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Incorporating permafrost into climate mitigation and adaptation policy

Susan M Natali[1,*], **Robin Bronen**[2], **Patricia Cochran**[3], **John P Holdren**[4], **Brendan M Rogers**[1] **and Rachael Treharne**[1]

[1] Woodwell Climate Research Center, Falmouth, MA 02540, United States of America
[2] Alaska Institute for Justice, Anchorage, AK 99501, United States of America
[3] Alaska Native Science Commission, Anchorage, AK 99524, United States of America
[4] Belfer Center for Science and International Affairs John F. Kennedy School of Government, Harvard University, Cambridge, MA 02138, United States of America
[*] Author to whom any correspondence should be addressed.

E-mail: snatali@woodwellclimate.org

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Abstract

Permafrost thaw is drastically altering Arctic lands and creating hazardous conditions for its residents, who are being forced to make difficult and urgent decisions about where and how to live to protect themselves and their lifeways from the impacts of climate change. Permafrost thaw also poses a risk to global climate due to the large pool of organic carbon in permafrost, which, when thawed, can release greenhouse gasses to the atmosphere, exacerbating an already rapidly warming climate. Permafrost thaw has significant implications for adaptation and mitigation policy worldwide. However, it remains almost entirely excluded from policy dialogues at the regional, national, and international levels. Here we discuss current gaps and recommendations for increasing the integration of permafrost science into policy, focusing on three core components: reducing scientific uncertainty; targeting scientific outputs to address climate policy needs; and co-developing just and equitable climate adaptation plans to respond to the hazards of permafrost thaw.

1. Reducing scientific uncertainty

The Arctic has been a carbon sink for tens of thousands of years, but it is expected to transition to a carbon source as permafrost thaws. In some areas, this transition is already underway (Commane *et al* 2017, Virkkala *et al* 2021). The magnitude of permafrost carbon emissions by the end of this century could be on par with present-day emissions from major fossil fuel emitting nations. However, the wide range of projected permafrost emissions (figure 1) creates a major barrier for determining the impact of permafrost thaw on humanity's remaining carbon budget to limit global warming to 1.5 °C or 2 °C.

Large uncertainties in the permafrost climate feedback persist, in part, due to major Arctic carbon monitoring and modeling gaps. Because of the vast and largely inaccessible land area underlain by permafrost, the multiple nations governing permafrost lands, and persistent funding limitations relative to research needs, most of the permafrost region is unrepresented by current efforts to monitor carbon fluxes between the land and atmosphere. For example, current landscape-scale carbon monitoring sites (i.e. using eddy covariance methodology) that measure both carbon dioxide and methane on an annual basis represent less than 25% of ecological and climatic conditions of Arctic lands, with widespread monitoring gaps across Russia and the Canadian High Arctic (Pallandt *et al* 2022). The first step to filling these gaps, and thereby reducing scientific uncertainty in the permafrost carbon feedback, is a strategically planned and coordinated carbon flux monitoring network that spans the range of ecological, climatic, and physiographic conditions that occur across the northern permafrost regions (Pallandt *et al* 2022).

Atmospheric carbon dioxide and methane concentration measurements from surface stations, airborne platforms and satellite column retrievals (in

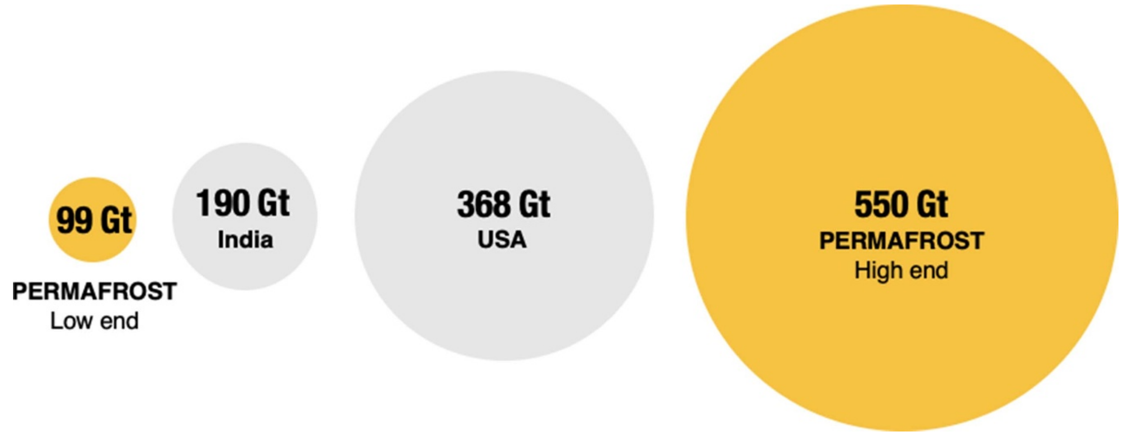

Figure 1. Range of projected cumulative permafrost carbon emissions from 2022 through 2100 (Gt CO_2; 1 Pg C = 3.67 Gt CO_2) for low (Gasser *et al* 2018) to high emissions scenarios (Schuur *et al* 2015) compared to cumulative emissions from major fossil fuel emitting nations (Friedlingstein *et al* 2022), if their current (2020) emissions rates continue through the end of the century. Note that the rates of permafrost emissions are not consistent over this time period; they will increase through 2100 and will likely continue for decades or centuries beyond this timeframe.

combination with atmospheric transport models and land-atmosphere fluxes from *in situ* monitoring) also provide important constraints on flux budgets at large scales (e.g. Saunois *et al* 2020). However, large disagreements and uncertainties at the regional level still persist (Bastos *et al* 2020). Improved models, increased data coverage in space and time, and novel ways of combining outputs from monitoring towers, atmospheric measurements, and process models will reduce this uncertainty.

More accurate Arctic carbon monitoring and forecasting also require an accounting of the carbon consequences of disturbances, such as abrupt permafrost thaw (i.e. thermokarst processes) and wildfire. These disturbances are not necessarily occurring at existing monitoring sites and also are not fully included in modeled projections of the permafrost climate feedback. For example, only two of 11 Earth System Models (ESMs) in the Coupled Model Intercomparison Project Phase 6 (CMIP6) represented permafrost, and none represented thermokarst processes, wildfire-mediated thaw, or below-ground combustion (Canadell *et al* 2021). By not accounting for these key disturbances that can greatly accelerate thaw rates and carbon emissions, current ESMs that represent permafrost carbon are likely underestimating permafrost thaw emissions (Canadell *et al* 2021, Natali *et al* 2021). Key model improvements needed for more accurate permafrost carbon assessments include: incorporation of relevant Arctic processes, including abrupt thaw and wildfire (Treharne *et al* 2022); increased model spatial resolution to accurately simulate these processes (Lara *et al* 2020); and data assimilation to integrate *in situ* and remote sensing data to optimize and constrain model behavior (Lopez-Blanco *et al* 2019). A data assimilation model for Arctic carbon cycling would drastically improve efforts to track the changing Arctic in near-real time and more accurately project permafrost carbon emissions into the future.

In general, increased funding to support international collaboration on permafrost carbon science is necessary to address knowledge and data gaps across the Arctic. Because satellites are needed to bridge the gaps in space and time between field observations, designing satellites optimized for the unique remote sensing characteristics of high latitude environments (Duncan *et al* 2020) and making existing satellite data available to the entire scientific community (e.g. high spatial resolution commercial imagery) would greatly enhance the scientific community's ability to understand, monitor, and forecast Arctic carbon fluxes.

2. Mitigation policy

For almost a decade, the Intergovernmental Panel on Climate Change (IPCC) has reported with high confidence the likelihood of a permafrost carbon feedback on global climate (Ciais *et al* 2013, IPCC 2018, Canadell *et al* 2021). More recently, the IPCC has assessed the impact of permafrost carbon on remaining carbon budgets to limit warming to 1.5 °C or 2 °C. Yet, there continues to be low confidence in the assessment of the timing, magnitude, and form (i.e. carbon dioxide or methane) of this feedback (IPCC 2018, Canadell *et al* 2021). This uncertainty has, in part, limited the incorporation of the current state of scientific knowledge of the permafrost climate feedback in global climate policy. As a result, the targets being embraced for reducing emissions from fossil-fuel consumption and land-use changes are likely insufficient to achieve their stated goals. Addressing this problem will not only require reducing scientific uncertainty; it will also require that scientific information is communicated to key decision makers expeditiously and in policy-relevant formats, and, importantly, that the information is then integrated into ambitious climate policy.

Expeditious and targeted communication of the evolving understanding of the permafrost climate feedback to decision makers means disseminating scientific outputs beyond academic journals (and particularly beyond closed-access journals) and more rapidly than the seven-year cycle of the IPCC Assessment Reports. While the IPCC process has been an outstanding model of science-policy collaboration and remains central to disseminating scientific knowledge to policy and other audiences, it is not ideal for disseminating highly relevant and rapidly updated knowledge. Further, its consensus format has sometimes made it overly cautious in characterizing Earth system feedbacks, including permafrost thaw, that have a high likelihood of affecting future climate but whose timing and magnitude remain uncertain.

While peer-review is a critical process for maintaining scientific rigor, there are additional avenues of communication beyond academic articles and IPCC reports may reach policy communities more efficiently. These include: presentations at the United Nations Framework Convention on Climate Change Conference of the Parties; policy briefs by climate research centers and consortia; articles and op-eds in political news site; testimony before legislatures; and individual meetings and briefings that bring decision-makers together with researchers and policy experts. Clearly, a successful path forward will involve developing collaborations between researchers and communications and policy experts who engage in this space. Mainstreaming relationships between science and policy communities is essential to delivering policy impact and ensuring that the international policy community is aiming for the right target when assessing progress toward the Paris Agreement's climate mitigation goals (i.e. to keep global average temperature increase well below 2 °C).

Integration of new findings from permafrost science into mitigation policy will also be greatly facilitated if scientific outputs better align with actual policy needs. For example, the Shared Socioeconomic and Representative Concentration Pathways (SSP/RCP) framework is well understood within the scientific community, but reporting projections of permafrost emissions in the SSP/RCP framework alone can limit their integration into efforts to assess progress toward the Paris Agreement goals. An alternative approach with greater clarity for the policy community is to project permafrost emissions associated with reaching or avoiding the 1.5 °C and 2.0 °C thresholds. These outputs are more easily related to the global stocktake, which takes place every five years to assess collective progress towards the Paris Agreement goals. Doing so with a reduced-complexity ESM (e.g. Gasser *et al* 2018) that incorporates the latest information from evolving mechanistic models (as described above) allows for a less computationally intensive, nimbler approach that can provide timely and policy-relevant scientific input to evolving policy landscapes. Assessing policy needs early in the scientific process can guide both research priorities and approaches and facilitate the integration of scientific understanding of the permafrost climate feedback into climate decision making.

3. Adaptation response

While ambitious climate-mitigation policy that accounts for emissions from permafrost thaw is essential for reducing future harm from climate change, immediate and comprehensive adaptation action is needed to address the devastating impacts of permafrost thaw that are already underway across the Arctic. Current and future impacts of permafrost thaw on Arctic communities and their lands need to be comprehensively assessed, and just and equitable adaptation plans, led by indigenous and local knowledge holders in collaboration with scientists and decision makers, need to be developed and implemented.

Community-led environmental monitoring has been identified as an immediate need for adaptation planning and long-term climate resilience for Arctic communities (Bronen *et al* 2020). An indigenous-led environmental monitoring and assessment process that integrates multiple ways of knowing can support adaptation planning, resource mobilization, cooperative partnerships, and long-term climate resilience (Cochran *et al* 2013). Permafrost monitoring using *in situ* observations of ground temperatures and active layer depths, as well as satellite observations of landscape changes, can generate much-needed quantified rates of change in permafrost conditions. These observations can inform modeled projections of permafrost thaw, ground collapse, habitat and landscape changes, and flooding at spatial and temporal scales (e.g. ∼30 m spatial resolution and sub-decadal timeframes) relevant for risk assessment and decision making. When combined with indigenous knowledge of environmental change and its relationship to indigenous culture, values, and social-ecological systems, these monitoring tools can help support just and equitable approaches for adaptation decision making that respects tribal self-determination (Whyte 2013). Achieving this goal will require interdisciplinary and diverse governmental (city, state, tribal, federal) and nongovernmental actors to engage in a collaborative process of knowledge production and problem solving.

Comprehensive approaches for responding to climate change hazards, including permafrost thaw, are currently hampered by limited support for climate adaptation decision-making and action at the national and international levels. In the United States, there is no centralized governance framework to assess the effects of permafrost thaw on impacted communities nor to identify when communities can no longer protect themselves in their current location and therefore will need to relocate. As permafrost thaw, erosion and flooding (i.e. usteq) continue to cause loss and damage of Arctic lands, there is an urgent need for a climate-relocation governance framework that respects the human rights of climate-threatened communities, ensures the right to self-determination for Arctic indigenous people, and fosters long-term climate resilience (Bronen 2021). When relocation is the only option, a just relocation approach must include a community relocation decision-making process, a process for identifying and choosing relocation sites, and access to government resources to facilitate climate resilience (Bronen 2021). This governance framework should be indigenous-led, including the design of the social-environmental monitoring and assessment tools needed to understand impacts of Arctic climate change and to guide the response (Bronen *et al* 2020).

The increasing urgency of the climate crisis in the Arctic and across the globe demands an ambitious and coordinated effort to address and ameliorate the impacts of permafrost thaw. This effort requires a coalition of Arctic residents, indigenous knowledge holders, Western scientists, Arctic and climate policy influencers, and government agencies to address this problem with the urgency it deserves. Rapid advances in technology, coupled with an opening in the policy window, make this a critical moment to accelerate understanding of thawing permafrost and incorporate that knowledge into responsible global mitigation strategies and just and equitable adaptation measures.

Data availability statement

No new data were created or analyzed in this study.

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ORCID iDs

Susan M Natali https://orcid.org/0000-0002-3010-2994
John P Holdren https://orcid.org/0000-0002-9643-8060
Brendan M Rogers https://orcid.org/0000-0001-6711-8466
Rachael Treharne https://orcid.org/0000-0002-3238-5959

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