avoid additional amplification of warming from WIE. Policies must account for WIE otherwise, achieving current mitigation and climate targets may be insufficient.

WIE by the numbers

Permafrost & wildfire emissions

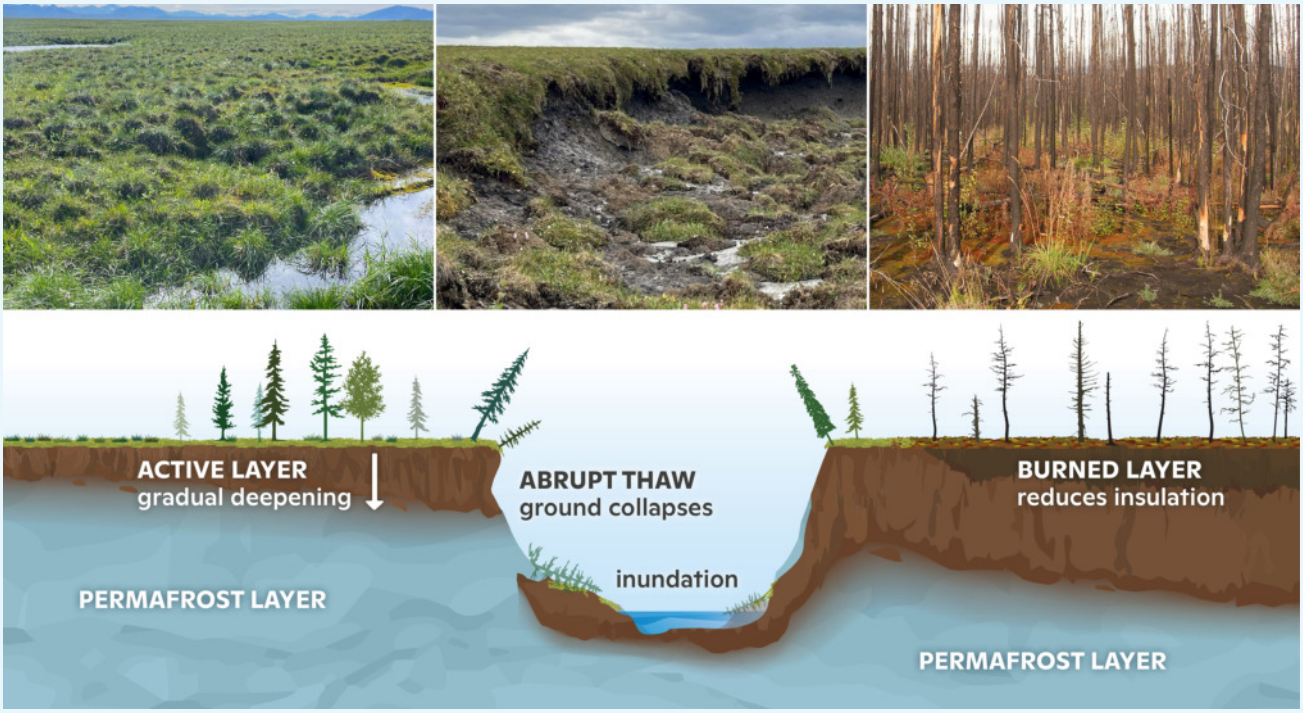
- When accounting for carbon emissions from permafrost thaw and intensifying wildfire regimes, the remaining carbon budgets to keep global temperatures below 2°C was reduced by about 17%. (Schädel et al. 2026)
- Permafrost thaw and wildfire alone could release 50–83 billion metric tonnes of carbon between 2025 and 2100 (Schädel et al. 2026). By 2100, annual permafrost emissions could match or exceed today's total annual fossil fuel emissions of the United States.

Permafrost, wildfire, wetlands, freshwater emissions

- Four WIE types combined could amplify post-2020 anthropogenic warming by 20%–30%. Specifically, WIE (both carbon dioxide and methane combined) could add 0.2 °C–0.4 °C of warming by 2100. (Abernethy et al. 2026)

What is permafrost?

Permafrost—continuosly frozen ground that underlies roughly 15% of the of the exposed land surface in the Northern Hemisphere—can contain soil carbon that has stayed frozen for thousands of years, locking away ancient plant and animal remains. Permafrost-region soils contain an estimated 1.5 trillion tonnes of carbon, nearly twice as much carbon as is currently in the Earth's atmosphere; counting deeper deposits and subsea permafrost, the total approaches three times the atmospheric amount. As it thaws, microbes break that organic matter down, releasing carbon dioxide where soils are well-drained, or methane in wetter, oxygen poor areas. Because deeper layers can take decades to thaw, this source keeps growing long after the warming that started it. In ice-rich permafrost, thaw can lead to abrupt ground collapse and release of ancient carbon.



Images and schematic diagram illustrating permafrost processes. Left to right: gradual thaw through deepening of the active layer, abrupt thaw via collapsing ground leading to inundation, and wildfire impacts where burned surface layers reduce insulation. / photos (left to right) by Emily Longano, Christina Minions, Brendan Rogers; illustration by Julianne Waite

Policy recommendations

The primary goal of reducing emissions globally (both direct and WIE) should remain, and may include reducing WIE by targeted mitigation efforts like enhanced fire management and wetland water level management. To facilitate achieving Paris Agreement temperature goals, 1) WIE should be quantified, 2) reporting frameworks designed, funded, and established, and 3) countries encouraged to report and reduce WIE.

Increase WIE visibility in international climate negotiations

- Convene an independent coalition and dedicated discussions to address WIE under the UN Framework Convention on Climate Change (UNFCCC).

  ASK: Launch a coalition of Parties and organizations to start quantifying WIE.

- GHG reporting frameworks need to address the blind spot that WIE represent so that the full scope of human-caused emissions is captured and enables better data for achieving climate ambitions (Buma et al. 2026).

  ASK: The second UNFCCC Global Stocktake (GST) should encourage interested Parties to voluntarily quantify WIE and explore ways to reflect WIE in their reporting.

Invest both financially and technically in monitoring, measurement, data collection, and new research so that the UNFCCC GST has adequate information about all emissions affecting the carbon budget.

- Enhance monitoring and reporting frameworks, including by inviting the IPCC to develop best practices for quantification & reporting of WIE, and enhance its guidelines for national GHG inventories to ensure adequate consideration of WIE.

  ASK: Donor countries and other funders of climate modeling efforts should mobilize further financing to integrate permafrost dynamics into climate models being advanced during CMIP7 and towards IPCC AR7 at the scale of USD $10 M for each Earth System Model.

- Commit to open access and data sharing on GHG (carbon & methane) and landscape changes across the Arctic.

  ASK: Arctic Council member states and Permanent Participants should establish terms for open access and data sharing of high-resolution satellite imagery and on-the-ground early detection of landscape changes, and support Tribal governments with data access.

- Conduct a regional assessment of WIE in the Arctic.

  ASK: The Arctic Monitoring and Assessment Program should conduct a full evaluation and accounting of GHG emissions from Arctic wildland fire and cascading impacts to permafrost thaw and the global atmosphere to establish a regional accounting mechanism on these climate induced forces that includes the full pan-Arctic accounting of carbon dioxide, methane, and nitrous oxide, as well as black carbon.

Learn more

Abernethy et al. 2026, DOI: 10.1088/1748-9326/ae9e24
Schädel et al. 2026, DOI: 10.1038/s43247-026-03189-5
Buma et al. 2026, DOI: 10.1016/j.oneear.2025.101571

sparkclimate.org/explainers/warming-induced-emissions

Who we are

Woodwell Climate Research Center
PERMAFROST PATHWAYS
Environmental Defense Fund
SPARK CLIMATE SOLUTIONS

Connect with us at COP31

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cover photo by Anna Liljedahl

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